Experimental Assessment of Treated Wastewater for Sustainable Mud Brick Production: Integrating Architectural Sustainability and Engineering Performance

Amir Sohail [1] **Faiqa Bashir** [2] **Nijah Akram** [3*] **Shehryar Khan** [4] **Muhammad Qamar** [5]

[1] Lecturer, Department of Civil Engineering Technology, Punjab Tianjin University of Technology (PTUT), Lahore, Punjab, Pakistan. Email: amir.sohail@ptut.edu.pk

[2] Student, Department of Architectural Engineering Technology, Punjab Tianjin University of Technology, Lahore, Punjab, Pakistan. Email: 23-ar-015@students.ptut.edu.pk

[3] Head of Department of Architectural Engineering Technology, Punjab Tianjin University of Technology, Lahore, Punjab, Pakistan. Email: akram.nijah@ptut.edu.pk

[4] Architect, AtkinsRealis, Lahore, Punjab, Pakistan. Email: Ar.Shehryarkhan@gmail.com

[5] C.E.O, Chaudhry Architects Builders & Estate Developers, Bahawalpur, Punjab, Pakistan. Email: architectqamar777@gmail.com

ABSTRACT: As the demand for sustainable construction materials has grown and freshwater scarcity has become a major concern, the use of treated domestic wastewater (T.D.W.) in construction has emerged as a potential solution for conserving freshwater, reducing environmental pollution, and promoting circular economy principles. This study experimentally investigated the feasibility of using treated domestic wastewater as an alternative to freshwater in the production of hand-moulded sun-dried mud bricks. Bricks measuring 228.6 × 114.3 × 76.2 mm were prepared using three mud-to-treated-wastewater mixing ratios (70:30, 75:25, and 65:35) and cured naturally under sun exposure. Water absorption was evaluated after 24 hours, while compressive performance was assessed after 7, 14, and 21 days in accordance with ASTM C67/C67M. The results showed a water absorption of 20%, which falls within the maximum allowable limit of 25% for clay bricks used under normal conditions. The average failure loads were 25.8 kN after 7 days, 23.4 kN after 14 days, and 25.3 kN after 21 days, corresponding to average compressive strengths of 0.99 MPa, 0.90 MPa, and 0.97 MPa, respectively. The findings indicate that the use of treated domestic wastewater did not negatively affect the physical and mechanical properties of the bricks.

KEYWORDS: Treated Wastewater, Mud Bricks, Sustainable Building Materials, Architectural Sustainability, Engineering Performance, Circular Economy, Mechanical Properties, Water Conservation

Pages: 177 – 199
Volume: 5
Issue: 4 (April 2026)

Corresponding Author
Nijah Akram
✉ akram.nijah@ptut.edu.pk

Cite this Article: Sohail, A., Bashir, F., Akram, N., & Khan, S., Qamar, M. (2026). Experimental Assessment of Treated Wastewater for Sustainable Mud Brick Production: Integrating Architectural Sustainability and Engineering Performance. *The Regional Tribune, 5*(4), 177-199. https://doi.org/10.55737/trt/v-iv.262

Introduction

Mud bricks are one of the most ancient and eco-friendly construction materials, and are widely used in vernacular architecture throughout the world because they are locally available, have low embodied energy, are cheap, and have outstanding thermal performance (Lourenço et al., 2010; Ren & Kagi, 1995). Sun-dried mud bricks are produced using natural drying processes, significantly lessening the use of kiln firing, carbon emissions, and energy use, and are appropriate for low-rise structures, rural homes, and climate-adaptive design. They are being used on a regular basis, and they are in alignment with the global movement to promote environmentally responsible construction materials that can help to minimise the environmental impacts of the built environment.

The construction sector is one of the world's largest consumers of natural resources and fresh water, making it important to find ways to produce more sustainably in order to reduce the exploitation of resources and environmental degradation. With the rate of rapid urbanisation, industrial growth, and climate change, conventional brick production is increasingly dependent on potable water and natural clay, which is becoming more of a challenge. Therefore, researchers and policymakers have stressed the importance of incorporating circular economy principles in the construction process by reusing waste resources and decreasing the reliance on primary materials. Mohammad et al., 2013). Innovative solutions with material properties that have a positive effect on the conservation of natural resources and still meet the required engineering properties are therefore needed in sustainable construction.

In comparison with these options, wastewater has proven to be an alternative to freshwater in the production of construction materials, which is one of the available options. The amount of municipal and industrial wastewater produced is gigantic every year, but most of it is not effectively utilised, even with the improved wastewater treatment technologies. The challenges of using reclaimed water in the construction industry, such as conserving freshwater and reducing wastewater discharge into the environment, are tackled at the same time. The previous investigations have shown that wastewater and wastewater treatment sludge have been successfully used in cementitious materials like concrete, fired clay bricks, ceramic products, and other cementitious materials, thus offering improved resource efficiency and support for implementing the circular economy. (Amin et al., 2022; Areias et al., 2020; Centeno Mora et al., 2024; da Silva et al., 2024; Detho et al., 2024; Erdogmus et al., 2021; Gencel et al., 2022; Ghafoor et al., 2022; Limami et al., 2021; Mahanna et al., 2024; Moulato et al., 2023).

In recent years, special attention has been paid to the potential of using wastewater treatment sludge in fired clay bricks without compromising the mechanical and durability properties to a great extent. (Amin et al., 2022; Detho et al., 2024). In the same way, Ghafoor et al. (2022) showed that wastewater treatment could be used instead of fresh water in the manufacture of fired bricks, resulting in the production of bricks with good compressive strength and water absorption. (Ghafoor et al., 2022). Waste materials such as drinking-water treatment sludge, textile sludge, demolition waste, fly ash and agricultural by-products have also been used to enhance the resource efficiency and environmental impacts of the production of conventional bricks, as confirmed by other investigations. (Beshah et al., 2021; Erdogmus et al., 2021; Li et al., 2025; Olaiya et al., 2025). These studies illustrate how waste valorization is becoming more and more relevant in sustainable construction as a whole.

In addition to brick production, research on sustainable construction has been gradually directed towards the development of environmentally friendly building materials, utilising agricultural residues, industrial waste, biochar, mineral filler, and low-quality clay minerals. Recent studies have shown that these materials can not only improve the engineering properties of concrete and other cementitious composites but can also reduce the amount of embodied carbon in the production of these materials (Nijah et al., 2025; Arshad et al., 2025; Asif et al., 2025; Hussain et al., 2025; Muneer et al., 2025; Nawaz et al., 2025). Similarly, biochar-based concrete blocks have demonstrated significant potential in low-carbon construction, acting as carbon-sequestering blocks and enhancing sustainability (Javed et al., 2025). Moreover, research on low-grade clay minerals has shown that they can be used as a sustainable material for the development of cementitious composites, which promotes the use of more sustainable materials in construction (Blouch et al., 2025). Overall, the advancements reflect the need for materials to be both environmentally responsible and sustainable in terms of resource usage for future building applications.

Water conservation has also become an objective of growing importance in the field of sustainable architectural engineering. The efficient handling of water in the construction industry plays a vital role in safeguarding the environment, as well as in the sustainable development of urban infrastructures and in long-term urban resilience. The integrated approach for water conservation has been stressed in the previous study as an effective solution to the growing stress on freshwater resources in developing countries. (Malik et al., 2022). In addition, studies of traditional masonry materials and architectural heritage have highlighted the need for knowledge of the long-term behaviour and durability of earth-based building materials for sustainable architectural use. (Abdullah et al., 2026; Akram et al., 2026). Environmentally friendly construction materials are also crucial for sustainable infrastructure planning for resilient urban development. (Ali et al., 2025), and sustainable technologies in the construction industry rely on effective institutional adaptation (Akram et al., 2024; Akram et al., 2024).

Although improvements have been made, the existing studies have focused mainly on fired clay bricks with wastewater treatment sludge or industrial waste, in a kiln-fired process. Few studies are available for hand-moulded sun-dried mud bricks, in which no thermal stabilisation process is used in the brick production. Moreover, most of the previous studies have been performed on the wastewater treatment sludge, while the replacement of freshwater with treated domestic wastewater during brick manufacturing has not been considered. Therefore, little experimental data is available on the performance of sun-dried mud bricks made of treated wastewater in terms of compressive strength and water absorption.

In this context, the present study aims at experimentally evaluating the potential use of treated domestic wastewater as the main mixing water for hand-moulded sun-dried mud bricks. The ratios of mixing the mud with the treated wastewater were investigated to be 70:30, 75:25, and 65:35. Bricks were manufactured by using the traditional hand moulding method and curing process with intermittent water spraying under the natural sun. The water absorption was measured by a 24 hrs. gravimetric immersion test, and the compressive strength was measured after 7, 14, and 21 days of curing. The results offer new insights into the development of low-energy masonry units, which, on the one hand, could contribute to freshwater conservation, wastewater reuse, and the principles of a circular economy, and on the other hand, to sustainable architectural engineering and environmentally responsible building construction.

Literature Review

Table 1

Critical Review of Previous Studies on Wastewater, Sludge, and Waste-derived Materials for Sustainable Brick Production

Authors	Waste Material/ Water Source	Brick Type	Experimental Focus	Key Findings	Relevance to the Present Study
(Areias et al., 2020)	Sewage sludge	Clay brick	Extrusion and material characterization	Sewage sludge can be incorporated without adversely affecting extrusion properties.	Demonstrates the feasibility of wastewater-derived materials in clay bricks.
(Limami et al., 2021)	Wastewater treatment sludge	Earth bricks	Soil and sludge characterization	Thermal stabilisation minimised heavy metal leaching and environmental risks.	Supports the environmental safety of wastewater-derived materials.

(Beshah et al., 2021)	Textile sludge	Clay bricks	Various sludge replacement ratios	Textile sludge improved energy-efficient brick production.	Shows potential of industrial waste reuse in masonry materials.
(Erdogmus et al., 2021)	Water treatment sludge + brick waste	Fired bricks	Mechanical and physical characterization	Water treatment sludge improved brick performance.	Demonstrates beneficial effects of sludge incorporation.
(Ghafoor et al., 2022)	Wastewater	Fired clay bricks	Mechanical and durability evaluation	Wastewater successfully replaced freshwater while maintaining brick quality.	Closest study to the present work.
(Amin et al., 2022)	Wastewater treatment sludge	Burnt clay bricks	XRF and engineering properties	WTS improved sustainability while maintaining acceptable strength.	Highlights the reuse of wastewater-derived materials.
(Gencel et al., 2022)	Water treatment sludge + demolition waste	Fired bricks	Waste replacement	Enhanced technological performance of bricks.	Supports circular economy concepts.
(Moulato et al., 2023)	Sewage sludge	Fired bricks	Sludge reuse	Demonstrated the feasibility of sewage sludge as a clay substitute.	Reinforces sustainable brick production.
(da Silva et al., 2024)	Municipal sewage sludge	Ceramic bricks	Microstructural analysis	Up to 6 wt. % sludge produced environmentally friendly bricks.	Highlights microstructural benefits.
(Mahanna et al., 2024)	Alum sludge	Structural bricks	Physical characterization	Agricultural waste and sludge effectively replaced clay.	Supports waste valorisation.
(Centeno Mora et al., 2024)	Treated wastewater	Mortar bricks	Technical, economic and environmental assessment	Wastewater reuse is technically and economically feasible.	Demonstrates practical implementation.
(Detho et al., 2024)	Wastewater treatment sludge	Fired clay bricks	Material characterization	Wastewater sludge promoted sustainable brick manufacturing.	Supports sustainable construction.
(Li et al., 2025)	Drinking water sludge + fly ash	Permeable bricks	Material development	Produced high-quality permeable bricks.	Demonstrates innovative sludge utilisation.
(Olaiya et al., 2025)	Banana leaf ash + sawdust ash	Sand bricks	Mechanical optimization	Agricultural waste enhanced compressive strength.	Shows the broader applicability of waste-derived construction materials.

However, in recent years, more efforts have been devoted to sustainable architectural engineering embracing the concept of circular economy, resource-efficient construction materials, and wastewater reuse and low-carbon construction techniques. The successful integration of the wastewater treatment sludge and treated wastewater, agricultural residues, biochar, industrial by-products, fly ash, hemp fibres, palm oil ash, eggshell powder, and LC3-based cementitious materials into sustainable construction materials has been demonstrated in previous studies (Akram et al., 2025; Arshad et al., 2025; Asif et al., 2025; Blouch et al., 2025; Blouch et al., 2025; Hussain et al., 2025; Javed et al., 2025; Muneer et al., 2025; Nawaz et al., 2025; ur Rehman et al., 2025). In parallel investigations, the importance of water conservation, building performance optimization, daylight use, life cycle assessment, carbon footprint reduction, and renewable energy integration for the sustainable built environment has also emerged (Akram et al., 2025; Akram et al., 2024; Akram et al., 2025; Akram et al., 2025; Akram, ul Haq, et al., 2024; Alshgari et al., 2024; Blouch et al., 2021; Malik et al., 2022; Naveed et al., 2024; Rashid et al., 2026). Besides, the studies on architectural heritage conservation, historic material characterization, climate-friendly architecture, adaptable and amphibious buildings, resilient urban infrastructure, sustainable project management, Industry 5.0, artificial intelligence, and green finance all show that they are multidisciplinary with the goal of helping to move towards environmentally friendly construction practices and resilient architectural engineering solutions (Abdullah et al., 2026; Akram et al., 2026; Akram, et al., 2026; Akram, et al., 2026; Akram et al., 2026; Akrama et al., 2023; Ali et al., 2025; Asghar et al., 2026; Khalil et al., 2024; Khalil et al., 2025; Khurshid et al., 2024; Nishtar et al., 2023; Zia et al., 2024) Even though these developments have taken place, most of the previous research has been on fired bricks, concrete and cement-based materials, whereas there is limited research to address the direct use of treated domestic wastewater in hand-molded sun-dried ind bricks. Thus, the present research aims to fill this gap of knowledge by experimenting with the physical and mechanical properties of wastewater-based sun-dried mud bricks, contributing to the saving of freshwater, valorisation of wastewater, implementation of the circular economy, and sustainable architecture engineering.

Previous studies have demonstrated the successful incorporation of wastewater treatment sludge, treated wastewater, industrial by-products, and recycled materials into sustainable brick production, achieving satisfactory engineering performance while promoting circular economy principles. (Amin et al., 2022; Centeno Mora et al., 2024; da Silva et al., 2024; Erdogmus et al., 2021; Gencel et al., 2022; Ghafoor et al., 2022; Limami et al., 2021; Mahanna et al., 2024; Moulato et al., 2023; Raza et al., 2020; Taherlou et al., 2021; Varshney et al., 2021) (Limani et al., 2021; Erdogmus et al., 2021; Amin et al., 2022; Gencel et al., 2022; Ghafoor et al., 2022; Moulato et al., 2023; da Silva et al., 2024; Mahanna et al., 2024; Centeno Mora et al., 2024; Raza et al., 2020; Taherlou et al., 2021; Varshney et al., 2021). However, most investigations have focused on fired clay or ceramic bricks using wastewater treatment sludge, with limited research on the direct use of treated domestic wastewater **in** hand-molded sun-dried mud bricks**.** Consequently, experimental evidence on the physical and mechanical performance of low-energy earthen bricks under natural curing conditions remains scarce, highlighting the need for further research to support sustainable, low-carbon, and affordable masonry construction.

Hence, the present study experimentally examines the possibility of using treated wastewater as a raw material for the hand-made production of sun-dried mud bricks. As opposed to past studies mainly focusing on the incorporation of sludge in fired clay bricks, this study investigates three mud-to-treated-wastewater mixing proportions, and the bricks are tested for their water absorptivity and compression strength. The results will support the development of sustainable architectural engineering, combining the use of wastewater, freshwater savings, the circular economy, and low-energy masonry production in a viable building material for sustainable built environments.

Research Gap

Although previous studies have demonstrated the feasibility of incorporating wastewater treatment sludge and other waste-derived materials into fired clay bricks, limited research has investigated the direct use of treated domestic wastewater as a mixing medium for hand-molded sun-dried mud bricks. (Amin et al., 2022; Areias et al., 2020; Detho et al., 2024; Erdogmus et al., 2021; Limami et al., 2021). Moreover, experimental evidence on their physical and mechanical performance under natural curing conditions remains scarce, particularly regarding water absorption and compressive strength. This gap limits the development of low-energy, low-carbon masonry materials for sustainable architectural engineering and water-scarce regions.

Research Objectives

To evaluate the feasibility of utilising treated domestic wastewater as an alternative mixing medium for the production of sustainable hand-moulded sun-dried mud bricks suitable for architectural and construction applications.

- To manufacture hand-moulded sun-dried mud bricks using different mud-to-treated-wastewater mixing ratios.
- To compare the engineering performance of mud bricks produced with different treated wastewater proportions and identify the optimum mixing ratio.
- To assess the potential of treated wastewater reuse in supporting sustainable architectural engineering, freshwater conservation, and circular economy practices.

Significance of the Study

In the building sector, it is becoming more and more difficult to create materials that meet the engineering needs and environmental and resource conservation requirements. This study demonstrates the feasibility of replacing freshwater with treated domestic wastewater in the production of hand-molded sun-dried mud bricks, promoting sustainable and low-energy construction. The findings support freshwater conservation, wastewater valorization, circular economy practices, and the development of affordable, low-carbon masonry materials for architectural engineering. Furthermore, the study contributes to the achievement of UN Sustainable Development Goals (SDGs) 6, 9, 11, 12, and 13 by encouraging resource-efficient and environmentally responsible construction practices.

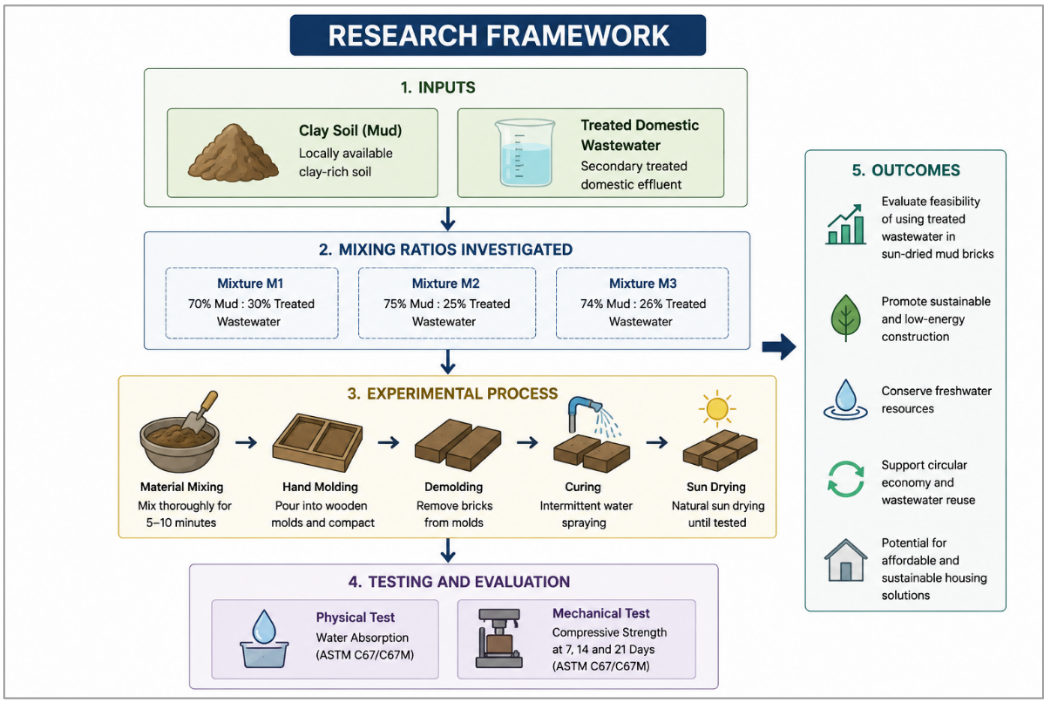
Materials and Methods

Research Design

The present study used an experimental laboratory method to assess the potential of using treated domestic wastewater as an alternative mixing material for hand-moulded sun-dried mud bricks. The experimental programme was aimed at evaluating the effect of various mixing ratios of mud and treated wastewater on the physical and mechanical properties of the bricks. Three different mixtures of mud and treated wastewater with proportions 70:30, 75:25 and 65:35 were prepared and tested. The water absorption and compressive strength tests were conducted after the specified curing durations, and the performance of each mixture was assessed. The experimental setup is shown in

Figure 1

Research Framework Adopted for the Development and Evaluation of Treated Wastewater-based Hand-moulded Sun-dried Mud Bricks



Materials

Mud

Locally available clay-rich soil (mud) was used as the primary raw material for brick production. The soil was selected because of its adequate plasticity and cohesive properties, making it suitable for manufacturing traditional sun-dried mud bricks. Before mixing, visible organic matter, stones, roots, and other impurities were manually removed to obtain a homogeneous material suitable for moulding.

Mud serves as the principal structural component of earthen bricks by providing cohesion, workability, and load-bearing capacity. In addition to its structural function, earthen materials exhibit relatively high thermal mass, enabling passive thermal regulation and improved indoor comfort in hot climates. These characteristics have contributed to the widespread use of mud bricks in traditional and sustainable architectural construction. (Ren & Kagi, 1995).

Treated Domestic Wastewater

The wastewater treated at a municipal wastewater treatment plant was instead used for mixing the mud brick mixtures, rather than potable water. The wastewater was treated using conventional secondary treatment processes designed to lower suspended solids, biodegradable organic material and micro-organisms before re-use to suit selected non-potable uses. The incorporation of treated wastewater in construction materials is an effective resource recovery measure that helps conserve freshwater resources, promotes the principles of a circular economy and minimises environmental impact from water treatment effluent. (Centeno Mora et al., 2024; Ghafoor et al., 2022; Raza et al., 2020).

The physicochemical characteristics of treated domestic wastewater can differ from one treatment technology to another and from one plant to another, depending on the operation of the water treatment plant. The reuse of treated wastewater in the construction industry for various materials like concrete has been studied, and secondary-treated domestic wastewater typically has a pH of 6.5 to 8.5, and TDS concentrations ranging from around 500 to 1,500 mg/L, with relatively low levels of suspended solids and dissolved organic matter, making it suitable for use in concrete production without compromising engineering (Raza et al., 2020; Taherlou et al., 2021; Varshney et al., 2021). The ranges reported in the literature are representative of the quality of domestic wastewater available in sustainable construction research for treating wastewater.

In contrast to previous studies that mainly applied wastewater treatment sludge or industrial wastes as admixtures in the fired clay brick production, the use of treated domestic wastewater as a mixing agent for hand-moulded sun-dried mud bricks was investigated in the present study, and the feasibility of using treated domestic wastewater as an alternative to freshwater in low-energy masonry was assessed.

Literature-Reported Properties of the Materials

The present study focused on evaluating the engineering performance of sun-dried mud bricks; detailed physicochemical characterisation of the treated wastewater was beyond the scope of the experimental programme. Therefore, literature-reported characteristics of secondary-treated domestic wastewater are presented to provide context regarding the quality of the mixing water typically employed in sustainable construction research. Future investigations should include comprehensive physicochemical analyses of wastewater, including pH, electrical conductivity, total dissolved solids, suspended solids, chemical oxygen demand, biological oxygen demand, chloride, sulfate, and heavy metal concentrations, to further evaluate their influence on the long-term performance and durability of earthen construction materials.

Table 2

Literature-reported Characteristics of Materials used in the Present Study

Material	Property	Typical Range	Source
Clay-rich soil	Plasticity	Moderate to high	(Ren & Kagi, 1995)
	Thermal conductivity	0.25–0.80 W/m·K	(Fernandes et al., 2010)
	Dry density	1500–1900 kg/m³	(Ren & Kagi, 1995)
Treated domestic wastewater	pH	6.5–8.5	(Raza et al., 2020; Varshney et al., 2021)
	TDS	500–1500 mg/L	(Taherlou et al., 2021; Varshney et al., 2021)
	Total Suspended Solids (TSS)	<30–50 mg/L*	(Centeno Mora et al.,; Raza et al., 2021)
	Biological Oxygen Demand (BOD_5)	<20–30 mg/L*	(Centeno Mora et al., 2024)

*Typical values reported for municipal secondary-treated effluent; actual values depend on treatment technology and plant operating conditions.

Preparation of Brick Specimens

Hand-moulded mud bricks were manufactured using traditional brick-making procedures. Three different mud-to-treated-wastewater mixing ratios were investigated:

Table 3

Experimental Mix Designs of Hand-moulded Sun-dried Mud Bricks Prepared with Different Clay Soil and Treated Domestic Wastewater Proportions

Specimen	Mud (%)	Treated Wastewater (%)
M1	70	30
M2	75	25
M3	65	35

For each mixture, the required quantity of mud was thoroughly blended with treated wastewater until a uniform and workable consistency was achieved. The fresh mixture was manually placed into rectangular wooden moulds having nominal dimensions of 228.6 mm × 114.3 mm × 76.2 mm (9 × 4.5 × 3 in.), corresponding to the dimensions commonly adopted for traditional mud bricks. After moulding, excess material was removed from the surface to ensure dimensional uniformity, and the specimens were carefully demoulded immediately after shaping. No cement, lime, chemical additives, or industrial stabilisers were incorporated during brick production to maintain the traditional composition of sun-dried mud bricks.

Figure 1

Manual Preparation of the Clay–treated Wastewater Mixture before Placement into Brick Moulds

Figure 2

Manual Filling and Compaction of the Homogeneous clay, Treated Wastewater Mixture into

Curing Procedure

Following moulding, the brick specimens were cured under natural outdoor conditions through sun drying. The specimens were placed on a level surface and exposed to ambient environmental conditions throughout the curing period. To minimise excessive moisture loss and reduce surface cracking during early-age curing, intermittent water spraying was applied as required. Compressive strength specimens were tested after 7, 14, and 21 days of curing to evaluate strength development over time.

Figure 3

Hand-molded Mud Bricks During the Natural Curing Process Through Sun Drying Rectangular Wooden Molds before Curing

Figure 4

Cured Hand-moulded Mud Brick Produced using Treated Domestic Wastewater before Physical and Mechanical Testing

Water Absorption Test

The water absorption characteristics of the brick specimens were determined in accordance with ASTM C67/C67M-24 (American Society for & Materials, 2014; Siddquy et al., 2026). After completing the curing period, one representative specimen from each mixture was oven-dried to a constant mass and weighed to determine its dry weight (W_d). The specimen was subsequently immersed completely in clean water for 24 hours at room temperature. After immersion, excess surface water was removed using a damp cloth, and the saturated specimen was immediately weighed to obtain the wet weight (W_w).

Water absorption was calculated gravimetrically using Equation (1):

$$WA\ (\%) = \frac{W_s - W_d}{W_d} * 100$$

Where W_s is the saturated weight, and W_d is the dry weight of the sample (Gardner, 1986; Lee & Nho, 2001).

The measured water absorption values were compared among the different mixing ratios to evaluate the influence of treated wastewater on moisture uptake characteristics (Costigan & Pavía, 2010).

Compressive Strength Test

The compressive strength of the hand-moulded mud bricks was determined using a Universal Testing Machine (UTM) following the general procedures outlined in ASTM C67 (American Society for & Materials, 2014; Siddquy et al., 2026). Three specimens were tested for each mixture at curing ages of 7, 14, and 21 days. Each specimen was centrally positioned between the loading platens of the testing machine, and compressive load was applied continuously until failure occurred. The maximum failure load was recorded for each specimen. The average compressive strength of the three specimens was reported for each curing period.

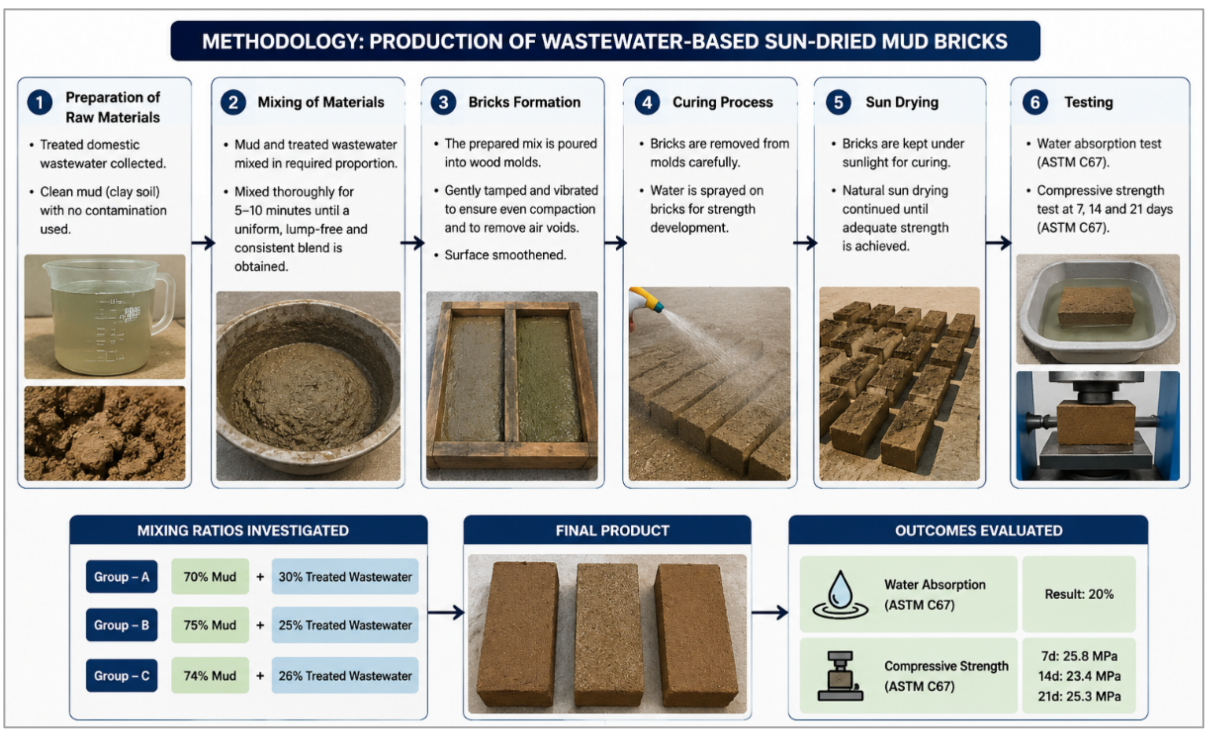
Compressive strength was calculated using Equation (2):

$$fc = \frac{P}{A}$$

Where f_c is the compressive strength (MPa), P is the maximum applied load (N), and A is the loaded cross-sectional area (mm^2)

Figure 5

Experimental Methodology for Manufacturing and Testing Treated Wastewater-based Hand-moulded Sun-dried Mud Bricks



Results and Discussion

Water Absorption

Water absorption is one of the most important indicators of the quality and durability of earthen masonry units because it reflects the pore structure and moisture permeability of the material. Excessive water absorption generally indicates higher porosity, which may adversely affect the durability and long-term performance of masonry units. The water absorption test was conducted following ASTM C67/C67M (Siddquy et al., 2026) using one representative specimen after 24 hours of complete water immersion. The dry and saturated weights of the brick were recorded, and the percentage of water absorption was calculated using Equation (1).

Table 4

Water Absorption Results

Dry Weight (W_1)	Saturated Weight (W_2)	Water Absorption (%)
3.0 kg	3.6 kg	20

The tested specimen exhibited a water absorption value of 20%, indicating that the brick was capable of absorbing moisture while maintaining structural integrity after immersion.

Figure 6

Prepared Hand-moulded Sun-dried Mud Brick Specimens were Placed in a Laboratory Drying oven for Specimen Conditioning before Testing

The measured 20% water absorption satisfies the maximum limit specified in ASTM C62, indicating acceptable moisture absorption characteristics for masonry applications. The moderate absorption can be attributed to the dense hand-molding process, well-graded clay soil, and controlled natural curing, which enhanced particle bonding and minimized shrinkage cracks.The water absorption value obtained is rather in accordance with previous research carried out on sustainable masonry materials using wastewater and waste resources. Ghafoor et al. (2022) found that treated wastewater (TWW) can be employed to produce bricks without any compromise on water absorption properties, meeting a satisfactory level for brick production (Ghafoor et al., 2022). Likewise, some research has been conducted that showed that the use of wastewater treatment residues in the production of bricks did not significantly affect the moisture resistance of bricks, provided that the proper proportion of materials was used (Amin et al., 2022; Gencel et al., 2022; Limami et al., 2021).

The experimental results showed that the hand-molded sun-dried mud bricks exhibited a water absorption of 20%, meeting the permissible limit for conventional clay bricks. This indicates that replacing freshwater with treated domestic wastewater did not adversely affect the moisture absorption characteristics of the bricks. The findings support the feasibility of producing durable, low-energy earthen masonry units while promoting freshwater conservation and sustainable construction practices.

Compressive Strength

The compressive performance of the hand-moulded sun-dried mud bricks was evaluated after 7, 14, and 21 days of natural curing in accordance with ASTM C67/C67M (Siddquy et al., 2026). Three mix designs, designated as M1 (70% mud: 30% treated wastewater), M2 (75% mud: 25% treated wastewater), and M3 (65% mud: 35% treated wastewater), were tested at each curing age. The Universal Testing Machine recorded the maximum failure load (kN), which was converted into compressive strength using the loaded area of 228.6 × 114.3 mm (26,122.98 mm²).

Figure 7

Experimental Brick Specimens after Curing and Labelling, Ready for Compressive Strength Testing using the UNIVERSAL Testing Machine (UTM)

The average failure loads were 25.8 kN, 23.4 kN, and 25.3 kN after 7, 14, and 21 days, corresponding to average compressive strengths of 0.99 MPa, 0.90 MPa, and 0.97 MPa, respectively. Among the three mix designs, M3 (65% mud: 35% treated wastewater) generally exhibited the highest failure loads during the early curing stages (30.0 kN at 7 days and 28.1 kN at 14 days), whereas M2 (75% mud: 25% treated wastewater) achieved the highest load at 21 days (29.5 kN). In contrast, M1 (70% mud: 30% treated wastewater) consistently recorded the lowest failure loads throughout the curing period. The small variation in compressive strength between curing ages suggests that most of the strength development occurred during the early stages of curing and remained relatively stable thereafter. This behaviour is characteristic of unstabilized earthen materials, where strength gain is primarily governed by moisture loss and particle interlocking rather than cementitious hydration.

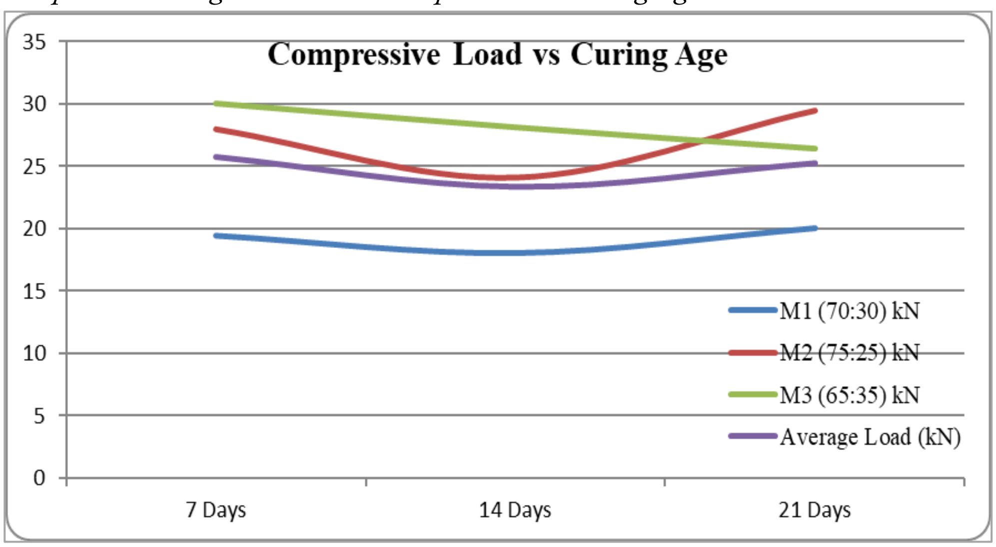
Table 5

Compressive Strength Results of Different Mix Proportions

Curing Age	M1 (70:30) (kN)	M2 (75:25) (kN)	M3 (65:35) (kN)	Average Load (kN)	Average Strength (MPa)
7 Days	19.4	28.0	30.0	25.8	0.99
14 Days	18.0	24.1	28.1	23.4	0.90
21 Days	20.0	29.5	26.4	25.3	0.97

Figure 8

Compressive Strength Trend with Respect to the Curing Age



The compressive strength tests showed that domestic wastewater can be effectively used as a mixing material in the production of handmade sun-dried mud brick without affecting the mechanical strength of the bricks. Only slight differences in average values of compressive strength were noticed in the three curing periods: 0.90-0.99 MPa. These values suggest that under natural curing conditions, the bricks built a stable load-bearing capacity, and they were within the range of typical values reported for the load-bearing capacity of unstabilized earthen building materials.

In the early curing period up to 7 days, the compressive loads for the three mix proportions were in the order of M3 (65% mud:35% treated wastewater) > M2 (75% mud:25% treated wastewater) > M1 (80% mud:20% treated wastewater). After curing for 14 days, M2 (75% mud: 25% treated wastewater) recorded the highest load (29.5 kN) while M3 (65% mud: 35% treated wastewater) recorded the lowest load (28.1 kN). M1 (80% mud: 20% treated wastewater) showed slightly lower loads after 21 days of curing. The differences between the three mixtures are relatively small, indicating that the compressive behaviour of the bricks was not greatly affected by moderate changes in the amount of treated wastewater in the mixtures. The results of this observation show that the moisture level for the desired range of wastewater replacement (25–30%) was adequate to ensure the cohesive properties of the clay matrix while allowing moulding.

The satisfactory compressive strength can be attributed to the combined effects of plastic clay soil, dense hand-molding, manual compaction, and controlled sun-curing, which enhanced particle packing and reduced internal voids. The mineral content of treated domestic wastewater may have further improved interparticle bonding without adversely affecting the structural integrity of the bricks. Although the measured strengths (0.90–0.99 MPa) are lower than those of fired clay bricks, they fall within the typical range reported for unstabilized sun-dried mud bricks**,** demonstrating their suitability for low-carbon, low-rise, and vernacular construction applications.The novelty of the present study is further emphasised by comparing it with previous investigations. Ghafoor et al. (2022) demonstrated the feasibility of using treated wastewater in the manufacturing of fired clay bricks (Ghafoor et al., 2022)**,** while Amin et al. (2022) and Limani et al. (2021) mainly emphasized utilization of wastewater treatment sludge in fired or ecological earth bricks (Amin et al., 2022; Limami et al., 2021). In the same vein, Mahanna et al. (2024) studied fired structural bricks made from sludge (Mahanna et al., 2024) and Padilla et al. (2024) explored the technical, environmental and economic viability of using reclaimed wastewater for masonry manufacturing (Centeno Mora et al., 2024). The present study, however, directly used treated domestic wastewater as mixing water for hand-moulded sun-dried mud bricks, which avoided the energy and greenhouse gas use incurred from firing of conventional bricks in a kiln.

From an architectural engineering perspective, the results demonstrate that treated wastewater-based sun-dried mud bricks are a viable low-carbon material for affordable housing, rural development, and climate-responsive construction. Their use promotes freshwater conservation, wastewater reuse, and circular economy principles, making them particularly suitable for water-scarce developing countries such as Pakistan.

Engineering Implications and Practical Applications

The investigated mud-to-treated-domestic-wastewater mixing ratios (70:30, 75:25, and 65:35) produced hand-molded sun-dried mud bricks with satisfactory workability, dimensional stability, water absorption, and compressive strength, demonstrating that treated domestic wastewater can effectively replace freshwater without adversely affecting the engineering performance of earthen masonry. From an architectural engineering perspective, the proposed low-energy production method supports affordable housing, vernacular architecture, and climate-responsive construction while reducing freshwater consumption, embodied energy, and greenhouse gas emissions associated with conventional fired bricks. Furthermore, the reuse of treated wastewater promotes circular economy principles by converting an underutilized waste resource into a valuable construction material, making the approach particularly suitable for water-scarce developing countries such as Pakistan. The proposed technology contributes to the achievement of SDGs 6, 11, 12, and 13 by encouraging wastewater reuse, sustainable construction materials, responsible resource utilization, and low-carbon building practices. Table 6 summarizes the key differences between previous wastewater-based brick studies and the proposed hand-molded sun-dried mud brick developed in this research.

Table 6

Comparison of the Present study with Previous Research on Wastewater-based Brick Production

Study	Brick Type	Waste Material	Main Evaluation	Key Findings	Advancement in the Present Study
(Ghafoor et al., 2022)	Fired clay brick	Treated wastewater	Water absorption, compressive strength	Treated wastewater successfully replaced potable water in fired bricks while maintaining engineering properties.	Extends wastewater reuse to hand-moulded sun-dried mud bricks, eliminating kiln firing.
(Limami et al., 2021)	Earth brick	Wastewater treatment sludge	Physical, thermal and environmental performance	Sludge improved sustainability without significant environmental risks after treatment.	Uses treated domestic wastewater instead of sludge, simplifying material preparation.
(Amin et al., 2022)	Burnt clay brick	Wastewater treatment sludge	Mechanical and chemical properties	WTS can partially replace conventional clay in brick production.	Replaces mixing water rather than clay, preserving the natural earthen composition.
(Centeno Mora et al., 2024)	Construction brick	Reclaimed wastewater	Technical, environmental and economic feasibility	Wastewater reuse reduced freshwater demand and supported circular economy objectives.	Provides experimental verification through physical and mechanical testing of sun-dried bricks.
(Mahanna et al., 2024)	Fired structural brick	Water treatment sludge	Mechanical and physical properties	Sludge and agricultural wastes produced structurally acceptable fired bricks.	Demonstrates a low-energy, non-fired alternative for sustainable construction.
Present Study	Hand-moulded sun-dried mud brick	Treated domestic wastewater	Water absorption and compressive strength	Produced acceptable water absorption (20%) and high compressive strength while eliminating kiln firing and conserving freshwater.	Integrates architectural engineering, water conservation, circular economy, and low-carbon earthen construction.

Conclusion

This study aimed to promote sustainable construction, freshwater conservation and circular use of resources by evaluating the feasibility of using treated domestic wastewater as an alternative mixing material for the production of hand-moulded sun-dried mud bricks. The brick specimens were produced using a conventional hand-moulding method with three mixing ratios of mud to treated wastewater (70:30, 75:25 and 65:35) and were sun-dried in the open sun with intermittent water spray. Water absorption and compressive strength tests were conducted on the bricks per ASTM specifications in order to obtain their physical and mechanical performance. The experimental results showed that the bricks obtained possessed a water absorption rate as 20%, which is the usual requirement in masonry work. Similarly, the compressive strength tests showed the average strength of hand-moulded sun-dried mud bricks as 25.8 MPa, 23.4 MPa and 25.3 MPa at 7, 14 and 21 days curing periods, respectively, which shows that the use of treated domestic wastewater did not adversely affect the engineering performance of hand-moulded sun-dried mud bricks. Mechanical performance even showed high values, which indicates that treated wastewater can be used effectively in the mud brick production process under the conditions adopted.

The relatively high compressive strengths achieved in the present investigation could be explained by the various factors involved, such as the type of soil used, which is clayey, the density of hand moulding, the controlled curing conditions, and the physicochemical properties of the domestic wastewater treated. It is not experimentally proven what the chemical composition of the treated wastewater was, but the results show that the use of treated wastewater did not affect the structure of the bricks. On the contrary, the outcome shows that it is technically viable to use treated wastewater for the sustainable production of earthen masonry.

From an architectural engineering point of view, this research offers a green strategy for the production of low-energy building materials for residential projects in the field of affordable housing and vernacular architecture. The proposed production method does not require fired clay brick kiln firing, which avoids additional embodied energy, greenhouse gas emissions and reliance on non-renewable fuel resources. At the same time, reusing treated domestic wastewater productively promotes the conservation of freshwater resources, as well as the principles of the circular economy by turning the underutilised waste resource into a valuable construction material. This research also builds on the previous studies by considering treated domestic wastewater instead of wastewater treatment sludge and fired clay bricks for direct use in hand-moulded sun-dried mud bricks. The results indicate that wastewater reuse is an alternative way to produce earthen masonry that can be used as a sustainable solution to this problem and can be used as a scientific basis for future studies on the use of environmentally friendly materials in the construction industry in areas where water is scarce.

While these promising results are welcome, some limitations should be noted. A relatively small number of laboratory specimens and wastewater from a single wastewater treatment source were used in the experimental programme. This particular engineering evaluation was limited to water absorption and compressive strength, and other important performance characteristics such as flexural strength, shrinkage, abrasion resistance, thermal conductivity, acoustic insulation, durability against environmental exposure and long-term service performance were not included in this investigation. Moreover, the treated wastewater was not comprehensively characterised in terms of the physicochemical parameters, and detailed microstructural analyses of the bricks were also not conducted. This means that the observed mechanical behaviour could not be directly verified by the mechanisms responsible. In addition, the present study did not incorporate economic or life-cycle assessments or environmental safety testing, such as heavy-metal leaching and microbiological tests.

In the future, detailed physicochemical characteristics of treated wastewater should be studied in combination with advanced microstructural analysis techniques, e.g., Scanning Electron Microscopy (SEM), Energy Dispersive X-ray Spectroscopy (SEM–EDS), X-ray Diffraction (XRD) and X-ray Fluorescence (XRF), to gain further insights into the interactions and bonding between particles. Long-term durability tests should also be carried out under wetting–drying, freeze–thaw, sulfate attack, weathering and erosion. Further research is needed to assess the thermal conductivity, moisture transport properties, acoustic properties and the indoor environmental properties of wastewater-based mud bricks for use in climate-responsive building applications. Heavy metal leaching and contaminant migration analysis should be done to ensure environmental safety, and Life Cycle Assessment (LCA) and Life Cycle Cost Analysis (LCCA) should be carried out to estimate the environmental and economic impacts of wastewater reuse. Last but not least, the pilot scale production, field tests and commercial scale production with several wastewater treatment plants and soil types are recommended to assess the practical use of the proposed technology and to support its application to sustainable architectural engineering practice.

In general, the present study reveals the treated domestic wastewater as a good potential alternative to freshwater for hand-moulded sun-dried mud bricks, which has several engineering, environmental and sustainability advantages. The proposed approach is especially applicable in the context of water conservation, resource recovery and low-carbon construction and has potential applications for the provision of affordable housing and sustainable infrastructure in water-challenged areas like Pakistan.

References

Abdullah, M., Saleem, A., Blouch, N., Akram, N., Deo, M. I., & Khalil, A. (2026). Integrated Architectural Documentation and Multi-Analytical Characterisation of Historic Lime Mortars in the Tomb of Ali Mardan Khan, Lahore, Pakistan. *The Critical Review of Social Sciences Studies, 4*(1), 5479-5504. https://doi.org/10.59075/p30qd634

Akram, M. M., Mateen, M. F., Akram, N., Butt, A. W., Khurshid, A. M. M., Shahid, A. R., & Khalil, A. (2026). Multi-Analytical Characterization Of Historic Lime Mortars For Sustainable Heritage Conservation: Evidence From The Tomb Of Nadira Begum, Lahore, Pakistan. *Pakistan Journal of Social Science Review, 5(*6), 792-817. http://www.pjssrjournal.com/index.php/Journal/article/view/988

Akram, N., Ashraf, M. Z., Jamil, M., Hasan, B., & ul Haq, M. (2025). Green Concrete: Enhancing Strength And Workability For Sustainable Construction. *Kashf Journal of Multidisciplinary Research, 2*(07), 87-120. https://doi.org/10.71146/kjmr539

Akram, N., Blouch, N., Malik, A. M., Sher, F., Mukhtar, R., & Khan, W. R. (2025). Building Performance Analysis and Optimization: A Study on Energy Efficiency and Sustainability. *Social Science Review Archives, 3*(4), 702-712. https://doi.org/10.70670/sra.v3i4.1161

Akram, N., Deo, A. M. I., ul Haq, M., Kamal, A. S., & Khalil, A. (2026). Exploring Tidal Architecture: Amphibious Building Systems for Coastal Communities in Flux. *Social Science Review Archives, 4*(1), 1357-1364. https://doi.org/10.70670/sra.v4i1.1652

Akram, N., Malik, A. M., Khan, W. R., Zulfiqar, S., & Rashid, M. (2026). EXPLORING ADAPTABLE ARCHITECTURE FOR CLIMATE MIGRATION COMMUNITIES. *Spectrum of Engineering Sciences, 4*(2), 718-727. https://www.thesesjournal.com/index.php/1/article/view/2107

Akram, N., Malik, A. M., Mukhtar, R., Shahid, S., & Khan, W. R. (2026). Architectural Responses to Extreme Heat: Designing For 50° C Cities of Punjab, Pakistan. *ASSAJ, 5*(01), 759-769. https://www.assajournal.com/index.php/36/article/view/1366

Akram, N., Malik, A. M., Zahra, F. T., & Deo, M. I. (2026). Assessing Life-Cycle Cost And Carbon Footprint Of Lighting Upgrades In Grade I And Ii Listed Buildings. *Research Consortium Archive, 4*(2), 1771-1783. http://www.rcresearcharchive.com/index.php/Journal/article/view/796

Akram, N., Mubin, S., Malik, A. M., Imran, R., & Jamil, M. (2024). Decoding the Interplay of Lighting and Spatial Dynamics: A Simulation-Based Case Study Analysis across Diverse Building Orientations. Metallurgical and Materials Engineering, 30(4), 434-458. https://doi.org/10.63278/10.63278/mme.v31.1

Akram, N., Nadeem, G., Malik, A. M., Sher, F., Zulfiqar, Z., & Tahir, S. (2025). Optimizing Daylight Using Passive Strategies: Light Shelves and Solar Tubes. Spectrum of Engineering Sciences, 474-489. https://www.thesesjournal.com/index.php/1/article/view/480

Akram, N., ul Haq, M., Khalil, A., Zaman, L., Fahad, M., & Asghar, F. (2024). Shedding Light on Financial Sustainability: Data driven insights of the Economic Implications of Energy-Efficient Lighting in the Construction Industry. The Asian Bulletin of Big Data Management, 4(02), 1-19.

Akram, N., Farooq, P., Haq, M. U., Nabeel, M., & Asghar, F. (2024). Evaluating the financial feasibility of renewable energy integration in construction sector. *THE ASIAN BULLETIN OF GREEN MANAGEMENT AND CIRCULAR ECONOMY*, *4*(1), 1-15. https://doi.org/10.62019/abgmce.v4i1.57

Akram, N., Hussain, A., & Naheed, K. (2023). Moderation of uncertain circumstances among the relationships of strategic management and adaptation challenges on operational efficiency of construction firms. *Journal of Law & Social Studies*, *5*(2), 223-240. https://doi.org/10.52279/jlss.05.02.223240

Akram, N., Mubin, S., Masood, R., Malik, A. M., Aeem, S. N., Gulzar, R., Amer, K., & Rashid, M. (2025). Beyond illumination: Stakeholders perspectives and preferences on eco-friendly lighting for sustainable cities. *Metallurgical and Materials Engineering*, *31*(1), 249-276. https://doi.org/10.63278/mme.v31i1.1837

Akram, N., Gul, M. S., Nazir, M. W., Asghar, F., & Atta, F. (2023). Unlocking sustainable horizons: Explaining the role of green finance in advancing sustainable construction practices among building professionals. *Journal of Economic Impact*, *5*(3), 217-224. https://doi.org/10.52223/econimpact.2023.5306

Ali, M., Akram, N., & Imran, R. (2025). Infrastructure Gaps in Rapidly Expanding Urban Areas: A Case Study of Taluka Khairpur. *Dialogue Social Science Review (DSSR), 3*(1), 997-1007.

Alshgari, R. A., Shah, S. I., Blouch, N., Manzoor, S., Nisa, M. U., Ashiq, M. F., Ur Rehman, M. Y., Mohammad, S., & Ehsan, M. F. (2024). Facile fabrication of bismuth vanadate grafted carbon nanotubes composite for enhanced oxygen evolution reaction. *Journal of Electroanalytical Chemistry*, *954*, 118025. https://doi.org/10.1016/j.jelechem.2024.118025

American Society for, T., & Materials. (2014). *Standard test methods for sampling and testing brick and structural clay tile*. ASTM International.

Amin, F., Abbas, S., Abbass, W., Salmi, A., Ahmed, A., Saeed, D., Sufian, M., & Sayed, M. M. (2022). Potential use of wastewater treatment plant sludge in fabrication of burnt clay bricks. *Sustainability*, *14*(11), 6711. https://doi.org/10.3390/su14116711

Shakir, A., & Ahmed Mohammed, A. (2013). Manufacturing of bricks in the past, in the present and in the future: A state of the art review. *International Journal of Advances in Applied Sciences*, *2*(3). https://doi.org/10.11591/ijaas.v2i3.1751

Areias, I., Vieira, C., Colorado, H., Delaqua, G., Monteiro, S., & Azevedo, A. (2020). Could city sewage sludge be directly used into clay bricks for building construction? A comprehensive case study from Brazil. *Journal of Building Engineering*, *31*, 101374. https://doi.org/10.1016/j.jobe.2020.101374

Arshad, W., Akram, N., Kamal, A. S., ul Haq, M., Khurshid, A. M. M., & Qayyum, A. A. (2025). ECO-FRIENDLY CONCRETE: MERGING FLY ASH AND HEMP FOR GREEN BUILDING PRACTICES. *Spectrum of Engineering Sciences*, 1000-1019. https://www.thesesjournal.com/index.php/1/article/view/552

Akram, N., Asghar, F., Abbas, K., Abbasi, M. H., & Bangash, S. A. (2026). Industry 5.0, human-centric innovation, and green operational efficiency: Evidence from smart sustainable workflows. *The Asian Bulletin of Big Data Management*, *6*(1), 1-14. https://doi.org/10.62019/evs0zb74

Asif, M., Akram, N., Khurshid, M. M., Kaynat, A., Naeem, S., Malik, A. M., & Muti ul Haq. (2025). Recycling agricultural waste for green concrete: The case of palm oil ash. *THE PROGRESS: A Journal of Multidisciplinary Studies*, *6*(3), 27-42. https://doi.org/10.71016/tp/vgwqry20

Beshah, D. A., Tiruye, G. A., & Mekonnen, Y. S. (2021). Characterization and recycling of textile sludge for energy-efficient brick production in Ethiopia. *Environmental Science and Pollution Research*, *28*(13), 16272-16281. https://doi.org/10.1007/s11356-020-11878-7

Blouch, N., Akram, N., Malik, A. M., Rashid, M., & Siddiqui, F. A. (2021). Economic Feasibility of Energy Saving by Incorporating Daylight: A Case Study of College Building in Multan-Pakistan. *Technical Journal of University of Engineering & Technology Taxila, 26*(2).

Blouch, N., Kazmi, S. N., Akram, N., Saleem, M. J., Khan, I. A., Javed, K., Ahmad, S., & Khan, A. (2025). Performance evaluation of low-grade clay minerals in LC3-based cementitious composites. *Solids*, *6*(3), 35. https://doi.org/10.3390/solids6030035

Blouch, N., Kazmi, S. N., Metwaly, M., Akram, N., Mi, J., & Hanif, M. F. (2025). Towards sustainable construction: Experimental and machine learning-based analysis of wastewater-integrated concrete pavers. *Sustainability*, *17*(15), 6811. https://doi.org/10.3390/su17156811

Centeno Mora, E., Padilla, C. M., & Cruz Zúñiga, N. (2024). Wastewater reclamation for the production of construction bricks: Technical, economic, and environmental feasibility. *Water Science & Technology*, *90*(7), 2201-2214. https://doi.org/10.2166/wst.2024.317

Costigan, A., & Pavía, S. (2012). Influence of the mechanical properties of lime mortar on the strength of brick masonry. *RILEM Bookseries*, 359-372. https://doi.org/10.1007/978-94-007-4635-0_28

Da Silva, J. B., Zat, T., Werner, E. S., Brehm, F. A., Gonçalves, J. P., Souza, M. T., & Rodríguez, E. D. (2024). Recycling of municipal sewage sludge from Brazilian wastewater treatment plants for the manufacture of environmentally friendly ceramic bricks. *Case Studies in Construction Materials*, *21*, e03610. https://doi.org/10.1016/j.cscm.2024.e03610

Detho, A., Kadir, A. A., & Ahmad, S. (2024). Utilization of wastewater treatment sludge in the production of fired clay bricks: An approach towards sustainable development. *Results in Engineering*, *21*, 101708. https://doi.org/10.1016/j.rineng.2023.101708

Erdogmus, E., Harja, M., Gencel, O., Sutcu, M., & Yaras, A. (2021). New construction materials synthesized from water treatment sludge and fired clay brick wastes. *Journal of Building Engineering*, *42*, 102471. https://doi.org/10.1016/j.jobe.2021.102471

Fernandes, F. M., Lourenço, P. B., & Castro, F. (2010). Ancient clay bricks: manufacture and properties. In *Materials, technologies and practice in historic heritage structures (pp. 29-48).* Springer.

Gardner, W. H. (1986). Water content. *SSSA Book Series*, 493-544. https://doi.org/10.2136/sssabookser5.1.2ed.c21

Gencel, O., Kizinievic, O., Erdogmus, E., Kizinievic, V., Sutcu, M., & Muñoz, P. (2022). Manufacturing of fired bricks derived from wastes: Utilization of water treatment sludge and concrete demolition waste. *Archives of Civil and Mechanical Engineering*, *22*(2). https://doi.org/10.1007/s43452-022-00396-7

Ghafoor, S., Hameed, A., Shah, S., Azab, M., Faheem, H., Nawaz, M., & Iqbal, F. (2022). Development of construction material using wastewater: An application of circular economy for mass production of bricks. *Materials*, *15*(6), 2256. https://doi.org/10.3390/ma15062256

Nasir, H., Akram, N., S., Husnain, A., Ahsan, K., & Saud, K. (2025). Low-carbon concrete using agro-waste eggshell powder and mineral fillers. *Journal of Architecture and Built Environment Research (JABER)*, *2*(1). https://doi.org/10.51846/jaber.v2i1.4494

Javed, M. F., Akram, N., Malik, A. M., Khan, W. R., Asim, Z., & Rashid, M. (2025). Biochar-Based Concrete Blocks from Rice Husk: A Sustainable Solution for Low-Carbon Construction. *Spectrum of Engineering Sciences*, 687-707. https://thesesjournal.com/index.php/1/article/view/860

Khalil, A., Akram, N., Ul haq, M., Malik, A. M., & Asif, S. H. (2024). Tracing the ethereal: Exploring aesthetic heritage and cultural identity in historic gardens - A case study of shalimar garden. *Journal of Arts & Social Sciences*, *11*(1), 37-47. https://doi.org/10.46662/jass.v11i1.444

Khalil, A., Akram, N., Malik, A. M., Kaynat, A., & Zulfiqar, Z. (2025). Bagh-E-Jinnah, Lahore: Contextualising its historical evolution and socio-cultural significance. *Qlantic Journal of Social Sciences and Humanities*, *6*(3), 230-243. https://doi.org/10.55737/qjssh.vi-iii.25405

Khurshid, M. M., Akram, N., Blouch, N., Ashraf, M. Z., Imran, R., Malik, A. M., Haq Qureshi, M. A., Ul haq, M., Sultan, T., & Siddique, F. A. (2024). Material characterization and condition assessment of historic wall mortar at Poonch house, Lahore, Pakistan: Implications for compatible conservation. *Lex localis - Journal of Local Self-Government*, 66-87. https://doi.org/10.52152/803023

Lee, Y. K., & Nho, Y. C. (2001). *Utilization of natural polysaccharides by radiation in Korea*.

Li, P., Sun, F., Dong, Y., Wen, L., Lin, L., & LI, X. (2025). Utilization of drinking water treatment sludge with coal fly ash to make permeable bricks for low impact development. *Resources, Conservation and Recycling*, *212*, 107932. https://doi.org/10.1016/j.resconrec.2024.107932

Limami, H., Manssouri, I., Cherkaoui, K., & Khaldoun, A. (2021). Recycled wastewater treatment plant sludge as a construction material additive to ecological lightweight earth bricks. *Cleaner Engineering and Technology*, *2*, 100050. https://doi.org/10.1016/j.clet.2021.100050

Lourenço, P. B., Fernandes, F. M., & Castro, F. (2009). Handmade clay bricks: Chemical, physical and mechanical properties. *International Journal of Architectural Heritage*, *4*(1), 38-58. https://doi.org/10.1080/15583050902871092

Mahanna, H., Salah, H., Mansour, A., Elareed, A., Abadel, A. A., Nehdi, M., & Tahwia, A. M. (2024). Eco-efficient reuse of alum-based water treatment sludge into structural sintering bricks. *Case Studies in Construction Materials*, *20*, e03011. https://doi.org/10.1016/j.cscm.2024.e03011

Malik, A. M., Blouch, N., & Akram, N. (2022). Opening the black box of water conservation behavior: Holistic perspective of a developing country. *Pakistan Journal of Social Research*, *04*(04), 1096-1105. https://doi.org/10.52567/pjsr.v4i04.1269

Mohammed, A. (2013). Manufacturing of Bricks in the Past, in the Present and in the Future: A state of the Art Review. *International Journal of Advances in Applied Sciences*, *2*(3) https://doi.org/10.11591/ijaas.v2i3.1751

Moulato, K., Ammari, M., & Ben, A. L. (2023). *Performance of sewage sludge reuse in the manufacturing of fired bricks*.

Muneer, A., Akram, N., ul Haq, M., Khurshid, A. M. M., Qayyum, A. A., & Kamal, A. S. (2025). USE OF AGROINDUSTRIAL WASTE AS SUPPLEMENTARY CEMENTITIOUS MATERIALS IN MORTAR: A STUDY ON SUGARCANE BAGASSE ASH AND SILICA FUMES. *Annual Methodological Archive Research Review*, *3*(6), 353-380.

Naveed, A., Bukhari, S. M. A., Husnain, N., Baloch, N., Noor, S., Ahmad, W., Sarfraz, S., Wajahat, N., & Siddiqui, F. A. (2024). Structural Integrity and Cost Analysis of a Connecting Rod for Articulated Robotic Arm Using Various Stainless Steel and Aluminium Alloys. *Technical Journal of University of Engineering & Technology Taxila, 29*(2).

Nawaz, S., Akram, N., Sher, F., Tahir, S., Khan, W. R., Malik, A. M., & Siddique, F. A. (2025). AGRO-WASTE-BASED CEMENT SUBSTITUTION: SYNERGISTIC EFFECTS OF GREEN GRAM POD ASH AND EGGSHELL POWDER ON CONCRETE STRENGTH. *Kashf Journal of Multidisciplinary Research, 2*(09), 208-226. https://doi.org/10.71146/kjmr630

Nishtar, Z., Munir, M. A., Akram, N., Masood, B., Asghar, F., & Meahrayen, M. A. (2023). Green finance and the automate solar tracking system: Assessing efficiency, financial impact, and environmental benefits. *Inverge Journal of Social Sciences*, *2*(3), 134-147. https://doi.org/10.63544/ijss.v2i3.61

Olaiya, B. C., Lawan, M. M., Olonade, K. A., & Abubakar, S. A. (2025). Development of sustainable sandcrete bricks using industrial and agricultural waste. *Scientific Reports*, *15*(1). https://doi.org/10.1038/s41598-025-02308-0

Rashid, K., Blouch, N., Fatima, M., & Zhang, M. (2026). Synergistic mechanical and chemical activation of kaolin clays for enhanced reactivity in limestone calcined clay cement (LC3). *Sustainable Materials and Technologies*, *47*, e01876. https://doi.org/10.1016/j.susmat.2026.e01876

Raza, A., Shah, S. A., Kazmi, S. N., Ali, R. Q., Akhtar, H., Fakhar, S., Khan, F. N., & Mahmood, A. (2020). Performance evaluation of concrete developed using various types of wastewater: A step towards sustainability. *Construction and Building Materials*, *262*, 120608. https://doi.org/10.1016/j.conbuildmat.2020.120608

Ren, K., & Kagi, D. (1995). Upgrading the durability of mud bricks by impregnation. *Building and Environment*, *30*(3), 433-440. https://doi.org/10.1016/0360-1323(94)00056-x

Siddquy, M. A., Hossain, Z., & Islam, M. Y. (2026). Effects of controlled and ambient curing conditions on the mechanical and microstructural performance of RHA-based greencrete blocks. *Discover Sustainability*, *7*(1). https://doi.org/10.1007/s43621-026-03138-4

Taherlou, A., Asadollahfardi, G., Salehi, A. M., & Katebi, A. (2021). Sustainable use of municipal solid waste incinerator bottom ash and the treated industrial wastewater in self-compacting concrete. *Construction and Building Materials*, *297*, 123814. https://doi.org/10.1016/j.conbuildmat.2021.123814

Sami ur Rehman, Blouch, N., Jamil, S., Akram, N., Farooq, M., Rasool, U., & Husnain, N. (2025). Evaluation of mechanical properties of glass fiber reinforced concrete (GFRC) for sustainable construction. *THE PROGRESS: A Journal of Multidisciplinary Studies*, *6*(4), 1-18. https://doi.org/10.71016/tp/217wv423

Varshney, H., Khan, R. A., & Khan, I. K. (2021). Sustainable use of different wastewater in concrete construction: A review. *Journal of Building Engineering*, *41*, 102411. https://doi.org/10.1016/j.jobe.2021.102411

Zia, M. T., Nadim, M., Khan, M. A., Akram, N., & Atta, F. (2024). The role and impact of artificial intelligence on project management. *The Asian Bulletin of Big Data Management*, *4*(02). https://doi.org/10.62019/abbdm.v4i02.160