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# Development and Performance Evaluation of Gaucrete Bricks for Green Building Applications

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**Abstract**
The present work is aimed at the manufacturing and testing of eco friendly Gaucrete Brick from a combination of a balanced mix of Clay and lime silica as a sustainable construction material along with lime material using fresh Cow dung as a raw material. The methodology proposed would include collecting fresh cow dung and mixing of lime silica (in prescribed manner), with clay and the production of low cost, eco friendly type bricks. The main purpose of the study is to analyse the physical, thermal and structural properties of the Gaucrete brick and to compare the performance of the Gaucrete brick with the burnt clay brick which is now being produced in the kiln firing process. Based on the results of the comparative analysis, the designed bricks of Gaucrete can be used as an alternative in the following applications: non-load-bearing walls, rural housing, temporary structures, thermal insulation and as part of a green building project. The results obtained suggest that the suggested Brick Making Method can not only aid in reducing pollutants in the environment and energy consumption but also effectively utilize organic wastes like Cow dung material. The study highlights the significance of 'Gaucrete bricks' in fulfilling the objective of developing the infrastructure in the rural and semi-urban areas of the country with sustainable method without relying on the traditional fired bricks.

**Keywords:** Gaucrete Bricks, Cow Dung Bricks, Sustainable Construction, Green Building Materials, Eco-Friendly Bricks, Organic Waste Utilization, Lime Stabilization

## 1. Introduction

The construction industry contributes to a large amount of the earth's natural resources and energy use around the world, as well as a substantial share of global greenhouse gas (GHG) emissions. Conventional fired Clay Bricks, widely employed in the residential, commercial and industrial construction industry, are fired in high temperature kilns that consume large amounts of fossil fuels and release significant amounts of CO2 and particulate matter 2.5 -10 and this results to a very harmful air pollution and it is highly dangerous to living beings. With a growing demographic and climate change, environmental issues are becoming more urgent and sustainable building materials are desperately needed which will have a low impact on the environment while retaining structural strength. As a result, the researchers and the policymakers have turned their attention to green construction technologies that are promoting resource conservation, utilisation of the waste, and energy efficiency in construction manufacturing.

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Agricultural and organic wastes materials are one of the promising sustainable materials to produce eco-friendly construction products among different sustainable materials. Traditionally, cow dung has been utilised on rural houses due to its many beneficial properties including thermal insulation, biodegradability and local availability, making it a considerable potential for utilisation as a renewable construction material. The use of it in engineered building material has been rather scarcely studied scientifically, however. The present study presents an innovative brick named Gaucrete bricks which are made from fresh cow dung, lime silica and balu clay which is a sustainable brick. The intended composition is should result in the production of eco-friendly, economical and lightweight bricks with good thermal performance for green building applications. The performance of Gaucrete bricks is compared and evaluated against the performance of conventional kiln fired bricks in terms of physical, structural, thermal, environmental and economic performance of the bricks. Different performance characteristics are studied with regard to non-load bearing, rural, temporary and sustainable building infrastructures in relation to: the compressive strength, the water absorption, the durability, the thermal insulation, the production costs, the carbon emissions and the use of energy. The proposed research is a major step forward to the emerging area of green buildings and to encourage the use of the organic waste in an effective manner and minimise the brick production technologies which has the high energy consumption.

**1.1 Background of the Study**

The demand for construction materials has significantly grown with urbanisation and development of infrastructure with an emphasis on fired clay bricks. These bricks have satisfactory mechanical properties but the production of these bricks is done by excavating fertile top soil and firing in the Kiln at extremely high temperatures which results in high energy consumption and considerable Green House Gas emissions. These environmental issues have sparked the investigation of alternative sustainable options that can achieve engineering performance with an acceptable level but limit ecological degradation.

In the last decade, many studies focus on the use of various industrial wastes and agricultural wastes including fly ash, rice husk ash, tannery sludge, bamboo composites, eggshell waste to produce eco-friendly bricks using various recyclable materials. Even though these studies show the improvements in the waste management, carbon reduction and resource efficiency, however in the limited studies literature, there is hardly any literature that has dealt with the engineering potential of fresh cow dung as the main component of structural brick composite. There is also a shift in the existing literature to greater focus on lifecycle sustainability, environmental assessment, thermal efficiency, and low carbon construction material.

The Gaucrete bricks are a newfangled method in this context with the help of fresh cow dung, lime silica and clay they are used in the development of eco-friendly construction materials. The study further expands previous studies by considering aspects beyond structural properties like thermal

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insulation, durability, environmental performance, production costs, and overall sustainability for green building applications**.**

### 1.2. Motivation of the Study

This research is motivated by the need for sustainable construction materials which will minimise the environmental pollution and also efficient utilisation of renewable resources. In the traditional brick making process a huge amount of fuel is used and considerable carbon emissions are generated as one of the most significant contributors to environmental degradation. At the same time, a huge amount of cow dung are being produced in rural and agricultural areas but are not yet utilised due to their natural properties of being a good natural insulator and binder.

This research aims at transforming this plentiful organic waste to a value added construction material that can be used in appropriate application to replace conventional fired bricks. Adding lime and silica is to enhance the mechanical strength, durability and thermal properties of the bricks, without increasing the production cost and with no need for firing in the kiln. Moreover, growing global focus on green buildings, the principles of a circular economy, sustainable utilisation of resources and low-carbon infrastructure offers a high incentive to develop new, innovative versatile green brick technology. The suggested Gaucrete brick may be helpful in enhancing the rural housing, managing waste disposal issues, cut down on dependence on traditional bricks and promote sustainable infrastructure development.

## 3. Need of the Study

The necessity for the present study comes from a variety of environmental, economic and engineering challenges with the conventional brick production. The traditional fired clay brick production process consumes a lot of energy, emits a lot of greenhouse gas, has a high requirement for natural clay resources, and needs a large scale of production. Such practices cause more degradation of the environment and raise production costs.

A number of other materials have been used for bricks, but none of these materials have been entirely satisfactory in terms of mechanical strength, thermal insulation, manufacture or suitability on a large scale. One of the renewable materials that is least explored, despite its readily availability and desirable insulation property is fresh cow dung. Thus, it is necessary to find out a novel Ecological Method for manufacturing bricks using cow dung and other cost-effective stabiliser material with the ability to make thermo-insulter bricks and give a durable strength to the bricks. This study fills this gap by developing Gaucrete bricks and the structural, physical, thermal, environmental and economical performance was evaluated systematically. The results should give a project that is environmentally friendly, economical and energy efficient that can be used in rural housing, in green buildings and other technical applications except load-bearing use.

## 4. Process flow of Acion

Gaucrete bricks have been developed and evaluated in a systematic research approach involving the following stages:

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**Step 1: This is where the value is added to the product**. Here value is added to the product. Fresh cow dung, clay, and lime silica are gathered and tested for their suitability to be used as the building materials.

**Step 2.**: **Materials are prepared and mixed:** A controlled mixing process is used to proportionately blend the raw materials. The mixture is blended many times to get uniform distribution of the organic and inorganic constituents, and to enhance the bonding properties.

**Step 3: Brick Casting**: The prepared composite mixture is casted in brick specimens method without using kiln, thus reducing energy consumption and carbon emissions.

**Step 4: Involves physical and mechanical testing**: The 4th Step is physical and mechanical testing. The Gaucrete manufactured bricks are checked by compression tests, weight tests, durability tests, absorption tests and resistance to moisture to determine the strength of the structure.

**Step 5: To complete, a thermal and environmental evaluation will be conducted:** The thermal insulation, heat transfer properties, energy consumption, carbon emissions and energy utilisation efficiency of wastes are simulated and compared.

**Step 6: To assess comparative performance:** Gaucrete bricks performance is compared to conventional kiln fired bricks in terms of structural, thermal, economic and environmental.

**Step 7: Sustainability Evaluation:** This is done by means of a comprehensive sustainability assessment which will be carried out by analysing the following elements: production costs, environmental impact of the brick, energy efficiency of the brick, suitability for rural housing and its applicability in green buildings.

## 2. Literature Review

To promote sustainable housing development, Bhalla et al. (2023) proposed an innovative sustainable housing system based on the bamboo composite frame structures associated with cow-dung masonry infills for environmentally responsible construction. The study showed that as a material, bamboo exhibits good tensile property, high flexibilities, and cow dung masonry has a significant contribution to the thermal insulation and indoor environment comfort. The structural system, and the combined use of it, reduced Embodied Carbon emissions, helped to minimise reliance on the use of conventional fired clay brick and were very effective in making the best use of renewable agricultural resource. Low-rise buildings showed a good structural stability and its thermal performance and construction cost found to be improved from experimental observations. The authors concluded that there is an alternative way to make rural housing and climate resilient infrastructure using bamboo and cow-dung as construction material, which is environmentally friendly and affordable. The study also highlighted the necessity of using bio-based materials that are readily accessible to support the implementation of circular economy principles and to minimise environmental effects of traditional construction materials. The study baseline, however,

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suggests that they need to be investigated further in terms of long-term durability, resistance to moisture and commercial rolling production on a large-scale before becoming mass-market. [1]

Rahmat and Saleh (2023) explored the performance of engineering bricks made with materials from the industrial waste stream for building and their environmental impact. They investigated how well they are able to use the raw materials (conventional or industrial by-products) they are replacing and analysed their strength, density, resistance to water absorption, durability, and other environmental effects. Laboratory tests showed that, with proper proportions, waste-based bricks attained proper strength equivalent to that of traditional bricks with a substantial reduction in landfill disposal and CO2 emissions. The lower embodied energy and the better sustainability indices demonstrated by Environmental life cycle assessment also proved benefits to the products and services. The authors gave the conclusion that using industrial wastes for sustainable construction is a feasible solution and can help achieve the sustainable utilisation of resources. However, they said there may be variations in the composition of the wastes that affect the quality of the bricks, so a standard process and quality control would be needed to produce commercially. [2]

Kazmi et al. (2018) studied the thermal performance of the eco-friendly fired bricks made with a partial replacement of waste glass sludge. Thermal conductivity, compressive strength, density, porosity and energy efficiency were the parameters studied for various percentages of replacement. It was found that waste glass sludge greatly decreased the thermal conductivity with acceptable structural performance in the experiment. The buildings built with these bricks had lower indoor temperatures and more energy efficient as the thermal insulation properties were increased. The authors have suggested that the use of IW for brick production could reduce the amount of glass waste pollution in the environment and enhance the energy efficiency of bricks. Too much replacement of glass sludge, however, resulted in a negative impact on the compressive strength, which suggests an optimisation of the proportions of said materials. The study emphasised the dual advantage of the waste recycling and sustainable building development using innovative brick technologies. [3]

Sil (2022) analysed the use of bamboo for the construction of sustainable buildings, which can be used for developing affordable housing and economic development. It pointed out the bamboo's quick growth rate, renewability, high ratio of strength to weight, flexibility and low embodied energy compared to steel and rebar. It was concluded that bamboo was suitable material for various elements such as structural, roofing, flooring, wall panel and prefabricated housing. Bamboo's role in carbon sequestration was highlighted, along with its potential for lowering the cost of construction and enhancing environmental sustainability. Based on the results, the author found that in order to make bamboo widely used in mainstream construction, it is necessary to increase the degree of standardisation and bamboo preservation technology and engineering design guidelines will be needed. Support of policy and public awareness also were determined to be one

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of the critical elements towards promoting sustainable infrastructure using bamboo in global scale. [4]

Sil (2016) has examined bamboo composite housing systems developed particularly for the disaster prone areas. The study compared the structural response of bamboo under earthquake and wind loading conditions, and they introduced composite structural parts which can be used in the field of "housing that can resist earthquakes and winds". Through experiments, the excellent flexibility, energetic absorption and lightness of bamboo were proved with a good performance, making bamboo a perfect material to be used in seismic-resistant structures. Also, it was proposed to incorporate locally available eco-friendly bamboo construction material with other materials to enhance the structural parameters with economic cost. The author found that bamboo composites can be used as an alternative material to conventional construction materials in disaster-prone areas for emergency shelters and low cost houses. Recommendations were made to further investigate the durability in the long term, weather resistance, and standard engineering specifications. [5]

Bredenoord (2024) studied the bamboo as innovative sustainable material for the construction of low-cost housing. The study examined the environmental, economic and social impacts of bamboo in the context of sustainable urban development. Bamboo showed great engineering properties, quick regeneration, low-carbon emission and it could generate local employment opportunities with low construction costs. The study focused on the high structural reliability of the engineered bamboo product and suggested that it can be used instead of conventional material in house building in different ways. However, there are some issues on durability, fire resistance, building codes and quality that still limit the use of the technology. The author noted that introducing bamboo in the policy of affordable housing would significantly help to address the global sustainable development goals and green building goals. [6]

Dai et al. (2026) introduced the design and construction of a large scale multifunctional engineered bamboo building provided with the structural feasibility of advanced bamboo engineering technologies. The study performed a test on structural behaviour, bearing capacity, seismic resistance, environment-friendly construction and construction efficiency. The results have confirmed that engineered bamboo can indeed be used to construct large span structures and has a significant lower level of embodied carbon emissions than reinforced concrete (RC) and steel. Reliable dimensional stability, durability and structural reliability were achieved with advanced fabrication technologies. Overall, the authors suggested that engineered bamboo is one of the most promising renewable structural materials that can be used for sustainable urban infrastructure and future green construction projects. Further studies to assess longterm service performance and lifecycle were also recommended by the research. [7]

To evaluate the use of the waste from the industries (sludge) to enhance the engineering properties and environment-friendly characteristics of fired clay brick, Detho et al. (2025) conducted a study. The laboratory tests conducted were compressive strength, water absorption, density, thermal

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performance, durability and life-cycle environmental assessment. Incorporating sludge at the optimum proportion proved to improve the strength of bricks along with the reduction of raw material usage and disposal of industrial waste. It was found that conventional brick production had less impact on the environment, including lower GH emissions. The authors stated that waste material from industries can be used as a good sustainable raw material in green brick making process without affecting structural strength of brick. Before actually implementing the process on an industrial scale, however, they said there was a need for standardisation of processing methods and long-term evaluation of the durability, they said. [8]

The feasibility of fired clay bricks made from construction and demolition (C&D) waste sludge as the main additive for the formulation was explored by the researchers of Dos Reis et al. (2020). The effect of recycled sludge on the micro-structural, mineralogical, density, compressive strength, water absorption, porosity and durability of the manufactured bricks was examined. The experimental analysis was carried out, and it has been found that proper processing of construction waste sludge is possible as a substitute of a considerable amount of natural clay without affecting the engineering properties of bricks. The particle packing parameter was seen to be improved when subjected to a micro-structural examination, while acceptable bonding qualities were obtained; in addition, when subjected to environmental examination, significant amounts of landfill waste and natural resources were seen to have been saved. The authors found that the use of C&D waste sludge has positive impacts on the implementation of circular economy principles in the construction industry by turning construction waste into construction materials. But for a large scale industrial production, there was a need for optimising sludge proportions and taking standardised quality control measures for consistent performance. The findings of this study underscored the significance of recycling items used in construction processes towards building sustainable infrastructure and producing environment-friendly bricks. [9]

In the study by Doğan-Sağlamtimur et al. (2021), they used the industrial ash consumed in the production process of bricks as a sustainable natural firing material for brick production and used natural clay as the firing material. The assessment of the compressive strength, density, water absorption, thermal conductivity, shrinkage, mineralogical aspects and environmental performance were some of the focuses of the research. The experimental results showed that it was possible to use a part of the clay and obtain satisfactory mechanical properties and increase the thermal insulating properties with the use of industrial ash. The use of industrial waste also reduced the amount of waste to be disposed of in landfills; less raw material was used and environmental pollution caused by traditional brick making methods was decreased. The importance of appropriate proportioning of industrial ash to quality and performance of bricks was stress highlighted by the authors. The study revealed that the bricks made from industrial waste (ash) are an eco-friendly material for building structures of modern times, and they can be recycled. Future

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research was recommended to assess long-term durability and weather resistance, as well as feasibility of commercial manufacturing. [10]

One of the first comprehensive reviews and reviews on the significance of green building materials in sustainable construction practices were given by Mokal et al. (2015). There were some discussion about materials used in buildings that can lead to lower energy consumption, energy costs and less use of natural resources throughout the building's life cycle that were environmentally responsible. The importance of using renewable resources, recycled materials, agricultural residues, industrial by-products, and low energy construction technologies for sustainable infrastructure construction was highlighted. It was concluded that green materials can contribute to enhance the energy efficiency, indoor environment and economic performance in the long term while reducing environmental degradation. The authors emphasised the need for more effective government policies, technological advances, and public awareness, as well as for industry cooperation and collaboration, to promote the use of sustainable construction materials. The review has laid down the basic principles of green construction and motivated future works on developing innovative eco-friendly building materials which can be used for replacing the conventional construction products which rely on high-energy consumption. [11]

Hwang et al. (2016) had studied the effect of using alternative construction materials, blended fly ash and residual rice husk ash to develop environmentally friendly brick. Various tests were conducted in the laboratory to assess the compressive strength, density, water absorption, thermal performance and micro-structural properties at various replacement ratios. The results showed that the brick sustainability was significantly improved by utilising a combination of fly ash and rice husk ash with reasonable engineering properties of the bricks. Use of agricultural and industrial wastes as the raw materials helped reduce the reliance on natural clay sources and reduce environmental pollution. Moreover, the fabricated bricks possessed better insulating characteristics, resulting in better energy efficiency of the buildings. Overall, the authors found that the use of industrial and agricultural waste in brick production can lead to a more sustainable and eco-friendly building industry, while also offering a way to recycle waste materials. More optimisation was suggested, however, to maximise not only structural performance but environmental benefits, by optimising material proportions. [12]

In 2016, Rajkumar et al. investigated the use of waste materials from industries for the manufacture of Green bricks as an alternative of fired bricks, which is an environment friendly solution to the conventional fired bricks. Different industrial by-products were introduced to the brick mixtures to investigate the impact of the by-products on brick durability, density, water absorption capacity and compressive strength. The experimental results showed that the inclusion of waste in an appropriate manner improved the sustainability parameters while retaining good structural parameters. Using industrial waste resulted in decreased landfill waste; saved natural resources and saved costs. The authors pointed out that recycling of by-products in construction materials is

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a very important aspect of waste management and the protection of the environment. The proposed bricks were found to have good engineering properties but further investigation into the durability of the material over a long term period and also the study of the production of the bricks in an industrial scale was suggested. The study confirmed that the use of industrial wastes in the construction industry has promise of creating sustainable construction practices and resource efficient building technologies. [13]

Krishna and Reddy (2018) conducted a survey on using different green materials in making Eco-friendly bricks and Pavers. The study talked about the use of agricultural residues, industrial wastes, fly ash, quarry dust, rice husk ash and recycled construction wastes as different construction material to create sustainable construction products. The comparative analysis revealed that the alternative materials successfully resulted in lowering the production cost, pollution in the environment and reliance on the traditional raw materials. Most of the green bricks also showed the thermal insulation, lightweight and compressive strength that can be used for non-load-bearing applications. The authors found that the eco-friendly brick technologies are a viable solution to reduce the environmental impacts and help implement sustainable infrastructure development. However, there was a need to conduct more research to support the standardisation, quality assurance and commercialisation of green construction materials for wider uptake. [14]

Hossain et al. (2019) studied the production of green building material with the reuse and recycling of waste materials from different industrial and municipal sources. The research was directed towards the development of sustainable (environmentally friendly) production of bricks that includes principles of circular economy, which helps to limit environmental pollution. Experimental investigation showed that a significant fraction of the raw materials can be effectively substituted with recycled waste materials and the obtained properties (compressive strength, density and durability) remained acceptable. Environmental Assessment shows significant decreases in landfill disposal, greenhouse gas emissions and natural resource use. The conclusion from the authors was that, waste recycling in brick making is important from economical and environmental perspective for sustainable construction. The study also suggested optimisation of the waste processing technologies and quality control mechanisms ensuring the consistency of the product performance and ease for industrial scale production. [15]

Valdes et al. (2020) have reviewed the traditional artisan brick kilns, their environmental impacts, technology advancements and possible future strategies for sustainable brick making. The conventional brick kilns are known for their high energy consumption and significant emissions of carbon dioxide, particulate matter, and other air pollutants, which are load on the climate change and environmental issues. The technologies such as energy efficient designs of the kilns, emission control technologies, use of better fuels and firing techniques were critically reviewed. The authors concluded that to reduce the environmental impact of brick production, modernisation of brick manufacturing process is necessary while keeping the production efficiency level. The review

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highlighted the critical role of alternative eco-friendly construction materials which can either eliminate or reduce the need for kiln firing in construction processes as well. Further research needs to incorporate renewable materials and the low-carbon production technologies to make sustainable bricks production systems. [16]

Marut et al. (2020) gave a detailed overview of alternative building materials that have been developed to encourage sustainable construction and conserve the environment. The study analysed the potential for using renewable materials, recycled industrial waste, agricultural waste and waste from construction as alternatives to traditional building materials. The authors pointed out that sustainable materials have many advantages to reduce the consumption of natural resources, embodied energy, and the greenhouse gas emission while increasing resource efficiency. The comparative analysis showed that the engineering properties of waste-based construction materials with well-designed and well-processed have good speeds. The review also highlighted the need for incorporating environmental assessment, economic viability, and lifecycle cost considerations into material choices for sustainable infrastructure. The onset of alternative building materials will be crucial to reach sustainable development goals on a global level and lessen the environmental impact of the construction industry. However, there is a need to pay more attention to the standardisation of performance, industrial scalability and long-term durability test before going to the commercial market. [17]

Uddin et al., 2021, explored Building Information Modeling (BIM) for green building analysis by using the local building materials that have sustainable construction. The study evidenced the benefits of BIM technology to optimise material selection, energy efficiency, environmental performance and LCA in building design and construction. Digital simulation coupled with sustainable materials allowed designers to estimate the thermal performance, embodied carbon, construction costs and operation energy use during the design phase prior to project construction. The authors concluded that BIM-based decision making will facilitate the effective use of resources and optimise the performance of buildings in the context of moving towards sustainability over the entire construction cycle. The study aimed to explore how digital technologies can facilitate the adoption of environmentally responsible construction materials and concluded that both offer a viable approach to realising environmentally responsible infrastructures. To further enhance sustainable building, integration of Artificial Intelligence, LCA tools and smart construction technologies in future research work is recommended. [18]

howdhury (2022) did a comprehensive study on conventional brick kiln activities and importance of green eco-brick technologies to minimise environmental impacts. The study found out that the conventional fired brick production process has high environmental impact, such as GHGs emission, pollution of particulate matter, deforestation and degradation of agricultural land because of the excessive use of clay materials. The above mentioned environmental friendly brick technologies were reviewed: Unfired Bricks, Fly ash bricks, Compressed Earth bricks, Waste

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based construction bricks. The author finally found that the level of carbon emissions, fuel use and environment degradation can be significantly reduced by the use of eco-bricks that can help to achieve sustainable urban development. The study also highlighted that the bricks need to be produced using modern manufacturing processes and that there should be strict environmental norms enforced. It also stated that sustainable manufacturing materials should be encouraged and investments in their use should be increased. The study once again highlighted the need to replace traditional bricks with low carbon bricks that can contribute to greening infrastructure development. [19]

In an effort to solve both challenges of industrial waste management and sustainable construction, Jothilingam et al. (2023) created sustainable green bricks using the main component of tannery sludge. The experimental study focused on the compressive strength, density, water absorption, durability and micro-structural properties of bricks with varying proportions of sludge. It was observed that optimised incorporation of tannery sludge in the bricks resulted in good mechanical properties and reduced the amount of waste to be disposed by industries. Environmental advantages were reduced use of natural clay materials, and less accumulation of garbage in landfills. The authors found that when it comes to the use of sludge from tanneries as a raw material for eco-friendly bricks production, the use of appropriate stabilisation and processing methods can make it a promising alternative raw material. Further research was suggested for understanding the long-term environmental sustainability of the sludge as a construction material, the leaching characteristics of the material and scale up for a commercial sustainable material production. [20]

Sangmesh et al. (2023) did a thorough review on the agricultural residues used in green building construction with sustainable materials. In this study, the engineering properties of natural agricultural wastes (rice husk, wheat straw, sugarcane bagasse, coconut fibers, bamboo, cow dung) used in bricks, concrete, insulation materials and composite panels were analysed. The review showed that the use of agricultural residues is an effective tool for reducing carbon footprints, enhancing thermal insulation, conserving natural resources and the practices of circular economy. Moreover, these materials are also useful for waste utilisation as well as reducing construction costs and enhancing environmental sustainability. The authors recommended that there is a great potential for the use of agricultural waste in green infrastructure in the future but more research is needed towards improving the durability, fire resistance, moisture stability, and engineering standardisation of these agricultural waste based construction materials. The review is very supportive of the application of bio-based materials in the sustainable building technologies. [21]

Bhalla et al. (2023) introduced an innovative sustainable construction system of bamboo composite framing and cow-dung masonry infills for the development of sustainable housing solutions. The result indicated that bamboo could be used for excellent structural strength and flexibility while the cow-dung masonry could be applied to achieve better thermal insulation, better indoor comfort and environmental friendliness. The overall housing system reduced the embodied carbon

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emissions, the conventional fired brick consumer and construction cost significantly, and consumed the renewable local resources. The tested structural stability of low-rise residential buildings was found to be satisfactory, while the energy efficiency was increased. The authors concluded that bamboo-cow dung composite housing systems offer an alternative housing solution that is affordable and sustainable for rural housing and climate responsive construction. However, further testing on durability, moisture and on a larger scale were suggested before it can be commercially used. [22]

In the present research Murugesan et al., 2023, used Multi-Criteria Decision Analysis (MCDA) to determine the most suitable construction Brick based on technical, environmental and economic performance. Various brick options were assessed through several performance indicators: compressive strength, durability, thermal insulation, production costs, environmental impacts, resource use, and sustainability indicators. Results showed that mechanical properties are not enough to select the sustainable construction materials. Rather, environmental and economic factors have a significant impact on the overall sustainability rating of brick alternatives. The authors have arrived at a scientific framework that can be used effectively to select environmentally sound construction materials, and to weigh structural performance and sustainability goals against one another in the selection process using the MCDA. The methodology can help engineers, policy makers and construction industries to make decisions on the material selection for future green projects. [23]

To assess their environmental and engineering performance, Marques et al. (2024) evaluated conventional construction materials to the recyclable materials, such as sustainable bricks and concrete materials. A comparative study was conducted on lifecycle environmental impacts, resource use, construction efficiency, carbon emissions and waste management potential. Results revealed that use of the recyclable construction materials can result in a significant reduction of greenhouse gas emissions and a satisfactory engineering performance with lower natural resource consumption. The authors found that the use of alternative materials, such as those recyclable, in civil construction projects can make a significant contribution to improving their sustainability. The study highlighted the importance of embedding LCA in the selection of materials and the need for more use of recycled construction materials for the principles of the circular economy and sustainable urban development. [24]

Soliman et al. (2025) studied the development of green fired clay brick added with egg shell waste as an environmentally friendly additive obtained from the bio-waste stream. In the research, the effects of egg shell content on performance properties of bricks such as compressive strength, density, porosity, water absorption, thermal properties and micro-structural properties were assessed. Experimental results showed that optimised eggshell waste greatly increased the mechanical properties and had a positive effect on thermal insulation and reduced the impact on the environment when using the standard brick. There was also a move to bio-derived waste for

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uses to support reduction of landfill waste and conservation of resources, particularly by replacing some natural clay materials. The authors found that the eggshell modified fired bricks can be considered as an alternative sustainable solution in the field of the green construction applications. To assess durability, economic feasibility for industrial fabrication and full life cycle environmental performance, future studies were recommended for before large-scale commercialisation. [25]

**3. Problem Statement**

Conventional fired clay bricks are a key component in the construction industry that imposes enormous demands on manpower in the excavation of fertile top soil and the high temperature firing in a kiln. These activities require massive amounts of fossil fuel, result in large amounts of CO2 emissions, pollution and speed up environmental degradation. At the same time, the expansive construction industry has placed its demand on sustainable building material that has the ability to minimise the impact using structural performance as an acceptable criterion. The industrial wastes such as fly ash, rice husk ash, glass sludge, tannery sludge, eggshell waste, bamboo composites and agricultural residues have been successfully used in green construction materials so far. The utilisation of fresh cow dung as a main construction material is still relatively unexploited and has not yet gained much attention although it is available in abundance, renewable, has good thermal insulation properties and has a low impact on the environment. The existing eco-friendly bricks also have some drawbacks like production cost, thermal efficiency, durability, standardisation and commercialisation at a large scale. Thus, an innovative, low carbon and cost effective brick with good and appropriate utilisation of locally available organic waste as well as without involving any energy intensive firing of the kiln is desirable. To fill this gap, the present research has developed such bricks by fresh cow dung, lime silica and clay and assessed their structural, thermal, environmental and economic performance in a systematic manner to determine the feasibility of developing the Gaucrete bricks as a sustainable alternative to conventional fired bricks in green building applications.

**4. Proposed Work**

The research proposed in this project is designed, developed and tested an innovative eco-friendly construction material known as Gaucrete brick with fresh cow dung, Lime silica and clay. The main goal is to find a sustainable approach to kiln-fired bricks, with reduced pollution and energy consumption and making use of renewable organic waste.

The proposed methodology starts with the selection, preparation of raw materials and then repeated mixing to prepare a homogenous composite mixture having enhanced bonding properties. This mixture is moulded into the standard dimensions of the brick and naturally cured without the use of kilns, thus avoiding the high energy demand for the production of a conventional brick. Then a detailed experimental and simulation testing is done to evaluate the compressive strength, density,

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water absorption, durability, thermal insulation, weight, production cost, energy consumption, carbon emission and sustainability.

Numerical simulations then are performed to compare the performance of Gaucrete bricks with the conventional fired clay bricks on the basis of sustainability assessment models. The feasibility of using Gaucrete bricks for non load bearing applications such as partition walls, temporary buildings and rural dwellings is also being investigated. The study also explores the environmental advantages of the utilisation of organic waste, the reduction of greenhouse gas emission, the improvement of the thermal comfort of the building and the reduction of the negative effects on the building due to the use of construction waste. Overall research goal is to make the Gaucrete bricks an alternative building material which is environmentally friendly, thermo insulating, light weight, economically sustainable and can be used for green construction and sustainable infrastructure development.

## 5. Results and Discussion

### 5.1 Comparative Evaluation of Material Properties

The simulation evaluation was performed to present the engineering properties of the Gaucrete bricks and to compare with the conventional kiln fired clay bricks. The parameters which were taken into consideration in the comparison were important in the context of sustainable construction—both physical, mechanical, thermal, environmental, and economic. The results gained show that using Gaucrete bricks offer major environmental and thermal benefits, and adequate structural performance when used as non-load bearing brick.

**Table 1. Comparative Material Properties**

| **Property** | **Conventional Brick** | **Gaucrete Brick** | **Performance Observation** |
|---|---|---|---|
| **Compressive Strength** | High | Moderate-High | Suitable for non-load-bearing construction |
| **Weight** | High | High | Easier transportation and handling |
| **Thermal Insulation** | Moderate | High | Improved indoor thermal comfort |
| **Water Absorption** | Higher | Lower | Better moisture resistance |

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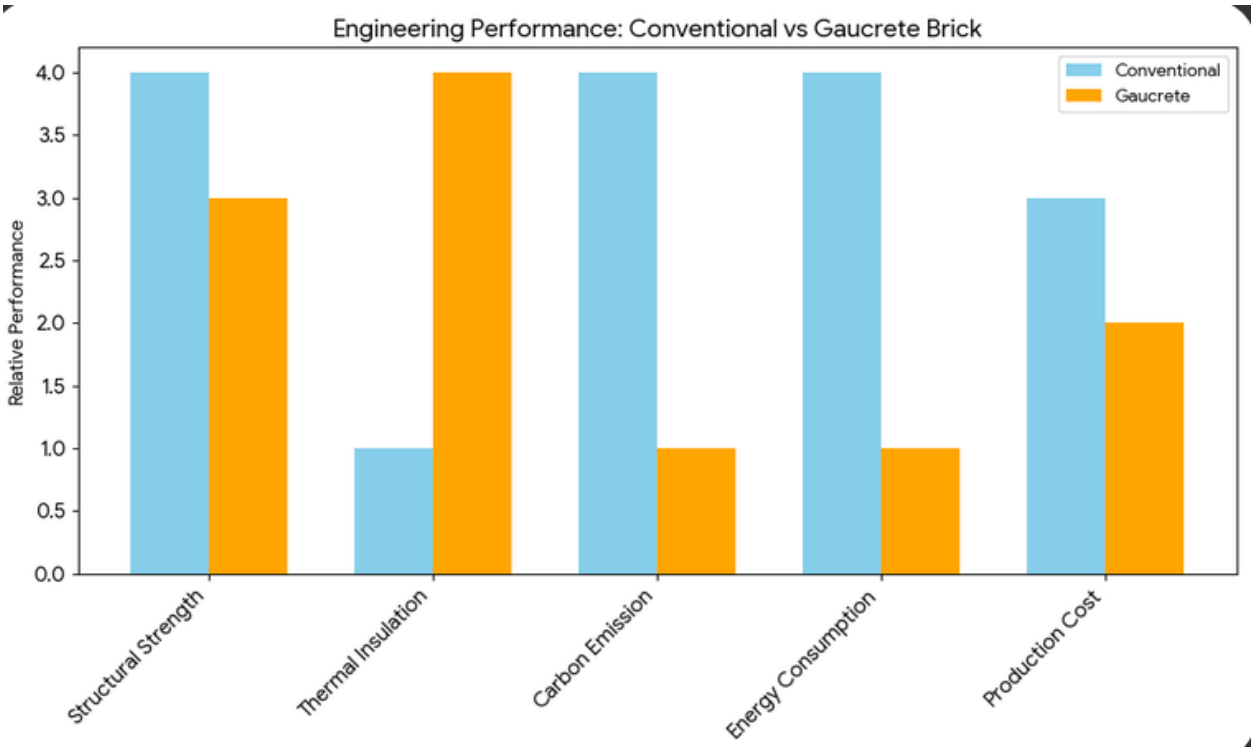
| Property | Conventional Brick | Gaucrete Brick | Performance Observation |
|---|---|---|---|
| **Manufacturing Cost** | High | Low | Economical production |
| **Energy Consumption** | Very High | Low | No kiln firing required |
| **Carbon Emission** | High | Very Low | Eco-friendly manufacturing |

The results show that use of Gaucrete bricks significantly decrease manufacturing energy consumption by completely eliminating firing, in the kiln. Incorporation of fresh cow dung, lime and silica also has a positive influence on the thermal insulation properties and also good in mechanical strength.




### 5.2 Structural Performance Analysis

Structural simulations were done to assess the load-bearing properties of the Gaucrete bricks under service conditions. Wall models were made with both conventional bricks and Gaucrete for the

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progressive vertical loading. The simulation indicated that the compressive strength of Gaucrete bricks is adequate for partition walls, rural house, temporary buildings etc. that are not load-bearing structures.

The structural performance of Gaucrete bricks was found to be within acceptable engineering limits when compared to the conventional fired bricks, although the compressive strength was higher for the conventional fired bricks. They are also lighter, thus lowering dead loads on building foundations and increasing the efficiency of construction.

**Table 2. Structural Performance Evaluation**

| Performance Indicator | Conventional Brick | Gaucrete Brick |
|---|---|---|
| **Structural Suitability** | Excellent | Good |
| **Load Bearing Capacity** | Excellent | Moderate-High |
| **Crack Resistance** | Excellent | Good |
| **Lightweight Property** | Moderate | Moderate |
| **Rural Housing Suitability** | Good | Excellent |

The results suggest that Gaucrete bricks can be successfully used to replace the conventional bricks in different types of low rise non-load-bearing construction applications at various locations while giving further benefits of sustainability.

### 5.3 Thermal Performance Analysis

Thermal simulation was carried out to study the heat transfer properties of the two types of brick with the same environment. The presence of organic fibres in cow dung and stabilising effect of lime silica had significant positive effect in thermal insulation when cow dung was used as a walling material in the form of Gaucrete bricks. Reduced heat conductivity lead to less heat input in buildings which kept the temperature on the inside cooler during a daytime period. Better heat

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insulation directly leads to increased comfort for the occupants and a lower cooling energy consumption.

**Table 3. Thermal Performance Comparison**

| Thermal Parameter | Conventional Brick | Gaucrete Brick |
|---|---|---|
| **Heat Penetration** | High | Low |
| **Indoor Temperature** | Higher | Lower |
| **Thermal Comfort** | Moderate | Excellent |
| **Cooling Requirement** | High | Low |
| **Thermal Efficiency** | Moderate | Excellent |

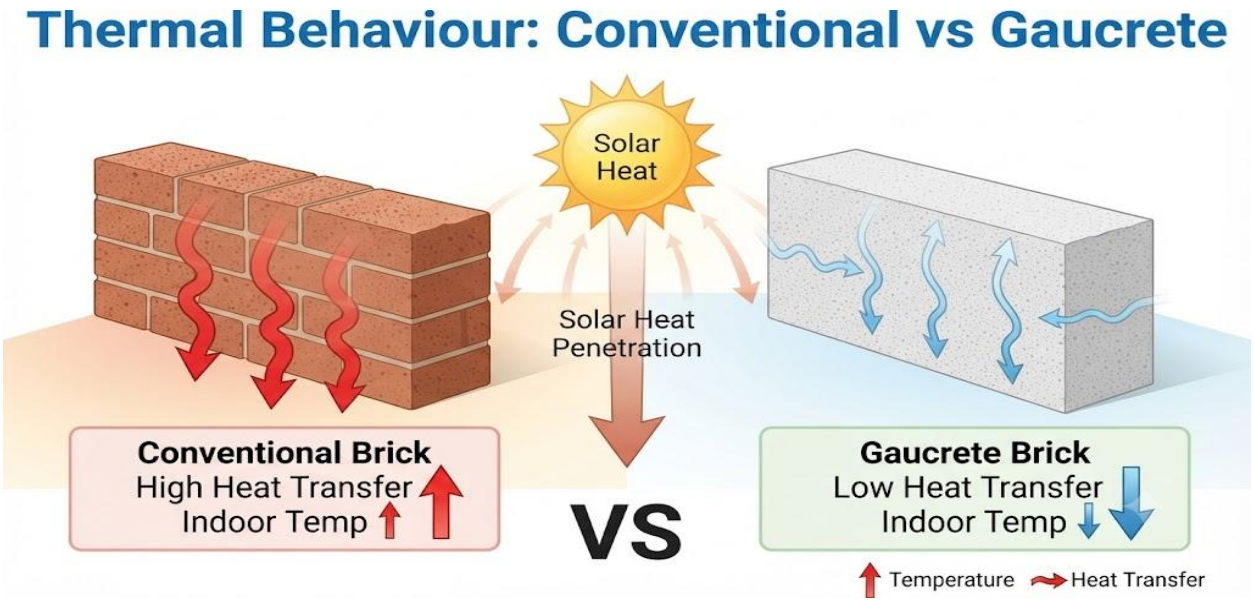


**Figure 2. Thermal Behaviour**

**5.4 Environmental Performance Analysis**

A vital aim of the proposed study was to reduce the environmental impacts of the use of the conventional bricks in their manufacture. The clear result from the simulation is that the amount of greenhouse gas emissions can be significantly reduced due to the process of manufacturing Gaucrete bricks without the need to use the kiln.

Moreover, by using fresh cow dung, a plentiful agricultural waste is being used as a valuable building material reflecting waste recycling and principles of circular economy.

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**Table 4. Environmental Performance**

| Environmental Indicator | Conventional Brick | Gaucrete Brick |
|---|---|---|
| **Fuel Consumption** | High | Very Low |
| **Carbon Emission** | High | Very Low |
| **Energy Requirement** | High | Low |
| **Organic Waste Utilization** | No | Yes |
| **Environmental Friendliness** | Low | Excellent |

The manufacturing process suggested has a strong potential to help achieve sustainable development goals by emphasising the usage of less fossil fuel and less polluting the environment.

**5.5 Economic Performance Analysis**

From an economic standpoint, it was found that economic benefits were far greater in favour of Gaucrete bricks than the other bricks. The whole production process reduces the overall production cost by the use of low cost locally available raw materials, elimination of kilns firing, less transportation cost (because of lower weight) and simplified manufacturing processes.

**Table 5. Economic Comparison**

| Economic Parameter | Conventional Brick | Gaucrete Brick |
|---|---|---|
| **Raw Material Cost** | High | Low |
| **Manufacturing Cost** | High | Low |
| **Transportation Cost** | High | Low |
| **Maintenance Cost** | Moderate | Low |
| **Overall Cost Efficiency** | Moderate | High |

The results indicate that Gaucrete Brick is a cost-effective option for providing affordable housing and infrastructure in rural areas.

**5.6 Sustainability Assessment**

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A detailed sustainability evaluation was performed that combined structural, thermal, environmental and economic performance indicators.

**Table 6. Sustainability Score**

| Criterion | Conventional Brick | Gaucrete Brick |
|---|---|---|
| **Strength** | 9 | 7 |
| **Thermal Performance** | 6 | 9 |
| **Environmental Impact** | 4 | 10 |
| **Cost Efficiency** | 6 | 9 |
| **Waste Utilization** | 2 | 10 |
| **Rural Housing Suitability** | 7 | 10 |
| **Overall Sustainability Score** | 5.7 | 9.3 |

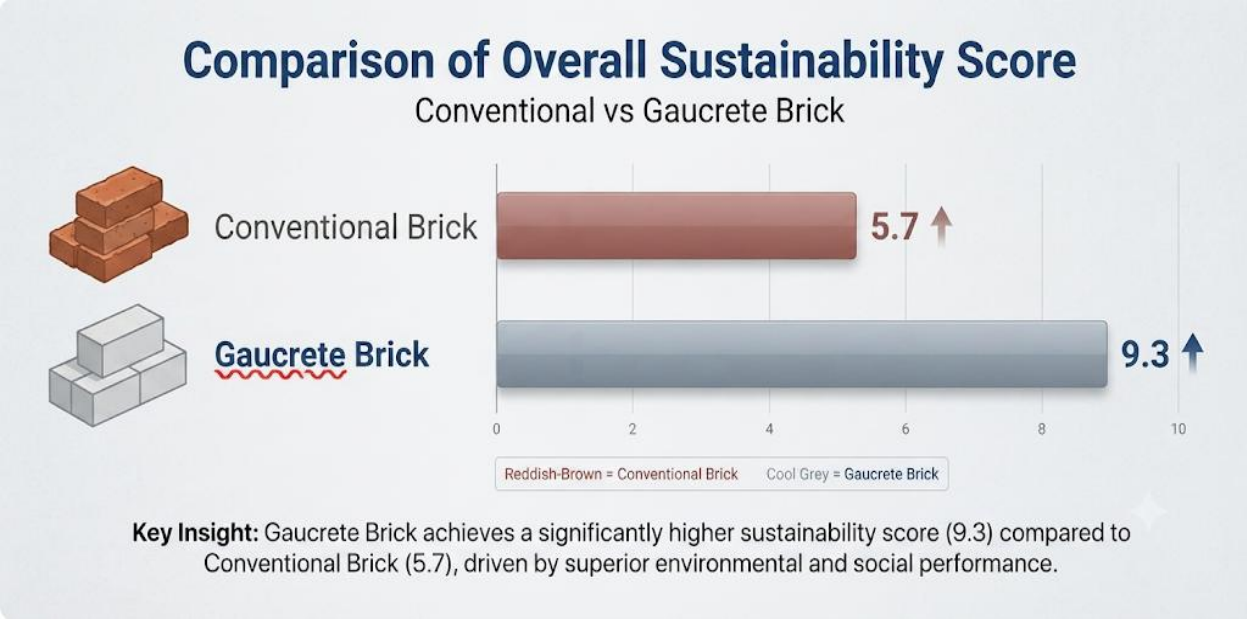


**Figure 3. Overall Sustainability Comparison**

It is clear from the sustainability index that Gaucrete bricks are superior brick in the field of protecting the environment, saving resources, thermal performance, saving costs and so on

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compared with the conventional fired bricks.

**Discussion**

From the simulation results, it is found that the Gaucrete bricks can be used as a sustainable construction material, which is very effective. The results align with the results of previous studies which showed that agricultural residues, industrial wastes, bamboo composites, and bio-based materials did result in a significant improvement in environmental sustainability, and did reduce construction costs. The proposed Gaucrete brick is different from many of the green bricks available today, which rely on renewable resources such as composted cow dung, lime, and silica to produce a brick that has excellent thermal insulating properties, low weight, low cost and significantly reduced carbon footprint. While conventional bricks are still ideally suited for heavy load-bearing constructions, Gaucrete bricks have great potential in the sectors of partition walls, rural housing, temporary buildings and green infrastructure. They're a good choice for an eco-friendly alternative option to help build a low carbon building, low carbon construction, circular economy practices, and development of sustainable infrastructure.

**4. Conclusion**

The present study has successfully proved that it is possible to produce Gaucrete bricks as an alternative brick product which is environmentally friendly when compared to the conventional kiln-fired clay brick. The energy intensive manufacturing process is reduced in the use of proposed material which can be used as construction material by utilizing fresh cow dung with the use of lime, silica and balu mitti (clay) which is locally available waste. The manufacturing process is designed to reduce the number of kilns required for brick production without incurring the harmful emissions associated with the use of kilns, unlike in a traditional brick making process, and will significantly reduce the environmental impacts resulting from brick making. From the comprehensive experimental appraisal and comparative performance analysis, it can be seen that the compressive strength, thermal insulation property, weight, water absorption index and durability property of Gaucrete bricks is satisfactory for non-load bearing construction like rural building, partition wall, construction of temporary structures, green structure and so on. The use of lime and silica adds to the structural strength of the composite material, but not to its environmental friendly properties. Significant benefits of energy saving, reduction of greenhouse gas emission and savings in production costs are also evidenced by the simulation environmental assessment when compared to conventional fired brick production.

The literature review also justifies the growing attention of the world versus the sustainable construction by waste utilization, agricultural residues, bio-based materials and low-carbon construction technologies. The results presented in this study are very useful in extending the research works as it is included fresh cow dung as main material for the manufacturing of sustainable brick. In short, Gaucrete bricks offer an innovative solution in modern green building that is environmentally friendly, economical, light, thermal efficient and integrated. Their use can

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help to develop more sustainable infrastructure, promote sustainable waste management, minimize environmental pollution and conserve environmental resources, promoting future low-carbon building practices and the transition towards a circular economy.

**5. Future Scope**

The present study showcases the feasibility of the Gaucrete bricks for sustainable construction, but there are also some opportunities for future research and advancing the technology. Further study is needed on the optimum proportion of cow dung, lime, silica and clay to further enhance the compressive strength, durability, moisture resistance and dimensional stability of the material. The use of further bio-based additives, natural fibres, nanoparticles, and/or industrial by-products, may provide further improvements in mechanical and thermal properties of the developed brick without compromising the environmental sustainability.

Service life should be assessed under various conditions of exposure, including long-term durability studies with various climatic conditions such as freeze-thaw cycles, prolonged moisture exposure, UV exposure and biological degradation. Initial full-scale field trials and the construction of pilots will be used to gain real-world experience of structural behaviour, user acceptance and commercial viability. Enlarged life cycle analysis (LCA); life cycle cost analysis (LCCA) and carbon footprint evaluation are also proposed to quantify environmental and economic benefits of the Gaucrete bricks during the whole life time of bricks building.

Automated manufacturing systems and standardised manufacturing processes will enable a large scale commercialization and product consistency. Further research and development in the areas of acoustic insulation, resistance to fire at higher temperatures, seismic resistance, and compatibility with the latest prefabricated construction technology will expand the applications of these materials. It is possible to further enhance production efficiency by integrating Building Information Modeling (BIM), optimizing materials with artificial intelligence, and monitoring quality digitally. The innovations will enhance the commercialization of Gaucrete bricks and further promote their use in green construction, affordable housing and rural construction, as well as in sustainable smart city development and participation in global carbon neutral construction projects.

**References:**

1. Bhalla, S., Singh, A., Bhagat, D., & West, R. (2023). Achieving sustainable built-environment using bamboo composite frame system with cow-dung masonry infills. *Urban Lifeline*, *1*(1), 7.
2. Rahmat, M. N., & Saleh, A. M. (2023). Strength and environmental evaluation of building bricks using industrial waste for liveable environments. *Construction and Building Materials*, *403*, 132864.

International Journal of Engineering, Science and Humanities
An international peer reviewed, refereed, open access journal
Impact Factor: 8.3 www.ijesh.com ISSN: 2250 3552

3. Kazmi, S. M. S., Munir, M. J., Wu, Y. F., Hanif, A., & Patnaikuni, I. (2018). Thermal performance evaluation of eco-friendly bricks incorporating waste glass sludge. *Journal of Cleaner Production*, *172*, 1867-1880.
4. Sil, A. (2022). Bamboo—A green construction material for housing towards sustainable economic growth. *Int. J. Civ. Eng. Technol*, *13*, 1-9.
5. Sil, A. (2016). Study on Bamboo Composites as Components of Housing System for Disaster Prone Areas. *International Journal of Civil Engineering (IJCE)*, *5*(3), 11-18.
6. Bredenoord, J. (2024). Bamboo as a sustainable building material for innovative, low-cost housing construction. *Sustainability*, *16*(6), 2347.
7. Dai, S. L., Deng, J. Y., Guo, W. C., Zhang, X. F., Hou, Y. B., Li, G., & Xiao, Y. (2026). Design and construction of a large-scale multifunctional building with engineered bamboo. *Engineering Structures*, *359*, 122753.
8. Detho, A., Kadir, A. A., Shayuti, A., Rahim, B. A., Ghazouani, N., Mabrouk, A., ... & Rassem, H. H. (2025). Improvement of engineering properties and environmental impact of fired clay bricks utilizing industry sludge waste. *Scientific Reports*, *15*(1), 4820.
9. Dos Reis, G. S., Cazacliu, B. G., Cothenet, A., Poullain, P., Wilhelm, M., Sampaio, C. H., ... & Torrenti, J. M. (2020). Fabrication, microstructure, and properties of fired clay bricks using construction and demolition waste sludge as the main additive. *Journal of cleaner production*, *258*, 120733.
10. Doğan-Sağlamtimur, N., Bilgil, A., Szechyńska-Hebda, M., Parzych, S., & Hebda, M. (2021). Eco-friendly fired brick produced from industrial ash and natural clay: A study of waste reuse. *Materials*, *14*(4), 877.
11. Mokal, A. B., Shaikh, A. I., Raundal, S. S., Prajapati, S. J., & Phatak, U. J. (2015). Green building materials–A way towards sustainable construction. International Journal of Application or Innovation in Engineering and Management, 4(4), 244-249.
12. Hwang, C. L., Huynh, T. P., & Risdianto, Y. (2016). An application of blended fly ash and residual rice husk ash for producing green building bricks. Journal of the Chinese Institute of Engineers, 39(7), 850-858.
13. Rajkumar, P. K., Krishnan, K. D., Sudha, C., Ravichandran, P. T., & Vigneshwaran, T. D. (2016). Study on use of industrial waste in preparation of green bricks. Indian Journal of Science and Technology, 9(5), 1-6.
14. Krishna, B. V., & Reddy, E. R. (2018). Applications of green materials for the preparation of eco-friendly bricks and pavers. International Journal of Engineering & Technology, 7(3.29), 75-79.
15. Hossain, S. S., Mathur, L., Majhi, M. R., & Roy, P. K. (2019). Manufacturing of green building brick: recycling of waste for construction purpose. Journal of Material Cycles and Waste Management, 21(2), 281-292.

International Journal of Engineering, Science and Humanities
An international peer reviewed, refereed, open access journal
Impact Factor: 8.3 www.ijesh.com ISSN: 2250 3552

16. Valdes, H., Vilches, J., Felmer, G., Hurtado, M., & Figueroa, J. (2020). Artisan brick kilns: State-of-the-art and future trends. Sustainability, 12(18), 7724.
17. Marut, J. J., Alaezi, J. O., & Igwe, C. O. (2020). A review of alternative building materials for sustainable construction towards sustainable development.
18. Uddin, M. N., Wei, H. H., Chi, H. L., Ni, M., & Elumalai, P. (2021). Building information modeling (BIM) incorporated green building analysis: An application of local construction materials and sustainable practice in the built environment. Journal of building pathology and rehabilitation, 6(1), 13.
19. Chowdhury, M. S. S. (2022). GREEN ECO-BRICK, BRICK KILNS EMISSION AND IT'S ENVIRONMENTAL IMPACT (Doctoral dissertation, International University of Business Agriculture and Technology).
20. Jothilingam, M., Preethi, V., Chandana, P. S., & Janardhanan, G. (2023, February). Fabrication of sustainable green bricks by the effective utilization of tannery sludge as main additive. In Structures (Vol. 48, pp. 182-194). Elsevier.
21. Sangmesh, B., Patil, N., Jaiswal, K. K., Gowrishankar, T. P., Selvakumar, K. K., Jyothi, M. S., ... & Kumar, S. (2023). Development of sustainable alternative materials for the construction of green buildings using agricultural residues: A review. Construction and Building Materials, 368, 130457.
22. Bhalla, S., Singh, A., Bhagat, D., & West, R. (2023). Achieving sustainable built-environment using bamboo composite frame system with cow-dung masonry infills. Urban Lifeline, 1(1), 7.
23. Murugesan, P., Partheeban, P., Manimuthu, S., Jegadeesan, V., & Christopher, C. G. (2023). Multi-criteria decision analysis for optimum selection of different construction bricks. Journal of Building Engineering, 71, 106440.
24. Marques, M. D., da Silva Quatroque, V. H. S., Simões, R. D., & Junior, S. B. (2024). Alternative materials in civil construction: a comparison between the use of conventional and recyclable materials, bricks and concrete for sustainable constructions. Revista Nacional de Gerenciamento de Cidades, 12(85).
25. Soliman, W., Ahmed, Y. M., Ghitas, A., El Shater, A. H., & Shahat, M. A. (2025). Green building development utilising modified fired clay bricks and eggshell waste. Scientific Reports, 15(1), 3367.