Sustainable Concrete-Based Structures: Review for the Potential Benefits of Basalt Fiber Reinforced Concrete (BFRC) in Enhancing the Environmental Performance of Buildings

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1 ABSTRACT

Incorporating Basalt Fibers composites that are caused by the melting process of basalt rocks into the concrete mixture to create the composite of the Basalt Fiber Reinforced Concrete (BFRC) is a good idea to enhance concrete's mechanical properties, thus the concrete structural performance. However, modern building materials must fulfill not only structural performance criteria but also reduce the environmental impact accompanied by their production. As informed by related literature in the field of BFRC, benefits linked with mechanical properties in terms of structural performance were illustrated widely. While there is only a very limited amount of information available on the impact of using BFRC in terms of environmental impact. Thus, this review identified this research gap and drew a potential linkage for how to assess the environmental performance of BFRC-based buildings to be used in future research which relies on sustainability perspectives.

Keywords: Fiber Reinforced Concrete Composites (FRCC), Basalt Fiber Reinforced Concrete (BFRC), Environmental performance, Sustainable architecture, Building Planning

2 INTRODUCTION

Concrete is one of the most used construction materials in the present day due to its advantages of versatility, and generally highly reliable performance of this material, and also the widespread availability and comparatively low cost of the necessary raw materials and processing technology [1, 2, 3, 4]. Concrete-based materials are usually affected and affect the construction process negatively due to their brittle nature [5]. Many recent studies focused on these deficiencies, so that, the use of different materials as reinforcement so as to improve the properties of the hardened concrete was necessary [6, 7, 8, 9, 10, 11, 12]. These studies and other similar studies were focusing mainly on enhancing the structural aspect of the building through different approaches. One such approach to enhancing the constructional materials is the incorporation of short-length fibers at minimal dosage to develop what is termed fiber-reinforced concrete composites (FRCC) which were directly aimed at increasing positively the concrete structural properties [6, 12, 13, 14, 15, 16]. One of well reputed of these fiber composites due to its countless enhanced concrete structural benefits is Basalt Fiber Reinforced Concrete (BFRC) [17, 18, 19].

In terms of the environmental aspect, the concrete-based materials industry is facing increased pressure as concrete production is being perceived as unsustainable material. Although the energy intensity per functional unit remains lower than most other available constructional materials [20], the very large production volumes required to serve global needs for concrete lead to high worldwide consumption of energy, as well as raising in the emission of greenhouse gases (GHGs). Thus, there is a growing global interest within the housing and construction industry in the development of sustainable construction and building materials that have a diminished environmental impact throughout their manufacturing and operational lifecycle stages [4]. Thus, the development of sustainable constructional materials with reduced environmental footprint through both manufacturing and operational phases is currently a key focus in the sustainable construction industry. Furthermore, this key solution of creating sustainable construction materials is shown as essential demand.

When considering the approach of utilizing fiber composites to reinforce the concrete, a clear gap is being unfolded in terms of studying the enhancement of FRCC's environmental properties. Which can play a significant role in confronting the sustainability challenges that are linked with the worldwide large production of concrete. Specifically using the BFRC in enhancing the environmental properties of concrete constructional material. This paper attempts to discuss the concept of BFRC in terms of the literature gap of the enhanced environmental concrete properties as a potential solution to the global issue of the resulting sustainability challenges of concrete high production as well as the energy consumption rates within concrete-based structures. As a basis for this, the current status of BFRC's approach to enhancing concrete properties is reviewed. This review highlights some of the issues in the specific context of BFRC production and outlines the importance of developing a deeper and more comprehensive understanding of thermal parameters as part of the process of broadening the uptake of this approach for creating sustainable architectural structures.

3 SUSTAINABILITY AND CONCRETE INDUSTRY

In response to the increasing pressures faced by the environment and limited resources, the term "sustainability" has been created, which includes how natural systems function, and give whatever is needed to keep the environment in balance now and in the future [21]. There are two definitions of sustainability that were considered comprehensive. The first type reflects the social scientific definitions that are summarized in treating sustainability as a relationship between the present and future welfare of persons [22, 23]. Furthermore, in the [24], the definition of sustainability is considered as it is the development that meets the needs of the present people without affecting negatively the ability of future generations to meet their own needs. This type of definition imposes ambiguity about how to make a balance between generations' welfare, which led to the emergence of the second type of definition of sustainability; the ecological definition that requires the protection of ecological processes as a condition of sustainability [25,26]. Also, again, this type of sustainability definition presents some vague related to the way in which we can protect the ecological processes. Indeed, in scientific contextualisms, sustainability should not follow any of these types on its own, instead, it should be combined. This review is trying to answer the question raised here which is (What strategy we should adopt to protect the ecological process while maintaining human welfare throughout the human development stages?) through linking sustainability with the concrete industry in the field of sustainable architecture. For more illustration about this review strategy note fig.1 below.

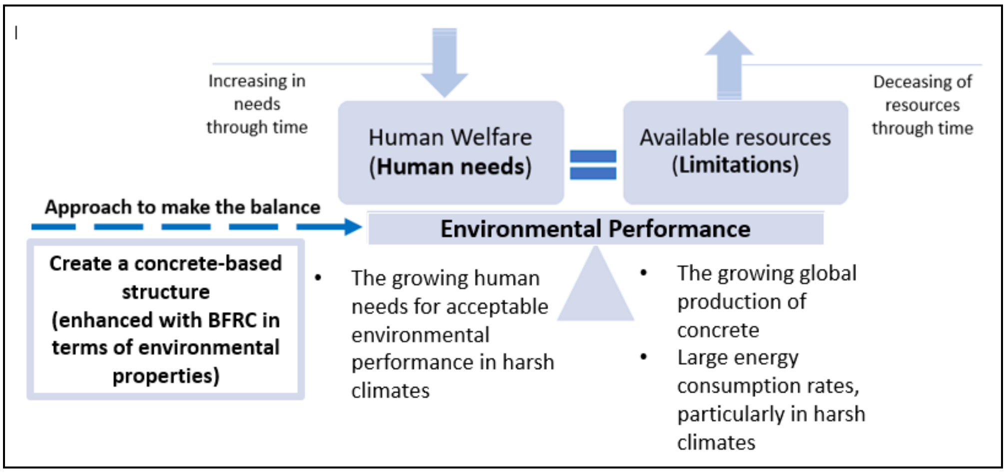

Fig. 1. The Review Paper Strategy. (Al-Bqour. N, 2023).

The key components of concrete include cement, aggregates (such as sand and gravel), and water, with additional materials like admixtures and fibers being optionally incorporated for specific purposes [27]. The total volume of cement production worldwide in 2022 amounted to 4.1 billion tons. The total global production of cement in 1955 reached 1.39 billion tons, which indicates the large growth of cement-based construction. With production surpassing two billion metric tons, China was recently the leading cement-producing country in 2022, with production surpassing two billion metric tons. Also, India ranked a distant second that year, producing 370 million metric tons [28]. A potential future shortage of low-cost raw materials is the first key point that should be considered in the context of the cement and concrete industry, regarding its huge consumption of conventional limestone-based materials [6]. The manufacturing process of cement involves the production of clinkers, which is a key component. Limestone plays a significant role in clinker manufacturing as it is used as a raw material and can also be used as a clinker replacement or additive [29]. Limestone is a widely available material, potential shortages could arise if there is an imbalance between demand and supply, particularly in regions with high cement production. The sustainability of limestone extraction forms an important consideration to ensure the long-term availability of this resource for the next generations [30]. It is crucial for the concrete and cement industry to continually explore sustainable alternatives, such as alternative and high-performance raw materials, to reduce the reliance on limestone, and thus to mitigate any potential shortage concerns. In terms of Cement industry emissions and energy consumption, the production process of cement requires the heating of a mixture of minerals to temperatures of more than 1400 degrees Celsius in a kiln. This heating step requires energy in large amounts as an essential demand, which ends up in worldwide greenhouse gas emissions. Which could be a real threat to human welfare in harsh climates. Carbon dioxide emissions from cement production have increased nearly continuously for several decades, reaching 1.7 billion metric tons in 2021 [28]. It should be highlighted that the total emissions of the cement and concrete industry, as a whole sector, may contribute nearly 10% of global anthropogenic CO2 emissions [6]. It is quite clear now that the process of cement and concrete production has large negative effects on the environment in terms of consumption of limited resources, energy consumption, as well as air emissions that contribute to global warming, therefore, negatively impacting human welfare.

In addition to the environmental impacts discussed during the manufacturing process previously, the environmental impacts generated during the operation of the concrete-based building are equally important or even higher. This is because the embodied energy of construction materials during the manufacturing stage is only a small fraction of the total energy consumption of a building during its whole lifespan [6]. Generally, environmental assessments of buildings have tended to concentrate on the impacts occurring in operation and use. It should be noted that the environmental impacts through the building operational stage occur throughout the whole lifetime of the building, which indicates how important is to consider those long-term impacts [31]. The environmental impacts over the complete life cycle of the buildings are determined using the indicators of air pollution index, energy consumption, global warming potential, resource use, solid waste emissions, and water pollution index [32]. Considering the sustainability of buildings mainly focuses on the energy demand and emissions during the building use phase [33]. In terms of concrete-based buildings, related studies revealed that concrete-based buildings showed higher negative environmental impacts [34, 35, 36]. Also, it should be noted that concrete-based buildings have higher environmental and structural negative impacts within harsh climates [37, 38, 39, 40].

Overall, in the next decades, cement and concrete production is expected to continue to show increased growth. Demand for cement in industrialized is increasing slowly if at all, but in developing countries and regions such as India, other developing parts of Asia, the Middle East, South America, and Africa which are linked usually with harsh climates, cement demand will continually increase due to fast urbanization and associated infrastructure development [41]. Therefore, the environmental issues associated with limitations on natural resources, CO2 emission, high energy consumption, and environmental performance within concrete-based structures will play a leading and directing role in the sustainable development of the concrete industry in the coming century. Unsurprisingly, the cement and concrete industry has been fully aware of the discussed environmental challenges and has keenly focused on many positive activities over a long period toward sustainable development in the concrete-based construction sector [6]. Please note Table 1 below for more demonstrations.

Sustainable development strategy	Practices
Saving resources/ energy and reducing emissions from cement and concrete manufacturing plants	Improving energy efficiency [42]. Using biofuels [43]. Replacing limestone with other high-calcium industrial by-products [44].
Reducing clinker content in cement and concrete	Utilizing more supplementary materials, such as Blast Furnace Slag (BFS), fly ash, natural pozzolans, and silica fume [45,46].
More precise design and determined use of concrete	Selecting the correct concretes for specific applications [47]. Recycling construction and demolition wastes to produce recycled aggregates [48,49]. Improving the durability of concrete [50].

Table 1: Practices toward sustainable development within the concrete construction sector.

Undoubtedly, the above-described approaches will enhance the concrete industry's sustainability as a whole. It should be understood that the environmental impact of a building is very sensitive to the construction material choices [33]. This paper review puts forward a key solution by utilizing BFRC in concrete-based buildings in terms of environmental impacts within the manufacturing and operational stages of buildings.

Therefore, to increase sustainable development within the concrete and cement construction sector through establishing the basis for sustainable structure based on sustainable innovative construction materials.

4 BFRC AS A PROMISING CONSTRUCTION MATERIAL

4.1 Fiber Reinforced Concrete Composites (FRCC)

Predictably, cement will remain the key material to serve the construction sector's needs. Thus, as a consequence, the concrete and cement worldwide industry sector contributes to the sustainability challenges regarding environmental impacts. According to the International Energy Agency (IEA), the main levers for cement and concrete producers are the increase in energy efficiency and the use of alternative materials. Noting that these new materials might be able to play a role as cement constituents or reinforcing-concrete materials in the future [41].

FRCC gained increasing attention within the construction industry due to its enhanced mechanical properties and improved durability [51]. It is a combination of cementitious matrix and discrete fibers, which work together to provide additional strength and reinforcement to the concrete [52]. Generally, in terms of structural performance, it is well-known that traditional concrete is brittle in nature and lacks sufficient tensile strength. By introducing fibers into the concrete matrix, these shortcomings can be overcome [51]. Introducing FRCC has led to significant advancements in the construction industry. Fibers can be added to various cementitious materials such as concrete, mortar, and geopolymer composites to enhance their performance [51,52]. The fibers used in these composites can be extracted of different types, including synthetic fibers (e.g., glass fibers, carbon fibers, aramid fibers), natural fibers (e.g., plant fibers, basalt fibers), and metallic fibers [53,54]. Highlighting that fiber technology is a versatile and effective method of enhancing construction materials. By adding fibers to building materials, the resulting materials can be made stronger, more durable, and more resistant to damage from weathering and other environmental factors. This can help to extend the lifespan of buildings and infrastructure, reduce the need for maintenance and repairs, and promote sustainability in the construction industry [55].

4.2 Basalt Fiber Reinforced Concrete (BFRC)

Basalt is a common extrusive volcanic rock. It is formed by the decompression of the melted lava. As a worldwide rock, it has long been known for its thermal and structural properties. Its fibers are like carbon fiber and fiberglass, but they have better physical-mechanical properties than fiberglass and are significantly cheaper than carbon fiber [56]. Basalt fibers are natural fibers derived mainly from basalt rocks, making them a natural material rather than a synthetic one. Basalt fibers are produced by exposing basalt stones to high temperatures with the intent of melting and converting them into fibers [57].

Among many other reinforcing fibers, basalt fiber has been the least studied fiber [58]. The history of basalt fiber dates to 1923, and it was further improved during World War II. The United States and the Soviet Union investigated basalt fiber, especially for aerospace and military purposes [59]. Basalt fibers could not be widely used for other than military applications because of the political issues at that time. After 1995, and due to declassification, basalt fibers were produced and used on a commercial scale. Then, after 2000, scientific research on basalt fiber applications gradually increased. Today, the basalt fiber industry is improving based on the technology in composite research and applications that improved day by day. Basalt fiber is considered a viable alternative to traditional glass fiber by the composite industry. Therefore, many manufacturers and suppliers around the world are interested in basalt fiber, but with unlimited basalt reserves, Russia plays a key role in basalt fiber technology [60,61]. The Basalt fibers are manufactured mainly in Eastern Europe, Russia, and the USA, now in Israel, China, and India [62].

This review paper concentrates on a recent innovative constructional material, BFRC, which comprises the advantages of Basalt fibers technology and provides the opportunity to reduce energy consumption, limited resources consumption, and CO2 emissions, along with providing acceptable human welfare within buildings in harsh climates. Before detailing the properties of this new innovative material in terms of performance, it is worth introducing the state of the art with regard to its composition and manufacturing.

4.3 Composition of Basalt Fibers

BFRC is a type of fiber-reinforced concrete that utilizes basalt fibers to enhance the performance of plain concrete. The chemical composition of basalt fibers typically consists of significant proportions of SiO2 and Al2O3, followed by MgO, CaO, and iron oxides [63]. Fig. 2 shows the content of each component of basalt fibers. The proportion of SiO2 in the BF is nearly 51–59%, which provides good chemical stability and mechanical properties. Al2O3 is about 14–18%, which provides good thermal stability and durability. Also, iron oxides are generally 9–14%, which improves the high-temperature resistance of the fiber. Basalt fiber is a silicate material, and its characteristics are very similar to those of cement-based materials; therefore, it has been widely used in cement concrete recently [66].

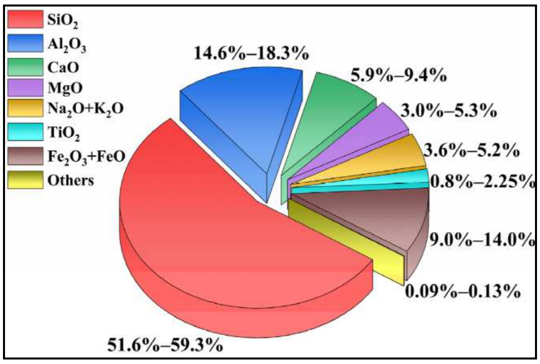

Fig. 2. Chemical composition of basalt fiber [66,67].

It should be noted that Basalt is distributed in many regions of the world, such as Russia, Indonesia, and the western United States, and there are abundant reserves in almost every province in China. As well as it constitutes an al large area of the Sham region in the middle east. Therefore, the specific chemical composition of BF will vary according to the geographical location of the basalt stone [66,67]. It is important to note that the primary component of BFRC is concrete, which consists of cement, aggregates, water, and various admixtures. The basalt fibers are added as a reinforcement material to the concrete mix, typically in the form of short fibers or continuous filaments. The proportions and specific composition of the concrete mixture can vary based on the desired performance characteristics and application requirements of BFRC [68]. There are different types of basalt fibers that can be added to concrete, such as chopped fibers or continuous fibers. The addition of basalt fibers can improve the mechanical properties of concrete, including compressive strength, flexural strength, and toughness, depending on the fiber content and the fiber-matrix interface. BFRC can also be used to produce precast concrete products, such as panels, pipes, and slabs. Basalt fibers have also been used for external reinforcement and retrofitting of concrete structures [69].

4.4 Manufacturing of BFRC

The manufacturing process of BFRC typically involves several steps. Firstly, basalt Fiber Production where the basalt fibers are manufactured mainly from basalt rock. The rock is mined from selected excavations and then washed. Afterward, the basalt rock is melted at a temperature of around 1400°C to produce molten basalt. The molten basalt is then drawn into fine fibers through a spinning process similar to that used for glass fiber production [70]. The second step is the concrete mixture preparation which combines cement, aggregates (such as sand and crushed stone), water, and any necessary admixtures. In the case of BFRC, chopped basalt fibers are added to the concrete mixture as a reinforcement material [71]. Then the mixing step comes where the concrete ingredients, including basalt fibers, are mixed thoroughly to achieve a uniform distribution of fibers within the concrete matrix [72]. Afterward, the casting step proceeds where the resulting BFRC is cast into the desired formwork or molds. This could involve pouring the concrete into structural elements such as beams, columns, or slabs, depending on the specific building application. Finally, the BFRC needs to undergo a curing process to allow the concrete to harden and gain strength. Curing involves maintaining proper temperature and moisture conditions for an appropriate duration. This manufacturing process which relies on mixing in the first place translated into taking advantage of the excellent mechanical properties of basalt fibers and combining them with the properties of concrete, resulting in a composite material with enhanced tensile strength, flexural resistance, and durability. The environmentally friendly manufacturing process of basalt fibers further adds to their appeal for concrete reinforcement applications [73]. It's important to highlight those specific details of the manufacturing process, such as the fiber content, mixing procedures, and curing conditions, which can vary depending on the desired properties and the specific application requirements in building construction.

4.5 Properties of BFRC

It is worth reminding that the BFRC is the result of mixing concrete and basalt fibers. Thus, the advantage of properties of those two materials is considered in BFRC, whether they are directed to structural purposes or environmental purposes which is the point to be highlighted in this review paper. Additionally, noting that the BFRC as a new innovative material within the field of building construction sector was found to focus on strengthening the concrete structurally in the first place. Therefore, this section starts with concluding the basalt fiber's and BFRC's mechanical properties and then turn to the focal point in this paper; the potential benefits of BFRC within the environmental performance. This combines the sustainable perspective of this new material by highlighting how to assess the impact of such a new innovative material.

4.5.1 Mechanical properties and structural performance

As mentioned previously, the BFRC is a result of mixing basalt fibers and concrete, the BFRC took advantage in terms of the mechanical properties of the two mixed materials which already translated as structural performance in the building construction field. Indeed, there are quite a number of recent studies have been conducted to investigate the mechanical and structural properties of BFRC. For example, but not limited to, Al-Rousan, Khalid, and Rahman (2023) summarize their research findings on the properties of basalt fibers, including their mechanical properties. They discuss the effects of parameters such as fiber content and length on the structural properties of BFRC [74]. Also, another study held by Bheel (2021) explored the structural properties of BFRC, including compressive strength, tensile strength, flexural strength, and modulus of elasticity. It examines the effects of mechanical properties such as volume fraction and length of basalt fibers on these mentioned structural properties [71]. A review held by Zheng, et al (2022) suggested mechanical properties of basalt fibers enhance the structural properties of concrete by strengthening it at a microscopic level and bridging cracks due to its high elastic modulus and tensile strength [75]. Additionally, an investigational study by Wu, et al (2023) focused on the structural properties of BFRC by highlighting the basalt's natural properties, such as density, solidness, and high melting temperature. They emphasize basalt fiber's potential as a reinforcement in concrete structures [76]. Overall, those types of studies offer valuable insights into the mechanical and structural properties of BFRC and can serve as references for further exploration in this field.

Based on the related literature, we can conclude some key mechanical and structural properties that BFRC exhibits. Noting that the mechanical and structural properties can vary depending on factors such as fiber content, fiber length, concrete composition, and testing methods. As indicated previously within this section, it is worth to consider the key mechanical properties of BFRC before demonstrating the structural characteristics, as the last depends on the first. Basalt fiber reinforced concrete (BFRC) exhibits improved mechanical properties compared to plain concrete. The addition of basalt fibers enhances the cohesion and adhesiveness of the concrete, affecting its workability [70]. Also, BFRC shows increased compressive strength, which is an important indicator of concrete quality. The length and amount of basalt fibers influence the compressive strength of BFRC. The addition of basalt fibers can affect the modulus of elasticity (Young's modulus) of concrete, which is a measure of its stiffness. Noting that different proportions of basalt fibers can impact Young's modulus of BFRC [71]. Worth mentioning also that Basalt fiber-reinforced geopolymer concrete demonstrates improved impact mechanical properties, including dynamic compressive strength, deformation, and energy absorption capacity [77]. Basalt fiber reinforcement improves the structural properties of concrete by enhancing its mechanical performance, durability, and resistance to high temperatures, acids, and alkalis [75,78]. To highlight the potential of basalt fiber reinforcement in concrete structures, the post-cracking mechanical behavior of concrete reinforced with basalt fibers is comparable to that of steel fibers [73]. Eventually, concluding that the mechanical properties and synergistic mechanism of basalt fiber and concrete matrix under different temperatures can be evaluated to assess the structural performance of BFRC [79]. At this point of the review, highlighting that the evaluation of mechanical properties under different conditions to assess the structural performance would be useful for exploring of how to assess the environmental performance of BFRC within the building construction field.

4.5.2 Thermal properties and environmental performance

As mentioned previously, to meet sustainability targets, it is essential to mitigate the environmental effect of concrete structures. Thus, the main purpose of the construction industry is to develop a durable and strong sustainable concrete structure that can decrease the negative impact on the environment through minimizing the consumption of energy, limited resources, along with increasing the human welfare and protecting the future generations' welfare.

In fact, in the related literature in the field of the environmental performance of the building, there is a strong relationship between the thermal properties of construction materials and their environmental performance [80,81,82,83]. Where the related studies referred to several key points to consider in this relationship. For example, thermal conductivity and energy efficiency. The thermal conductivity of a material measures its ability to conduct heat. When it comes to buildings, it is preferable for thermal conductivity to be moderate in relation to materials with high thermal mass. This helps with the absorption and release of heat, aligning with the cooling and heating cycles of the building, and promoting energy efficiency [84]. Additionally, thermal insulation materials play a vital role in reducing the dependence on heating, ventilation, and air conditioning (HVAC) systems in buildings. Properly applied thermal insulation products retard the rate of heat flow by conduction, convection, and radiation, contributing to improved energy efficiency [85]. Also, one of the thermal properties is the moisture which can degrade the performance of insulating materials. When measuring the thermal conductivity of insulating materials, the drying conditions (temperature and time) are important factors to consider [86]. It is important to say that the environmental performance of a material can be influenced by its thermal properties. For example, materials with low thermal conductivity can contribute to energy-efficient designs and reduce heat transfer between different environmental compartments. Furthermore, there are other considerations that should be considered. It's important to note that thermal properties alone may not fully determine the environmental performance of a material. Other factors such as embodied energy, durability, recyclability, and life cycle analysis should also be considered when assessing the overall environmental impact of a material or a building [87].

At this stage of this section, it is worth to conclude the thermal properties of basalt fiber and BFRC in order to put forward the potential benefits of BFRC within the field of a building's environmental performance. A very potential benefit in the field of environmental performance is that the addition of basalt fibers to concrete has been found to reduce its thermal conductivity. BFRC exhibits lower thermal conductivity compared to conventional concrete, making it more resistant to heat transfer. Thus, it enhances the decrease of energy consumption. Related studies have examined the heat transfer characteristics of BFRC and observed improvements in heat transfer resistance compared to plain concrete [88,89]. Overall and besides the mechanical properties, investigations into the thermal properties of BFRC have shown promising results that can open new horizons in the field of sustainable building construction. Basalt fiber reinforcement contributes to lower thermal conductivity, improved heat transfer resistance, increased compressive strength, and enhanced durability, making it a potentially favorable material for various construction applications [71,76,79,88]. It is important to note that the specific properties of BFRC may vary based on factors such as the volume fraction of basalt fibers, mix design, curing conditions, and testing methods employed in different studies. Therefore, further research and specific testing are necessary to fully understand and optimize the thermal properties of BFRC for specific applications within the sustainable construction field. As a conclusion of this section, a hint that can be given to further future research in the field of BFRC-based buildings is that to enrich the environmental performance of such buildings, a great focus should be given to monitoring the thermal properties of enhanced materials such as BFRC. Therefore, to reach sustainable development targets within the sustainable building construction field and particularly in harsh climates where the need for energy consumption is at its peak.

4.6 Sustainable perspectives of BFRC

The sustainable perspectives in this section highlight the potential benefits of utilizing BFRC in the field of building construction. By leveraging its eco-friendly nature, improved performance, waste utilization, and energy efficiency. The raw material of basalt fiber originates from natural volcanic rock, which is low-cost extraction since they are found on the surface, there is no need to expend energy. Also, it incorporates high chemical and thermal stability and produces no harmful gas or waste residue in the fiber production process. It is a kind of new green material that meets the requirements of environmental protection; it is a kind of green fiber that does not create environmental pollution or pose a cancer risk, Basalt fibers have a low carbon footprint and are environmentally safe and non-toxic. Also, the strength of basalt fiber is much higher than that of synthetic fiber. More to include is that its elastic modulus is similar to carbon's fiber, which is higher than that of other fibers. Though their comprehensive performance is parallel, the cost of basalt fiber is lower than one-tenth of carbon fiber [90,91,92,93].

Furthermore, Basalt fiber technology is a versatile and effective method of enhancing construction materials. By adding basalt fibers to building materials, the resulting materials can be made stronger, more durable, and more resistant to damage from weathering and other environmental factors. This can help to extend the lifespan of buildings and infrastructure, reduce the need for maintenance and repairs, and promote sustainability in the construction industry [73,94,95,96]. Additionally, the following Table 2 can conclude the key points of BFRC's sustainable perspectives in the field of building construction.

Sustainable perspectives	Illustration
Sustainable and eco-friendly material	Basalt fiber is derived from basalt rock, which is formed from volcanic eruptions. It is considered a green fiber because it has a minimal environmental impact and does not cause pollution during production. This makes it an attractive choice for sustainable construction practices [97].
Improved performance and durability	BFRC exhibits high elastic modulus, fracture strength, frost resistance, and corrosion resistance. By incorporating basalt fibers into concrete, the resulting composite material can enhance the performance and durability of structures, reducing the need for frequent repairs or replacements [97].
Reduced environmental footprint	The use of basalt fibers in concrete can contribute to the reduction of carbon emissions and energy consumption. Basalt fibers have a lower carbon footprint compared to other reinforcement materials like steel fibers, as their production requires less energy and generates fewer greenhouse gas emissions [71].
Improved energy efficiency	The use of BFRC can contribute to the thermal efficiency of buildings. Basalt fibers have good insulating properties, which can help reduce energy consumption for heating and cooling purposes [98].
Longevity and reduced maintenance	BFRC has the potential to extend the service life of structures due to its enhanced durability and resistance to environmental factors. This can result in reduced maintenance requirements, lower life-cycle costs, and a smaller environmental impact over the long term [99].

Table 2: Practices toward sustainable development within the concrete construction sector.

5 CONCLUDING REMARKS

Facing the new sustainability challenges resulting from construction materials, a detailed description of material alternatives needs to be provided. Future research studies aimed at the modification and optimization of building materials should include, at least, simplified environmental analysis, since the mitigation of environmental impact represents a major challenge for the sustainability of modern society. The eco-efficiency of the modern building corresponds not only to decrease energy consumption but also to the environmental impacts including resource consumption and human welfare should also be counted.

In conclusion, this paper indicated the related studies that explored and investigated the features of BFRC in the field of construction buildings, that particularly found encouraging results. However, most of the related research focused on mechanical properties and structural performance, while Studies focusing on thermal properties and environmental performance have been modest and still sketchy. Therefore, in the field of environmental performance for a BFRC-based building, the collected information is still scattered. Thus, this paper draws hints at how to evaluate the environmental performance of such buildings as well as drives for potential environmental benefits of utilizing BFRC in order to face the sustainability challenges mentioned earlier in this paper.

The challenge of reducing energy and raw material consumption and at the same time complying with human welfare, quality, and cost requirements in the context of the huge demand for cement as a construction material in the future will only be met with highly efficient research in the field of assessing the environmental performance. Overall, BFRC is a novel and promising green material with excellent capabilities and will have a lot of promise in the sustainable construction sector. Both sides of performance, the structural and environmental, should be considered.

Eventually, this review paper recommends further experimental research on the composition of basalt fiber in terms of basic materials that enhance the environmental performance of BFRC, and the building's environmental performance in turn. As the same for what has been studied previously in terms of BFRC's structural performance. With noting the different conditions that could be exposed to through manufacturing the BFRC. Which affects the thermal parameters for these basalt fiber compositions. Then, to conclude the suitable conditions for reaching the best environmental performance of the BFRC-based building. Which can be evaluated based on operational and use periods, therefore enhancing the sustainable development of the concrete industry.

6 REFERENCES

1. Kulshreshtha, Y., Mota, N., Jagadish, K., Bredenoord, J., Vardon, P., Loosdrecht, M., & Jonkers, H. (2020). The potential and current status of earthen material for low-cost housing in rural India. Construction and Building Materials, 247. doi:https://doi.org/10.1016/j.conbuildmat.2020.118615
2. Akinyemi, B., Ojediran, J., Olawale , O., & Ayanwola, S. (2020). Efficacy of expanded polystyrene as fine aggregate in cement mortars modified with latex paint as an alternative to polymer admixture. Journal of the Mechanical Behavior of Materials. doi:https://doi.org/10.1515/jmbm-2020-0016
3. Akinyemi, B., & Adesina, A. (2020). Recent advancements in the use of biochar for cementitious applications: A review. Journal of Building Engineering, 32. doi:https://doi.org/10.1016/j.jobe.2020.101705
4. Ayobami, A. (2021). Performance of wood bottom ash in cement-based applications and comparison with other selected ashes: Overview. Resources, Conservation and Recycling, 166. doi:https://doi.org/10.1016/j.resconrec.2020.105351
5. Geng, K., Chai, J., Qin, Y., Li, X., Duan, M., & Liang, D. (2022). Exploring the brittleness and fractal characteristics of basalt fiber reinforced concrete under impact load based on the principle of energy dissipation. Materials and Structures, 55(78). doi:https://doi.org/10.1617/s11527-022-01891-2
6. Chen, S., Liu, T., Zheng, Z., Ishaq, M., Liang, G., Fan, P., . . . Tang , J. (2022). Recent progress and perspectives on Sb2Se3-based photocathodes for solar hydrogen production via photoelectrochemical water splitting. Journal of Energy Chemistry, 67, 508-523. doi:https://doi.org/10.1016/j.jechem.2021.08.062
7. Dinarvand, P., & Rashno, A. (2022). Review of the potential application of bacteria in self-healing and the improving properties of concrete/mortar. Journal of Sustainable Cement-Based Materials, 11(4), 250-271. doi:https://doi.org/10.1080/21650373.2021.1936268
8. Ahmad, J., & Zhou, Z. (2022). Mechanical Properties of Natural as well as Synthetic Fiber Reinforced Concrete: A Review. Construction and Building Materials, 333. doi:https://doi.org/10.1016/j.conbuildmat.2022.127353
9. Ray, S., Haque, M., Ahmed, T., Mita, A., Saikat, M., & Alom, M. (2022). Predicting the strength of concrete made with stone dust and nylon fiber using artificial neural network. Heliyon, 8(3). doi:https://doi.org/10.1016/j.heliyon.2022.e09129
10. Khaloo, A., Raisi, E., Hosseini, P., & Tahsiri, H. (2014). Mechanical performance of self-compacting concrete reinforced with steel fibers. Construction and Building Materials, 51, 179-186. doi:https://doi.org/10.1016/j.conbuildmat.2013.10.054
11. Mehdipour, S., Nikbin, I., Dezhampanah, S., Mohebbi, R., Moghadam, H., Charkhtab, S., & Moradi, A. (2020). Mechanical properties, durability and environmental evaluation of rubberized concrete incorporating steel fiber and metakaolin at elevated temperatures. Journal of Cleaner Production, 254. doi:https://doi.org/10.1016/j.jclepro.2020.120126
12. Abiola, O. (2017). 8- Natural fibre cement composites. Advanced High Strength Natural Fibre Composites in Construction, 205-214. doi:https://doi.org/10.1016/B978-0-08-100411-1.00008-X
13. Yeol Yoo, D., Ha Lee, J., & Soo Yoon, Y. (2013). Effect of fiber content on mechanical and fracture properties of ultra high performance fiber reinforced cementitious composites. Composite Structures, 106, 742-753. doi:https://doi.org/10.1016/j.compstruct.2013.07.033
14. Tao Huang, B., Hua Li, Q., Lang Xu, S., & Zhou, B. (2019). Strengthening of reinforced concrete structure using sprayable fiber-reinforced cementitious composites with high ductility. Composite Structures, 220, 940-952. doi:https://doi.org/10.1016/j.compstruct.2019.04.061
15. Chang Choi, W., Do Yun, H., Geun Cho, C., & Feo, L. (2014). Attempts to apply high performance fiber-reinforced cement composite (HPFRCC) to infrastructures in South Korea. Composite Structures, 109, 211-223. doi:https://doi.org/10.1016/j.compstruct.2013.10.027
16. Bolander, J., Choi, S., & Duddukuri, S. (2009). Fracture of fiber-reinforced cement composites: effects of fiber dispersion. International Journal of Fracture, 154, 73–86. doi:https://doi.org/10.1007/s10704-008-9269-4
17. Li, Z., Shen, A., Zeng, G., Chen, Z., & Guo, Y. (2022). Research progress on properties of basalt fiber-reinforced cement concrete. Materials Today Communications, 33. doi:https://doi.org/10.1016/j.mtcomm.2022.104824
18. Chen, F., Xu, B., Jiao, H., Chen, X., Shi, Y., Wang, J., & Li, Z. (2021). Triaxial mechanical properties and microstructure visualization of BFRC. Construction and Building Materials, 278. doi:https://doi.org/10.1016/j.conbuildmat.2021.122275
19. Li , Y., Shen, A., & Wu, H. (2020). Fractal Dimension of Basalt Fiber Reinforced Concrete (BFRC) and Its Correlations to Pore Structure, Strength and Shrinkage. Materials, 13(14). doi:https://doi.org/10.3390/ma13143238
20. Purnell, P. (2011). Material Nature versus Structural Nurture: The Embodied Carbon of Fundamental Structural Elements. Environemntal Science Technology. Retrieved from https://pubs.acs.org/doi/abs/10.1021/es202190r
21. Costanza, R., Daly, H., Folke, C., Hawken, P., Holling,, C., McMichael, A., . . . Rapport , D. (2000). Managing Our Environmental Portfolio. BioScience, 50(2), 149–155. doi:https://doi.org/10.1641/0006-3568(2000)050[0149:MOEP]2.3.CO;2
22. Heal, G. (2012). Reflections—Defining and Measuring Sustainability. Review of Environmental Economics and Policy, 6(1). doi:https://doi.org/10.1093/reep/rer023
23. Moore, J., Mascarenhas, A., Bain , J., & Straus , S. (2017). Developing a comprehensive definition of sustainability. Implementation Science, 12. doi:https://doi.org/10.1186/s13012-017-0637-1
24. Keeble, B. (2007). The Brundtland report: 'Our common future'. Medicine and War, 4(1). doi:https://doi.org/10.1080/07488008808408783
25. Maude, A. (2014). A sustainable view of sustainability? Geography, 99(1), 47-50. doi:https://doi.org/10.1080/00167487.2014.12094391

26. Norton, B. (1992). Sustainability, Human Welfare and Ecosystem Health. Environmental Values, 1(2), 97-111. doi:https://doi.org/10.3197/096327192776680133
27. Guo, S., Hu, J., & Dai, Q. (2018). A critical review on the performance of portland cement concrete with recycled organic components. Journal of Cleaner Production, 188, 92-112. doi:https://doi.org/10.1016/j.jclepro.2018.03.244
28. Garside, M. (2023, April 11). Cement production worldwide from 1995 to 2022. Retrieved from Statista: https://www.statista.com/statistics/1087115/global-cement-production-volume/
29. van Oss, H., & Padovani, A. (2008). Cement Manufacture and the Environment: Part I: Chemistry and Technology. Journal of Indutrial Ecology, 6(1), 89-105. doi:https://doi.org/10.1162/108819802320971650
30. Miller, S., John, V., Pacca, S., & Horvath, A. (2018). Carbon dioxide reduction potential in the global cement industry by 2050. Cement and Concrete Research, 114, 115-124. doi:https://doi.org/10.1016/j.cemconres.2017.08.026
31. Brocklesby, M., & Davison, J. (2000). The environmental impacts of concrete design, procurement and on-site use in structures. Construction and Building Materials, 14(4), 179-188. doi:https://doi.org/10.1016/S0950-0618(00)00010-6
32. Kahhat, R., Crittenden, J., & Fonseca, E. (2009). Environmental Impacts over the Life Cycle of Residential Buildings Using Different Exterior Wall Systems. Journal of Infrastructure Systems, 15(3). Retrieved from https://ascelibrary.org/doi/epdf/10.1061/%28ASCE%291076-0342%282009%2915%3A3%28211%29
33. Häfliger, I., John, V., Passer, A., Lasvaux, S., Saade, M., & Habert, G. (2017). Buildings environmental impacts' sensitivity related to LCA modelling choices of construction materials. Journal of Cleaner Production, 156, 805-816. doi:https://doi.org/10.1016/j.jclepro.2017.04.052
34. Linkevičius, E., Žemaitis, P., & Aleinikovas , M. (2023). Sustainability Impacts of Wood- and Concrete-Based Frame Buildings. Sustainability, 15(2). doi:https://doi.org/10.3390/su15021560
35. Mocová, K., Sackey, L., & Renkerová, P. (2019). Environmental Impact of Concrete and Concrete-Based Construction Waste Leachates. IOP Conference Series: Earth and Environmental Science. Prague. doi:10.1088/1755-1315/290/1/012023
36. Fraj, A., & Idir, R. (2017). Concrete based on recycled aggregates – Recycling and environmental analysis: A case study of paris' region. Construction and Building Materials, 157, 952-964. doi:https://doi.org/10.1016/j.conbuildmat.2017.09.059
37. Gjørv, O. (2011). Durability of Concrete Structures. Arabian Journal for Science and Engineering, 36, 151–172. doi:https://doi.org/10.1007/s13369-010-0033-5
38. Reider, R., & Meir, I. (2019). Comparing the energy implications of FRP and concrete residential construction in a hot arid climate. Energy and Buildings, 186, 98-107. doi:https://doi.org/10.1016/j.enbuild.2019.01.003
39. Basheer, P., Chidiact, S., & Long, A. (1996). Predictive models for deterioration of concrete structures. Construction and Building Materials, 10(1), 27-37. doi:https://doi.org/10.1016/0950-0618(95)00092-5
40. Rashid, A., & Yusoff, S. (2015). A review of life cycle assessment method for building industry. Renewable and Sustainable Energy Reviews, 45, 244-248. doi:https://doi.org/10.1016/j.rser.2015.01.043
41. Schneider, M., Romer, M., Tschudin, M., & Bolio, H. (2011). Sustainable cement production—present and future. Cement and Concrete Research, 41(7), 642-650. doi:https://doi.org/10.1016/j.cemconres.2011.03.019
42. Komnitsas, K. (2011). Potential of geopolymer technology towards green buildings and sustainable cities. Procedia Engineering, 21, 1023-1032. doi:https://doi.org/10.1016/j.proeng.2011.11.2108
43. Damtoft, J., Lukasik, J., Herfort, D., Sorrentino, D., & Gartner, E. (2008). Sustainable development and climate change initiatives. Cement and Concrete Research, 38(2), 115-127. doi:https://doi.org/10.1016/j.cemconres.2007.09.008
44. Pera, J., Boumaza, R., & Ambroise, J. (1997). Development of a pozzolanic pigment from red mud. Cement and Concrete Research, 27(10), 1513-1522. doi:https://doi.org/10.1016/S0008-8846(97)00162-2
45. Bleszynski, R., Hooton,, R., Thomas, M., & Rogers, C. (2002). Durability of Ternary Blend Concrete with Silica Fume and Blast-Furnace Slag: Laboratory and Outdoor Exposure Site Studies. Materials Journal, 499-508.
46. Hendriks, C., Jager, D., Worrell, E., Price, L., Martin, N., Ozawa, M., & Riemer, P. (1999). Emission reduction of greenhouse gases from the cement industry. United Kingdom.
47. Ramamurthy, K., Nambiar, E., & Ranjani, G. (2009). A classification of studies on properties of foam concrete. Cement and Concrete Composites, 31(6), 388-396. doi:https://doi.org/10.1016/j.cemconcomp.2009.04.006
48. Worrell, E., Heijningen, R., Castro, J., Hazewinkel, J., Beer, J., Faaij, A., & Vringer, K. (1994). New gross energy-requirement figures for materials production. Energy, 19(6), 627-640. doi:https://doi.org/10.1016/0360-5442(94)90003-5
49. Corinaldesi, V., & Moriconi, G. (2009). Behaviour of cementitious mortars containing different kinds of recycled aggregate. Construction and Building Materials, 23(1), 289-294. doi:https://doi.org/10.1016/j.conbuildmat.2007.12.006
50. Shen, W., Liu, Y., Yan, B., Wang, J., He, P., Zhou, C., . . . Ding, Q. (2017). Cement industry of China: Driving force, environment impact and sustainable development. Renewable and Sustainable Energy Reviews, 75, 618-628. doi:https://doi.org/10.1016/j.rser.2016.11.033
51. Mahmood, A., Noman, M., Pechočiaková, M., Amor, N., Petrů,, M., Abdelkader, M., . . . Hassan, S. (2021). Geopolymers and Fiber-Reinforced Concrete Composites in Civil Engineering. Polymers (Basel), 13(3). Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8272018/
52. Labib, W. (2018). Fibre Reinforced Cement Composites. Cement Based Materials. doi:DOI: 10.5772/intechopen.75102
53. Vikas, G., & Sudheer, M. (2017). A Review on Properties of Basalt Fiber Reinforced Polymer Composites. American Journal of Materials Science, 7(5), 156-165. doi:10.5923/j.materials.20170705.07
54. Amruth, Y., Mohandas, K., & Babu, L. (2021). Mechanical characteristics study on basalt/epoxy laminates. Materialstoday Proceedings, 46(10), 4407-4411. doi:https://doi.org/10.1016/j.matpr.2020.09.670
55. Wang,, S., Xu, Q., & Sun, H. (2022). Functionalization of Fiber Devices: Materials, Preparations and Applications. Advanced Fiber Materials, 4, 324–341. doi:https://doi.org/10.1007/s42765-021-00120-9
56. Gamal, T., & Chiadighikaobi, P. (2019). Comparative analysis of reliability of non-destructive methods of strength control of concrete impregnated with vegetable oil: Basalt fiber for increasing the concrete strength. Materialstoday Proceedings, 19(5), 2479-2482. doi:https://doi.org/10.1016/j.matpr.2019.08.113
57. Sunaga, D., Namiki, K., & Kanakubo, T. (2020). Crack width evaluation of fiber-reinforced cementitious composite considering interaction between deformed steel rebar. Construction and Building Materials, 261. doi:https://doi.org/10.1016/j.conbuildmat.2020.119968

58. Czigány , T. (2005). Discontinuous Basalt Fiber-Reinforced Hybrid Composites. In Polymer Composites (pp. 309–328). Boston: Springer. doi:https://doi.org/10.1007/0-387-26213-X_17
59. Jamshaid, H., & Mishra, R. (2015). A green material from rock: basalt fiber – a review. The Journal of The Textile Institute, 107(7), 923-937. doi:https://doi.org/10.1080/00405000.2015.1071940
60. Einde, L., Zhao, L., & Seible, F. (2003). Use of FRP composites in civil structural applications. Construction and Building Materials, 17(6-7), 389-403. doi:https://doi.org/10.1016/S0950-0618(03)00040-0
61. Xu, X., Rawat, P., Shi, Y., & Zhu, D. (2019). Tensile mechanical properties of basalt fiber reinforced polymer tendons at low to intermediate strain rates. Composites Part B: Engineering, 177. doi:https://doi.org/10.1016/j.compositesb.2019.107442
62. Smil, V. (2008). Global Catastrophes and Trends: The Next 50 Years. MIT Press.
63. Li, Z., Ma, J., Ma, H., & Xu, X. (2018). Properties and Applications of Basalt Fiber and Its Composites. IOP Conference Series: Earth and Environmental Science. 186. IOP Publishing Ltd.
64. Khan, M., Cao, M., Hussain, A., & Chu, S. (2021). Effect of silica-fume content on performance of CaCO3 whisker and basalt fiber at matrix interface in cement-based composites. Construction and Building Materials, 300. doi:https://doi.org/10.1016/j.conbuildmat.2021.124046
65. Chakartnarodom, P., Prakaypan, W., Ineure, P., Kongkajun, N., & Chuankrerkkul, N. (2018). Feasibility Study of Using Basalt Fibers as the Reinforcement Phase in Fiber-Cement Products. Key Engineering Materials, 766, 252-257. doi:https://doi.org/10.4028/www.scientific.net/KEM.766.252
66. Liu , H., Yu, Y., Liu , Y., Zhang , M., Li, L., Ma, L., . . . Wang, X. (2022). A Review on Basalt Fiber Composites and Their Applications in Clean Energy Sector and Power Grids. Polymers, 14(12). doi:https://doi.org/10.3390/polym14122376
67. Segev, A., Reznik, J., & Schattner, U. (2022). Miocene to sub-Recent magmatism at the intersection between the Dead Sea Transform and the Ash Shaam volcanic field: evidence from the Yarmouk River gorge and vicinity. Geological Magazine, 159(4), 469–493. doi:https://doi.org/10.1017/S0016756821001072
68. Zhou, H., Jia, B., Huang, H., & Mou, Z. (2020). Experimental Study on Basic Mechanical Properties of Basalt Fiber Reinforced Concrete. Materials, 13(6). doi:https://doi.org/10.3390/ma13061362
69. Yang, L., Xie, H., Fang, S., Huang, C., Yang, A., & Chao, Y. (2021). Experimental study on mechanical properties and damage mechanism of basalt fiber reinforced concrete under uniaxial compression. Structures, 31, 330-340. doi:https://doi.org/10.1016/j.istruc.2021.01.071
70. AL-Kharabsheh, B., Arbili, M., Majdi, A., Alogla, S., Hakamy, A., Ahmad, J., & Deifalla, A. (2022). Basalt Fibers Reinforced Concrete: Strength and Failure Modes. Materials (Basel), 15(20). doi:10.3390/ma15207350
71. Bheel, N. (2021). Basalt fibre-reinforced concrete: review of fresh and mechanical properties. Journal of Building Pathology and Rehabilitation, 6(12). doi:https://doi.org/10.1007/s41024-021-00107-4
72. Al-Kharabsheh , B., Arbili , M., Majdi, A., Alogla, S., Hakamy, A., Ahmad, J., & Deifalla, A. (2023). Basalt Fiber Reinforced Concrete: A Compressive Review on Durability Aspects. Materials, 16(1). doi:https://doi.org/10.3390/ma16010429
73. Branston, J., Das, S., Kenno, S., & Taylor, C. (2016). Mechanical behaviour of basalt fibre reinforced concrete. Construction and Building Materials, 124, 878-886. doi:https://doi.org/10.1016/j.conbuildmat.2016.08.009
74. Al-Rousan, E., Khalid, H., & Rahman, M. (2023). Fresh, mechanical, and durability properties of basalt fiber-reinforced concrete (BFRC): A review. Developments in the Built Environment, 14. doi:https://doi.org/10.1016/j.dibe.2023.100155
75. Zheng, Y., Zhang, Y., Zhuo, J., Zhang, Y., & Wan, C. (2022). A review of the mechanical properties and durability of basalt fiber-reinforced concrete. Construction and Building Materials, 359. doi:https://doi.org/10.1016/j.conbuildmat.2022.129360
76. Wu, H., Qin, X., Huang, X., & Kaewunruen, S. (2023). Engineering, Mechanical and Dynamic Properties of Basalt Fiber Reinforced Concrete. Materials, 12(6). doi:https://doi.org/10.3390/ma16020623
77. Li, W., & Xu, J. (2009). Mechanical properties of basalt fiber reinforced geopolymeric concrete under impact loading. Materials Science and Engineering: A, 505(1-2), 178-186. doi:https://doi.org/10.1016/j.msea.2008.11.063
78. Ramesh, B., & Eswari, S. (2021). Mechanical behaviour of basalt fibre reinforced concrete: An experimental study. Materials Today Proceedings, 43(2), 2317-2322. doi:https://doi.org/10.1016/j.matpr.2021.01.071
79. Lu, L., H., F., Qin, Y., Wu, S., Yuan, G., Zhao, Q., & Hwan-Doh, J. (2022). Experimental study of the mechanical properties of basalt fibre-reinforced concrete at elevated temperatures. European Journal of Environmental and Civil Engineering, 26(15), 7586-7600. doi:https://doi.org/10.1080/19648189.2021.2003253
80. Madurwar, M., Ralegaonkar, R., & Mandavgane, S. (2013). Application of agro-waste for sustainable construction materials: A review. Construction and Building Materials, 38, 872-878. doi:https://doi.org/10.1016/j.conbuildmat.2012.09.011
81. Niachou, A., Papakonstantinou, K., Santamouris, M., Tsangrassoulis, A., & Mihalakakou, G. (2001). Analysis of the green roof thermal properties and investigation of its energy performance. Energy and Buildings, 33(7), 719-729. doi:https://doi.org/10.1016/S0378-7788(01)00062-7
82. Abdul Awal, A., & Shehu, I. (2015). Performance evaluation of concrete containing high volume palm oil fuel ash exposed to elevated temperature. Construction and Building Materials, 76, 214-220. doi:https://doi.org/10.1016/j.conbuildmat.2014.12.001
83. Schutter, G., Lesage, K., Mechtcherine, V., Nerella, V., Habert, G., & Juan, I. (2018). Vision of 3D printing with concrete — Technical, economic and environmental potentials. Cement and Concrete Research, 112, 25-36. doi:https://doi.org/10.1016/j.cemconres.2018.06.001
84. Sharaf, F., & Zampieri, P. (2020). The impact of thermal mass on building energy consumption: A case study in Al Mafraq city in Jordan. Cogent Engineering, 7(1). doi:https://doi.org/10.1080/23311916.2020.1804092
85. Anh, L., & Pásztory, Z. (2021). An overview of factors influencing thermal conductivity of building insulation materials. Journal of Building Engineering, 44. doi:https://doi.org/10.1016/j.jobe.2021.102604
86. Wi, S., Park, J., Kim, Y., Yang, S., & Kim, S. (2021). Thermal, hygric, and environmental performance evaluation of thermal insulation materials for their sustainable utilization in buildings. Environmental Pollution, 272. doi:https://doi.org/10.1016/j.envpol.2020.116033
87. Sevilla, L., & Radulovic , J. (2021). Exploring the Relationship Between Heat Absorption and Material Thermal Parameters for Thermal Energy Storage. Energy and Sustainable Features, 27–32. doi:https://doi.org/10.1007/978-3-030-63916-7_4

88. Borhan, T. (2013). Thermal and Mechanical Properties of Basalt Fibre Reinforced Concrete. International Journal of Civil, Environmental, Structural, Construction and Architectural Engineering, 7(4).
89. Qsymah, A., Arbili, M., Ahmad , J., Alogla , S., Al-Sodani, K., Hakamy, A., & Özkılıç, Y. (2023). Thermal properties, microstructure analysis, and environmental benefits of basalt fiber reinforced concrete. Journal of Engineered Fibers and Fabrics, 18. doi:https://doi.org/10.1177/15589250221146547
90. Amran, M., Fediuk, R., Klyuev, S., & Qader, D. (2022). Sustainable development of basalt fiber-reinforced high-strength eco-friendly concrete with a modified composite binder. Case Studies in Construction Materials, 17. doi:https://doi.org/10.1016/j.cscm.2022.e01550
91. Fořt, J., Kočí, J., & Černý, R. (2021). Environmental Efficiency Aspects of Basalt Fibers Reinforcement in Concrete Mixtures. Energies, 14(22). doi:https://doi.org/10.3390/en14227736
92. Ayub, T., Shafiq, N., & Nuruddin, M. (2014). Mechanical Properties of High-performance Concrete Reinforced with Basalt Fibers. Procedia Engineering, 77, 131-139. doi:https://doi.org/10.1016/j.proeng.2014.07.029
93. Torres, J., Hoto, R., Andrés, J., & Manrique, J. (2013). Manufacture of Green-Composite Sandwich Structures with Basalt Fiber and Bioepoxy Resin. Advances in Materials Science and Engineering. doi:https://doi.org/10.1155/2013/214506
94. Guo, S., Hu, J., & Dai, Q. (2018). A critical review on the performance of portland cement concrete with recycled organic components. Journal of Cleaner Production, 188, 92-112. doi:https://doi.org/10.1016/j.jclepro.2018.03.244
95. Tavadi, A., Naik, Y., Kumaresan, K., Jamadar, N., & Rajaravi, C. (2021). Basalt fiber and its composite manufacturing and applications: An overview. International Journal of Engineering, Science and Technology, 13(4). doi:10.4314/ijest.v13i4.6
96. Sim, J., Park, C., & Moon, D. (2005). Characteristics of basalt fiber as a strengthening material for concrete structures. Composites Part B: Engineering, 36(6-7). doi:https://doi.org/10.1016/j.compositesb.2005.02.002
97. Li, Y., Zhang, J., He, Y., Huang, G., Li, J., Niu, Z., & Gao, B. (2022). A review on durability of basalt fiber reinforced concrete. Composites Science and Technology, 255. doi:https://doi.org/10.1016/j.compscitech.2022.109519
98. Grzesiak, S., Pahn, M., Klingler , A., Akpan, E., Cornelius, M., & Wetzel , B. (2022). Mechanical and Thermal Properties of Basalt Fibre Reinforced Polymer Lamellas for Renovation of Concrete Structures. Polymers, 1