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Recycled-Textile-Waste-Based Sustainable Bricks: A Mechanical, Thermal, and Qualitative Life Cycle Overview

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Abstract: The textile industry, renowned for its comfort-providing role, is undergoing a significant transformation to address its environmental impact. The escalating environmental impact of the textile industry, characterised by substantial contributions to global carbon emissions, wastewater, and the burgeoning issue of textile waste, demands urgent attention. This study aims at identifying the feasibility of the future use of textile scraps in the construction and architecture industry by analysing the effect of different binders. In this study, synthetic knitted post-consumer-waste fabrics were taken from a waste market for use as a reinforcement, and different binders were used as the matrix. In the experiment phase, the waste fabrics were mixed with synthetic binders and hydraulic binders to form brick samples. The mechanical and thermal properties of these samples were tested and compared with those of clay bricks. In terms of mechanical properties, unsaturated polyester resin (UPR) samples showed the highest mechanical strength, while acrylic glue (GL) samples had the lowest mechanical strength. White cement (WC) samples showed moderate mechanical properties. Through several tests, it was observed that UPR samples showed the highest values of tensile, bending, and compressive strengths, i.e., 0.111 MPa, 0.134 MPa, and 3.114 MPa, respectively. For WC, the tensile, bending, and compressive strengths were 0.064 MPa, 0.106 MPa, and 2.670 MPa, respectively. For GL, the least favourable mechanical behaviour was observed, i.e., 0.0162 MPa, 0.0492 MPa, and 1.542 MPa, respectively. In terms of thermal conductivity, WC samples showed exceptional resistance to heat transfer. They showed a minimum temperature rise of 54.3 °C after 15 min, as compared to 57.3 °C for GL-based samples and 58.1 °C for UPR. When it comes to polymeric binders, UPR showed better thermal insulation properties, whereas GL allowed for faster heat transfer for up to 10 min of heating. This study explores a circular textile system by assessing the potential of using textile waste as a building material, contributing to greener interior design. This study demonstrated the usefulness of adding short, recycled PET fibres as a reinforcement in UPR composites. The use of the PET fibre avoids the need to use a surface treatment to improve interfacial adhesion to the UPR matrix because of the chemical affinity between the two polyesters, i.e., the PET fibre and the unsaturated polyester resin. This can find application in the construction field, such as in the reinforcement of wooden structural elements, infill walls, and partition walls, or in furniture or for decorative purposes.

Keywords: recycling; sustainable textile bricks; decorative bricks; waste management; resource conservation; responsible consumption; cradle-to-grave; qualitative life cycle overview

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1. Introduction

The growing human population and advancements in technology are highly responsible for high energy consumption, pollution, waste, greenhouse gas generation, and resource depletion. As mentioned by Global Footprint Network in 2018, "if we keep on using resource at current rate, we will need 3 times more of the resources available currently on planet Earth to meet our yearly demands" [1]. The increase in population and living standards has increased the amount of textile waste produced every year. There are several large brick-manufacturing companies that are the primary sources of air pollution in the world. They use trash, tires, textiles, and plastics as fuel. The global textile sector is also the highest-waste-producing sector, amounting to 55% of total global waste. Nowadays, reusing textile waste is an important step that can contribute to environmental sustainability in several countries. Construction is a field that can reuse this waste in the form of bricks. Using this waste in the manufacturing of construction materials can also lead to the minimisation of landfill use and reduce the consumption of natural resources and energy [2].

The textile industry is the world's second-largest industrial polluter after the oil and petrochemical industry, amounting to 14% of landfill material [3]. The clothing and textile industry is notorious for contributing to environmental degradation, including greenhouse gas emissions and the generation of wastewater and solid waste at various stages of production and along the supply chain. The harmful impact of this growing volume of waste is increasing our environmental footprint [3]. It has been observed that textile waste generation has increased due to fast-changing fashion, rises in population, and an increased consumption of clothes per person in wealthier families. The escalating environmental impact of the textile industry demands urgent attention. It has also been noted that 90% of post-consumer textile waste is reusable [4]. Circular business concepts for textile creation, sharing, recycling, and reuse have recently emerged. Textile waste might be regenerated in a circular economy, and different methodologies can be used to maximise its life cycle duration. In order to reduce the environmental and climate challenges caused by the textile industry while retaining its economic and social advantages, a systematic shift towards circularity is required. A lot of research is being conducted to decrease textile waste by reusing it in furnishings and interior applications. Reusing textiles is a better practice in terms of environmental protection and is 20–100 times more beneficial than incineration (lower emissions) and chemical recycling [4].

This predicament prompts a critical examination of the current disposal practices and accentuates the pressing need for transformative solutions. This triggers a compelling call to action for stakeholders, emphasising the gravity of the situation and the crucial role of sustainable practices in mitigating the environmental footprint of the textile sector. As the industry grapples with the inadequacies of traditional methods like incineration and landfilling, a change in basic assumptions towards sustainable waste management becomes imperative. At present, systemic solutions and a shift towards a circular economy centred around the reuse or minimisation of waste have been an important point for the textile industry. The profound implications of this challenge underscore the need for innovative strategies, particularly in the integration of textile waste into emerging industrial processes [5].

The global construction market is expected to grow in the next few years, and it is driven by the growing population and increasing urbanisation. The size of the global construction industry was USD 6.4 trillion in 2020, and it is expected to reach 14.4 trillion by 2030, which is almost twice as high as it was in 2020. The rising population has heightened the demand for innovative building materials. To minimise the depletion of resources, research is being conducted on construction/furniture materials that can be sustainably produced [6]. To address this need, certain types of industrial waste are being repurposed in the production of construction materials. The accumulation of unmanaged waste poses significant environmental challenges. Utilising this waste in construction not only is cost-effective but also promotes environmental sustainability. The textile and construction industries are significant contributors to excessive carbon dioxide emissions (about 12%), necessitating sustainable solutions for the future [7].

Researchers have used different types of waste in concrete mixes to develop bricks, e.g., cuttings of textile waste [8], sludge from textile effluent treatment plants [9], cotton micro-dust waste [10], polyester/cotton fabric waste [11], glass wool waste [12], and cotton stalk fibre waste [13]. It was observed that using textile wastes in different ratios in construction materials results in several types of benefits, including higher thermal insulation (increased by 3–4%), enhanced noise protection, and lower costs [14]. Kamble and Behera developed sustainable composites reinforced with recycled cotton shoddy, waste glass fibre preforms, and needle-punched nonwoven sheets from jute in furniture manufacturing as an alternative to timber [15]. Up to 5% improvement in mechanical properties was observed by adding 3% of cellulosic fillers by volume.

Marlet and her studio FabBRICK used fabric scraps mixed with eco-friendly starch-based glue and moulded into bricks through a mechanical compression technique [16–19]. Improvements of up to 4% and 7% were observed in tensile and bending performances, respectively. Andreu used acrylic fabric selvedge wastes to make decorative bricks. The fabric waste was mixed with water-based solvent-free acrylic resin, and an improvement of 2–3% in thermal insulation was observed [20]. Ackermans designed carbon-neutral fabric bricks by utilising wastes of fabrics, buttons, zippers, and other trimmings. An overall reduction in CO_2 emission was reported [21]. Combining these bricks with insulation materials results in building homes that would not require heating and cooling, thus leading to carbon neutrality [22]. E. Kagitci conducted research on the upcycling of textile waste as a sustainable building material for architectural design. To produce bricks of this material, 100% cotton, silk, and viscose fabric wastes were combined with starch-based glue. Up to 30% cost saving was predicted [19]. D Trajkovic et al. used polyester apparel cuttings waste in insulation applications. All such bricks manufactured exhibited 10% enhanced fire resistance, a 22% increase in moisture resistance, a 25% increase in acoustic insulation, increased life span, easier recyclability, and higher durability. These bricks were proposed to be used for making partition walls in a room, decorative walls, lamps, stools, shelves, tables, and other types of home furnishings [23].

Despite the potential of utilising textile wastes in the production of bricks, several areas of research remain unexplored. The reported studies provide encouraging results, but the understanding of the effect of different binders on the quality of bricks was not reported; therefore, it is the subject of the present study. The available literature lacks understanding and comparisons of how different binders would affect the qualities and performance of textile-waste-based bricks. The best available binders for integrating textile waste, the physical properties of the bricks, their resilience in different environmental conditions, the impact of environmental changes, economic viability, and the practicality of large-scale brick manufacturing remain unanswered [24,25].

Both the textile and construction industries generate huge amounts of carbon dioxide, create large-scale environmental pollution, and consume huge amounts of natural resources. This study explores a methodology for upcycling post-consumer textile wastes for producing sustainable bricks. The purpose of this work is to highlight the importance of integrating textile wastes into civil engineering and construction materials and, thus, to reduce the carbon footprint left by textile and civil/architectural industries. It aims at developing a sustainable building design and construction practice. In this work, several upcycled interior architectural samples were developed in combination with different types of binders. Besides tests of thermal insulation, tests of mechanical properties, e.g., tensile, flexural, and compression tests for the prepared samples, were performed. In addition, traditional clay bricks were used for the assessment and comparison of a qualitative life cycle. A technology roadmap is demonstrated in Figure 1.

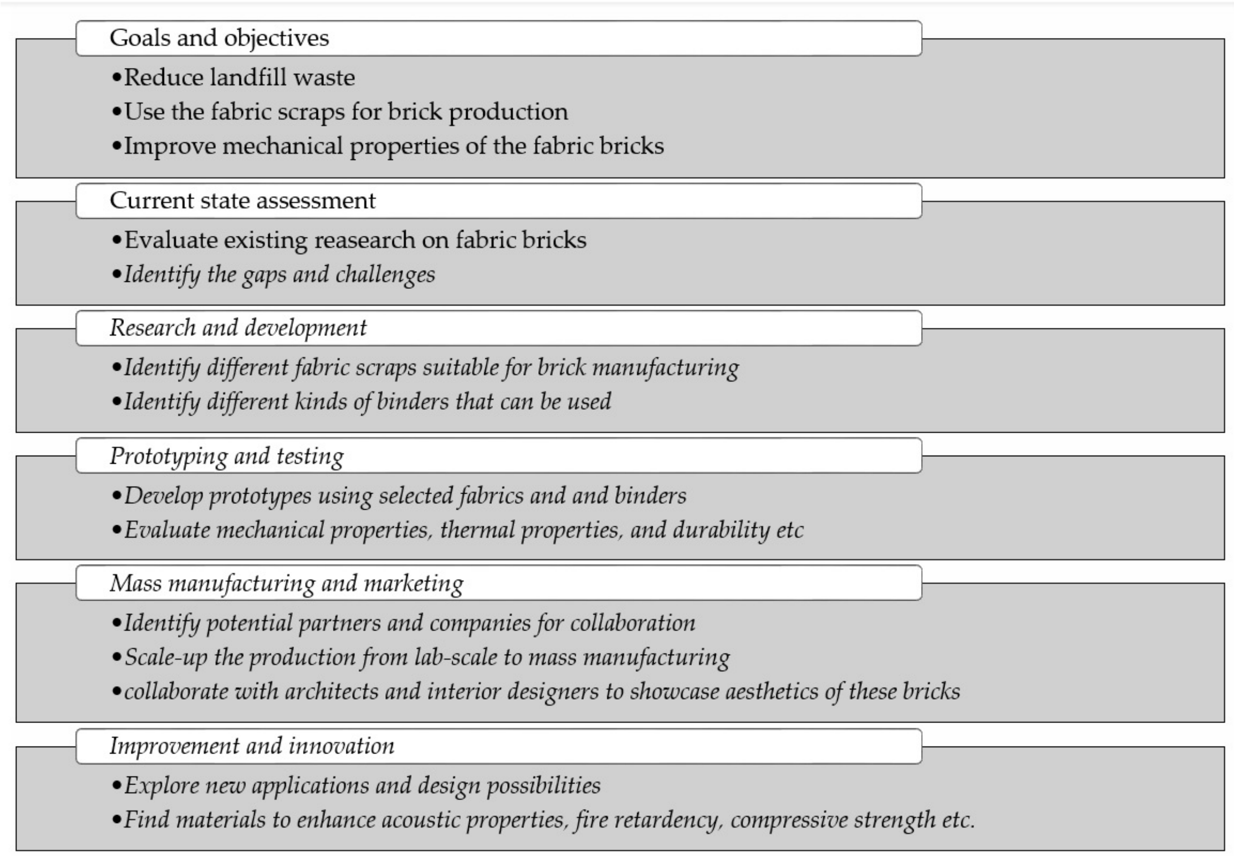


Figure 1. A technology roadmap for recycled-textile-waste-based sustainable bricks.

2. Materials and Methods

2.1. Materials

For this study, wastes of synthetic knitted fabric were procured from a local market. For binding purposes, synthetic binders, e.g., unsaturated polyester resin (UPR) and acrylic glue (GL), and hydraulic binders, white cement (WC), plaster of Paris, and lime (L), were used as demonstrated in Figure 2. These binders were mixed to achieve an accurate proportion for maintaining the material consistency.

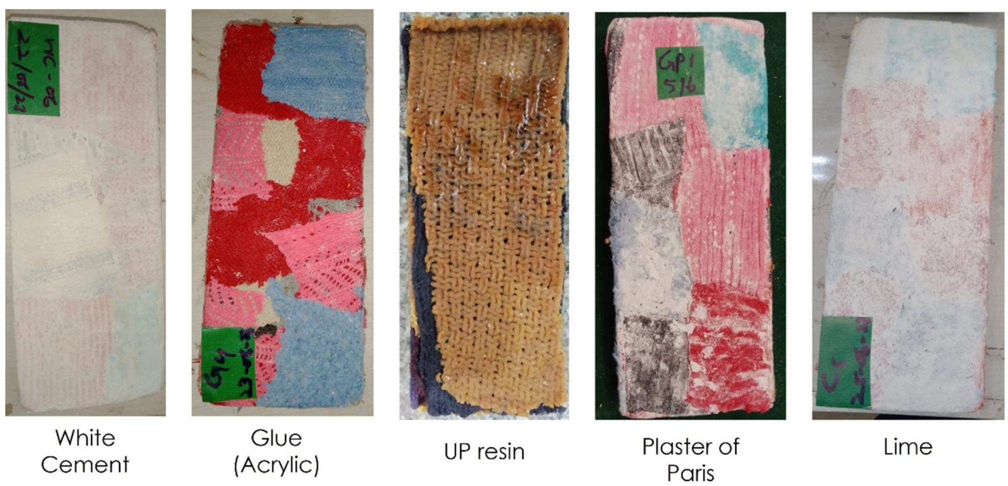


Figure 2. Brick samples using white cement (WC), unsaturated polyester resin (UPR), acrylic glue (GL), plaster of Paris, and lime (L).

However, among all these binders, only three led to the successful manufacturing of brick samples, namely white cement (WC), unsaturated polyester resin (UPR), and acrylic glue (GL). Mixing of successful blends (fabric scraps with binders) was carried out as per standard recipes given in Table 1. A cobalt accelerator and Methyl Ethyl Ketone Peroxide (MEKP) were used for curing UPR as per supplier specifications. The mixtures were then filled into the moulds, and pressure was applied to form the bricks/tiles as shown in Figure 3, with specific dimensions (25 cm × 10 cm × 2.5 cm) according to different test standards These samples were then dried and cured for 24 h for final stabilisation. All the samples were dried and cured in an open atmosphere. The weathering conditions might affect the curing process.

Table 1. Recipes for GL, WC, and UPR brick samples.

Binder	Recipe			
Acrylic Glue (GL)	Fabric	Glue		Water
	100 g	500 g		500 mL
White Cement (WC)	Fabric	Cement		Water
	100 g	500 g		300 mL
Unsaturated Polyester Resin (UPR)	Fabric	Resin	Cobalt	MEKP
	100 g	450 g	8 drops	14 drops

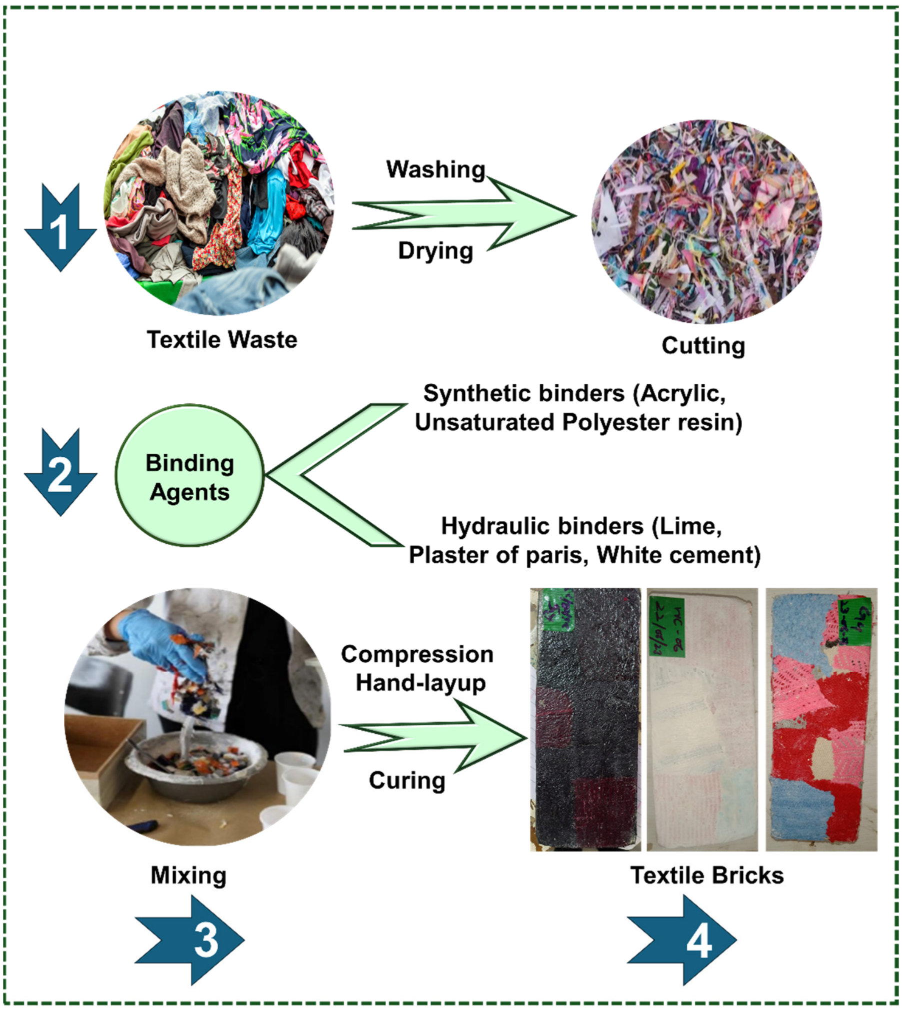


Figure 3. Schematic for the fabrication of textile-waste-based bricks.

2.2. Testing

2.2.1. Mechanical Test

To evaluate the mechanical properties of the prepared brick samples, tensile, flexural, and compression tests were performed using a Digital-Display Hydraulic Universal Testing Machine (UTS International Co., Ltd., Zhangzhou, China) as shown in Figure 4. The size of the test specimens was determined according to ASTM C 67-03a [26]. To evaluate the resistance to axial stresses, tensile tests were performed for the brick samples. The samples were subjected to a 3-point flexural test to determine their bending behaviour and flexural strength. The viability of the brick samples for construction applications was determined by performing the compression tests. The loading speed was maintained at 0.1 kN/s (maximum load 100 kN). Five specimens were tested to determine the average value of each parameter. The CV% was found to be lower than 5% in each case.

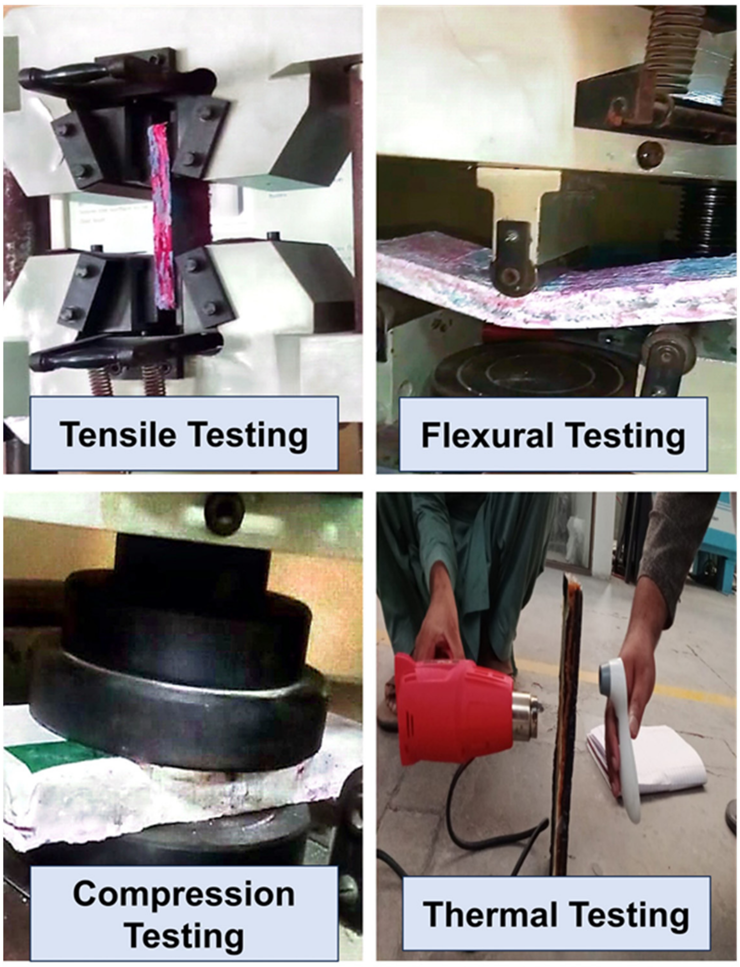


Figure 4. Mechanical and thermal testing of the sample bricks.

2.2.2. Thermal Conductivity Test

Thermal conductivity tests were also performed for the prepared brick samples. The specimens were heated by a heat gun as shown in Figure 4. The thermal properties were determined by using standard ČSN EN ISO 10211 (730551) [27]. For this test, a heating gun was held 5 cm away from the sample, and a temperature sensor was held on the other side at a distance of 7.5 cm. The heating temperature of the heat gun was 450 °C (in the range of 40–450 °C). The temperature on the other side of the brick was checked after 5 min, 7.5 min, 10 min, and 15 min. This measurement determined the transmission of thermal energy from one surface of the material to the opposite surface.

3. Results and Discussion

3.1. Mechanical Properties

The average results obtained from the above-mentioned tests are given in Table 2.

Table 2. Mechanical testing results of the developed brick samples.

Tests	Tensile Strength			Bending Strength			Compressive Strength		
	Load (kN)	Strength (MPa)	Strength (kg/cm^2)	Load (kN)	Strength (MPa)	Strength (kg/cm^2)	Load (kN)	Strength (MPa)	Strength (kg/cm^2)
GL	0.405	0.0162	0.165	1.230	0.0492	0.501	38.564	1.542	15.720
WC	1.593	0.064	0.649	2.650	0.106	1.080	66.756	2.670	27.220
UPR	2.766	0.111	1.120	3.351	0.134	1.366	77.858	3.114	31.753

With reference to the results of tensile strength given in Table 2, all the brick samples showed huge gaps in their performances. Through repeated tests, it was observed that UPR-based samples showed the highest values for tensile, bending, and compressive strengths, i.e., 0.111 MPa, 0.134 MPa, and 3.114 MPa respectively. For WC-based brick samples, the tensile, bending, and compressive strengths were observed to be 0.064 MPa, 0.106 MPa, and 2.670 MPa, respectively. For GL-based textile bricks, minimum values of mechanical properties, i.e., 0.0162 MPa, 0.0492 MPa, and 1.542 MPa, respectively, were observed. The samples prepared with GL binder showed minimum values for tensile, bending, and compression strength as compared to WC and UPR. Comparative results are further shown in Figure 5a–c.

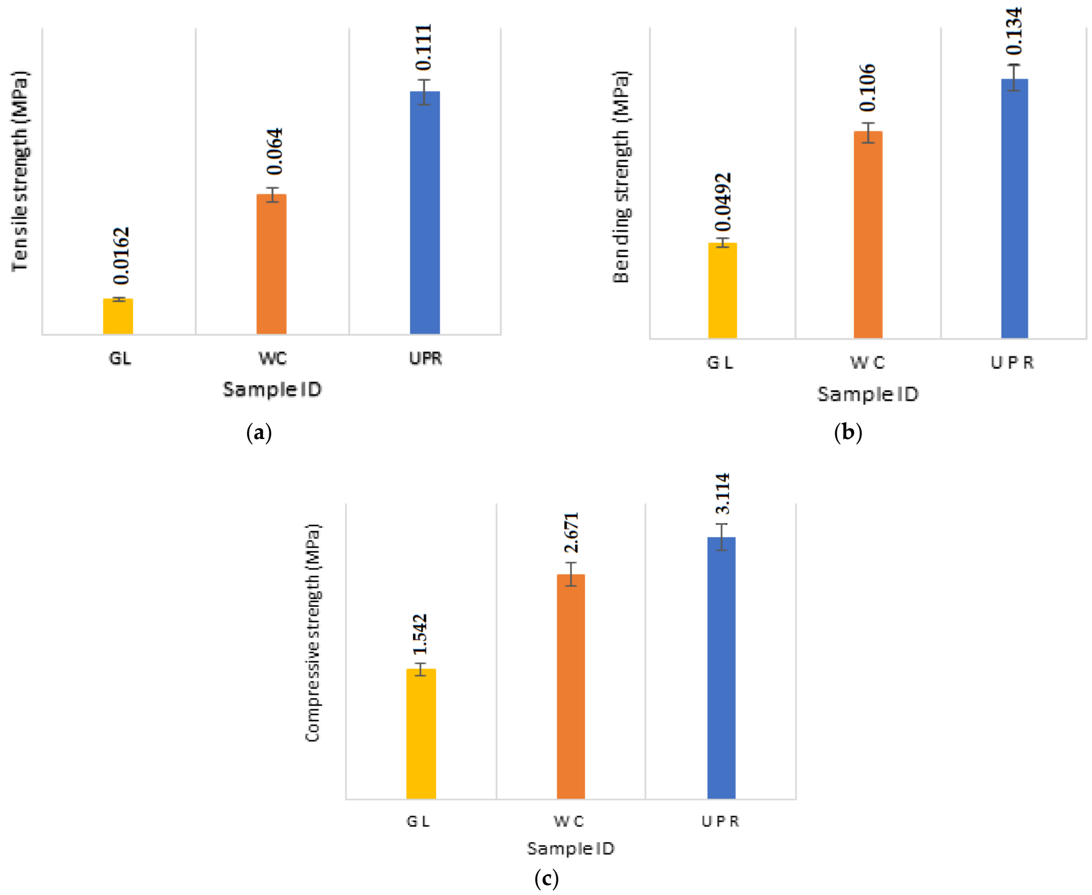
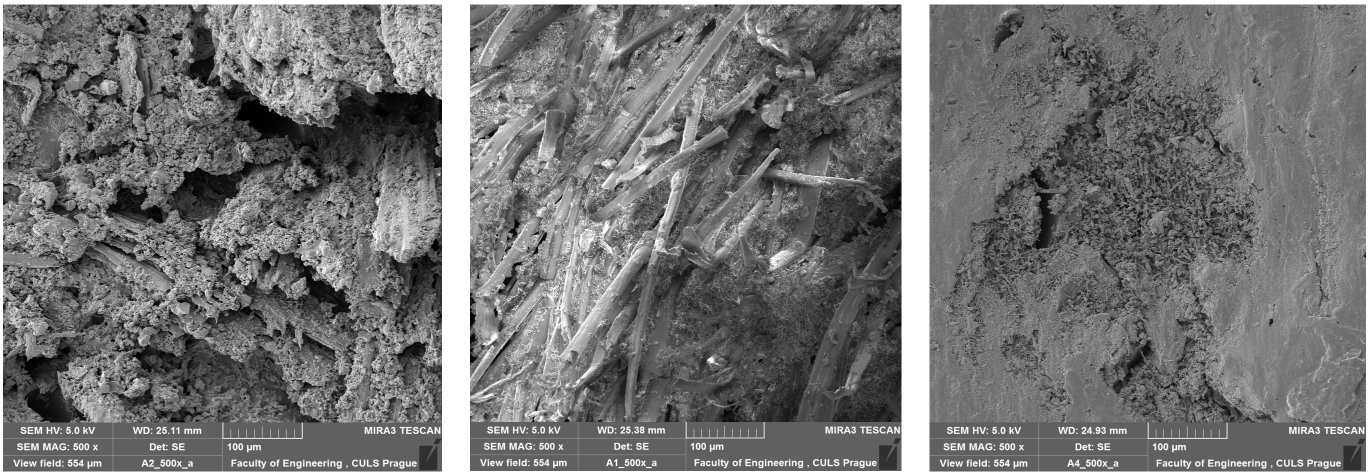


Figure 5. Mechanical properties of samples: (**a**) tensile strength, (**b**) bending strength, (**c**) compressive strength.

The UPR-based brick samples showed exceptional mechanical performances in tensile, bending, and compression modes. This type of durable and long-lasting composite brick material was a result of a stronger cross-linking between the molecules of the fibres and the binder/resin during the curing process. This cross-linking led to an increase in bonding strength, thus making it difficult to separate the fabric materials from the resin [28–30]. Hence, the superior mechanical behaviour of UPR-based bricks, which required the highest amount of force to break the bond formed between the fabric and resin, was observed. The SEM images of the tensile-tested brick samples are shown in Figure 6.



(**a**) GL (**b**) WC (**c**) UPR

Figure 6. SEM images of the tensile-tested brick samples using (**a**) GL, (**b**) WC, (**c**) UPR.

This study demonstrated the usefulness of adding short, recycled PET fibres as reinforcement in UPR resin-based composite bricks. The use of PET fibres avoided the need for surface treatment to improve the interfacial adhesion to the UPR matrix. This is because of the chemical affinity between similar materials, e.g., PET fibres and unsaturated polyester resin, as depicted in previous studies [30].

Despite a visually appealing look, GL-based brick samples showed the lowest mechanical strengths. Acrylic glues are thermoplastic in nature. Thermoplastic polymers do not show any chemical bonding during the curing process. The thermoplastic nature of the binder led to a weaker adhesion between fabric and binder during the curing process. The absence of a strong chemical bond resulted in the formation of a relatively weaker composite brick that can deform or break easily when stresses are applied. The WC resin-based brick samples showed moderate mechanical properties. The presence of pores in the structure of WC-based bricks during the curing process impacts their mechanical strength due to the formation of voids and weak zones. These voids act as stress-concentrating zones leading to the failure of the matrix when mechanical stresses are applied. The higher strength of WC-based composite bricks as compared to GL-based samples was due to the formation of silicate that is known to enhance mechanical strength. Although the WC-based brick samples did not demonstrate the same level of mechanical strength as the UPR-based brick samples, they did not experience a mechanical failure like the GL-based samples.

These scientific observations can provide valuable guidance in the process of selecting suitable materials for building applications. This also involves careful evaluation of aesthetic factors vis-à-vis mechanical properties, considering the bonding and curing methods employed.

3.2. Thermal Properties

It is possible to acquire a better understanding of the heat resistance of brick materials by investigating the thermal transmission behaviour. Textile-based bricks can withstand high amounts of heat due to their inherent porosity. The heat resistance may change depending on the type and nature of the binder that was used in the manufacturing of the bricks. The thermal resistance behaviour of WC-, UPR-, and GL-based samples is given in Table 3, and the behaviour is also shown in Figure 7.

Table 3. Heat resistance behaviour of brick samples.

Samples	Temperature (°C) after 5 min	Temperature (°C) after 7.5 min	Temperature (°C) after 10 min	Temperature (°C) after 15 min
GL	43.0	46.0	48.5	57.3
WC	35.0	42.0	46.8	54.3
UPR	34.4	40.7	48.1	58.1

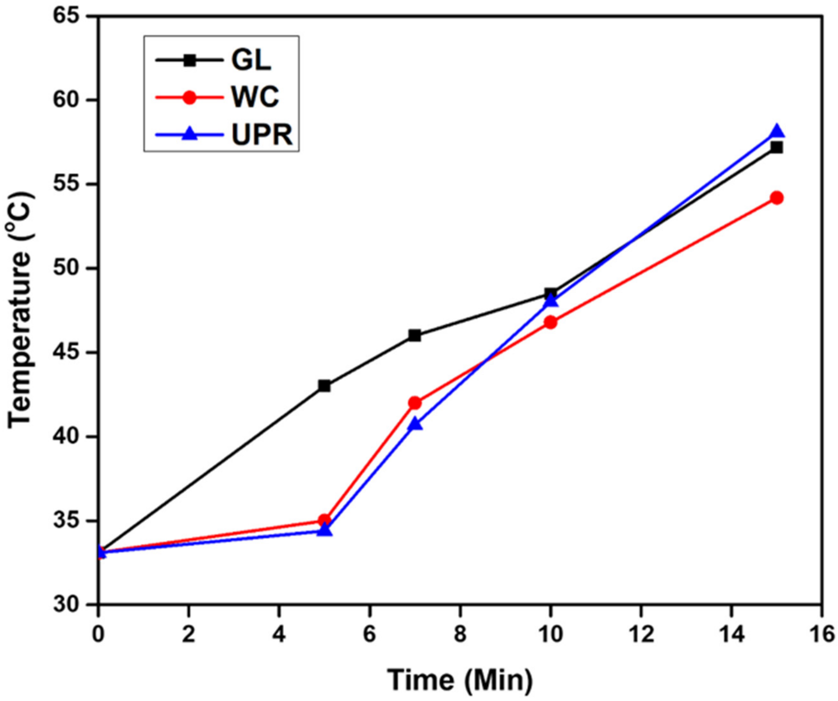
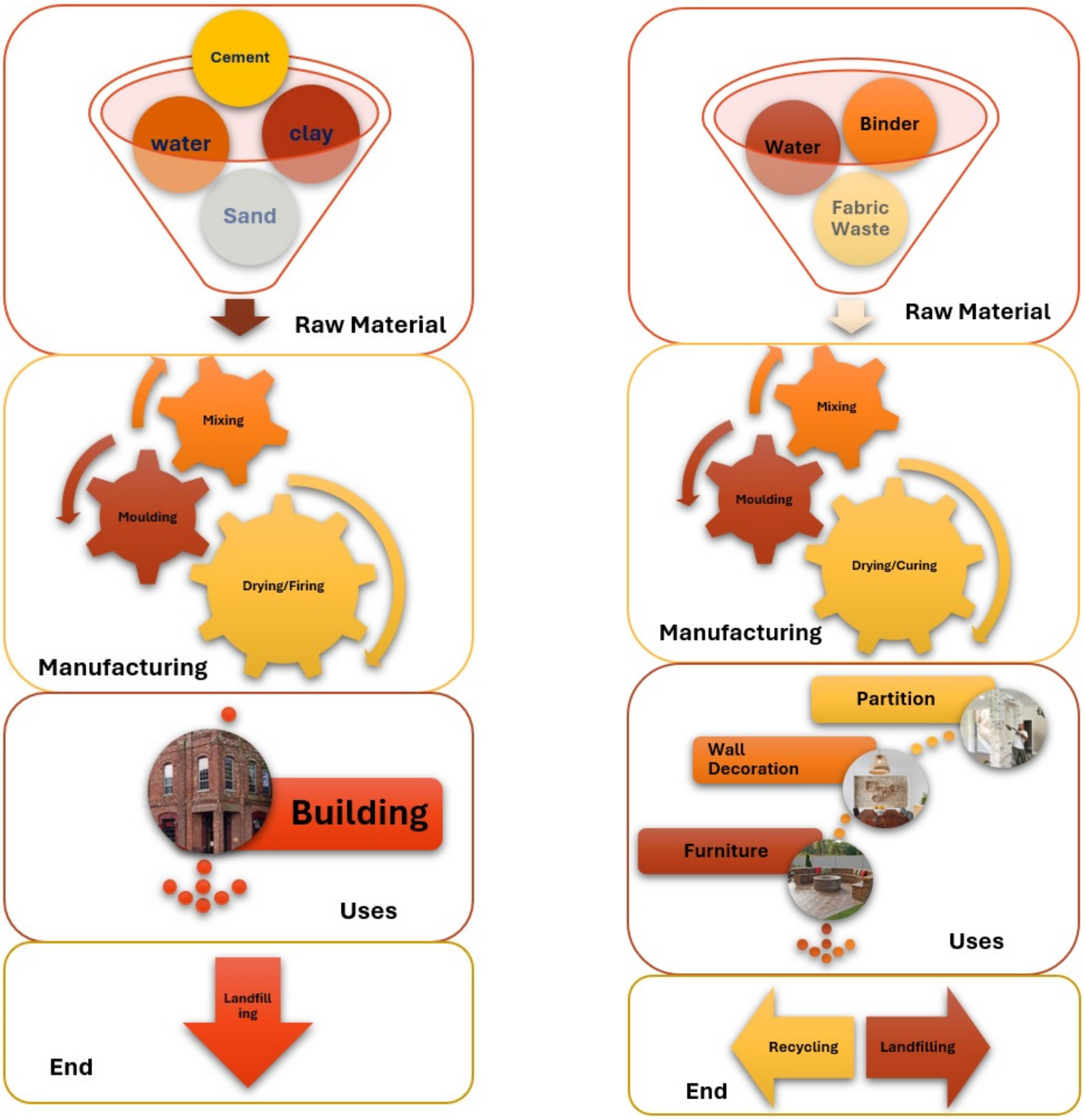


Figure 7. Results of thermal resistance.

The remarkable thermal insulation observed in the case of WC-based composite brick samples was due to the presence of micro-pores in their structure. These pores allow the development of air pockets which serve as heat insulators. When WC-based brick samples were heated, the air pockets slowed down the transfer of heat through the bulk of the material. As a result, WC-based bricks could withstand high temperatures without experiencing an increase in the temperature. This ability of WC-based bricks to impede the flow of heat makes them effective thermal insulators for interior home applications. In contrast, the UPR and GL binders exhibited relatively more compact structures with relatively lower porosity. These materials showed higher thermal conductance as compared to WC-based samples due to increased density and reduced porosity. The UPR and GL binders belong to the high-density polymeric class of materials. GL is a thermoplastic polymer, while UPR is a thermoset polymer. GL, being thermoplastic in nature, can be melted and re-moulded multiple times. There is relatively higher mobility of the polymer chains in the case of GL-based materials which facilitates the transfer of heat. As a result, GL-based bricks exhibited a faster rate of heat conduction through the material. On the other hand, UPR, being a thermoset polymer resin, underwent irreversible chemical bonding during the curing process. Once cured, it exhibited much higher rigidity due to the formation of cross-links. The molecular chains cannot move freely within the cross-linked structure. The limited mobility of these chains results in a much lower thermal conductivity in the case of UPR-based composite bricks as compared to GL-based samples.

3.3. Qualitative Life Cycle Overview for Traditional Bricks and Textile Bricks

To understand the sustainability of the developed composite bricks, a qualitative life cycle overview/analysis was carried out. This overview included four main stages of the life cycle, as shown in Figure 8. These stages are defined as the selection of raw material, manufacturing process, application phase, and end of life of the composite bricks. This overview does not include the generation of by-products in each stage, preparation of the raw material, material transportation, effects on the environment after the end of life, etc. The target units used to quantify some of the performance and impact of the developed products included energy consumption in megajoules (MJ) and strengths in megapascals (MPa). Aesthetic properties and end-of-life adaptability were analysed through qualitative assessment.



(a) (b)

Figure 8. Life cycle overview diagram of (a) traditional bricks and (b) recycled textile bricks.

3.3.1. Raw Material Selection

Traditional Clay Bricks

There are mainly two popular types of bricks used around the world, i.e., cement-based and clay-based bricks. Clay-based bricks are comparatively less expensive and manufactured in several developing countries. Soil is preferred as a raw material for making these bricks. The clay used for brick manufacturing is a finite natural resource. The widespread use of clay in brick manufacturing and the ever-increasing demand for more construction materials are leading to the depletion of this natural resource. Several studies have been conducted to use alternative raw materials for partial replacement of clay-based bricks and to prevent depletion and landfilling at the end of life [31,32].

Sustainable Composite Bricks from Recycled Textile Waste

The robust mechanical properties, finite raw material source, and negative environmental effects of the traditional bricks make them unsuitable for interior design applications such as furniture, partition walls, and decorative items. Since the need for construction materials is ever-increasing, studies are being conducted for the development of alternative materials that can be used in such construction activities in place of traditional bricks. Large amounts of wastes are produced at every stage of the textile production process, i.e., during yarn spinning, knitting, weaving, garment manufacturing, chemical processing, and use as a clothing material [33]. The burning of these textile wastes results in the emission of large amounts of greenhouse gases, causing severe threats to the environment. The reuse of these wastes will reduce this negative impact [34]. The incorporation of textile fabric wastes as reinforcement materials will lead to the development of sustainable bricks and the prevention of large-scale landfilling traditionally caused by textile wastes.

3.3.2. Manufacturing Process

Traditional Clay-Based Bricks

The process involves the preparation of clay, shaping, drying, firing, and cooling operations. The firing of bricks requires a large amount of traditional fuels, and it emits a lot of CO_2. Firing also requires a high temperature between 900 °C and 1200 °C. This consumes on average about 24 million tons of coal every year. Each brick consumes around 2.0 MJ to 3.5 MJ of energy. Such a huge amount of energy required severely affects the environment as it emits a large amount of greenhouse gases [35,36]. Brick kilns emit harmful greenhouse gases that not only affect human life but are harmful to plants and animals as well. Mostly low-quality coal is used in the chimneys of kilns in several developing countries, resulting in severe air pollution. These emissions from traditional brick kilns are the major causes of ozone depletion and acid rain. The large-scale use of coal is also causing widespread deforestation in several countries [37,38]. Brick-making processes are the major sources of air pollution and soil degradation in these areas.

Sustainable Textile-Waste Based Bricks

The focus of this study was to manufacture sustainable textile-waste-based composite bricks that are well-suited for interior applications. For the manufacturing of such bricks, different types of binders were used for different types of fabric wastes depending upon the essential performance in the interior applications. These bricks do not require the traditional firing process leading to environmental conservation. The energy consumption during this process was negligible, as compared to traditionally fired bricks. The sustainable textile-waste-based composite bricks were moulded manually using clamps and were dried and cured under the sun in an open environment.

3.3.3. Application Phase

Traditional Clay-Based Bricks

The traditional clay-based bricks manufactured in kilns are used for the construction of buildings especially due to their robust mechanical performance. According to studies reported by different researchers, the average compressive strength of these bricks ranges from 2.5 to 4.5 MPa (average ≈ 3.28 MPa) [39–41]. With an average compressive strength of 3.28 MPa, these bricks are widely used for construction applications, leading to a prolonged lifetime of the structures.

Sustainable Textile-Waste-Based Bricks

Since the need for construction materials is always increasing, studies are being conducted for the development of alternative materials that can be used in different construction activities as replacements for traditional clay-based bricks. They exhibit acceptable strength, sustainable usage of raw materials, and positive environmental effects as compared to traditional bricks. Therefore, these textile bricks are more suitable for interior design applications such as furniture, partitions of walls, and interior decorations. Despite the slightly lower compressive strength of these sustainable bricks (3.11 MPa for UPR resin), there is a harmonious balance between mechanical performance and aesthetic attributes, making them highly suitable for interior design applications.

3.3.4. End-of-Life Assessment

Traditional Clay-Based Bricks

After the demolition of the conventional buildings, the traditionally fired clay-based bricks are incinerated or buried as they cannot be reused. This practice further damages the environment by releasing pollutants [42]. The cradle-to-grave diagram for traditionally fired clay-based bricks is shown in Figure 8a.

Sustainable Textile-Waste-Based Bricks

One of the most noteworthy advantages of these sustainable bricks is their end-of-life adaptability. Depending upon the type of binders and the fabric wastes used, these bricks can either be used as a landfill or can be recycled again using suitable methods. This recyclability aspect of such bricks aligns with the principles of circular economy practices, sustainable production, and responsible consumption. The idea of incorporating waste textile materials into the creation of bricks not only helps protect the environment, but also opens the possibilities for sustainable manufacturing of aesthetically pleasing construction materials. The cradle-to-grave diagram for textile-waste-reinforced polymeric composite bricks is shown in Figure 8b.

Table 4 shows the comparison of the sustainable bricks with clay-based traditional bricks.

Table 4. Comparison of potential data for sustainable bricks and clay bricks.

Life Cycle Stage	Sustainable Bricks			Clay-Based Bricks		
	Energy	Strength	Aesthetic	Energy	Strength	Aesthetic
Raw Material Selection	Moderate for sourcing	Based on binders	Different textures and colours	High for clay sourcing	Based on ingredient percentage	Plain solid colour
Manufacturing Process	Minimal; dried and cured in sun	-	Customisable shapes	High due to firing	-	Traditional brick shape
Application Phase	Minimal	Suitable for interiors	Various creative possibilities	Moderate	Suitable for building applications	Traditional appearance
End-of-Life	-	Lower than traditional	Retain aesthetics	-	Durable	Retains appearance

Since sufficient quantitative data were not available, the life-cycle analysis was not quantified. However, it was conducted qualitatively using the data in Table 4. The qualitative overview shows that the attributes and characteristics of the sustainable textile-waste-based composite bricks are as follows:

- Raw Material Selection: They consume a moderate to low amount of energy for raw material sourcing, can have adequate mechanical strength based on the type of binder used, and can be produced with various textures and colours. However, there are limitations with respect to 100% recyclability of these bricks in contrast to traditional clay-based bricks.
- Manufacturing Process: These bricks involve minimal energy consumption during manufacturing processes since they show very high flexibility in design and do not require kiln firing. The absence of kiln firing reduces the environmental impact as compared to conventional clay-based brick manufacturing.
- Application Phase: Minimal effort is required for the installation of sustainable textile-waste-based composite bricks, making them suitable for various household and interior applications.
- End-of-Life: After their lifetime, the composite bricks do not consume any energy and still retain their aesthetic appeal. But the recycling options may be limited as compared to the kiln-fired traditional bricks which can be reused due to traditional appearances.

4. Conclusions

The primary objective of this study was to identify the effect of different types of binders used in composite brick manufacturing along with fabric scraps/textile leftovers as reinforcements. In this study, synthetic knitted fabric wastes were mixed with white cement (WC), acrylic glue (GL), and unsaturated polyester resin (UPR) to form sustainable composite brick samples.

To compare the mechanical properties of the prepared brick samples, tensile, flexural, and compression tests were performed. The differences in the mechanical properties of these samples were mainly attributed to the variations in binding and curing processes. It was observed that the UPR-based sample showed the highest values for tensile, bending, and compressive strengths, i.e., 0.111 MPa, 0.134 MPa, and 3.114 MPa, respectively. For WC-based composite bricks, the tensile, bending, and compressive strengths were 0.064 MPa, 0.106 MPa, and 2.670 MPa, respectively. For GL-based samples, minimum mechanical performance was observed, i.e., 0.0162 MPa, 0.0492 MPa, and 1.542 MPa, respectively. The maximum mechanical performance of UPR-based samples is attributed to their ability to form cross-linking with the fabric substrates. The visual appearance of the GL-based brick samples was dominated by their lower mechanical strength. WC-based samples showed moderate mechanical properties due to the presence of pores contributing to relatively lower strength as compared to UPR-based bricks. The presence of silicate led to greater strength in these samples as compared to GL-based composite bricks.

The thermal behaviour of the composite bricks was also investigated and compared. The thermal conductivity of the samples can be attributed to the micro-porosity of the structures. Due to the presence of micro-pores, WC-based samples showed exceptional resistance to heat transfer. This resulted in a minimum rise of temperature (54.3 °C) after 15 min of heating as compared to 57.3 °C for GL-based samples and 58.1 °C for UPR-based samples. When it comes to polymeric binders, UPR showed better thermal insulation, whereas GL allowed faster transfer of heat up to 10 min of heating. UPR shows better thermal insulation properties due to its thermoset nature, whereas the thermoplastic nature of GL facilitated greater mobility of polymer chains and faster heat transfer. Recycling of fabric wastes as building materials appears to be a sustainable and viable solution that will not only reduce environmental difficulties but also be sufficiently cost-effective.

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