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STRUCTURAL ANALYSIS FOR ENVIRONMENTAL SUSTAINABILITY IN TRADITIONAL ARCHITECTURE

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Abstract

Introduction: This research is based on the premise that traditional architecture comprises buildings constructed using natural, locally sourced materials. These structures are designed to adapt to environmental changes and promote environmental compatibility — commonly referred to as environmental sustainability — by considering the design of the exterior form. The research problem centers on the negative impacts of modern industrial building materials. These materials are often costly, require significant energy for production, and rely on artificial means to ensure thermal comfort within spaces. Consequently, this research explores the inherent potential of natural materials in architectural design — examining their properties, climatic performance, structural strength, and the construction systems in which they are employed — to address the issue of high energy consumption. Additionally, **the research aims** to investigate the characteristics and performance of natural building materials, identifying their constants and variables, as well as their structural and architectural applications. **Results**: By harnessing the benefits of nature, the study seeks to advocate for the use of natural materials in sustainable building practices. This research adopts a combined descriptive and analytical methodology to support the economic and sustainable use of natural materials in architecture.

Keywords: environmental sustainability; vernacular architecture; traditional architecture; karshif; bamboo.

Introduction

In the past, people lived in natural shelters such as caves, the hollows of large trees, and underground pits, or in structures made from natural materials like reed and palm fronds. This was to protect them from the cold, lightning, thunder, and wild animals. In these shelters, people found refuge as well as psychological, physical, and climatic comfort. Many ancient civilizations inhabited these primitive shelters, including the people of ancient Iraqi cities and others who built underground dwellings or carved homes into mountains and ice. Over time, human intervention in material technology transformed these primitive forms into more geometric shapes, enhancing the performance of the materials and fulfilling functional needs. With each stage of scientific progress, people have sought to modify the natural forms of materials and load-bearing structural systems, especially when new methods of utilizing materials are discovered, which increase their natural capacities. Materials are often combined with others to alter their properties, improving their strength and adapting them to meet the demands of contemporary architectural functions. While technological developments generally yield positive outcomes, they can also produce adverse side effects. For instance, in medicine, chemotherapy treats the affected organ but can harm other parts of the body. Similarly, in engineering, research has improved the structural strength of concrete, but at the cost of reducing thermal comfort, leading to greater reliance on air conditioning and increased energy consumption. Modern architectural materials often lead to problems such as the depletion of natural resources, excessive energy use, and diminished thermal and psychological comfort. These issues, in turn, affect the efficiency and livability of architectural spaces. This concern is echoed by Ramses Wissa Wassef, who stated: "Machines shall not be employed at the expense of humans; rather, the environment must be considered" (Steele, 1997). Vernacular architecture has attracted significant attention from architects because it offers optimal regional solutions. It provides ingenious responses to climatic, technical, social, and cultural challenges. Leading architects have described vernacular architecture in the following ways:

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1.1 Bernard Rudofsky: Architecture without architects (Rudofsky, 1964).

1.2 Christopher Alexander: Distinctive primary architecture, with the foundational role in fostering social cohesion (Alexander, 1979).

1.3 Hassan Fathy: Environmentally sensitive architecture that preserves natural privacy (Fathy, 1973).

1.4 Louis Kahn: He believed that architecture should be inspired by local surroundings and grounded in inherited customs and culture. He considered vernacular architecture a true example of genuine architecture with a deep connection between people and place (Curtis, 2005).

1.5 Kenzo Tange: He drew inspiration from traditional architecture, creating contemporary designs that harmonize with local society and culture. He argued that architecture should integrate technology with local character to promote cultural identity and preserve the environment (Tange, 1984).

1.6 Frank Lloyd Wright: He adopted the concept of "organic architecture", an extension of traditional architectural philosophy. He also advocated that buildings should complement their natural surroundings and reflect the topography and features of the environment, rather than dominate or impose themselves upon it (De Long, 1996).

1.7 Norman Foster: Despite his focus on technology, he acknowledges the value of traditional architecture as a simple, environmentally friendly, and energy-efficient solution. These observations demonstrate that vernacular architecture is not merely a historical style, but a foundational element of global architectural discourse, deeply rooted in an understanding of the environment and society and offering sustainable solutions tailored to the specific conditions of each region (Sudjic, 2010).

1.8 Alvaro Siza: He believes that traditional architecture possesses an unparalleled ability to blend seamlessly with nature and local communities. He views it as a model of design that interacts harmoniously with the environment without relying on excessive industrial intervention (Frampton, 2000).

1.9 Tadao Ando: He emphasized that traditional architecture fosters a sense of tranquility and harmony with nature, strengthens the connection between humans and their surrounding environment, and creates spaces that positively impact mental health (Ando, 2011).

1.10 Rudolf Schindler: He emphasized the importance of employing sustainable construction methods inspired by vernacular architecture, explaining that a thorough understanding of the properties of local materials and their appropriate application can contribute to achieving environmentally sustainable architecture (Olsberg, 2001).

The aforementioned theories reflect a distinctive architectural style that relies on natural resources and manual craftsmanship, rather than the expertise of specialists, as seen in the visions of Bernard Rudofsky. This form of architecture is a cornerstone in the thought of Christopher Alexander, who emphasizes its role in strengthening social bonds. Similarly, Hassan Fathy highlights the importance of designs that respect the natural environment and preserve privacy within the framework of spontaneous and vernacular architecture.

Sustainable architecture offers a holistic approach to building design. On an individual level, buildings constructed with sustainable materials can enhance quality of life by providing healthier living environments and reducing energy consumption through improved insulation. At the community level, adopting sustainable technologies and materials reduces the carbon footprint, positively impacting environmental pollution and public health. Additionally, these practices create local job opportunities and contribute to the local economy by promoting the use of available resources. Traditional architecture stands out as a natural and effective solution to the challenges of climate change. In environments experiencing alarming climate fluctuations, traditional building methods offer innovative and sustainable solutions. For example, in hot and arid regions, the use of mud and timber provides natural cooling, reducing indoor temperatures without relying on energy-intensive air conditioning.

In areas prone to hurricanes and flooding, bamboo construction presents a sustainable and resilient alternative. Bamboo's inherent flexibility and strength make it ideal for withstanding high winds and water damage, offering crucial protection for coastal communities. Vernacular architecture is based on a philosophy of harmony between humans and the environment. The adoption of local and sustainable building methods and materials not only enhances environmental sustainability but also helps preserve cultural and architectural heritage. When architects rediscover and incorporate these methods, they contribute to developing contemporary designs that unite beauty, durability, and sustainability. Drawing inspiration from traditional architecture can lead to innovative solutions that address both current and future environmental challenges. Traditional architecture and sustainability together open new horizons in facing climate change. These methods invite us to return to our roots, where architectural heritage guides us toward a more sustainable future. Understanding the relationship between humanity and the environment within the framework of environmental architecture motivates us to protect the planet and ensure a better future. Traditional architecture symbolizes a positive interaction between humans and the environment — it is an open-air museum offering ideas and solutions that strengthen our resilience to climate change and emphasize the importance of environmental sustainability in our lives.

This perspective is closely linked to the concept of local and traditional architecture, which reflects the cultural identity of communities. Earthen architecture, stone structures, oasis dwellings, and karshif architecture all embody a philosophy of skillfully harnessing environmental materials to create living spaces that connect with the human spirit and sustainably meet daily needs. The insight that buildings should not exist in isolation but rather as integral parts of the environmental and cultural fabric remains a cornerstone of our architectural heritage (Abd Elrahman and Saleh, 2015).

Methods

This research aims to identify, analyze, and document architectural elements found in traditional structures located in green environments. The goal is to develop a comprehensive checklist that incorporates diverse features from various global regions.

The study is divided into two parts:

2.1 A theoretical historical-inductive study.

2.2 An applied and analytical study focusing on thermal comfort, lighting, and ventilation in vernacular buildings, examining how building materials and construction methods affect spatial comfort.

Study Samples and Architects' Trends

A list of eight traditional buildings from different parts of the world was compiled. These structures are characterized by simplicity, durability, and a sense of tranquility. Selection was based on architectural, aesthetic, and historical significance. A detailed analysis of each building (Table 1) was conducted to examine their unique features and document trends. Tables 2-10 present an analysis of the selected buildings.

Table 1. **Selected buildings of aesthetic and historical value**

No.	Building	Location
01	Primitive Hut	North German Plain
02	Primitive Hut	Notre-Dame de Paris
03	Grass Lodge	Kansas City, USA
04	Dome of Shaykh Idris “Al-Mahjoub”	Northern Sudan
05	Manyatta Hut	Tanzania and Kenya
06	Stone House in Meyrals Commune	Southwest France
07	House in the Ancient City of Shali	Siwa Oasis
08	Bamboo Sports Hall	Panyaden International School, Thailand

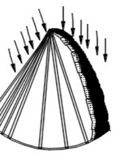
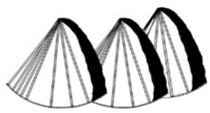
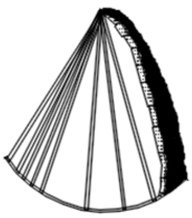
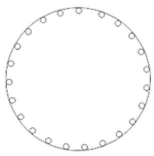
From the previous analyses, it is evident that traditional architecture offers a valuable global lesson in sustainable design. It is not merely a form of simple or vernacular construction but rather a reflection of a profound understanding of the balance between humanity and nature. The principles of traditional architecture can be leveraged to develop sustainable architectural solutions that are environmentally conscious and mitigate the negative impacts of modern technology. Striking a balance between technology and nature is essential for achieving sustainable development in the future. A prime example of this approach is the use of natural materials such as karshif and bamboo, both of which offer significant environmental and economic benefits:

- Karshif is a traditional, natural building material that has been used for thousands of years. Composed mainly of mud and straw, it is especially suited for desert and hot climates due to its exceptional thermal insulation properties and ability to regulate indoor temperatures. By combining simplicity with high efficiency, karshif promotes environmental sustainability and contributes to a stable indoor climate. As a thermal insulator, karshif helps maintain cool interiors in summer and retains warmth in winter, reducing the dependence on artificial cooling and heating systems. Due to its flexibility and moldability, karshif enables the creation of architectural designs that are well adapted to the surrounding environment. Its primary components — mud and straw — are both abundant and locally available, making it a practical and accessible building material.

From an environmental perspective, karshif is highly sustainable, relying on natural, renewable resources and leading to low production costs. While structures built with karshif may require periodic maintenance, especially in areas with significant rainfall, such maintenance is straightforward and can be performed using locally sourced materials. Shali, a city in the Siwa Oasis of Egypt, is a prime example of the use of karshif. It has stood as a complete urban settlement in a harsh desert environment since the 13th century. The thermal mass of its mud bricks provides exceptional insulation, ensuring a thermally comfortable interior environment throughout the year.

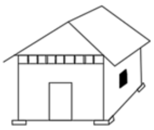
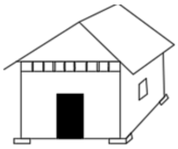
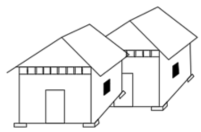
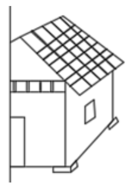
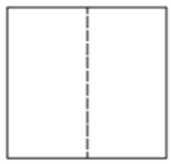
- Bamboo is one of the most prominent natural materials and has been widely celebrated in both traditional and contemporary architecture due to its unique properties — strength, flexibility, and rapid growth. As one of the most renewable and sustainable resources, bamboo can grow up to a meter per day in certain environments, making it an unparalleled natural alternative to timber, which requires significantly more time to mature. Extensively used in construction across Asia, Latin America, and Africa, bamboo is highly regarded

Table 2. **Building analysis (primitive hut — North German Plain, prehistory)**

<table>
<tr><th colspan="5">1. Primitive hut — North German Plain, prehistory</th></tr>
<tr><td rowspan="2">Materials</td><td>Disadvantages</td><td>These materials lack fame and recognition, and there is a prevailing trend toward using materials that negatively impact both the environment and human health.</td><td colspan="2" rowspan="3"></td></tr>
<tr><td>Advantages</td><td>The structure is formed using bamboo sticks arranged in a tapered semicircular shape, pointing upward. Bamboo is a fast-growing plant, reaching full maturity within three years. According to Chinese belief, it brings good luck and absorbs negative energy.</td></tr>
<tr><td colspan="2">Construction system</td><td>Ribbed dome system.</td></tr>
<tr><td colspan="2">Loading</td><td></td><td>Skyline</td><td></td></tr>
<tr><td rowspan="3">Ventilation openings</td><td>Windows</td><td>None</td><td>Load-bearing elements</td><td>The structure uses the same dome system, with beams at both edges of the dome to reduce lateral thrust.</td></tr>
<tr><td>Doors</td><td></td><td>Assembly</td><td>The cone shape is formed by assembling triangular components.
</td></tr>
<tr><td>Patios</td><td>None</td><td>Subtraction</td><td>A cone with a portion subtracted to create the door.
</td></tr>
<tr><td colspan="2">Building materials</td><td>Bamboo</td><td>Repetition</td><td>The same pattern is repeated in different areas.
</td></tr>
<tr><td colspan="2">Section</td><td></td><td>Roofs</td><td>The roof plan consisting of vertically oriented bamboo sticks, held together by a circular band at the base.
</td></tr>
</table>

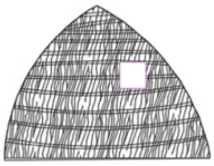
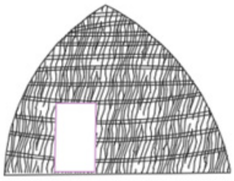
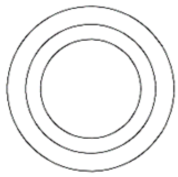
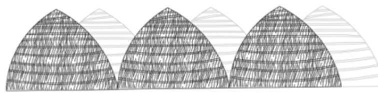
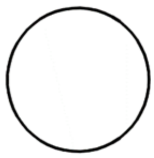
Reference: http://ocw.nd.edu/architecture/nature-and-the-built-environment/lecture-6/primitive-huts/view.

Table 3. **Building analysis (primitive hut (shape) — "Notre Dame", a city in Paris, prehistory)**

2. Primitive hut — "Notre-Dame", a city in Paris, prehistory				
Materials	**Disadvantages**	Natural materials are scarce. Preference for materials that have negative impacts on both the environment and human health.		
	Advantages	Natural materials harmonize with the surrounding climate, absorb negative energy, and provide thermal comfort.		
Construction system		A vertical system with a pyramidal roof.		
Loading			**Skyline**	
Ventilation openings	**Windows**		**Load-bearing elements**	Vertical elements consist of palm tree posts, while horizontal elements are made of brick beams and palm fronds.
	Doors		**Assembly**	The building's cubic form is composed of squares combined with a triangle to shape the facade. 
	Patios	The building does not contain a patio.	**Subtraction**	A cube from which parts are subtracted (the door and the window). 
Building materials		Bricks, reeds, and straw.	**Repetition**	The same pattern is repeated within the same area. 
Section			**Roofs**	The plan of the pyramidal roof. 

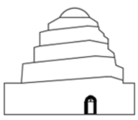
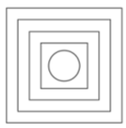
Reference: An article dated November 5, 2012 by Anna Longrigg, Marissa Morning, Logan Steele, Ilhan Gokay Ozdemir

Table 4. **Building analysis (grass lodge — Wichita, Kansas City, USA, 1541)**

<table>
<tr><th colspan="5">3. Grass lodge — Wichita, Kansas City, USA, 1541</th></tr>
<tr><td rowspan="2">Materials</td><td>Disadvantages</td><td>This type of building is rarely used.</td><td colspan="2" rowspan="3"></td></tr>
<tr><td>Advantages</td><td>All materials used are natural and do not harm the environment or human health.</td></tr>
<tr><td colspan="2">Construction system</td><td>Dome system with concentric rings.</td></tr>
<tr><td colspan="2">Loading</td><td></td><td>Skyline</td><td></td></tr>
<tr><td rowspan="3">Ventilation openings</td><td>Windows</td><td></td><td>Load-bearing elements</td><td>The same dome system, based on concentric rings — largest at the bottom, decreasing in size toward the top — with internal vertical tension elements connecting the rings.</td></tr>
<tr><td>Doors</td><td></td><td>Assembly</td><td>Constructed using rings arranged from bottom to top, decreasing in diameter.
</td></tr>
<tr><td>Patios</td><td>None</td><td>Subtraction</td><td>A vault from which parts are subtracted (the door and the window).
</td></tr>
<tr><td colspan="2">Building materials</td><td>The structure is made of bamboo and covered with grass.</td><td>Repetition</td><td>The pattern is repeated with variations in height and spacing.
</td></tr>
<tr><td colspan="2">Section</td><td></td><td>Roofs</td><td>The plan of the circular roof composed of rings.
</td></tr>
</table>

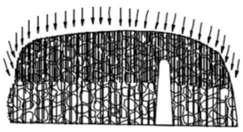
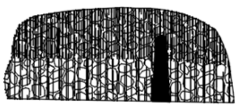
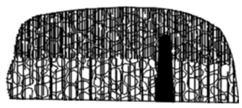
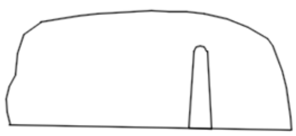
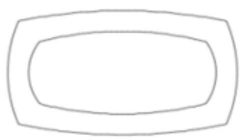
Reference: https://www.flickr.com/photos/smu_cul_digitalcollections/4876744423/

Table 5. **Building analysis (dome of Shaykh Idris "Al-Mahjoub" — Kowikka village, Northern Sudan, 1836)**

4. Dome of Shaykh Idris "Al-Mahjoub" — Kowikka village, Northern Sudan, 1836				
Materials	**Disadvantages**	Natural materials are scarce.		
	Advantages	The structure was built using natural materials, specifically mudbrick, which is inexpensive and environmentally balanced.		
Construction system		Stepped pyramidal system.		
Loading			**Skyline**	
Ventilation openings	**Windows**		**Load-bearing elements**	A brick dome composed of multiple tiers. The structure relies on vertical load-bearing elements.
	Doors		**Assembly**	The building has a stepped cubic form made up of squares, topped with a hemispherical vault. 
	Patios	The building includes a patio that appears on multiple levels and features ventilation openings.	**Subtraction**	A stepped pyramidal form from which parts are subtracted (the door and the window). 
Building materials		Mudbrick and stones.	**Repetition**	The design is repeated vertically rather than horizontally to enhance ventilation.
Section			**Roofs**	The plan of the roof consists of a stepped pyramidal structure topped with a dome. 

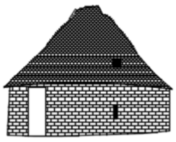
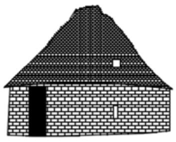
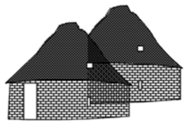
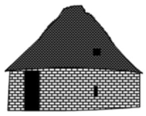
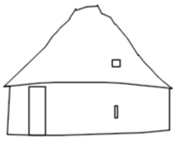
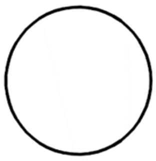
Reference: Article dated February 18, 2019, Al-Tahrir newspaper, "Here is Sudan" by Mohamed Mostafa Farah (Abu Mostafa)

Table 6. **Building analysis (Manyatta hut — Tanzania and Kenya, 2007)**

<table>
<tr><td colspan="5">5. Manyatta hut — Tanzania and Kenya, 2007</td></tr>
<tr><td rowspan="2">Materials</td><td>Disadvantages</td><td>It has a pungent smell initially, but this dissipates after drying.</td><td colspan="2" rowspan="3"></td></tr>
<tr><td>Advantages</td><td>The plastering material, made from cow dung, is a mineral-rich, protein-based mass. When applied to walls, it repels insects and serves as a thermal insulator.</td></tr>
<tr><td colspan="2">Construction system</td><td>Vertical system with a horizontal flat roof.</td></tr>
<tr><td colspan="2">Loading</td><td></td><td>Skyline</td><td></td></tr>
<tr><td rowspan="3">Ventilation openings</td><td>Windows</td><td>None</td><td>Load-bearing elements</td><td>The vertical elements are made from posts of palm fronds.</td></tr>
<tr><td>Doors</td><td></td><td>Assembly</td><td>The building has an irregular shape, resembling a rectangular parallelepiped, assembled from rectangles.
</td></tr>
<tr><td>Patios</td><td>None</td><td>Subtraction</td><td>A vertical form with a flat roof, from which a part is subtracted (the door and the window).
</td></tr>
<tr><td colspan="2">Building materials</td><td>Posts of palm fronds and plastering material made from cow dung.</td><td>Repetition</td><td>The design was not repeated within the same context.</td></tr>
<tr><td colspan="2">Section</td><td></td><td>Roofs</td><td>The plan of the roof follows a vertical system with a horizontal flat roof.
</td></tr>
</table>

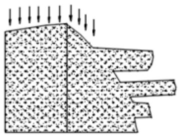
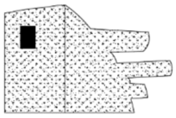
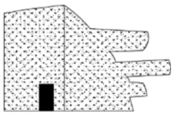
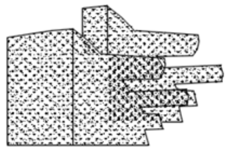
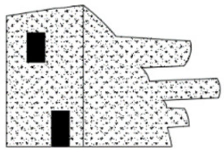
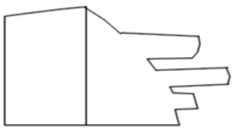
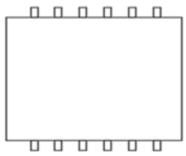
Reference: “From Vernacular to Modern” (2020), by Maureen Wangui Wanjiku and Samuel Mwituria Maina

Table 7. **Building analysis (stone house in Meyrals commune — Southwest France, 2007)**

6. Stone house in Meyrals commune — Southwest France, 2007				
Materials	**Disadvantages**	Natural materials are scarce.		
	Advantages	Constructed from natural materials that adapt well to human needs, providing thermal comfort and adequate lighting.		
Construction system		Cylindrical structure with a conical roof.		
Loading			**Skyline**	
Ventilation openings	**Windows**		**Load-bearing elements**	The house consists of walls topped with a complete roof structure. It relies on vertical load-bearing elements and is designed to resist some shear forces.
	Doors		**Assembly**	The building has a cylindrical form, composed of a cylinder topped with a pyramidal roof. 
	Patios	None	**Subtraction**	A conical structure with a pyramidal roof from which some parts are subtracted (the door and window). 
Building materials		Stones	**Repetition**	The same pattern is repeated throughout the available space at varying distances.
Section			**Roofs**	Circular roof plan. 

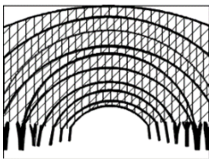
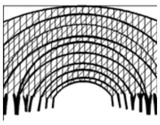
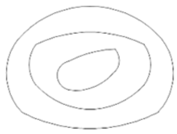
Reference: Boyer Site, Dordogne, France; author: Gilbert Bochenek

Table 8. **Building analysis (Siwa Center for Documentation of Cultural and Natural Heritage — ancient city of Shali in the Siwa Oasis, 2012)**

<table>
<tr><th colspan="5">7. Siwa Center for Documentation of Cultural and Natural Heritage — ancient city of Shali in the Siwa Oasis, 2012</th></tr>
<tr><td rowspan="2">Materials</td><td>Disadvantages</td><td>Natural materials are scarce.</td><td colspan="2" rowspan="3"></td></tr>
<tr><td>Advantages</td><td>Constructed from environmentally friendly materials. The roof is made of palm trunks, and the walls are built using karshif, a mixture of salt and sand.</td></tr>
<tr><td colspan="2">Construction system</td><td>Vertical system with a horizontal flat roof. Load-bearing walls.</td></tr>
<tr><td colspan="2">Loading</td><td></td><td>Skyline</td><td></td></tr>
<tr><td rowspan="3">Ventilation openings</td><td>Windows</td><td></td><td>Load-bearing elements</td><td>The loading is vertical, and the loads are distributed across the walls and roof.</td></tr>
<tr><td>Doors</td><td></td><td>Assembly</td><td>The building has a cubic form composed of square elements.
</td></tr>
<tr><td>Patios</td><td>A patio is essential in this building due to the intense desert heat.</td><td>Subtraction</td><td>A level structure from which parts are subtracted (the door and the window).
</td></tr>
<tr><td colspan="2">Building materials</td><td>Karshif</td><td>Repetition</td><td>The design is repeated throughout the surrounding space, but in varied forms.</td></tr>
<tr><td colspan="2">Section</td><td></td><td>Roofs</td><td>The plan of the roof.
</td></tr>
</table>

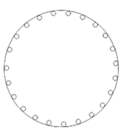
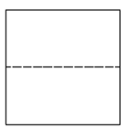
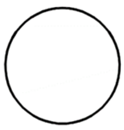
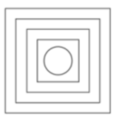
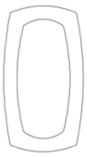
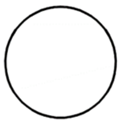
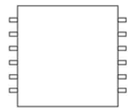
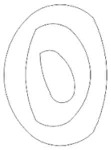
Reference: ©Hermann (FAO, 2016, www.fao.org/3/a-bp825e.pdf)

Table 9. **Building analysis (Bamboo Sports Hall — Panyaden International School, Thailand, 2017)**

<table>
<tr><th colspan="5">8. Bamboo Sports Hall — Panyaden International School, Thailand, 2017</th></tr>
<tr><td rowspan="2">Materials</td><td>Disadvantages</td><td>Natural materials are scarce.</td><td colspan="2" rowspan="3"></td></tr>
<tr><td>Advantages</td><td>Bamboo was used, which is highly flexible and can be harvested without killing the plant.
The building is designed to combat the hot climate.</td></tr>
<tr><td colspan="2">Construction system</td><td>Truss system
with sections for transferring and evenly distributing loads.</td></tr>
<tr><td colspan="2">Loading</td><td></td><td>Skyline</td><td></td></tr>
<tr><td rowspan="3">Ventilation openings</td><td>Windows</td><td>None, as it is an open hall.</td><td>Load-bearing elements</td><td>Curved horizontal elements such as domes, and vertical elements used to distribute loads in the truss.</td></tr>
<tr><td>Doors</td><td>Located at the beginning and end of the curved entrances.</td><td>Assembly</td><td>The truss shape was formed by assembling bamboo sticks.
</td></tr>
<tr><td>Patios</td><td>None</td><td>Subtraction</td><td>Entrances</td></tr>
<tr><td colspan="2">Building materials</td><td>Bamboo sticks
(Moses stick).</td><td>Repetition</td><td>The structural element was repeated over an area of 782 m² to accommodate 300 people.</td></tr>
<tr><td colspan="2">Section</td><td></td><td>Roofs</td><td>The plan of the roof.
</td></tr>
</table>

Reference: Bamboo Sports Hall for Panyaden International School / Chiangmai Life Construction, ArchDaily, 2017 [Date accessed April 15, 2020].

Table 10. **Comparative analysis of the eight buildings**

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8
1. Disadvantages	None	None	None	None	It has a pungent smell at first	None	None	None
2. Advantages	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
3. Construction system	Ribbed vault	Vertical pyramidal roof	Ribbed vault	Stepped pyramidal structure	Vertical flat roof	Cylindrical conical roof	Vertical flat roof	Trusses
4. Skyline								
5. Windows	None	Yes	Yes	Yes	None	Yes	Yes	None
6. Doors	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
7. Roofs								
8. Building materials	Bamboo	Bricks + reeds + + straw	Bamboo covered with grass	Mudbrick + + stones	Palm fronds and cow dung plaster	Stones	Karshif	Bamboo

for its exceptional strength-to-weight ratio. This makes it ideal for structures that must withstand earthquakes and harsh weather, enhancing both safety and comfort. Bamboo's compatibility with traditional techniques — such as lashing and knotting — further increases its appeal for those prioritizing sustainable practices. Beyond its role as a construction material, bamboo serves as a holistic environmental solution. Its rapid growth and low energy requirements make it a highly eco-friendly alternative to synthetic materials. Bamboo contributes to ecological balance by absorbing large amounts of carbon dioxide and releasing oxygen, playing a significant role in mitigating climate change. Additionally, bamboo offers natural thermal insulation, improving the energy efficiency of buildings. Its versatility allows it to be shaped for a wide range of applications, blending tradition with modernity and offering architects virtually limitless creative potential.

The Arc, a gymnasium at the Green School in Bali, Indonesia, stands as a testament to bamboo's architectural potential. It seamlessly blends traditional Balinese design with contemporary principles, enhancing environmental integration and promoting sustainability. Thanks to bamboo's flexibility and strength, the gymnasium features curved walls, vaulted ceilings, and shaded outdoor areas. Bamboo can also be fashioned into a wide range of products — such as furniture, umbrellas, and even bridges — demonstrating its remarkable versatility. In bamboo-growing regions, local communities are developing new crafts and techniques that respect tradition while renewing local resources, thereby supporting both the economy and sustainable development. Ultimately, bamboo is more than just a plant: it symbolizes innovation, balance, and harmony with nature.

Laboratory experiment: breaking five brick samples

Objective of the experiment:

- To manufacture environmentally friendly building materials (bricks).
- To measure the compressive strength of the bricks.

Experimental design

- Sample preparation: Five brick samples were prepared and numbered from 1 to 5.
- Tools and equipment used:

- Siwa sand;
- Fire marble powder;
- Lime marble powder;
- Dry bamboo (1 cm diameter, semi-hollow);
- Fire marble chips;
- Karshif stone;
- Addibond 65 (diluted in a 1:4 ratio);
- 5 wooden molds for samples (dimensions 20 × 10 × 7 cm);
- Measuring cup;

- Balance;
- Tamping tool.

Conducting the experiment:

- Sample casting date: 06.12.2024.
- The materials were mixed according to standard mixing procedures with compaction applied as shown in the Table 11.
- Sample 5 was subjected to drying at 140°C.

Photographs and recording of the experiment are shown in Figs. 2-4.

Test results

- Sample crushing date: 21.12.2024.
- Sample 4 was not tested due to its fragility and perishability.

Comparison	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Result	%
Disadvantages of building with natural materials	0	0	0	0	0	0	0	0	0/8	0 %
Advantages of building with natural materials	1	1	1	1	1	1	1	1	8/8	100 %
Circular roof	1	0	1	0	0	1	0	0	3/8	38 %
Square roof	0	1	0	1	1	0	1	0	4/8	50 %
Irregularly shaped ceilings	0	0	0	0	0	0	0	1	1/8	13 %
Ventilation openings	0.5	1	1	1	0.5	1	1	0.5	6.5/8	81 %
Climate resistance efficiency of natural materials	1	1	1	1	1	1	1	1	8/8	100 %

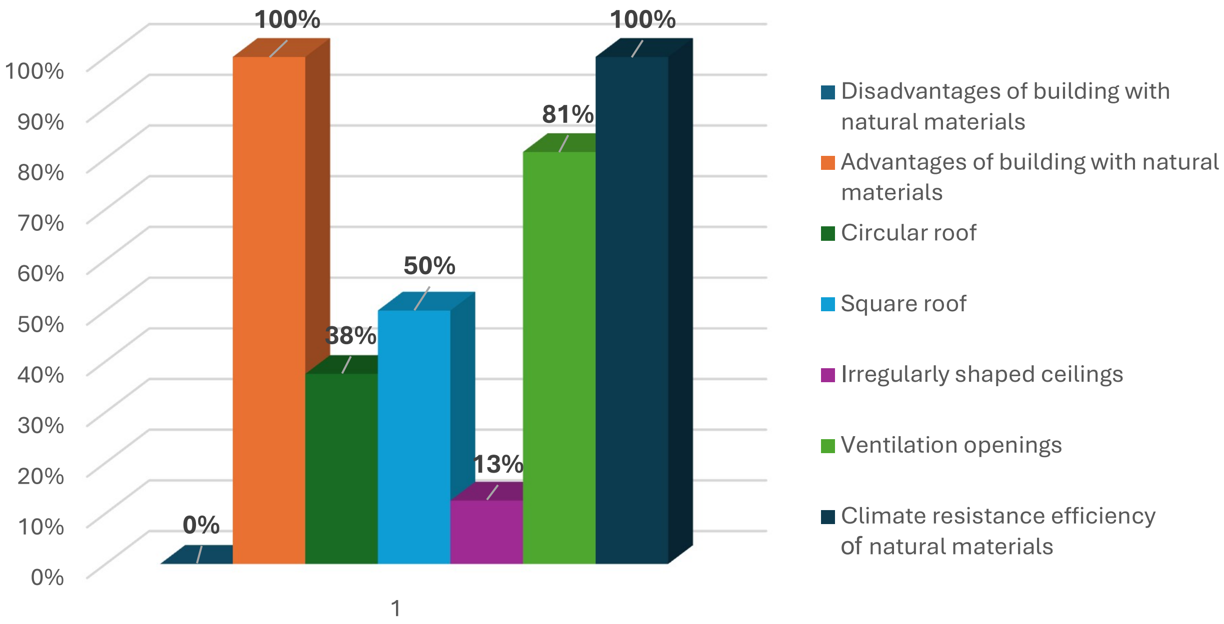


Fig. 1. Percentage of advantages, disadvantages, and effective ventilation in buildings constructed with natural materials

Table 11. **Compositions of mixtures**

Sample 1	***Raw materials***	Siwa sand	Water	–	–
	Standard number	12	3/4	–	–
Sample 2	***Raw materials***	Siwa sand	Fire marble powder	–	Addibond 65
	Standard number	6	2	–	2
Sample 3	***Raw materials***	Siwa sand	Bamboo	Lime marble powder	Addibond 65
	Standard number	6	Reinforcing	2	2
Sample 4	***Raw materials***	Siwa sand	Crushed karshif	Mousseline	Addibond 65
	Standard number	6	1	1	2
Sample 5	***Raw materials***	Siwa sand	Crushed karshif	Crushed fire marble	Addibond 65
	Standard number	3	3	1	1

Fig. 2. Broken karshif stone (researchers' work)

Fig. 3. Bamboo reinforcement visible within the brick sample (researchers' work)

Results

1. The construction systems in vernacular architecture vary widely, including ribbed dome systems, conical systems with pyramidal roofs, stepped pyramidal systems, and vertical systems with both pyramidal and horizontally flat roofs.

Fig 4. Five prepared brick samples (researchers' work)

2. Traditional heritage forms are utilized due to their ability to enhance the energy efficiency of buildings.
3. Primitive architecture demonstrated a richness in building forms that contributed to creating interior environments with thermal comfort, thereby reducing the need for artificial cooling and heating. This was achieved through methods such as integrated planning, narrow and winding streets, and the use of shrubs and trees.
4. Primitive architecture paid close attention to the treatment of building envelopes, aiming to reduce external environmental impacts and thus lower energy consumption and structural loads.
5. The internal environmental quality in primitive architecture was notable, relying on natural air renewal, interior humidification, thermal comfort, and effective use of natural lighting, while addressing limitations in lighting conditions through architectural design.
6. The results of the experiment, when compared with standard criteria for construction bricks, indicated that the four tested brick samples met the specified requirements.

Table 12. **The results of compressive strength testing for the five brick samples**

Sample No.	(1)	(2)	(3)	(4)	(5)
Weight, g	2132	1686	1335	0	1017
Dimensions, cm	19.8 × 10.0 × 5.6	19.8 × 9.6 × 5	19.9 × 9.8 × 4.0	0	19.5 × 10.3 × 3.3
Cross-sectional area, cm^2	198.0	190.1	195.0	0	200.8
Crushing load, kN	156.3	294.9	191.4	0	265.1
Compressive strength, kg/cm^2	80.5	158.1	100.0	0	201.8

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СТРОИТЕЛЬНЫЙ АНАЛИЗ ЭКОЛОГИЧЕСКОЙ УСТОЙЧИВОСТИ В ТРАДИЦИОННОЙ АРХИТЕКТУРЕ

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Аннотация
Введение: данное исследование основано на предпосылке о том, что традиционная архитектура представляет собой здания, построенные из природных местных материалов. Эти сооружения спроектированы так, чтобы адаптироваться к изменениям окружающей среды, то есть обеспечивать экологическую устойчивость, за счет продуманного внешнего облика. Проблематика исследования заключается в негативных последствиях использования современных промышленных строительных материалов. Эти материалы зачастую дороги, требуют значительных энергетических затрат на производство и нуждаются в искусственных системах для обеспечения теплового комфорта внутри помещений. В связи с этим исследование направлено на раскрытие потенциала природных материалов в архитектурном проектировании — изучение их свойств, климатической эффективности, конструкционной прочности и строительных систем, в которых они используются — с целью снижения высокого энергопотребления. **Также исследование ставит своей задачей** анализ характеристик и эксплуатационных свойств природных строительных материалов, выявление их постоянных и переменных параметров, а также определение областей их архитектурного и конструкционного применения. **Результаты**: Используя преимущества окружающей среды, данная работа стремится обосновать целесообразность применения природных материалов в устойчивом строительстве. Методология исследования сочетает описательный и аналитический подходы в целях обоснования экономически выгодного и устойчивого использования природных материалов в архитектуре.

Ключевые слова: экологическая устойчивость; национальная архитектура; традиционная архитектура; каршиф; бамбук.