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Application of Local Materials in Tropical Architecture: A Systematic Literature Review (SLR)

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ABSTRACT

The application of local materials in tropical architecture offers sustainable solutions for energy efficiency, cultural preservation, and social well-being. The study highlights the benefits of using materials such as bamboo, wood, and clay, which have low embedded energy and thermal properties suitable for tropical climates. Combined with passive design strategies, these materials reduce energy consumption while supporting the preservation of cultural heritage and strengthening the local economy. Key research gaps include the lack of comprehensive studies on the thermal comfort impacts of local materials, integration with modern technology, and the socio-cultural implications of their use. Future research should explore the synergy between local materials and advanced technologies, such as phase-change materials and digital fabrication, to improve performance and scalability. Expanding the geographical scope of the study and adopting a holistic methodology will enrich the understanding of the potential of local materials. The practical recommendations emphasize the prioritization of local materials for their thermal properties, integrating them with modern technology, and considering socio-cultural aspects to ensure long-term sustainability. Government policies and incentives are essential to encourage the adoption of local materials in construction. Interdisciplinary collaboration between architects, materials scientists, and social researchers is essential to developing innovative and sustainable tropical architectural solutions that address global climate challenges.

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1. INTRODUCTION

The application of local materials in tropical architecture has become an increasingly relevant topic in the context of sustainability and energy efficiency. The tropics, which encompass most of Southeast Asia, Latin America, and Africa, face major challenges in managing natural resources and energy. One solution that offers great potential is the use of local materials in development, which can reduce dependence on imported materials and at the same time minimize environmental impact. Not only that, the application of local materials also has important social and cultural benefits, by contributing to the preservation of local heritage and the economic development of local communities.

One of the main advantages of using local materials is their impact on sustainability and energy efficiency. Local materials often have lower embodied energy compared to modern building materials, which means the use of local materials can reduce the carbon footprint of development. For example, bamboo, wood, and clay—some of the local materials commonly used in the tropics—have excellent thermal properties for tropical climates, such as high insulation and low heat retention. This helps in reducing the energy requirements for cooling buildings, which is a major problem in hot and humid tropical regions. In addition, traditional architectural designs that utilize local materials often utilize passive strategies to improve thermal comfort, such as building orientation, proper use of openings, and the use of vegetation that can create a more naturally comfortable environment. (Alam et al., 2015; Austin et al., 2022; Hashemi et al., 2015)

Not only from a technical and sustainability perspective, the application of local materials in tropical architecture also provides very important cultural and social benefits. The use of materials derived from the surrounding environment can strengthen the community's sense of belonging and identity towards their buildings, while preserving local wisdom that has existed for centuries. This is very relevant in preserving the cultural heritage and traditions that have been formed in tropical societies. Furthermore, the use of local materials can provide local economic support by creating jobs and developing local industries, which in turn can improve the well-being of local communities. The use of more accessible materials also improves the accessibility and affordability of buildings, especially in rural and suburban areas that often face major challenges in terms of cost and availability of building materials. (Hashemi et al., 2015) .

1.1 Existing Scopes and Gaps Found

The existing literature on the application of local materials in tropical architecture covers several important aspects, such as their impact on sustainability and energy efficiency, social and cultural benefits, and frequently encountered geographical and methodological boundaries. Most studies identify that the use of local materials can reduce the carbon footprint and improve the energy efficiency of buildings, especially in the context of tropical climates that require careful thermal regulation. However, despite the many studies that have been conducted, there are some research gaps that still need to be addressed.

First, most research focuses on energy efficiency and sustainability, but there is a lack of discussion about the impact of local materials on the thermal comfort of residents, especially in the context of diverse local microclimates in the tropics. Second, although many discuss the traditional use of local materials, integration with modern technologies such as passive cooling systems or transition-phase materials is still less explored. Third, while there is recognition of the social and cultural benefits of using local materials, more research is

needed to explore its impact on cultural identity, local economy, and building accessibility for communities. (Alam et al., 2015; Austin et al., 2022; Hashemi et al., 2015)

1.2 Contributions and Objectives of the Systematic Review

This review aims to fill in the gaps in the literature by conducting a thorough evaluation of the application of local materials in tropical architecture, focusing on sustainability impacts, energy efficiency, and social and cultural aspects. This research will examine more deeply how local materials, such as bamboo, wood, and clay, can support more environmentally friendly and more energy-efficient building designs, as well as how the integration of these materials can be optimized with modern technology. In addition, the study will further investigate the social and cultural impacts of the use of local materials, as well as how they can increase the involvement of local communities in their own development. As such, the review aims to enrich understanding of the role of local materials in tropical architecture and provide practical guidance for architects and policymakers in integrating local materials into sustainable and efficient building projects.

1.3 Scope of Review

This review will include studies that address the use of local materials in tropical architecture, with a focus on tropical regions in developing countries, especially Southeast Asia, Latin America, and Africa. The research carried out includes various methodologies, ranging from case studies to quantitative simulations, to explore various aspects of the application of local materials. The findings of this review are expected to make a major contribution to the development of more sustainable architectural practices, as well as provide deeper insights into the potential of local materials in designing buildings that are environmentally friendly and in accordance with the social needs of tropical communities.

With this holistic approach, this review aims to make an important contribution to the study of the application of local materials in tropical architecture and broaden our understanding of the technical, social, and cultural benefits of this approach.

2. THEORETICAL FRAMEWORK/BACKGROUND

2.1 Definition of Local Materials in Tropical Architecture

Tropical architecture is designed as an effort to save energy in a building which is determined by natural lighting and air circulation flow (Saliim & Satwikasari, 2022). The orientation of buildings in tropical climates must take into account the direction of the sun's movement to avoid the heat of direct sunlight radiation entering the building, which is intended to be west and east (Arisal & Sari, 2020). Local materials in tropical architecture are defined as building materials that come from local natural resources and have characteristics that are suitable for the tropical climate. The use of this material has become a traditional practice rooted in the local culture of tropical societies. Common examples of locally used materials include bamboo, wood, clay, and stone, which are not only easy to obtain but also have physical and thermal properties that support sustainability as well as energy efficiency in development. (Austin et al., 2022; Hashemi et al., 2015) (Alam et al., 2015; Hashemi et al., 2015)

2.1.1 Characteristics of Local Materials in the Context of a Tropical Climate

Thermal comfort is a feature of tropical architecture as a solution to prevent the sun's heat into the buildings (Harsdani & Kartika, 2018). Local materials have a number of characteristics that make them ideal for use in tropical architecture, which are generally characterized by high temperatures, high humidity, and significant rainfall. The concept of modern tropical architecture combines tropical architecture and modern architecture, where

there is a combination of the use of materials such as concrete and steel (Saliim & Satwikasari, 2022a). The following are the main characteristics of local materials in the context of tropical climates:

1. Good Thermal Properties

Local materials such as bamboo, wood, and clay have high insulation ability and low heat retention ability. This characteristic allows the building to stay cool even in a tropical environment with hot and humid temperatures. For example, clay has a low thermal capacity, which allows buildings to absorb a minimal amount of heat during the day and release it slowly at night. Meanwhile, bamboo and wood have natural porosity that supports air circulation and helps improve thermal comfort without the need for artificial cooling. (Alam et al., 2015; Austin et al., 2022) (Hashemi et al., 2015)

2. Compatibility with Passive Design Strategies

Traditional architectural design in the tropics generally utilizes local materials to support passive design strategies. This strategy includes proper orientation of the building, the use of openings to improve natural ventilation, natural lighting, as well as integration with the vegetation around the building. Materials such as wood and bamboo are often used to build walls or roofs that allow for optimal air circulation, thereby reducing reliance on artificial refrigeration and significantly improving the energy efficiency of buildings. (Ruan & Liu, 2023)

3. Lower Contained Energy

One of the advantages of local materials is the low embodied energy or energy required during the process of extraction, production, and transportation of materials. Materials such as bamboo, wood, and clay can be processed simply with traditional technology, thereby reducing the carbon footprint generated in the construction process. Compared to modern materials such as concrete and steel that require high energy in their production process, local materials are more environmentally friendly and contribute to sustainable development. (Hashemi et al., 2015)

4. Conformity with Local Culture and Economy

The use of local materials in tropical architecture is not only technically relevant but also has cultural and economic advantages. This material reflects local wisdom that has been passed down from generation to generation, thus helping to preserve the cultural identity and traditions of the local community. In addition, the use of local materials supports the local economy by creating job opportunities for the surrounding community through the processing and distribution of building materials. It also improves the accessibility and affordability of buildings, especially in rural areas or areas with limited modern infrastructure. (Hashemi et al., 2015)

2.1.2 Local Materials as a Sustainable Solution

Overall, local materials have great potential in supporting sustainable development in the tropics. The use of this material contributes to three main aspects:

1. Environmental aspects: With the low energy contained and thermal properties that support energy efficiency, local materials help reduce the environmental impact of construction activities.
2. Economic aspects: Local materials can be obtained at a lower cost, support local industries, and improve people's welfare through job creation.
3. Social and cultural aspects: The use of local materials preserves local wisdom, supports cultural identity, and increases community connectivity with their built environment.

With characteristics that are suitable for the local climate, culture, and economy, local materials in tropical architecture not only offer efficient and sustainable solutions but are also capable of providing long-term benefits to the environment and society. The combination of

modern technology and traditional practices in the use of local materials can be key in designing environmentally friendly, energy-efficient, and sustainable tropical buildings. (Alam et al., 2015; Austin et al., 2022; Hashemi et al., 2015)

2.2 Sustainability Theory in Architecture

In the context of tropical architecture, the application of local materials not only focuses on technical aspects but also includes sustainability approaches involving environmental, economic, and socio-cultural aspects. The three main theories that are relevant in supporting the sustainability of the application of local materials in tropical architecture are sustainable architectural design theory, circular economy theory, and local wisdom theory.

2.2.1 Sustainable Architectural Design Theory

Sustainable architectural design theory emphasizes the responsible use of natural resources to reduce environmental impacts in the development process. One of the main principles of this theory is the selection of materials that are suitable for local climatic conditions, such as those found in local materials in the tropics. (Austin et al., 2022; Hashemi et al., 2015)

1. Suitable thermal properties: Local materials such as bamboo, wood, and clay have thermal properties that are well suited to tropical climates, such as high insulation ability and low heat retention ability. This allows the building to maintain a comfortable temperature without having to use additional energy for cooling (Alam et al., 2015; Austin et al., 2022) .
2. Integration with passive design strategies: Passive design strategies, such as optimizing natural ventilation, natural lighting, and the use of vegetation, are often more effective when combined with local materials. For example, bamboo which has lightweight and strong properties is often used in roof and wall design to improve air circulation, which is especially important in tropical climates. (Ruan & Liu, 2023)
3. Reduced carbon footprint: Local materials have lower energy content compared to modern materials such as concrete or steel. This is because local materials do not require an energy-intensive production process and are generally obtained from resources available around the construction site. The use of these materials helps to reduce the carbon footprint of construction and supports the achievement of sustainability goals. (Hashemi et al., 2015)

By applying the principles of this theory, local materials not only improve energy efficiency but also support environmentally friendly and sustainable development.

2.2.2 Circular Economy Theory

The circular economy theory focuses on the sustainable use of resources through reduction, reuse, and recycling of materials in development. In the context of tropical architecture, local materials play an important role in supporting the local economy and creating a balance between economic development and the environment. (Hashemi et al., 2015)

1. Support for the local economy: The use of local materials such as bamboo, wood, and clay encourages the development of local industries and creates new jobs. This has the potential to improve the welfare of local communities, especially in rural and suburban areas that have limited access to imported materials.
2. Accessibility and affordability: Local materials are generally more accessible and have lower costs than modern materials. This allows for more inclusive and affordable development for people with diverse economic backgrounds. (Hashemi et al., 2015)

3. Reduction of construction waste: The use of local materials is often accompanied by minimal recycling and processing practices, which contribute to the reduction of construction waste and support the principles of sustainability.

This theory shows that the application of local materials not only benefits the environment but also strengthens the sustainable economy at the local level.

2.2.3 Local Wisdom Theory

The theory of local wisdom recognizes the importance of local culture, traditions, and practices in supporting architectural design that is in accordance with environmental conditions and community needs. The use of local materials often reflects the hereditary knowledge passed down in tropical societies. (Hashemi et al., 2015; Ruan & Liu, 2023)

1. Preservation of local culture and identity: Materials such as bamboo, wood, and clay have strong cultural value, as they are often used in traditional architecture. Buildings that use these materials not only maintain a cultural identity but also reflect the close relationship between humans and their natural environment.
2. Source of modern design inspiration: Traditional architectural designs that use local materials can be an inspiration for an effective passive design strategy. For example, traditional homes in the tropics often use high roofs, large openings, and porous materials to support natural ventilation and thermal comfort. (Ruan & Liu, 2023)
3. Social connectivity: The use of local materials supports community involvement in the development process, creates a sense of belonging, and strengthens social bonds between communities.

By applying this theory, local materials in tropical architecture not only provide technical solutions but also build a harmonious relationship between people, culture, and the environment.

2.3 Tropical-climate Design Model

The tropical-climate design model is an architectural approach that utilizes local material characteristics and design strategies to respond effectively to tropical climate conditions. The tropical climate is generally characterized by high temperatures, high humidity, and significant rainfall throughout the year. In this context, the application of local materials is key in creating buildings that are thermally comfortable, energy efficient, and sustainable. The three main design models that support the application of local materials in tropical architecture are passive design, integration with modern technology, and cultural and social adaptation.

2.3.1 Passive Design

Passive design is an approach that optimizes the use of natural elements, such as sunlight, wind, and vegetation, to reduce reliance on artificial cooling or heating systems. In tropical architecture, passive design takes advantage of the thermal properties of local materials to create natural thermal comfort.

1. Utilization of thermal properties of local materials: Local materials such as bamboo, wood, and clay have high insulation ability and low heat retention ability. This characteristic helps to reduce the heat absorbed by the building during the day and maintain a comfortable temperature at night. For example, clay walls have a low thermal capacity so they can regulate the room temperature effectively, while bamboo allows for better air circulation inside the building. (Austin et al., 2022; Hashemi et al., 2015)
2. Integration of passive design strategies: Local materials are combined with passive design strategies, such as:

- Building orientation: Orient buildings to minimize exposure to direct sunlight during the day and maximize natural ventilation.
- Natural ventilation: The use of porous materials such as bamboo and wood allows for more optimal air circulation, reducing the need for artificial cooling.
- Use of vegetation: The integration of vegetation as a protector from direct sunlight helps to reduce overheating and create a cooler microenvironment. (Ruan & Liu, 2023)

The two main principles in the application of tropical architecture using the Passive Design approach are (1) the energy saving principle and (2) the passive cooling principle (Mutaqi & Saparwoko, 2020). Thus, passive designs that utilize local materials not only improve energy efficiency but also create thermal comfort for building occupants.

2.3.2 Integration with Modern Technology

In addition to passive design, the integration of local materials with modern technology offers innovative solutions to improve building performance in tropical climates. Modern technology allows local materials to adapt to the demands of higher energy efficiency and sustainability.

1. Passive cooling systems: Local materials such as clay can be used in passive cooling systems by utilizing the thermal properties of the material to absorb heat during the day and release it slowly at night. This strategy reduces the load on the mechanical cooling system. (Austin et al., 2022)
2. Phase Change Materials (PCM): Local materials can be combined with phase change materials to improve a building's ability to store and release heat. For example, clay or local stone combined with PCM is able to stabilize indoor temperatures and reduce energy requirements for cooling. (Austin et al., 2022; Hashemi et al., 2015)
3. Other innovative technologies: Local materials such as bamboo can be processed using modern technology to increase their structural strength, such as the use of bamboo laminate for stronger and more durable building elements. This technology expands the potential use of local materials in modern architectural design (Alam et al., 2015).

This integration allows tropical architecture to retain local material characteristics while meeting higher standards of building efficiency and performance.

2.3.3 Cultural and Social Adaptation

The tropical-climate design model also considers cultural and social context as important elements in the use of local materials. This adaptation ensures that architecture not only responds to the climate but also supports local values and the well-being of the community.

1. Preservation of local wisdom: The use of local materials such as bamboo and clay is often related to traditional practices that have been passed down from generation to generation. Traditional architectural design uses highly effective strategies in responding to tropical climates, such as the use of high roofs, large openings, and porous materials for ventilation. The use of local materials in a modern context preserves local wisdom and culture of the local community. (Ruan & Liu, 2023)
2. Local economic support: The use of local materials supports the local economy through job creation, the development of small industries, and the reduction of dependence on imported materials. This helps to improve the accessibility and affordability of buildings for people in rural and suburban areas. (Hashemi et al., 2015)

- Enhancing local identity: Buildings that use local materials reflect the cultural identity of the local community. This increases the sense of belonging and connectedness between the building and its environment, creating a more meaningful and socially sustainable architecture. (Ruan & Liu, 2023)

3. METHODOLOGY

3.1 Case Studies

This study uses the Systematic Literature Review (SLR) approach to evaluate the application of local materials in tropical architecture. The SLR approach was chosen for its ability to identify, evaluate, and synthesize relevant studies in a systematic and transparent manner. SLR allows for structured analysis of data spread across multiple sources, resulting in reliable and replicable findings. This study utilizes the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework to ensure clarity and accountability at every stage of the research, from literature identification to data synthesis. (Ayu et al., 2021; Erbara & Destiny, 2022)

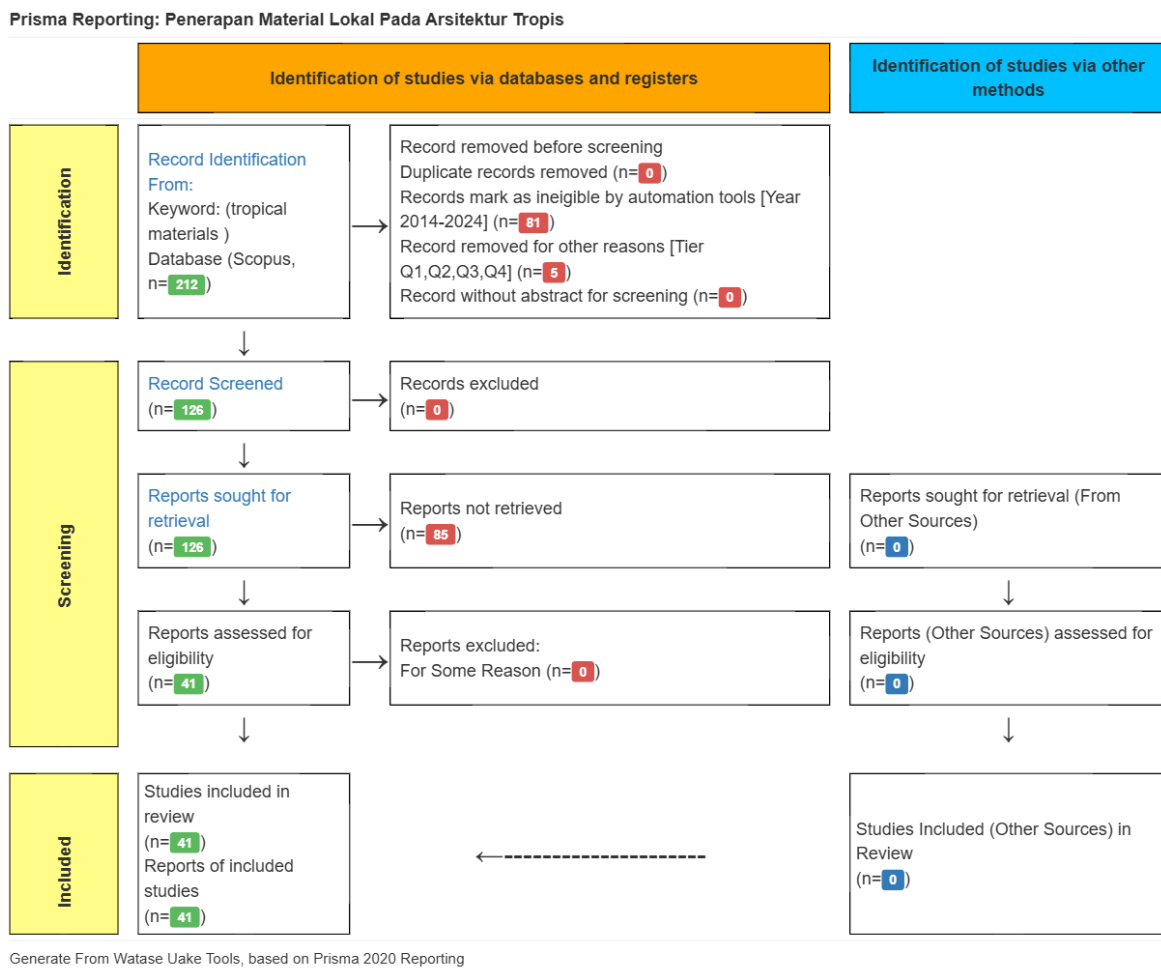


Figure 1 PRISMA flowchart
(Source: Personal document, 2024)

The PRISMA framework is used as a guideline to manage the article selection process. It includes the identification, screening, and inclusion of literature that meets the inclusion criteria. The PRISMA flowchart, depicted in Figure 1, shows the key steps in the review process. This process starts from a literature search using specific keywords in a database

such as Scopus, followed by a systematic evaluation of relevant articles, as well as a narrative and quantitative synthesis of research results. With this approach, this study ensures that all the data entered are of high relevance and good quality to discuss the theme of the use of local materials in tropical architecture.

3.2 Inclusion and Exclusion Criteria

To ensure the quality and relevance of the selected articles, this study applies predetermined inclusion and exclusion criteria. The inclusion criteria include peer-reviewed studies published between 2014 and 2024, which address the application of local materials in the context of tropical architecture. The selected article should focus on aspects of sustainability, energy efficiency, or environmental impact. Research using empirical methods, case studies, or qualitative and quantitative simulations is also included. In addition, articles published in English and Indonesian are considered to provide a wider scope of cross-regional research.

In contrast, exclusion criteria include articles that do not provide abstracts or full-text, opinions or editorial commentary that are not based on empirical research, and duplication of articles from the same search results. Studies that are not relevant to the theme of tropical architecture or local materials are also excluded from the analysis. This process is carried out manually through the evaluation of the title and abstract, followed by an assessment of the full-text article to ensure compliance with the criteria that have been set. By applying these criteria, this study is able to filter relevant and high-quality literature for further analysis.

3.3 Search Strategies and Keywords

The literature search is carried out systematically using the Scopus database as the main source, which is recognized as one of the most complete and reputable academic databases. Keywords for search are developed based on the main topic of the research, using a combination of Boolean (AND/OR) to ensure maximum search coverage. Some of the keywords used include: "tropical architecture AND local materials", "sustainability AND tropical building materials", and "energy efficiency AND indigenous materials". This search strategy also considers synonyms and term variations to increase the number of relevant articles.

The search process is carried out by the filter of publication year 2014–2024, document types that only include journal articles, and English or Indonesian. Search results are exported in CSV format for further processing using tools such as Microsoft Excel and Wase Uake software to organize the data. This process is followed by automatic deduplication before manual filtering. The emphasis on reputable databases and rigorous search strategies ensure the quality and relevance of the literature used in the analysis.

3.4 Data Extraction and Synthesis Process

The data extraction process is carried out systematically using tools such as Wase Uake, which allows the organization of data from selected articles. Each article is evaluated based on important information, including title, author, year of publication, research methods, local materials studied, as well as key findings related to energy efficiency, sustainability, or socio-cultural impact. The extracted data is then arranged in tables for easy further analysis.

Data synthesis is carried out in two approaches: narrative and quantitative. Narrative synthesis is used to identify key themes, patterns, and relationships between different studies. For example, themes such as local material sustainability and passive design strategies are identified through article content analysis. On the other hand, quantitative analysis is used to evaluate numerical data, such as an increase in energy efficiency or a

reduction in carbon footprint, reported in the relevant article. Quantitative data is analyzed using simple statistical tools to produce measurable and structured findings.

3.5 Qualitative and Quantitative Analysis Methods

This study uses a mixed analysis approach to ensure comprehensive results. Qualitative analysis is focused on socio-cultural aspects, such as the impact of local materials on cultural identity and affordability of buildings. This analysis involves coding the data to identify recurring patterns and themes throughout the analyzed literature. Tools such as Wata Uake are used to aid in the qualitative coding and synthesis process.

On the other hand, quantitative analysis is used to evaluate numerical data related to energy efficiency and local material performance. For example, data on the thermal conductivity and heat capacity of local materials are analyzed to evaluate their contribution to the reduction of cooling loads of tropical buildings. These quantitative analyses provide empirical evidence that supports qualitative findings, resulting in a more holistic and reliable synthesis.

3.6 PRISMA Reporting

The reporting of this study follows the PRISMA 2020 guidelines to ensure transparency and quality in the review process. PRISMA provides a clear structure for reporting every stage of the process, from identification to article inclusion. The PRISMA flowchart (see Figure 1) shows the number of articles identified, filtered, and finally incorporated into the analysis.

This process begins with the identification of 212 articles from the Scopus database. After automatic deduplication, 126 articles were filtered based on inclusion and exclusion criteria. From the results of the screening, 85 articles were eliminated because they did not meet the criteria of relevance or quality, leaving 41 articles eligible for in-depth analysis. This PRISMA diagram not only provides visualization of the selection process but also demonstrates the transparency of the methodology, which is important for future research validation and replication.

4. REVIEW OF THEMES/FINDINGS

4.1 Sustainability and Environmental Impact

Sustainable architecture is a way to minimize the negative impact of development on the environment by using efficiency and wisdom in the application of material processing, energy, and space (Satrya et.al, 2023). The application of local materials in tropical architecture offers a significant solution to improve environmental sustainability. One of the main benefits of using local materials is their ability to reduce the carbon footprint of development. Local materials such as bamboo, wood, and clay have much lower embodied energy than modern materials such as concrete and steel. This is due to the local material production process which generally does not require high energy and utilizes the resources available around the construction site. For example, sustainably harvestable bamboo requires minimal energy for its extraction and processing process, resulting in lower carbon emissions throughout the building's life cycle. Therefore, the use of local materials in development in the tropics directly supports climate change mitigation efforts by reducing carbon emissions. (Hashemi et al., 2015)

In addition, local materials have thermal properties that support the energy efficiency of buildings in tropical climates. Materials such as clay and wood have high insulation capabilities as well as low heat capacity, so they can help keep room temperatures comfortable without the need for artificial cooling. For example, clay can absorb heat during the day and release it slowly at night, which helps reduce the need for energy use for cooling. When combined with

passive design strategies, such as natural ventilation and proper building orientation, local materials can further reduce energy consumption. This strategy allows tropical buildings to function efficiently by taking advantage of the potential of the local climate, such as wind and natural lighting. (Austin et al., 2022; Hashemi et al., 2015) (Austin et al., 2022)

Another benefit is the ability of local materials to reduce the overall environmental impact. The use of local materials minimizes the overexploitation of natural resources and construction waste, which is often a major problem in the use of modern materials. For example, concrete production requires the excavation of large quantities of sand and stone, which can lead to environmental degradation and land degradation. In contrast, local materials such as bamboo are biodegradable and recyclable, resulting in less waste. In some cases, construction waste from local materials can even be reused for other purposes, such as composting or processing into new materials, thus supporting the circular economy and waste reduction. (Hashemi et al., 2015)

On the other hand, local materials also support environmental conservation through the reduction of long-distance material transportation. When materials are imported from distant locations, the energy spent on transportation can be a major contributor to carbon emissions. However, by utilizing local resources, the carbon footprint of material transportation can be minimized, making development more environmentally friendly. This is especially relevant in tropical regions, where the availability of natural resources is often abundant and can be utilized for local development with a smaller environmental impact.

Overall, the application of local materials in tropical architecture has a far-reaching positive impact on the environment. Reducing the carbon footprint is a key benefit in line with climate change mitigation efforts, while improved energy efficiency contributes greatly to the operational sustainability of buildings. In addition, reducing the exploitation of natural resources, reducing waste, and increasing recycling practices further strengthen the sustainability value of local materials. Thus, this strategy is not only relevant for tropical regions, but also becomes a sustainable model that can be adapted to other regions with similar environmental characteristics. The application of local materials integrated with passive design and sustainable practices can be a key approach in creating an environmentally friendly and energy-efficient built environment in the future.

4.2 Technology and Innovation in Local Materials

Innovations in processing technology and the utilization of local materials further expand their potential use in tropical architecture. By leveraging technological advancements, local materials can now be effectively integrated into modern designs to improve the energy efficiency, sustainability, and thermal comfort of buildings. One innovative approach is the integration of Phase Change Materials (PCM) with local materials such as bamboo, wood, and clay. PCMs, which are capable of storing and releasing thermal energy during phase changes, have been shown to improve the thermal performance of buildings in tropical climates. Research shows that incorporating local resource-based PCMs, such as tropical fruits, into a building's envelope can significantly reduce the energy requirements for cooling. (Austin et al., 2022)

In addition, the utilization of agricultural waste and tropical forestry offers sustainable solutions in resource management. Waste such as fruit peels and wood residues are now used as raw materials for environmentally friendly building components. For example, wood residues from the forestry industry can be processed into composite materials that have superior thermal and mechanical properties. This process not only supports waste reduction but also improves the environmental performance of building materials. This waste-based

material also reflects a circular economy approach that maximizes the use of tropical resources. (Okoro et al., 2022)

Advances in material characterization and modeling technologies have paved the way for a deeper understanding of the thermal, mechanical, and environmental properties of local materials. Using tools such as computational simulation and advanced imaging, researchers can evaluate and optimize the characteristics of local materials such as bamboo and clay. For example, thermal simulations help determine the optimal thickness of clay walls for maximum energy efficiency in tropical climates. This technique also supports data-driven innovation in the development of hybrid materials that combine the advantages of local materials with modern technology. (Hashemi et al., 2015)

The hybridization approach of local and modern materials is one of the main innovations in tropical architecture. Bamboo, for example, can now be reinforced with lamination technology to increase its structural strength, while soil composites can be combined with modern thermal insulation to improve the energy efficiency of buildings. This innovation ensures that local materials remain relevant amid the need for buildings with high performance standards. (Austin et al., 2022)

Finally, the application of digitalization and automation in local material processing, such as 3D printing and robotic fabrication, allows for more efficient and high-precision production. This technology supports the creation of building components based on local materials that are more consistent in quality and scalability. This innovation not only increases the potential for local material applications but also opens up new opportunities in tropical architecture that is more adaptive to the times. (Zamora et al., 2019)

With the integration of modern technology, local materials are now able to compete with conventional materials, offering innovative solutions that are environmentally friendly, energy-efficient, and culturally relevant.

4.3 Local Wisdom and Culture in Tropical Architecture

Local wisdom is an important element in the application of local materials to tropical architecture, which not only highlights adaptation to the environment, but also preserves cultural heritage and supports community welfare. In the context of tropical architecture, local materials such as bamboo, wood, and clay are often used due to their characteristics that suit the local climate. The thermal properties of local materials, such as high insulation ability and low heat retention ability, provide optimal thermal comfort without the need to use high-cost modern technology. Additionally, traditional designs that utilize local materials typically integrate passive strategies, such as the orientation of buildings to capture natural winds and the use of vegetation to reduce direct solar radiation. This strategy shows how local wisdom is able to provide efficient and sustainable solutions to tropical climate challenges. (Hashemi et al., 2015; Ruan & Liu, 2023)

Another aspect of local wisdom is its ability to preserve the cultural heritage of the community. Traditional architectural designs, which often utilize local materials, reflect cultural values and identities that have been passed down from generation to generation. Buildings made of bamboo or wood, for example, not only serve as residences but also as cultural symbols that reflect the community's relationship with the surrounding nature. The use of local materials in modern design can be a bridge between tradition and innovation, ensuring that local wisdom remains relevant and respected in the context of contemporary development. (Hashemi et al., 2015; Ruan & Liu, 2023)

In addition to cultural preservation, the use of local materials also contributes to the strengthening of the local community's economy. The production and distribution process of local materials, such as bamboo or clay, often involves local labor, which creates jobs and

encourages the development of small industries. This not only improves people's welfare but also makes buildings more affordable, especially in rural and suburban areas. By utilizing local materials, transportation and production costs can be minimized, thereby increasing the accessibility of buildings for various levels of society. (Hashemi et al., 2015)

Overall, local wisdom plays an important role in tropical architecture by blending environmental, cultural, and economic aspects. Through the use of local materials, tropical architecture not only meets functional needs but also maintains cultural values and creates a positive socio-economic impact. This approach shows that the preservation of cultural heritage and support for the local economy can go hand in hand with the development of environmentally friendly and sustainable designs.

4.4 Challenges and Obstacles in The Application of Local Materials

The application of local materials in tropical architecture, despite its many benefits, is faced with various challenges and obstacles that hinder its widespread adoption and implementation. One of the main obstacles is related to costs. Local materials that are not mass-produced often have a higher price than modern materials that are more available in the market. In addition, the lack of infrastructure and industries that support the efficient production of local materials contributes to higher construction costs. These barriers are even more significant in remote areas where access to local materials is still limited and their distribution requires additional costs. (Hashemi et al., 2015)

The next obstacle is technical, which includes a lack of comprehensive documentation and testing of local material properties. This raises doubts about the quality, safety, and durability of local materials, especially in more complex or large-scale building applications. In addition, there are still many construction practitioners who do not have knowledge or skills in processing and using local materials. The lack of technical training and applicable guidance makes the use of local materials more difficult than modern materials that already have well-established standards and technical guidance. (Hashemi et al., 2015)

From the point of view of public perception, the adoption of local materials also faces challenges. People's preferences that tend to prefer modern materials often hinder the adoption of local materials. Buildings with local materials are sometimes considered less prestigious or less than meeting the desired aesthetic standards. In addition, public awareness of the sustainability benefits and energy efficiency of local materials is still low, resulting in limited demand for local materials. (Hashemi et al., 2015)

The last obstacle is regulations and policies that have not fully supported the application of local materials. Many building regulations do not adequately accommodate the use of local materials, especially in terms of safety and quality standards. On the other hand, the lack of incentives or policies that encourage the use of local materials, such as subsidies or tax reductions, also hinders developers and contractors from choosing local materials as part of their construction projects. (Hashemi et al., 2015)

Overall, cost, technical, public perception, and regulatory constraints are the main obstacles in the application of local materials in tropical architecture. To address these challenges, an integrated approach is needed that includes technological innovation, technical training, public awareness campaigns, and policy reforms that support sustainability. These efforts are important to encourage the adoption of local materials as construction solutions that are efficient, environmentally friendly, and relevant to local needs.

4.5 Opportunities and Recommendations for Further Research

Although research on the application of local materials in tropical architecture has shown the benefits of sustainability and energy efficiency, there are still many opportunities to broaden understanding in this area. One of the important areas that needs to be further

researched is the impact of local materials on the thermal comfort of residents. Existing research has largely focused on energy efficiency, but a more comprehensive approach is needed to evaluate how the thermal properties of local materials, such as high insulation ability and low heat capacity, can improve indoor thermal comfort in tropical climates. In-depth research can also explore the integration of local materials with passive design strategies to improve the quality of the indoor environment, so that residents get maximum benefits. (Austin et al., 2022; Hashemi et al., 2015)

In addition, the integration of local materials with modern technology offers great opportunities for innovation. While much of the current research focuses on the traditional use of local materials, the exploration of synergies between local materials and advanced technologies, such as passive cooling and phase-changing materials (PCMs), could create new solutions for energy efficiency. The use of this energy-efficient technology allows for improved thermal performance of buildings without sacrificing sustainability. An in-depth study of modern fabrication technologies, such as 3D printing and automation, can also lead to more efficient and scalable local material processing techniques. (Austin et al., 2022)

Another important aspect for future research is the socio-cultural impact of the use of local materials. Although some studies have shown its benefits in preserving culture and improving local economies, more studies are needed to explore the relationship between local materials and people's cultural identities, especially in rural and suburban areas. This research can also help evaluate how the use of local materials can improve building accessibility for people with different economic backgrounds.

In terms of geographical coverage, most current studies still focus on tropical regions in certain developing countries. There is a great opportunity to expand the study to other tropical regions that have unique cultural diversity and environmental conditions. Research methodologies can also be developed by combining qualitative and quantitative approaches, resulting in a more holistic understanding of the application of local materials in different contexts. (Chewapreecha et al., 2022; Ruan & Liu, 2023)

Finally, the development of processing techniques and the integration of local materials is also a promising area. More in-depth research on the characterization of the thermal, mechanical, and environmental properties of local materials can help optimize their use in tropical architectural design. New technologies, such as digital fabrication and hybrid solutions, can amplify the potential of local materials to meet the needs of modern design without losing sustainability value.

By addressing these research gaps, further studies can contribute to the development of more sustainable, culturally relevant, and cutting-edge technology-enabled tropical building solutions. This will not only increase the adoption of local materials, but also support the development of more efficient and inclusive tropical architecture.

5. CONCLUSION

The application of local materials in tropical architecture offers significant sustainable solutions for energy efficiency, cultural preservation, and improved social welfare. The study highlights that local materials such as bamboo, wood, and clay have low embodied energy and thermal properties that support thermal comfort in tropical climates. The combination of local materials with passive design strategies allows for a reduction in energy consumption, while the use of these materials supports the preservation of cultural heritage and the strengthening of the local economy.

However, the study also found some gaps that need to be addressed in future studies. The impact of local materials on the thermal comfort of residents, the potential for

integration with modern technology, and socio-cultural impacts require more in-depth exploration. In addition, the need for wider geographical coverage and a more holistic methodology is an important concern. The integration of technologies such as phase-changing materials and digital fabrication offers a great opportunity to improve the efficiency and performance of local materials in the modern context.

Recommendations for architectural professionals include prioritizing the thermal properties of local materials in design, integrating modern technologies for optimal efficiency, as well as considering socio-cultural aspects to support long-term sustainability. With the support of government policies that encourage the adoption of local materials, this approach can accelerate greener, inclusive, and culturally relevant development in the tropics.

Further research involving interdisciplinary collaboration between architects, materials experts, and social scientists is needed to create holistic and sustainable tropical architectural solutions. By addressing existing research gaps, tropical architecture based on local materials can become a development model that is not only efficient and culturally relevant, but also capable of answering global climate challenges.

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