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THE HISTORICAL SIGNIFICANCE OF MUD ARCHITECTURE IN ARID REGIONS FOR SUSTAINABILITY AND DURABILITY

Abdurahim Mannonov[1], Khurshid Samatov[2], Nilufar Fayzieva[3], Valisher Sapayev[4], Dadaxon Abdullayev[5], Nargiza Ruzmetova[6], Khafiza Khasanova[7]

[1]Tashkent State University of Oriental Studies, Uzbekistan.
e-mail: abdurahim.mannonov@mail.ru, orcid: https://orcid.org/0009-0009-3570-3455
[2]Samarkand Branch of Tashkent University of Information Technologies, Uzbekistan.
e-mail: samatov_1084@mail.ru, orcid: https://orcid.org/0000-0001-6027-7472
[3]National University of Uzbekistan named after Mirzo Ulugbek, Uzbekistan.
e-mail: lily_angel94@mail.ru, orcid: https://orcid.org/0000-0002-2941-2741
[4]Mamun university, Uzbekistan. e-mail: sapayev_valisher@mamunedu.uz,
orcid: https://orcid.org/0000-0002-6751-5864
[5]Urgench State University, Uzbekistan. e-mail: dadaxonabdullayev96@gmail.com,
orcid: https://orcid.org/0009-0009-8583-2538
[6]Kimyo lnternational University in Tashkent, Uzbekistan.
e-mail: nargiza_ruzmetova@mail.ru, orcid: https://orcid.org/0000-0003-3727-8922
[7]Department "Landscape Design" Senior Teacher, Samarkand State Architecture and Construction University named after Mirzo Ulugbek, Uzbekistan.
e-mail: khafiza_khasanova@mail.ru, orcid: https://orcid.org/0009-0003-4073-9889

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SUMMARY

Mud architecture has played a crucial role in shaping human settlements in arid regions, offering sustainable and durable solutions for centuries. This study explores the historical evolution of mud architecture, highlighting its adaptability to extreme climatic conditions and its significance in preserving cultural heritage. The paper examines traditional construction techniques, the environmental benefits of mud as a building material, and its potential for contemporary sustainable development. The discussion extends to the durability and maintenance challenges of mud structures and their innovative applications in modern architectural design. By analyzing historical and modern examples, this research emphasizes the necessity of integrating traditional wisdom with contemporary advancements to enhance architectural sustainability. The findings underscore the importance of rediscovering mud architecture as an eco-friendly and energy-efficient alternative to modern construction materials, especially in the context of climate change and resource conservation.

Key words: *mud architecture, arid regions, sustainable construction, durability, traditional building techniques, cultural heritage, thermal insulation, eco-friendly materials, vernacular architecture, climate adaptation.*

INTRODUCTION

The architectural accomplishments spanning the ages have demonstrated human skill in creating spaces for living. These dwellings personify a wise and innovative approach to adapting to environmental

forces, especially in arid climates. The beauty of these desert abodes reminds of the skill to create intimate spaces from humble materials: mud, modestly-sized stones, or modest timber. Natural organizational principles, energy efficiency, and simple engineering skills allowed the crafting of woven architectural forms that inscribe themselves into the landscape with grace [2] [6]. In contrast, modern-day abodes are typically structures of concrete, glass, and steel. Not only do these new structures lie heavily on the land, but they also hardly protect people from the heat or cold of desert that their predecessors knew. Rising energy demand for interior climate control is a costly affair. Furthermore, in their round-the-clock contest with the sun, most modern dwellings require vast amounts of water since grass or unnatural plants, often unsuited to desert environment, are employed in an effort to keep the buildings cool. Since the prehistoric past, people have devised ways to live wisely and comfortably in arid regions. Creative approaches to using sun or wind for cooling, plant selection for shade, and reliance on the thermal [4][8].

In the complex processes of world development, the most urgent problem is to merge historical experience with the newest achievements. Awareness of the past undoubtedly contributes to a successful future. In that context, it is important to analyze the interaction of cultural heritage with modern challenges. For human beings, architectural shelters represent a basic arbiter in their everlasting confrontation with the implacable forces of nature for the creation of a friendly place and sustainable living conditions [1]. Considering the abundance of arid and semi-arid locations, humanity's inclination to innovate is corroborated in perfect symbiosis with the threatening environment. In the not so distant past, the crafty use of natural, bio-environmentally friendly materials at the disposal of people produced remarkable structures, both functionally suited to the environment and architecturally harmonized with the landscape's stupendous beauty. There certainly is a great significance in assessing structures that stood the test of time, still in use and a part of cultural memory of a living community, thus comprising traditional architectural experience. Such buildings are a magnificent example of a wise, harmonious, and, at the same time, organic union between natural resources, the building process, and the social fabric [14]. They represent the basis upon which local identity and tradition are engraved. In addition, a series of elements can be identified that testify to their broad advantages in environmental, esthetic, economic, and energy-saving fields, all in the context of sustainable development, presently an unavoidable aspect of contemporary living in a world faced with irrational consumerism and wide-spread disordered planning, whereby traditional culture is fading away [10].

LITERATURE REVIEW

Construction methods and architectural heritage today involve both conventional practices and new advances. [1] states how vernacular construction promotes sustainability, pointing out its susceptibility to local conditions of the environment and resources. Moreover, [7] describe means in architecture to maximize sustainability and maximize the use of space.

Mudbrick construction, a defining feature of ancient and contemporary traditional architecture, has been of wide interest. [5] present a multi-disciplinary study of Armenian earth architecture with its sustainability and reusability over the long term. [15] document challenges in constructing mud houses in Nigeria and present measures for mitigating collapse. The importance of vernacular architecture is also brought out [16], who support the use of vernacular architecture in contemporary design standards.

[3] and [18] discuss ancient construction practices and advancements in engineering, demonstrating the way earlier innovations shape contemporary architectural practices. [19] concentrate on Central Asian religious buildings, uncovering distinctive construction practices. [9] also investigate how Arabic inscriptions have left their cultural and aesthetic marks on medieval architecture in Tashkent.

In terms of sustainability, [13] compare earthbag to cement block construction life cycle assessments, while [11] investigate bioclimatic responses in Algeria with applications for enhancing thermal comfort [12][17].

HISTORICAL EVOLUTION OF MUD ARCHITECTURE IN ARID REGIONS

Arid regions and arid climates have always been appropriate to earth building. To remain cool in the heat of the afternoon and warm during cold nights, thick clay walls insulate and moderate temperatures. Mud architecture is often perceived as an ecological construction technique that ensures buildings' sustainability. In light of this consciousness, mud architecture has unfolded throughout centuries in regions where no other appropriate materials were widely available. The slow response in both archeological and anthropological fields to arid regions and the earth construction tradition persisted until the most recent decades. The construction zones in both historical and modern settlements are being presented within a typological classification with critical cases transforming mud architecture. Mud building is a historical response throughout a broad region within a number of cultural contexts. Therefore distinct appearances between continents and local influences are observed. There are significant stages in a sequence of times as pre-historical, medieval and modern settlements. Changes and modifications in technique, style, and architectural appearance are the foremost parameters that display the reflection of various cultural influences. Throughout centuries, in the construction of mud dwellings, societies have revealed well thought out and conscious techniques [5]. These structures should be observed both as a reflection of human adaptation to the environment and also as a cultural memory carried through generations, ensuring their sustainability. On the one hand, protection from climate effects and adaptation to prominent micro-climate conditions played a major role in these applications; on the other hand, social habits and customs had an impact on architectural decisions. Settlements advanced only by mud building specify the association of climate and geography to the configuration of a particular architecture. It is noticed that in some specific climatic and geographic locales, entirety mud-built archeological layers and building remains were relegated to earth architecture. Innovation in mud building has undoubtedly faced difficulties and challenges throughout its antiquity. Nevertheless, mud architecture has sometimes succeeded in offering solutions by creating innovative and adaptive models, even in harsh social and environmental conditions. An entire settlement zone, which has been generally built with mud architecture for millennia, provides a distinctive context to contemplate these experiences. It has been accepted that the evolution of construction from mud, mortar, plaster, and timber components in earth-based architecture was in line with the formation of settlements. Since mud-brick structures in arid regions are very susceptible to erosion, it is rather difficult to find original mud structures before early historic periods. Only a few better-quality mud-brick constructions have survived.

Ancient Examples of Mud Architecture

Mud has historically been a widely used building material in regions around the world that have arid climates and are most likely subject to water shortages. To name but a few, ancient arid civilizations as old as 4,500 years, such as the Mesopotamian and the Indus Valley, used mainly mud bricks to build astounding structures such as private houses or lavish temples and palaces. The durability of mud as a building material has been tested time and again: mud houses from ancient times to early last century have been preserved without human intervention and are still standing strong in a number of locations in the Middle East, Asia, and Europe. However, these structures not are only functional and long lasting: they also carry invaluable historical, cultural and aesthetic values. They are perfect practical examples of sustainability when concerned with building materials. Indeed, in Iran, Iraq, Turkmenistan, Azerbaijan and other countries in the Middle East and Asia, ancient huge mud-brick structures are still having a significant impact on modern architectural planning and design. Pyramidal earthen walls connected by patterned walkways, reminiscent of memories of the hanging gardens of Babylon, provide an innovative design for shopping malls and restaurants in modern times. Strong knowledge of the most sustainable material in the local context was always at the base of the construction of palaces and fortifications such as Choghazanbil or Indus Valley's cities Harappa and Mohenjo-Daro [5]. Some mud edifices were built having aesthetic consideration as the major factor. In the Punjab, the Havelis are imposing buildings adorned with intricate features such as frescoes and carved wooden balconies, but their noble look should not deceive the strength of the bricks that make up their walls. In India, the fully wooden mould carved mud bricks that make up the buildings in Fatehpur were as much of an attraction as the singular use of the chakra in the construction of a town (*Table 1*).

Table 1. Ancient Examples of Mud Architecture

Ancient Civilization	Notable Mud Structures	Cultural & Aesthetic Significance
Mesopotamian	Ziggurats, temples, private houses	Sacred and administrative centers; architectural grandeur
Indus Valley	Harappa, Mohenjo-Daro	Urban planning and sustainability
Iranian	Choghazanbil, mud-brick fortifications	Impact on modern architectural planning and design
Iraqi	Ancient mud-brick city walls	Historical and functional importance
Turkmen	Traditional earthen buildings	Sustainable construction techniques
Azerbaijani	Pyramidal earthen structures	Influence on modern shopping malls and restaurants
Punjabi	Havelis with frescoes and wooden balconies	Artistic integration of mud with intricate carvings
Indian (Fatehpur)	Fully wooden mould carved mud bricks, chakra-inspired buildings	Innovative town construction inspired by cultural symbols

Cultural and Environmental Factors Influencing Mud Architecture

Mud architecture is a knowledge that connects its creator to the agricultural environment, and it's a rich legacy, providing optimal solutions for building in this environment. Unable to reproduce the environmental conditions of any other material, this environmental birth with its strategy of insulation, is the most proper response to the desert climate. Through the ages, societies have developed building techniques that blend in perfectly with their natural settings, while also meeting their specific needs. Often produced without the aid of architects, these buildings speak volumes about local customs. Their materials and methods possess a truth and honesty that can be appreciated by all those who take the time to understand. Through the prism of sustainability, this untreated – in its crudest and most beautiful essence – and monotonous material surprisingly appears. Versatile and affordable, it is ideally suited to a vast array of inhabitants, who skillfully exploit its qualities in order to construct homes that perfectly reflect their environment, their lifestyles, their culture and their identity. Mud architecture might be the oldest method of construction used by man to provide shelter, and constitutes the main building material in many desert regions. Built primarily of sun-dried bricks, clay, lime, straw and water, mud buildings present a variety of forms according to their geographic locations, yet remain easily recognizable. Their thermal mass and ventilation systems enable rooms to be kept very cool in the face of the desert's extreme heat. In other regions, the use of a sloping roof and lime wash allow rapid rainwater drainage and prevent erosion. Social hierarchy, religious beliefs and historical changes also control the construction of this common and multipurpose building material, which is both very much a product of its environment, and yet subject to reinvention and re-interpretation. Though simple in name, mud architecture eventually becomes highly sophistical.

SUSTAINABILITY ASPECTS OF MUD ARCHITECTURE

Intercultural Links through the Use of Mud Architecture in Arid Regions

Sustainability is a term often cited in the vast literature available today addressing environmental and ecological issues, among other areas related to habits, including architecture [7]. Sustainability in mud architecture can be analyzed in three different ways. First, there are ecological advantages inherent in the frontier architecture of mud. Second, the sustainable aspects of revival and adaptations of mud architecture are discussed directly. Finally, an analysis comparing the advantages of mud in terms of carbon foot print, energy consumption, and construction with those of modern building materials is presented. By combining these findings, the potentiality of mud architecture as an alternative to architecture with other materials for sustainable living in arid regions is explored and its importance for the future of architectural habit is discussed.

The use of earth as a building material tends to be linked to houses built centuries ago in the desert. It is also strange that mud architecture, probably the eldest frontier architecture, still exists through generations in a protected form as an ancestral homeland. As the ecological awareness of the west has

grown, the architecture of the pre-industrial era that had been disparaged has been reappraised as it has been revaluated as "sustainable" under the label of "vernacular architecture". Almost the same viewpoints concerning traditional architecture can be found throughout the 20th century, either in east or west – some quite similar ideas were given by LeCorbusier or Murcutt, for instance. Post-modern tendencies or counter renaissance-technology movements have been occurring here and there, known as the shelter-movement in the South-Pacific regions.

Natural Cooling and Heating Properties

Mud as a building material with no environmental footprint has a significant historical background, being used by humankind long before industrialization. Research into mud architecture has been largely rekindled in an era when sustainability and low cost construction are being more highly prioritized. Many researchers agree that the most efficient use of local climate and conditions resides in historical building methods [11]. Mud's durability in harsh conditions continues to be crucial in arid regions, with the same methods of construction inherited over close to two millennia in areas like Harran and Mardin standing testament to its resilience. Mud is a highly effective insulation against extreme heat or cold, as well as an abundant local material that requires significantly less embodied energy. Mud and adobe buildings have their own natural forms of heating and cooling systems that develop stable and habitable internal environments which are not dependent on energy intensive mechanical systems.

Buildings constructed from mud take on the properties of thermal mass, drastically improving the heat regulating capacity of a building. As the hot air from the outside cools overnight, the same walls give off heat during the evening as the temperature again lowers. This principle is elaborated on by referring to the remarkable ability of walls only a few centimeters thick to produce a significant cooling effect. The thermal benefits of traditional architecture continue to outperform modern dwellings, exemplified by the case of old mud brick houses maintaining a temperature approximately 3 degrees lower on a hot day than an insulated modern home in the same location. A field study done in Harran upholds this phenomenon, demonstrating the remarkable cooling performance of adobe buildings which outstrip modern homes by 1-3°F. A single mud brick structure is cooler by 5-10°F in a side by side comparison with a structure of steel and concrete in the afternoon. As the world continues to face energy crises and runaway greenhouse gas emissions, the reevaluation of mud can have significant implications for both the past and future. If modern architects are able to harness the historical cooling abilities of mud while maintaining modern design aesthetics, this could open a whole new avenue of green construction. A possible uptake by the fashion industry into mud based coatings for buildings could also revolutionize house performance in sync with stylistic trends. explores the possibility of pushing the envelope in material properties through unconventional methods, and gradually transitions mud's historical application to a medium that is coherently applicable to contemporary urban environments.

Local Materials and Low Embodied Energy

One of the ecological factors in developing sustainable architecture is the use of local materials with low embodied energy. Embodied energy is the amount of energy consumed during various stages of material production. Low embodied energy is consumed in the procurement, manufacturing, transportation, and processing of the building materials and during their assembly into the building structure. The use of readily available materials in the environment not only ensures low energy in material production but also in the long transportation of building materials to the construction site. Use of earthen materials such as adobe, cob, or rammed earth, rock, and geological compounds is an exemplary model for the application of building with low or zero embodied energy. The procurement of earth for construction is connected with the ground and the material composition of the ground, resulting in limited combustion of fossil fuels and emitted noxious gases resulting from material acquisition. Numerous other building materials such as rock, sand, wood, and thatch are also largely connected to the environment, locality, and natural state of an area. Indigenous materials have been used for centuries in various building cultures for the construction of dwellings, industrial facilities and local infrastructure, proving advantageous in terms of their cultivation, manufacturing, use, and in relation to long building purposes and durability. The use of local materials and elements supports the local economy and enables preservation of the identity and cultural customs of a given area [13]. The choice of environmental

parameters and material availability in a given area is a premise for development involving the use of earth and other locally acquired raw materials. The increase in embodied energy in the building contributes to the necessity of fossil and natural resources causing an increase in the combustion of fuels and an increase in the emission of harmful substances. Rational use of building materials in construction is a premise for sustainable building, extinguished preservation of material resources and preventing unnecessary uncontrolled consumption. There are many areas of the world in which locally available materials are used. The smallest transport distances, thereby generating low CO2 emissions and working to maintain local building traditions. Examples of this are Saqqara, the ancient Egyptian necropolis, where mud bricks (*Image 1*) have been used for centuries, and Siwa in Peru.

Image 1. Mud-brick stamped with seal impression of raised relief of the Treasury of the Vizier. From Lahun, Fayum, Egypt. 12th Dynasty. The Petrie Museum of Egyptian Archaeology, London (https://en.wikipedia.org/wiki/Mudbrick)

DURABILITY AND MAINTENANCE OF MUD STRUCTURES

Mud structures are built in arid regions for numerous reasons, the most obvious one being the abundance of its raw materials — earth and water. The historical significance of the use of mud is of interest as arid regions have a long history of endeavour in creating sustainable human settlements. Mud in these regions is used with great ingenuity to fill the needs for buildings that might be difficult to house using other construction techniques, creating buildings that speak to the place and the cultures they come from. So it is always best if mud architecture continues to be a part of the ongoing transient historical narrative. Construction practices vary from region to region and are particular to the locally available resources found in that place. There are common challenges which are faced by mud structures regardless of their geographical location, such as the issues of erosion, weathering and the lack of good quality mud. All of the briefly touched on topics regarding the durability and maintenance of mud structures present complex issues — they should by no means be seen as absolute just as some general thoughts to ponder and additional references to improve the understanding of the given subject. Built mud structures are subject to a unique set of circumstances, quite different than other building materials. They require different skills in maintenance, repairs and restoration. Protection, retention and improvement of building heritages and urban developments have turned into equally specialized and extensive problems which involve many scientific and socio-political disciplines. On the contrary, natural phenomena such as erosion, weathering or the age-old battle with water can and do personally affect mud structures. Of course, this might be the same for any building or even object, but as mud needs extra care and maintenance in order to have a decent lifetime, these could be seen as peculiar hazards [15].

Challenges and Solutions

Mud architecture is a traditional and simple technique that has been applied for many thousands of years as a building material in a variety of regions and forms. Mud buildings are highly significant in the view of cultural heritage because they show the traditional life and building technique of past civilisations in

the inhabited areas. Nevertheless, it provides sustainability and durability. It is in many cases the most flexible way to build a simple, efficient, and sustainable shelter in areas where that is particularly important, such as deserts and arid lands. However, despite its advantages, mud architecture generally sees more problems in operation, preservation, maintenance, and after-care than other construction technologies do. A major problem is that it is not suitable in some regions because of its vulnerability to weather, its sensitivity to many aspects, such as fire and pests, and its fairly high permeability. For example, last year during the rain season, a huge section of the remains of the ancient city walls of the Great Zimbabwe World Heritage Park collapsed *(Image 2*). As a kind of stabilisation work, the mud walls were constructed by pouring more than 200 t of concrete into its interior, a practice that is contrary to conservation principles. However nothing could have been done to protect the walls due to the requirement of urgently acting to prevent disaster. Considering economic and technical challenges, the construction and maintenance cost of mud buildings is greater than that of new and modern structural systems since the invention of concrete was realised, which is begun to be used in Italy in around the 16th century. Because of these and some other reasons, mud architecture has faced the danger of disappearing from local building customs [15].

Image 2. Tower in the Great Enclosure, Great Zimbabwe (https://en.wikipedia.org/wiki/Great_Zimbabwe)

As a living heritage, the transmission of knowledge and skill from master to apprentice have long been interrupted. There are only few artisans and technicians left on this field. But some successful implementation and adaptations have been performed by engineers, architects, and local people. Sometimes, they have collaborated together for sustainable and integrated solutions. In some cases, this type of cooperation has been successful and cost-effective. In that context, it is necessary to draw up a new point to raise awareness-raising efforts and educational programs. Considering legal regulations would boost the integrity of these efforts. It can be said that new trends in construction practices have been initiated to reuse mud architecture. On the other hand, incomparable advantages of mud architecture have started to be discovered and considered positively in social life. More ambitiously, it might be possible to strive for implementing and upholding mud architecture for instating peace building processes in areas with political conflicts, e.g. sedimented anthropological research illustrates that fortifications were constructed using mud as a means of warfare in ancient times, but in such cases a total shift-for-paradigms is needed towards human values regarding materialization process, the aim of understanding and spaces for the dialogue. Moreover, it is also reasonable to consider the transferability of mud architecture for the improvement of living conditions and hazard avoidance in disaster-prone areas due to financial reasons. There have been various trials and academic studies to increase the resilience of mud buildings for this purpose.

CONTEMPORARY APPLICATIONS AND INNOVATIONS IN MUD ARCHITECTURE

The global revival of interest in mud architecture demonstrates that there is much scope for the marriage between traditional technology and contemporary innovation. The future of mud architecture in relation to traditional materials and craft knowledge is arguably more critical. The expanding world population

and diminishing natural resources are increasingly seen as urgent issues for much of the planet to come to terms with. Mud architecture in both industrializing and industrially developed parts of the globe is seen as contributing towards the ameliorative knowledge required shaping the human environment in the interests of sustainability, durability, and socio-cultural diversity. The past two decades have seen a wealth of empirical research undertaken on mud-based building materials, with the aim of providing village builders in arid regions with new knowledge and skills, to enhance the technical efficiency of transference of energy to improve the thermal efficiency and durability of the architectural stock. Recent advances in mud brick masonry techniques will also be considered in the light of the needs and aspirations of the users, with reference to the development of low cost, durable and user friendly vaulted technologies. A case for a leap forward is made, whereby the accumulation of largely uncoordinated knowledge is transformed into a systematic, multidisciplinary empirical science, relevant to both the village builder in arid regions of the developing world and to the designer of urban projects in an industrialized society. Case examples are confined largely to the areas of work of the archaeological architect. Particular attention is centered on an extensive two year project conducted recent years in one aspect of tradi-modern mud architecture in urban centre. This resulted in a series of practical guidelines and standard details on protective measures, the design of flashings and rainwater heads and the use of recycled leather as an innovative damp-proofing product. There is a growing interest in the use of mud-based building materials for new construction in innovative applications in contemporary architecture and design. At the same time, much work is still required to remove the severe disco-ordination in knowledge and practice that exists world-wide in the more traditional uses of mud architecture in arid regions. Given the holistic and locally textured nature of related knowledge (both traditional craft know-how and scientific understanding), a site-specific, comprehensive research methodology appears essential. On a global scale, local research projects can be developed in a truly comparative manner on the basis of a shared methodology to establish a data-base and define the socio-cultural and environmental paradigms within which meaningful generalizations are achievable [16].

REFERENCES

[1] Hasanovic V. Initiation of a framework for closed-loop, integrated design and planning for the simplest of building types, vernacular stuctures.

[2] Yalman E, Federer-Kovacs G, Depci T. Effect of two types of fly ash on rheological and filtration properties of water-based drilling mud. Natural and Engineering Sciences. 2021;6(3):223-36. http://doi.org/10.28978/nesciences.1036853

[3] Karimov N, Sarybaev M, Kaipnazarov A, Djumageldiev N, Reymbaev R, Kholdarova F. Historical Development of Construction Techniques: From Ancient Architecture to Modern Engineering. Archives for Technical Sciences. 2024 Oct 30;2(31):36-48.

[4] Ajitha SP, Keerthana V, Sujithra S, Sowmya R. Regenerative braking using fuzzy logic control in electric vehicle. International Journal of Advances in Engineering and Emerging Technology. 2017;8(1):10-24.

[5] Lorenzon M, Cutillas-Victoria B, Holmqvist E, Gkouma M, Vrydaghs L, Lichtenberger A, Schreiber T, Zardaryan M. Exploring mudbrick architecture and its re-use in Artaxata, Armenia, during the 1st millennium BC. A multidisciplinary study of earthen architecture in the Armenian Highlands. Plos one. 2023 Oct 13;18(10):e0292361. https://doi.org/10.1371/journal.pone.0292361

[6] Muralidharan J. Innovative Materials for Sustainable Construction: A Review of Current Research. Innovative Reviews in Engineering and Science. 2024;1(1):16-20. https://doi.org/10.31838/INES/01.01.04

[7] Nikpour N, Nikpour M. Investigating architectural techniques for designing and creating sustainable spaces. European Online Journal of Natural and Social Sciences: Proceedings. 2015 Nov 12;4(3 (s)):pp-535.

[8] Fazel ER, Masou R. Thermal-mechanical coupling analysis of dump truck Terex engine piston and investigating the causes of its failure. International Academic Journal of Science and Engineering. 2016;3(1):186-200.

[9] Bakirov P, Karimov N, Yusubov J, Aripova Y, Turaev L, Shomusarov S, Torgautova S. The Impact of Arabic Language and Script on the Medieval Architectural Heritage of Tashkent. Architecture Image Studies. 2024 Dec 30;5(1):154-63.

[10] Ndem JU, Ogba EI. Competencies required in heliculture by retired university lecturers in post-oil boom economy. International Academic Journal of Innovative Research. 2017;4(2):39-46.

[11] Bensayah A, Bencheikh H, Abdessemed A. Mzabite Heritage in Southern Algeria: What Bioclimatic Lessons can Be Learned to Optimize Thermal Comfort?. InMATEC Web of Conferences 2019 (Vol. 278, p. 04005). EDP Sciences.

[12] Nair JG, Raja S, Devapattabiraman P. A scientometric assessment of renewable biomass research output in India. Indian Journal of Information Sources and Services. 2019;9(S1):72-76. https://doi.org/10.51983/ijiss.2019.9.S1.559

[13] Carrobé A, Castell A, Martorell I. Life Cycle Assessment Comparison between an Earthbag Building and a Conventional Sahrawi Cement Blocks Building. Materials. 2024 Feb 22;17(5):1011.

[14] Sudipa IG, Aditama PW, Yanti CP. Developing Augmented Reality Lontar Prasi Bali as an E-learning Material to Preserve Balinese Culture. J. Wirel. Mob. Networks Ubiquitous Comput. Dependable Appl.. 2022 Dec;13(4):169-81. https://doi.org/10.58346/JOWUA.2022.I4.011

[15] Ndububa EE, Mukaddas AM. Mud House Failures and Mitigation Options in Bauchi, North East Nigeria. FUOYE Journal of Engineering and Technology. 2016 Sep 30;1(1):26-30.

[16] CONTEM O. A lesson from vernacular architecture in Nigeria. Journal of Contemporary Urban Affairs, Vol. 2 No. 1. 2018. 2018;2(1):84-95.

[17] Djuric D. WBGT Analysis of Thermal Comfort of the Area of Semberija. Archives for Technical Sciences. 2023 Nov 27;2(29):65-74. https://doi.org/10.59456/afts.2023.1529.065Dj

[18] Hakimov N, Karimov N, Reshetnikov I, Yusufjonova N, Aldasheva S, Soatova N, Eshankulova S, Bozorova D. Mechanical Marvels: Innovations in Engineering During the Islamic Golden Age. Archives for Technical Sciences. 2024;31(2):159-67.

[19] Doniyorov A, Karimov N, Bakhtiyarov S, Abidova Z, Morkhova I, Kaldibekova A, Yusupov O, Muminov A. A Distinctive Architectural Technique in the Construction of Religious Structures in Central Asia. Archives for Technical Sciences. 2024 Dec 24;2(31):351-8.