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ARTICLE
LOOKING INTO FEASIBILITY OF USING LOCALLY AVAILABLE SUSTAINABLE MATERIALS FOR CONSTRUCTION PURPOSES

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ABSTRACT

The construction industry contributes substantially to climate change and significantly alters the environment through extraction, processing, waste generation, and carbon emissions. Building materials and operations account for around 50% of all carbon emissions globally. Natural building materials were used for construction and were less damaging to the environment before advanced building technology was introduced. Material selection plays an important role in the construction industry and vital for valuing sustainability in construction for transitioning towards climate change adaptation and a low carbon economy. This study is an attempt to highlight the importance of valuing sustainability in the construction industry. This paper will look at the definitions of sustainable materials and their compliance with material assessment criteria to determine their feasibility for use in building construction. For this purpose, a site is selected with the availability of raw materials such as a forest, sheep farms, and straw in fields. Historical and contemporary use of selected materials in that region is studied to understand their suitability for construction. It is intended that this study will help the architects to make well-informed decisions about the use of construction materials to assist in designing healthy, resource-efficient, and affordable buildings suitable for individuals and communities.

1.0 INTRODUCTION

The Brundtland Commission defined sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (United Nations, 1987, p.16). Construction materials and products are extracted and manufactured hundred and even thousands of miles away from the project site affecting ecosystems at the extraction and manufacturing locations. Extraction of materials disrupts and impacts habitats, soil, air, and water; and affects human health either directly or indirectly due to environmental degradation. Moreover, transportations of these products and materials consume fuel and emit pollutants to the environment (Calkins, 2009). Consequently, the construction industry is contributing significantly to global climate change and many other environmental threats. Climate change awareness means that major changes are being achieved in the energy efficiency of buildings, though the focus is on the operational phase and does not yet extend sufficiently to the materials that are used to achieve this, as highlighted by the Building Services Research and Information Association report (BSRIA) (Hammond and Jones, 2011). According to Agenda 21, sustainable construction is a holistic process aiming to restore and maintain harmony between the natural and the built environment and establish settlements to sustain economic equity and human dignity. It includes implying principles of sustainable development to the complete construction cycle from material extraction till final deconstruction (Du Plessis, 2007).

There is a need to make radical shifts in construction practices if we are to mitigate the impacts of climate change. The construction industry can make a significant difference by adopting sustainable construction practices; yet, material selection always remains one of the most challenging and contentious issues. Sustainability in construction is considered vital for transitioning towards climate change adaptation and a low carbon economy (Acharya, 2013). Material selection in the 21st century must respond to an entirely different set of forces including global climate change, rising fuel cost, air pollution, ecological destruction, and loss of biodiversity (Calkins, 2009).

This manuscript aims to comprehend the feasibility of using sustainable and locally available materials for building construction. For this purpose, a site is selected with the availability of raw materials such as a forest, sheep farms, soil, and straw in fields. A review of characteristics of the materials and both historical and contemporary use of selected materials are explored to understand their appropriateness for building purposes.

For this purpose, this paper is divided into the following sections: (ii) sustainable materials; (iii) sustainable material assessment tools; (iv) the site; (v) materials selected; (vi) suitable material choice; (vii) historical and contemporary use of materials; and, (viii) conclusion. These are explained next.

2.0 SUSTAINABLE MATERIALS

While defining characteristics of sustainable materials, Calkins (2009) emphasized choosing materials that minimize resource use, Embodied Energy (EE) and Embodied Carbon (EC). The use of local material can support this criterion. According to him, the practice of reusing, reducing, and recycling materials leads to reduced consumption of resources thereby minimizing habitat destruction and ecosystem disruption resulted from resource extractions. Materials that can harm humans or the environmental health at any stage of their life cycle should be avoided.

The criteria for sustainable building materials include minimizing the use of energy and natural resources, maximizing recycling potential, and protecting the environment. Transport emissions, maintenance, and operational requirements of materials should also be considered (Thormark, 2006). Other than the environmental criteria of construction materials, it should also articulate the physical and economic health and well-being of individuals, communities, and organizations (Halliday, 2008).

Architecture has now moved away from traditional and sustainable building practices that used local materials. A pallet of materials from outside the locality that uses state-changing processes is currently the norm. Natural building materials (stone, soil, timber, bamboo, etc.) were used for construction and were less damaging to the environment before advanced building technology was introduced (Dixit et al., 2012). The building sector now is responsible for around 40% of global energy use and approximately 44% of the total material use as well as roughly one-third of the total carbon emission (Li, 2006). Under these circumstances, selecting materials that minimize buildings' environmental impact is essential.

3.0 SUSTAINABLE MATERIAL ASSESSMENT TOOLS

Sustainability assessment has become a growing concern worldwide to deal with the issues of climate change. Sustainability refers to the consideration of environmental, social, and economic aspects. Appropriate tools are required to ensure the complete coverage of these aspects and allow the participation of multiple stakeholders. Many tools and frameworks have been proposed to characterize and assess sustainability at different levels (Villeneuve et al., 2017). It is apparent that sustainable development fundamentally aims at a more equitable society through fair inter-and intra-generational exploitation of resources. To address the goal of sustainable development, the construction material production and construction industries must make radical shifts. This will necessitate significant changes in the material industry (Calkins, 2009).

The assessment of materials for sustainability begins by establishing criteria for evaluating building materials (Calkins, 2009). The first generation of rating tools for environmental assessment of buildings originated in developed countries. Worldwide, numerous sustainability assessment tools such as LEED (USA), BREEAM (UK), Green Star (Australia), and CASBEE (Japan) are in practice for building performance evaluation but these are tailored for developed countries (Acharya, 2013). Many of the tools in practice around the globe have been based on or inspired by BREEAM, but these have been adapted to exclusively suit certain regions. All these systems are relying on local regulatory minima to achieve certain aspects of performance. These are profoundly not helpful to set global standards (Saunders, 2008). In regions marked by poverty and economic problems, the sustainability of the construction industry and the environment is not regarded as a national priority. Saunders (2008) argues that assessment frameworks for developed countries appear less appropriate for less developed countries and require bio-regional adaptations.

Most of the sustainability tools and criteria for developed and developing countries such as LEED (USA), LEED (India), BREAM (UK), and GBI (Malaysia) aim at the performance evaluation of whole building and material selection is secondary. These assessment tools mostly focus on environmental criteria of materials (Table 1) and do not consider the impact of material selection on the economy and society. No single assessment tool specific for materials was found. However, studies suggest developing region-specific material selection criteria. This is also required to

include social and economic aspects of building materials in sustainability assessment tools (Acharya, 2013).
There are no mandated sustainability assessment tools in Pakistan. However, Pakistan Green Building Council (PGBC) has developed a voluntary, agreement-based tool that serves as a guideline and assessment mechanism. Materials and Resources (MR) is one of the eight green building categories of Pakistan Green Building guidelines. Different prerequisites are identified for the MR category including storage and collection of recyclables, building and material reuse, and building product disclosure and optimization (encouraging the use of environmentally, economically, and socially preferable material) (PGBG, 2016). However, no percentage weighting is given to the MR category. On the other hand, materials and resources are given 14%, 11%, and 12.5% weighting in LEED, GBI, and BREAM, respectively. Studies suggest that it is imperative to evaluate existing sustainability assessment tools to identify sustainable materials selection criteria. Therefore in addition to PGBC guidelines, one sustainability assessment tool from developed and two from developing countries (Asian context) are examined for material sustainability assessment (Table 1).

After reviewing the literature (Calkins, 2009; Halliday, 2008; Thormark, 2006) and various tools (Table 1), it is analyzed that material sustainability tools should include EE and EC clearly in their evaluation criteria. Moreover, the potential to boost the local economy and well-being of individuals and communities should also be considered while specifying materials.

Energy use and emissions associated with the production and transportation of materials are described as Embodied Energy (EE) and Embodied Carbon (EC) (Hammond and Jones, 2008). Greenhouse Gas (GHG) emissions are directly related to the EE of the construction material because of emissions generating from fossil fuel combustion during manufacturing. Higher EE materials have greater carbon emissions. EE can only be reduced if local and low energy-intensive materials and products are used for building construction. Using environmentally friendly, locally sourced and unprocessed materials is not only important to minimize GHG emissions but also supports local economies and should be encouraged wherever possible. BREEAM assessment tools include the issue of EE in their evaluation criteria whereas LEED emphasizes locally available materials and reduction in material consumption (Dixit et al., 2012). The latest version of LEED encouraged the use of materials that have environmentally, socially, and economically preferable life cycle impacts (USGBC, 2020).

It is vital to value sustainability in construction as the environmental selection of materials could result in energy-saving and reduction in carbon emissions. Thormark (2006) suggested a possible 17% reduction in embodied energy values due to the right selection of materials. González and Navarro (2006) emphasized that building materials with high EE could result in more carbon dioxide emissions than materials with low EE. They concluded the possibility of up to 30% reduction in carbon emissions in the construction phase with the selection of low environmental impact materials. According to studies, 75% of total energy is consumed in processing raw materials in global construction and these emit carbon emissions and toxic effluents. Therefore, it is crucial to use resources efficiently within the earth's carrying capacity (Acharya, 2013). We are currently exceeding the earth's carrying capacity by 20% according to the study of the National Academy of Science (Calkins, 2009).

4.0 THE SITE

A site is studied to evaluate the appropriateness of locally available sustainable materials for construction purposes. Harappa (Indus Valley Civilization) in district Sahiwal in Punjab Province of Pakistan is the selected location (Figure 1). Earth, straw, cotton, and timber materials are available in abundance in the selected area. This area is also famous for cattle and sheep yielding about 54 million tons of coarse wool annually (Doi, 2012).

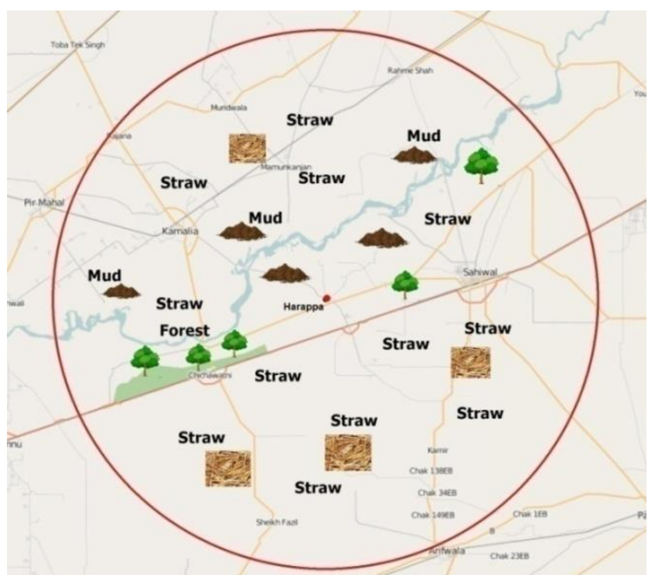

Figure 1. Location of the site and the availability of the material in that area. A 25-mile-radius circle is drawn to map the availability of materials in that area

Table 1. Summary of material aspects

Tool	Summary of material aspects considered by LEED (USA), LEED (India), and GBI (Malaysia)
LEED (USA) **(USGBC, 2020)**	Materials and Resources (MR) is one of nine green building categories addressed in the LEED rating system. Summary of the materials aspects: • Storage and collection of recyclables • Construction and demolition waste management planning • Building Life-Cycle impact reduction • Building Product Disclosure and Optimization- Environmental Product Declarations • Building Product Disclosure and Optimization- Sourcing of raw material • Building Product Disclosure and Optimization- Material Ingredients
LEED (India) **(IGBC, 2011)**	Material and Resources (MR) is one of the seven green building categories. Summary of the materials aspects: • Storage and collection of recyclable materials to facilitate the reduction of waste generated • Develop and implement construction waste management • Reuse materials to reduce demand for virgin materials • Use materials with recycled content • Use regional materials that are extracted, harvested as well as manufactured within 250 miles • Use rapidly renewable materials to reduce the use and depletion of finite raw materials • Use certified wood
Green building Index (GBI), Malaysia **(GBI, 2009)**	Materials and Resources (MR) is one of six green building categories addressed in the GBI. Summary of the materials aspects: • Recycling and reuse of materials • Sustainable sourcing • Waste management • Green products (environmental-friendly refrigerants and clean agents)

5.0 MATERIALS SELECTED

Earth, timber, and straw are available in the selected area. Characteristics of these available sustainable materials are explained in this section to underline their feasibility for construction. Using EE and EC to compare materials is complicated as different approaches with different boundaries and assumptions are applied. Values from Inventory of Carbon and Energy (ICE) are used as a reference to compare EE and EC aspects of various construction materials because of the unavailability of the local database. One criterion for relying on EE and EC values from Hammond and Jones's study (ICE) is that the data comply with ISO standards (Dixit et al., 2012; Cabeza et al., 2013). Both EE and EC are important considerations for justifying material use. EE and EC values of different construction materials indicate which materials have the lowest impact on the environment. Table 2 demonstrates EE and EC values of some materials used in building construction (Hammond and Jones, 2008). It is clear from Table 2 that the straw has the lowest EE and EC values.

Table 2. Embodied energy and embodied carbon values

Material	Embodied Energy (MJ/kg)	Embodied Carbon (kg CO_2/kg)
Timber	8.50	0.46
Straw	0.24	0.01
Earth (Rammed soil)	0.45	0.023
Glass	15	0.85
Steel	24.40	1.77

Source: Hammond and Jones (2008)

5.1 Timber

Timber is a renewable and natural material. It is a biodegradable material and degrades after its life cycle without much impact on the environment. Timber possesses inherent properties of thermal comfort, durability, and strength and has low EE and carbon emission in comparison to commonly used building materials such as aluminum and steel; hence, timber has almost all the characteristics of sustainable material. It also absorbs carbon (acts as a carbon sink). A study revealed that timber stores as much as 250 kg/m^3 of carbon dioxide and releases only 15 kg/m^3 into the atmosphere (Abimaje and Baba, 2014). Timber is available locally at the site. The forest within the site is the secondlargest plantation in Pakistan covering an area of 11521.7 acres. A linear plantation of 1032.98 km is present in the district along road, canal, and rail (Doi, 2012).

Economic growth and development in the construction sector at the beginning of this century resulted in massive timber consumption in the country. Around 20% of timber is consumed in the country by the construction sector. Timber for building construction is the most important utility of forest plants, but Pakistan has only 0.03 hectares of forest area per capita of population. Pakistan has to import timber and timber products to meet its demands (Zaman and Ahmad, 2012). Moreover, Pakistan has the highest rate of deforestation in the world. Poverty and population increase are identified as major causes of deforestation in the world. One of the major reasons for deforestation is the dependence of the rural population on timber for construction and fuel. The selected site has many rural settings that depend on timber for fuel.

5.2 Straw

Straw is annually renewable residue stems of grain production often considered as a waste product, and using it for construction purposes is a sustainable and ecological way of recycling. It is currently produced in surplus, so it is cheap and easily available in most countries. The use of straw bale as a construction material is evolving rapidly due to its numerous benefits. It has low EE, sequesters carbon, and helps reduce atmospheric CO_2. Each 10 kg of straw absorbs around 15 kg of carbon. Several studies have confirmed the effectiveness of straw bale as a construction and insulating material for both rural and suburban settlements in developed and developing countries (Steen et al., 1994; Cascone et al., 2019).

The first load-bearing straw-bale houses were erected hundreds of years ago by European settlers in the Sand Hills region of western Nebraska (USA). Now, the number of researches and laboratory tests worldwide has also proved this material to be capable of supporting substantial service loads. Straw bale walls can easily support the residential-scale load when baled, stacked, and plastered properly on both sides with cement, lime, or earth. The plastering also helps to provide lateral resistance. Construction techniques for straw bale buildings are load-bearing structures in which the weight of the roof and upper floors is carried by the bale walls or as an infill wall system (thermal insulation) when used in combination with structural frames (Cascone et al., 2019; Ashour et al., 2011; King, 2003). Straw bale has many advantages as a construction material. It is energy-efficient, renewable, durable, non-toxic, biodegradable, and even fire-resistant. Waste is produced in all construction processes that mostly end up in landfills but the waste straw during straw bale construction can either be used for animal bedding or composted. This low-cost material also reduces the overall budget of construction. Every type of straw locally available makes appropriate material for construction, and examples are wheat, barley, and rice. Moreover, straw construction is very useful in areas of the world with the shortage and unavailability of timber. Environmental-conscious researchers and practitioners considered straw to be a sustainable construction technique and recognize that some of its limitations can be overcome easily (Ashour et al., 2011; Steen et al., 1994).

Agriculture constitutes the largest sector of Pakistan's economy. It is the largest source of foreign exchange earnings and contributes around 24 percent of Gross Domestic Product (GDP) (AMIS, 2021). The Sahiwal district is a highly industrious agricultural area that is a major source of income for the population. Agricultural land in the district is 88.13%, indicating huge potential to use straw from the crops for building construction. The major crops sown are wheat, cotton, rice, maize, and sugar cane. Crop residue is not being properly utilized in Pakistan. According to estimates, 25-40% of the crop is food and 60-75% is a residue that could be low-cost raw material to be used for various purposes such as electricity production and building construction (Dawn, 2009). Around 6 tons of straw is produced for every 4 tons of wheat or rice grain and estimates suggest that in Pakistan, 43437 thousand tons of rice-wheat straw is produced annually (Yasin et al., 2010). The selected site has a surplus of crop residue which is transported to other areas and could be used for construction. Utilizing these straws for productive use will not only improve the agricultural sector but also provide economic benefits to farmers or the locals. Moreover, the use of straw for construction helps control carbon emissions and forest loss, and could boost the local economy and contribute to the sustainable development in the selected area.

5.3 Earth

Earth, the most significant natural building material is directly available from the site with no pollution and cost associated with its transportation. Around 50% of the world's population lives in earth-based dwellings (Pacheco-Torgal and Jalali, 2012; Minke, 2013). Earth as a building material, is given different names such as adobe or mud bricks, compressed unbaked bricks, or rammed earth. It has numerous benefits over conventional materials as it saves energy and reduces carbon emissions. Earth has low EE, is reusable and recyclable, protects the environment, and provides indoor climate beneficial for human health (Minke, 2013). Pacheco-Torgal and Jalali (2012) found that a 92-m^2 house built with an earth wall represents a reduction of 7 tons and 14 tons of CO_2 compared to ceramic bricks and aerated concrete blocks, respectively. Waste from earth construction can be deposited at the site of its extraction without causing environmental problems.

The soil used in earth construction consists of clay, silt, and sandy materials. The soils of district Sahiwal are sandy and have enough clay and silt. There are around 100 brick kilns in the district, which use this soil for molding bricks. However, no national standards for earth construction have been published in Pakistan to date. Several countries including Germany, Australia, and New Zealand have standards to revive earth construction. Despite earth construction being labour-intensive, it is regarded as economically beneficial especially for developing countries due to the availability of labour at a very low cost (Pacheco-Torgal and Jalali, 2012).

6.0 SUITABLE MATERIAL CHOICE

The selected materials are evaluated in compliance with the criteria for sustainable materials discussed in Section 3. Table 3 identifies the keys aspects of the materials (timber, straw, and earth as construction materials) against the criteria for assessing the feasibility of using sustainable material for construction in the selected region. Characteristics of the sustainable materials have already been discussed in Section 5. A comparison is developed here to select the most suitable among them. Though these three materials fulfill the criteria for sustainable materials yet they should also adhere to the definition of sustainable development. Only those materials are considered sustainable whose consumption is socially equitable, economically viable, and environmentally friendly. The current scenario does not mark timber as a feasible option for building construction in the selected context. As the definition of sustainable development implies satisfying social, environmental, and economic goals those are also in harmony with the nature. When forests are removed, they no longer provide ecological services such as habitat, erosion control, carbon sequestration, and regulation of the hydrological cycle. An abundance of locally available straw and soil along with other benefits make them feasible for construction.

7.0 HISTORICAL AND CONTEMPORARY USE OF MATERIALS

Historical and contemporary use of selected materials is looked at to signify their feasibility for building construction. The site of Harappa is South Asia's earliest urban society which was first discovered in 1920. The study of this archeological site suggests that the ancient civilization flourished there due to the availability of arable land and easy access to the river Ravi. Mud bricks were the predominant building material in earlier construction (Figure 2). Sun-dried and burnt bricks were used for construction. Bricks were sun-dried and straws were amalgamated to improve strength and utility during drying. The use of mud mortar is also evident in Harappa. It appeared that wooden frames were used for doors and windows. Ceramic technology was also highly developed. Clay, metals (copper and bronze), and stone were used for making utensils, toys, jewelry, and decorative items (Kenoyer, 1991).

Figure 2. Harappa excavations (mud and baked brick structures). Source: http://www.gandharatrails.com/destinations/details/harappa.html

During the survey of that area, it was found that the typical houses in villages of district Sahiwal are made up of mud bricks (Figure 3). The district has around 530 villages. In Pakistan, the use of mud for construction has evolved from local necessity. The mud is a preferred material being used in villages for construction mainly due to affordability and easy availability. The processing of sticky mud deposits along the river banks or surroundings with appropriate technology makes it a remarkable environmentally friendly material (Shirazi, 2009).

In the construction industry, timber is commonly used for making doors and window frames. Abundant dried stalks of threshed grains (wheat and rice) are used for covering floors and thatching roofs. There is no contemporary example of straw-bale construction in district Sahiwal, contrary to other regions in the country. PAKSBAB (Pakistan straw bale and appropriate building) organization was established after the devastating earthquake of 2005 with the vision to build high-performance natural houses for poor families using local and renewable materials (PAKSBAB, 2020). The local inhabitants were trained to build their own houses. They used compressed straw bales for building construction (Figures 4 and 5). 40 straw-bale buildings have been built by PAKSBAB in different areas of Pakistan mostly in seismic-affected regions at a one-third construction cost of middle-income homes. PAKSBAB has trained over 70 local builders but its operations are halted temporarily due to a lack of funds. According to them, the use of straw bale to build homes helps people cope with heat waves and other extreme weather conditions and also reduces carbon emissions (Ruppert, 2015; Saeed, 2016).

The rural population of the country is practicing sustainable architecture not by choice but by default. The use of these materials has not been extensively developed in Pakistan due to the apathy of government and society. Status-conscious people of society believe that straw-bale and mud houses are only good for poor people. However, the use of these materials can help control environmental degradation and boost the local economy.

Table 3. Comparison of characteristics of sustainable materials

Criteria	Timber	Straw	Earth
Local availability	Locally available but not adequately enough for construction as several other demands are already present.	A surplus of crops is produced in the Punjab region and exported after meeting the local requirements.	Directly available from the site
Renewability and reuse potential	Biodegradable and renewable material with reuse potential	Biodegradable and annually renewable material	Earth is recyclable and re-usable
Local employment	Potential to generate local employment	Potential to generate local employment. Local people could be trained for straw-bale construction as already being done in northern Pakistan.	Potential to generate local employment Earth construction is labour-intensive that is available at a very low cost in developing regions
Embodied energy	Highest embodied energy	Lowest EE	Low EE
Carbon emissions/ Environmental impacts	Timber sequesters carbon that results in significant carbon emissions reduction	Straw sequesters carbon and results in significant carbon emissions reduction	Low embodied carbon and saves energy and carbon emissions.
Suitability for local climate	Timber is resistant to heat flow and offers the advantages of using less energy for cooling the interior spaces. Suitable for the selected location	Straw has excellent insulation properties and suitable for the climate of Pakistan.	Earth construction has always been a prevalent choice for hot arid and temperate climates (Minke, 2013). The climate of the selected location is semi-arid hot.
Affordability	Affordable if easily available	Locally available and economical. Straw-bale construction costs almost three times less than conventional middle-income construction (Saeed, 2016).	Earth construction is economically beneficial for less developed countries.
Transport distance	Forest reserves are present near the selected location (Fig-1)	Wheat and rice straw could be sourced from nearby agricultural fields (Fig-1) which could be baled for construction.	Available in the vicinity and very few emissions associated with its transports (Fig-1)

Figure 3. Earth-based structures (cob and mud walls) found during survey in villages of the Sahiwal district. Source (Author)

Figure 4. Straw-bale construction in process for energy-efficient, environmentally friendly, and earthquake-proof homes in northern Pakistan. Source: https://www.greenprophet.com/2011/10/straw-houses-pakistan/

Figure 5. Families are trained to construct energy-efficient and cost-effective houses. Source: https://www.greenprophet.com/2011/10/straw-houses-pakistan/

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8.0 CONCLUSION

The construction industry contributes significantly to climate change as a result of the energy consumed during the extraction, processing, and transportation of raw materials. Environmentally friendly, locally sourced and unprocessed materials are important to minimize environmental degradation. Localized production also creates local employment and helps in sustaining a community's economy. However, the sustainability of the construction industry is not a national priority in developing countries. No single assessment tool for evaluating sustainable materials was found.

Available sustainability assessment tools of Asian context including Pakistan Green building guidelines, LEED (India), and GBI (Malaysia) were explored. It is analyzed that material sustainability tools should include EE and EC clearly in their evaluation criteria. Moreover, the social and economic impacts of materials should also be considered while selecting materials. The characteristics of timber, straw, and earth were compared after reviewing various tools and literature. It is seen that the use of sustainable materials in Pakistan has evolved from local necessity. Historical and contemporary examples make it clear that there exists a huge potential to use sustainable materials for construction purposes but it needs support from the government and the society.

Sustainable materials are those materials whose consumption is socially equitable, economically viable, and environmentally friendly. The current scenario marked soil and straw as a feasible option for building construction in the selected context to deal with the issues of climate degradation.

Issues of sustainability are now gaining momentum even in developing countries like Pakistan due to the adverse impacts of climate change. There is an avenue to develop a holistic tool for sustainable materials assessment for developing countries and empirically test its viability

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