PROCEEDINGS OF THE INTERNATIONAL CONFERENCE OF GRADUATE SCHOOL ON SUSTAINABILITY (ICGSS)

9th International Conference on Sustainability (ICoS9)
University of Merdeka Malang, November 9th, 2024
https://jurnal.unmer.ac.id/index.php/icgss

E-ISSN:
2721-13988

INCORPORATION OF SUSTAINABILITY IN TRADITIONAL ARCHITECTURE: A NARRATIVE REVIEW

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Abstract.

This study conducts a narrative review to explore the integration of sustainability principles into traditional architecture, a field that has garnered significant attention amid global sustainability challenges. Traditional architecture, with its use of locally sourced materials and climate-responsive designs, inherently supports sustainability by minimizing environmental impact and energy consumption. Using VOSviewer software, this study analyzes 50 research articles from the SciSpace platform (Typeset.io), identifying key thematic clusters related to traditional architecture, vernacular design, and energy efficiency. The results reveal that traditional building practices, particularly those using natural ventilation and eco-friendly materials, offer valuable insights for modern sustainable architecture. This analysis also highlights a trend toward incorporating traditional architectural wisdom into contemporary practices, particularly as the urgency to address climate change intensifies. By mapping research patterns and key concepts, this study provides a comprehensive overview of how traditional architecture can inspire innovative, sustainable design solutions in contemporary architectural practices, making significant contributions to the field. This research aims to fill the gap in the literature by providing a comprehensive study that maps the integration of sustainability practices in traditional architecture, which is currently limited. The findings are expected to offer new insights into how the concept of sustainability can be applied in traditional architecture and innovated in modern architectural practices.

Keywords: Bibliometric Analysis, Environmental Impact, Sustainability, Traditional Architecture, VOSViewer.

1. Introduction

In recent decades, global attention to sustainability issues has significantly increased, particularly in the context of architecture and urban development. The phenomenon of climate change, driven by carbon emissions, excessive exploitation of natural resources, and environmental degradation, has necessitated the adoption of more ecologically sustainable and environmentally friendly solutions in all dimensions of human existence (Asghari et al., 2024; Bai et al., 2024; Dunlop, 2022; Giraudet & Missemer, 2023; Karasek et al., 2023; Moriarty & Honnery, 2023; Nevskaya & Khaikin, 2023; Patel et al., 2021; Sundaramoorthy et al., 2023; Xu et al., 2024) (Akyildiz & OlÄŸun, 2020; Jagatramka, 2021). By using local materials, designing buildings according to climatic conditions, and minimizing dependence on external energy, traditional architecture offers inherent concepts of sustainability (Akyildiz & OlÄŸun, 2020; Din & Ishak, 2024; Eghbali & Didari, 2018; Flores et al., 2022; Jagatramka, 2021; Reddy, 2023). Studies on this approach have great potential to be adapted into environmentally oriented modern architectural practices.

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Generally, traditional architecture reflects sustainability values in various forms, including through the use of locally available materials, energy-efficient construction techniques, and designs that take into account the local climate (Akyildiz & OlÄŸun, 2020; Eghbali & Didari, 2018). In various cultures, traditional architecture has developed different adaptation methods, all with the same goal: to maintain a balance between human needs and the natural ecosystem. For example, in tropical regions, traditional architecture often employs natural ventilation and high roofs to maintain good air circulation and reduce heat. In contrast, in cold climates, buildings are designed to maximize solar heat absorption. Empirical studies demonstrate that this methodology is not only energy-efficient but also more sustainable than certain contemporary construction practices that heavily rely on artificial resources and energy. In this context, traditional architecture plays a crucial role in providing architectural solutions that have the potential to significantly reduce carbon footprints and environmental impacts.

This research aims to gain a deeper understanding of how traditional architectural practices adopt sustainability principles to minimize environmental impact. Using a bibliometric approach, this research will examine at least 50 scientific articles obtained from the Scispace (Typeset.io) platform related to the topic of traditional architecture and sustainability. Bibliometric analysis, facilitated by VOSviewer software, enables the identification of research trends, inter-concept relationships, and key contributions in this study. Although numerous studies have discussed sustainability in architecture, comprehensive studies mapping the integration of sustainability practices in traditional architecture through a bibliometric approach remain very limited. Thus, this research aims to fill the existing literature gap by providing a comprehensive and systematic analysis. The findings of this research are expected to provide new insights into the application of sustainability concepts in traditional architecture and how these concepts can be innovated in modern architectural practice.

2. Method

This research employed a qualitative approach, utilizing bibliometric analysis, to explore how traditional architecture incorporates sustainability principles and minimizes environmental impact.

2.1 Article Selection

2.1.1. Article criteria

- The article selection process is conducted through the Scispace platform. (typeset.io). The research was conducted using keywords such as "traditional architecture," "sustainability," "environmental impact," and other related combinations, and a specific list of keyword concepts was selected for the search column.
- The articles selected for this analysis are journal articles that appear based on concepts from keyword search results, then the top 5 concepts are chosen. Each of these concepts has 10 journal articles discussing the specific concept. Only articles written in English and published in the last 7 years will be considered.

2.1.2. Article Collection Process

- The process of article collection is carried out through the Scispace platform. (typeset.io). The research was conducted using keywords such as "traditional architecture," "sustainability," "environmental impact," and other related combinations in the specific column discussing the concept.

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- The results of the search for the specific concept were then narrowed down to the top 5 concepts. From each of these concepts, the top 10 high-quality articles were selected and then exported to RIS format, allowing them to be input into the VOSviewer application for analysis.

2.2 Bibliometric Analysis

2.2.1. Introduction to Bibliometric Analysis

Bibliometric analysis is a method used to analyze and evaluate academic literature by using statistics and visualization techniques. Its purpose is to understand research trends, author collaboration, and topic development.

2.2.2. Steps for Bibliometric Analysis using VOSviewer

1. Data Collection

- After identifying 50 relevant articles, bibliographic data from the articles were extracted. This data includes information such as title, author, year of publication, source, abstract, and keywords.
- The extracted data is then saved in RIS file format, for use in VOSviewer.

2. Import Data into VOSviewer

- Using VOSviewer, files containing bibliographic data are imported. VOSviewer supports various formats, including bibliographic files generated from bibliographic databases such as Web of Science and Scopus.
- After importing the data, users choose to conduct analysis based on authors, institutions, countries, or keywords.

3. Network Creation

- VOSviewer allows the creation of network visualizations based on various parameters. In this analysis, collaboration networks between authors and institutions can be generated.
- The network shows how authors or institutions collaborate in research and how this information is disseminated in the literature.

4. Frequency Analysis

- Using VOSviewer, keyword frequency and theme analysis can be conducted. This will provide insights into the most frequently researched topics in the context of traditional architecture and sustainability.
- Users can see the most frequently appearing keywords and the relationships between keywords, as well as identify trends in research.

5. Interpretation and Visualization

- After analyzing the data, the visualization results are explained narratively to provide context on how the findings are relevant to the research question.
- The visualization results, such as network maps and frequency graphs, are included in the article to support the analysis and help readers understand trends and patterns in the literature.

2.3 Analytical Approach

The data presentation method involved displaying the visualization results from VOSviewer in the form of network maps, keyword frequency diagrams, and tables that summarized the main articles and related information, including authors, publication years, and the primary focus of the research. This visualization enhances the understanding of the relationships between themes in the literature and research patterns that support the integration of sustainability in traditional architecture. The entire analysis is presented comprehensively and

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E-ISSN:
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systematically to demonstrate the interconnections of concepts and provide new perspectives in examining the adaptation of sustainability in architectural practice. With this approach, the research is expected to make a significant contribution to the architectural literature, particularly regarding how sustainability principles applied in traditional architecture can be adopted in the context of contemporary architecture.

3. Literature Review

3.1. Energy Efficiency

Energy efficiency is a complex concept that holds significant importance in mitigating energy consumption and reducing greenhouse gas emissions across various sectors. This includes the utilization of a reduced amount of energy to achieve equivalent output levels, thereby promoting environmental sustainability and economic benefits. The presented research paper provides various perspectives on energy efficiency, covering industrial applications, architectural technology, and national policies. This analysis underscores the importance of energy efficiency as a crucial pillar for sustainable development and initiatives aimed at decarbonization. The following are the main aspects of energy efficiency as outlined in the paper.

3.1.1. Industrial Energy Efficiency

- The industrial sector is a considerable contributor to energy consumption and CO2 emissions, representing 33% of the United States' primary energy utilization and 30% of its energy-related emissions. Energy efficiency technologies, such as strategic energy management and smart manufacturing, provide cost-effective avenues for decarbonization and can be implemented immediately to reduce energy consumption and emissions (Sundaramoorthy et al., 2023).
- Energy efficiency improvements in industrial environments can be achieved through an extensive evaluative framework, exemplified by the PSO + AHP - FCE model, which combines qualitative and quantitative metrics to optimize energy consumption and forecast prospective efficiency progress (Bai et al., 2024).

3.1.2. Building Energy Efficiency

- Structures contribute to approximately 40% of worldwide energy consumption and greenhouse gas emissions. Improving building envelopes through the incorporation of thermal insulation layers (TILs) and phase change materials (PCMs) has the potential to markedly reduce energy demand. For example, the incorporation of TILs and PCMs can result in a 37.88% reduction in thermal energy and a 26.749% reduction in cooling energy in residential structures (Asghari et al., 2024).

3.1.3. National and Policy Perspectives

- National energy consumption efficiency is shaped by a complex interaction of socioeconomic, environmental and technological determinants. A broad methodological framework is essential for the evaluation of these determinants and the improvement of energy efficiency in different countries (Nevskaya & Khaikin, 2023).
- Energy efficiency programs (EEPs) have been effectively implemented in various geographical locations, including Switzerland, where they serve to promote the utilization of energy-efficient commodities. These initiatives demonstrate superior cost-effectiveness in relation to expenditures associated with electricity provision and

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provide substantive additional benefits, which include ecological and social benefits (Patel et al., 2021).

3.1.4. Historical and Conceptual Insights

- The idea of energy efficiency has undergone significant evolution throughout history, reflecting broad economic and social considerations. Moving from the classical period's concentration on resource depletion to the modern era's climate change priorities, energy efficiency has consistently been a focal point of discourse and ongoing reinterpretation (Giraudet & Missemer, 2023).
- Contemporary energy efficiency strategies may not fully capture all relevant variables, including the energy inputs required for the establishment of renewable energy infrastructure. More sophisticated methodologies are essential to address this shortcoming and improve the efficacy of energy efficiency initiatives (Moriarty & Honnery, 2023).

Energy efficiency, while essential for reducing consumption and emissions, presents several challenges. Real-world applications involve subjective elements that complicate policy formulation and implementation. Additionally, rebound effects can limit the effectiveness of energy efficiency initiatives by increasing overall energy consumption. As a result, a holistic and integrated strategy is essential to maximize the benefits of energy efficiency in addressing environmental and societal issues.

3.2. Local Climate Knowledge

Local climate knowledge encompasses the insights that communities have about climate change, gained through their interactions with their environment. This expertise is derived from historical observations and is critical to climate adaptation strategies. Combining local knowledge with scientific data enhances the effectiveness of adaptation, particularly in areas where scientific information is scarce. The next section examines the various dimensions of local climate knowledge as articulated in the referenced papers.

3.2.1. The Importance of Local Climate Knowledge

- Local knowledge systems, especially those of indigenous peoples and local communities, are critical to detecting the impacts of climate change on atmospheric, physical and living systems. These systems have evolved through long-term interactions with the environment and can provide insights that are often missing from scientific data (Reyes-García et al., 2023).
- In areas such as Uganda, smallholder farmers' observations of rainfall patterns have been shown to align with satellite-based data, leading to better agricultural outcomes such as higher crop yields. This demonstrates the practical value of local knowledge in agricultural decision-making (Salerno et al., 2022).
- In Ghana, local climate knowledge, such as plant phenology and animal behavior, is critical to sustainable agro-ecological practices. This knowledge helps farmers anticipate weather patterns and plan accordingly, thereby increasing their adaptive capacity (Jabik, 2022).

3.2.2. Challenges and Integration with Scientific Knowledge

- Despite its importance, local climate knowledge is under threat due to lack of documentation and declining knowledge transfer. Efforts to integrate this knowledge with scientific data are critical for effective climate adaptation planning (Jabik, 2022).

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- In Ethiopia, there is a high degree of agreement between farmer observations and climatological data on changes in rainfall patterns. However, there are differences in perceptions of the length of the growing season, highlighting the need for a comprehensive approach that combines local cognition with scientific assessment (Bedeke & Tebeje, 2022).
- In Accra, Ghana, local perceptions of climate change are often aligned with scientific data, but there are striking differences, such as increased flooding that is not supported by scientific evidence. This suggests the need to integrate local perceptions into adaptation planning to address these differences (Adams et al., 2022).

3.2.3. Role in Climate Adaptation Strategy

- Local knowledge plays a critical role in climate adaptation strategies, particularly in the water sector in Africa. Indigenous and local knowledge systems have been shown to influence the adoption of water adaptation responses, such as irrigation and rainwater harvesting, which are critical to reducing climate risks (Zvobgo, 2022).
- In Indonesia, knowledge co-production through climate field schools has facilitated the flow of climate change adaptation knowledge within communities. This approach highlights the importance of involving local actors in knowledge dissemination to enhance adaptive capacity (Arifah et al., 2023).

Local climate knowledge is essential for adaptation but faces challenges in integrating with scientific knowledge. Population dynamics in Svalbard complicate the generation and retention of local knowledge. However, strong place attachment and community science methodologies can facilitate the collection and preservation of this knowledge, enhancing scientific understanding and local relevance (Lennert et al., 2023). This underscores the need for a coordinated approach that respects and combines multiple sources of knowledge for sustainable climate adaptation.

3.3. Natural Ventilation

Natural ventilation is a crucial component of building design, providing benefits such as enhanced indoor air quality (IAQ), improved energy efficiency, and reduced reliance on mechanical systems. It is particularly relevant in educational, residential, and vernacular architecture, where it can significantly impact environmental performance and occupant comfort. The effectiveness of natural ventilation depends on several factors, including building design, environmental conditions, and user behavior. This answer examines the potential and challenges of natural ventilation in various contexts, drawing on insights from recent research.

3.3.1. Building Design and Layout

- The shape and layout of the building significantly affect the performance of natural ventilation. In teaching building complexes, a staggered layout improves ventilation more effectively than an aligned layout, especially when the openings are aligned with the prevailing winds. Semi-enclosed courtyard blocks also outperform fully enclosed courtyard blocks in terms of ventilation efficiency (Deng et al., 2024).
- In multifamily residential buildings, integrating passive duct systems into structural elements can improve airflow dynamics, with complex configurations significantly increasing ventilation rates (Obeidat et al., 2024).
- The use of skycourts in high-rise buildings provides direct air flow, increases natural ventilation and reduces energy consumption in various climate zones (Ali et al., 2023).

3.3.2. Indoor Air Quality and Energy Efficiency

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- Natural ventilation is critical to maintaining acceptable IAQ in existing homes, especially older or vulnerable ones. Strategies such as minimum ventilation time (MVT) indicators help optimize ventilation while minimizing thermal discomfort and energy use (Fabian & Carlota, 2024).
- In air-conditioned rooms, single-sided window opening can effectively remove indoor contaminants, although it can lead to increased energy consumption. Intermittent window opening strategies can balance improved air quality with energy efficiency (Liu et al., 2024).

3.3.3. Vernacular and Bioclimatic Design

- Vernacular architecture uses bioclimatic design strategies that utilize natural ventilation for sustainable development. This design makes effective use of environmental resources, although challenges remain in prototyping and quantitative evaluation (Pan et al., 2024).
- In low-income housing, natural cross ventilation and appropriate building form can significantly improve indoor thermal conditions, reduce energy consumption and address energy poverty in hot and arid climates (Stasi et al., 2023).

3.3.4. Environmental and Urban Considerations

- The potential for natural ventilation in urban areas is influenced by climate, local wind conditions and air pollution levels. Real-time assessment of these factors can provide more accurate predictions of ventilation potential, highlighting the limitations imposed by urban air quality (Short et al., 2024).
- The effectiveness of natural ventilation as a cooling strategy varies with climate characteristics. Evaluation should consider meteorological uncertainties and key performance indicators to optimize design strategies (Li et al., 2024).

While natural ventilation offers many benefits, its effectiveness can be limited by factors such as urban air quality, building design constraints, and climate conditions. In some cases, mechanical or hybrid ventilation systems may be required to achieve desired levels of IAQ and thermal comfort. Additionally, the integration of advanced monitoring technologies, such as pendulum velocity anemometers, can enhance real-time assessment of natural ventilation performance, providing valuable data to optimize building design (Lv et al., 2024).

3.4. Sustainable Materials

Sustainable materials are increasingly recognized as a critical component in addressing environmental challenges and promoting a circular economy. These materials are designed to minimize environmental impacts throughout their life cycle, from production to disposal, while maintaining functionality and performance. The development and integration of sustainable materials spans a range of sectors, including construction, polymers, and innovative composites, each contributing uniquely to sustainability goals. The following sections explore key aspects of sustainable materials, drawing insights from recent research.

3.4.1. Safe and Sustainable by Design (SSbD) Principles

- The European Commission emphasizes the integration of SSbD principles into the innovation process to ensure the safety and sustainability of advanced materials. This approach involves considering ecological, social and economic factors early in the design phase to facilitate market introduction and reduce costs (Cassee et al., 2024).

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- Collaboration between stakeholders and regulatory alignment are critical to the successful implementation of SSbD, promoting responsible innovation and societal acceptance (Cassee et al., 2024).

3.4.2. Sustainable Polymers

- The shift from petroleum-based polymers to bio-based polymers is driven by the need for sustainable alternatives. Bio-based polymers offer environmental benefits, such as biodegradability and reduced carbon footprint, making them suitable for a variety of applications, including packaging and textiles (Kumar et al., 2024; Mehta et al., 2023).
- Challenges in adopting sustainable polymers include high production costs and limited mechanical properties compared to traditional polymers. Overcoming these challenges requires advances in processing techniques and supply chain sustainability (Mehta et al., 2023).

3.4.3. Environmentally Friendly Building Materials

- Innovations in building materials focus on reducing harmful emissions and increasing sustainability. For example, incorporating lignin nanoparticles into urea-formaldehyde resin significantly reduces formaldehyde emissions in medium-density fiberboard without compromising its mechanical properties. (Dorieh et al., 2024).
- The use of waste biomass in creating high-strength superhydrophobic materials demonstrates the potential of binder-free lamination methods in producing environmentally friendly structural materials for construction (Wang et al., 2024).

3.4.4. Mycelium-Based-Based Composite

- Mycelium-based bio-composites (MBCs) are emerging as sustainable materials for interior design, utilizing agro-industrial waste and fungal species. These composites offer biodegradability and mechanical properties comparable to traditional materials, highlighting their potential in modern applications (Aiduang et al., 2024).

3.4.5. Recycling and Reuse in Construction

- The construction industry is increasingly focusing on recycling materials from renovation and demolition projects. Sustainable materials engineering promotes the reuse of waste materials, such as steel, bricks and glass, in new composite materials, in line with the principles of a circular economy (Czarnecki & Rudner, 2023; Italia et al., 2023).
- Despite environmental benefits, consumer acceptance of recycled materials depends on quality and cost-effectiveness, which requires further education and certification initiatives (Czarnecki & Rudner, 2023).

While sustainable materials offer significant environmental benefits, their widespread adoption faces challenges such as cost, performance, and consumer acceptance. Overcoming these challenges requires interdisciplinary collaboration, technological advancements, and regulatory support to ensure that sustainable materials can effectively replace traditional options across industries.

3.5. Traditional Architecture

Traditional architecture encompasses a range of building styles and techniques that are deeply rooted in cultural, environmental and historical contexts. These structures often

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reflect the unique characteristics of their region, including local materials, climate adaptations and cultural values. Traditional architecture is not only a testament to historical building practices but also offers insights into sustainable design principles that are increasingly relevant today. The following sections explore various aspects of traditional architecture as discussed in the provided papers.

3.5.1. Cultural and Regional Influences

- Traditional architecture is heavily influenced by regional culture and historical context. For example, traditional buildings in Jiangxi, China, reflect a blend of Huizhou and Hakka cultural influences, resulting in unique architectural styles such as terrace-style buildings and high-rise buildings (Song & Liao, 2023).
- In Konya, Türkiye, traditional earthen architecture embodies the cultural practices and knowledge of local master builders, highlighting the importance of intangible cultural heritage in architectural design (GlobbulTheca, 2023).

3.5.2. Environmental Sustainability and Adaptation

- Traditional architecture often incorporates sustainable design elements that are adaptive to the local climate. The ancient mosques of the Gayo Highlands, Indonesia, for example, use local, low-energy materials and are designed to withstand earthquakes through specific structural systems (Sari et al., 2023).
- In the Tibetan town of Songpan, traditional houses use stone and wood structures that increase thermal comfort, demonstrating the integration of green building technologies with traditional design (Xie et al., 2024).

3.5.3. Architectural Features and Design Principles

- Courtyard houses in Erbil, Iraq, display common architectural features such as three-sided courtyards, wooden doors, and brick ornamentation, which are integral to the spatial organization and massing of these traditional houses (Mustafa & Ali, 2024).
- The geometric proportions and modular design principles found in traditional Libyan architecture contribute to the aesthetic harmony and beauty of these structures, emphasizing the importance of proportion in architectural design (Eltrapolsi et al., 2022).

3.5.4. Modern Challenges and Adaptations

- Preserving vernacular architecture faces challenges due to globalization and the demands of modern construction. However, integrating traditional elements into modern design can enhance sustainability and cultural continuity, as seen in the renovation of a traditional house in Serbia using natural materials to reduce environmental impact (Stanimirovic et al., 2023).
- In Yazd, Iran, the balance between preserving cultural heritage and meeting modern housing needs is critical. Traditional houses offer benefits such as increased well-being and a sense of community, which are often lacking in modern developments (Formolly & Saraei, 2024).

While traditional architecture offers valuable lessons in sustainability and cultural preservation, it also faces challenges in adapting to modern needs and technologies. Integrating traditional elements with contemporary design can provide a pathway to sustainable development, ensuring that this architectural practice continues to thrive in a rapidly changing world.

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4. Results and Discussion

This bibliometric analysis aims to identify key themes and conceptual relationships in research related to sustainable architecture, particularly those related to energy use and environmental sustainability. This network visualization was generated using VOSviewer software by analyzing keyword co-occurrence relationships in relevant literature.

Data were obtained from scientific articles related to the topics of sustainable architecture, environmental sustainability, and energy efficiency. VOSviewer was used to map frequently occurring keywords and to detect clusters indicating thematic relationships between concepts.

4.1 Results of Bibliometric Analysis – Network Visualization.

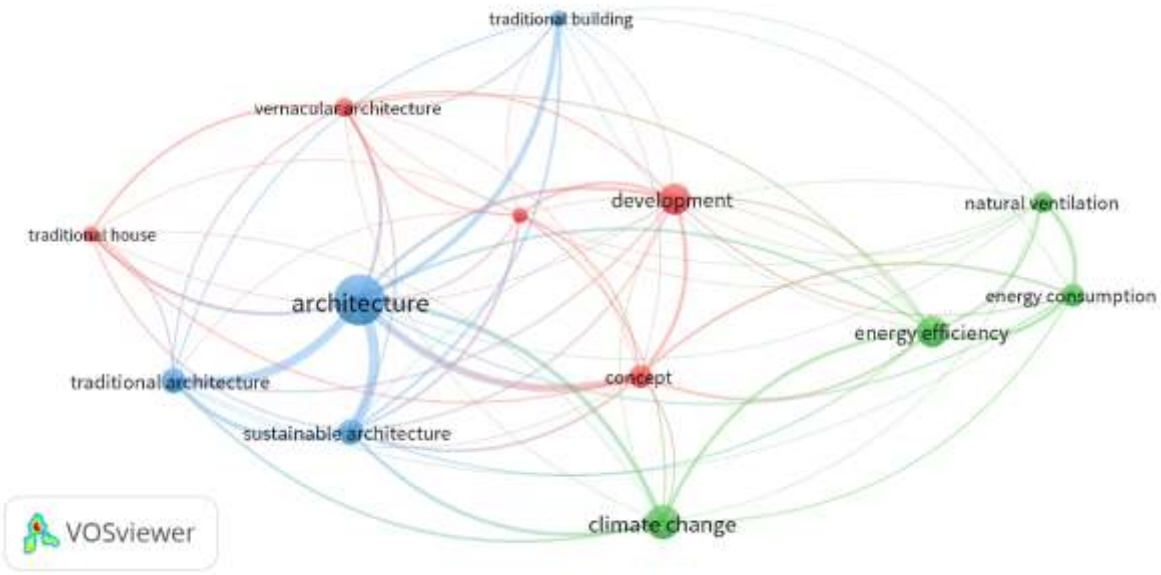

Figure 1. Results of Bibliometric Analysis – Network Visualization.

4.1.1 Blue Cluster: Focus on Traditional Architecture and Sustainability.

- Main Node: Architecture
- Other Keywords: Traditional Architecture, Traditional Building, Sustainable Architecture
- Explanation: The blue cluster highlights the main theme of traditional architecture and its application to sustainability concepts. The largest node is “architecture,” indicating that this is a central theme in all connected studies. Traditional architecture and traditional building show that traditional buildings have many advantages in sustainability because they are often built with local environmental conditions, local materials, and climate in mind.

Relationship with Sustainability: The keyword “sustainable architecture” is closely related to traditional architecture, indicating that traditional building methods are often considered as references in sustainable architectural design. This suggests that there are many lessons learned from traditional architecture that can be applied to modern buildings to make them more environmentally friendly.

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4.1.2 Red Cluster: Development of Vernacular Architecture Concept

- Main Node: Development, Vernacular Architecture
- Other Keywords: Traditional House, Concept
- Explanation: The red cluster underlines the theme of vernacular architecture or vernacular architecture related to the development of building concepts that are adapted to local culture and climate. The word "development" as a major node in this cluster indicates that the research here focuses on how vernacular architecture, or locally based architecture, develops in response to modern demands and remains relevant.

Relevance in the Context of Sustainability: Vernacular architecture often employs simple yet energy-efficient designs. By utilizing local materials and construction methods, vernacular architecture is considered more sustainable because it reduces carbon footprint and material transportation costs. The “concept” node indicates that concepts from vernacular architecture are still considered applicable in the context of modern architecture.

4.1.3 Green Cluster: Energy Efficiency and Adaptation to Climate Change

- Main Node: Energy Efficiency, Climate Change
- Other Keywords: Energy Consumption, Natural Ventilation
- Explanation: The green cluster focuses on the themes of energy efficiency and climate change adaptation. The nodes “energy efficiency” and “climate change” are prominent in this cluster, indicating that much of the research related to energy efficiency in architecture focuses on reducing environmental impacts and mitigating climate change.

Strategies for Energy Efficiency: The keywords “natural ventilation” and “energy consumption” indicate that natural ventilation and energy consumption are important aspects in this discussion. By utilizing natural ventilation, buildings can reduce their reliance on HVAC (Heating, Ventilation, and Air Conditioning) systems, thereby saving energy and lowering carbon emissions. This is especially relevant in the context of climate change, where buildings must be designed to reduce energy consumption as much as possible.

4.1.4 Inter-Cluster Interactions and Thematic Relationships

- Node "Architecture" as Main Center: The “architecture” node in the middle of the network is the main hub connecting the blue, red, and green clusters. This shows that all themes—whether traditional architecture, the development of vernacular architectural concepts, or energy efficiency—are closely related around architecture as the core field of study. In other words, although each cluster has a distinct focus, they are all situated within the context of architecture and influence one another.
- Integration of Sustainability Themes in Architecture: The relationship between “sustainable architecture” in the blue cluster and “climate change” in the green cluster shows that there is an effort to integrate sustainability into architecture in response to climate change. This indicates that much of the current research focuses not only on aesthetically pleasing designs, but also on how they can be sustainable and have a positive environmental impact.
- Relationship of Development to Vernacular Concepts: The keyword “development” connected to “vernacular architecture” suggests that the concept of locally based architecture continues to develop and adapt in a modern context. This illustrates the

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attention to how traditional architectural designs can be applied or adapted to modern buildings, making them more relevant to today's sustainability demands.

4.1.5 Key Conclusions

From the results of this visualization analysis, it can be concluded that research in sustainable architecture covers several main themes:

- Traditional Architecture as a Model of Sustainability: Traditional buildings often serve as inspiration in creating environmentally friendly buildings.
- Vernacular Architecture as a Local Solution: Local or vernacular-based architecture, which takes into account culture and climate conditions, remains relevant in the development of modern architectural concepts.
- Energy Efficiency in the Face of Climate Change: Much research focuses on strategies to improve energy efficiency to reduce environmental impacts, such as maximizing natural ventilation and reducing energy consumption.

These results show a clear direction that sustainable architecture is not only about efficient design, but also about adapting to climate change and utilizing principles already applied in traditional and vernacular architecture.

4.2 Results of Bibliometric Analysis – Overlay Visualization.

This visualization is an overlay of a bibliometric analysis showing keyword trends in research on sustainable architecture from 2021 to 2023. The colors in this figure indicate the average year each keyword appeared in the research, ranging from blue (earlier years, around 2021) to yellow (newer years, around 2023).

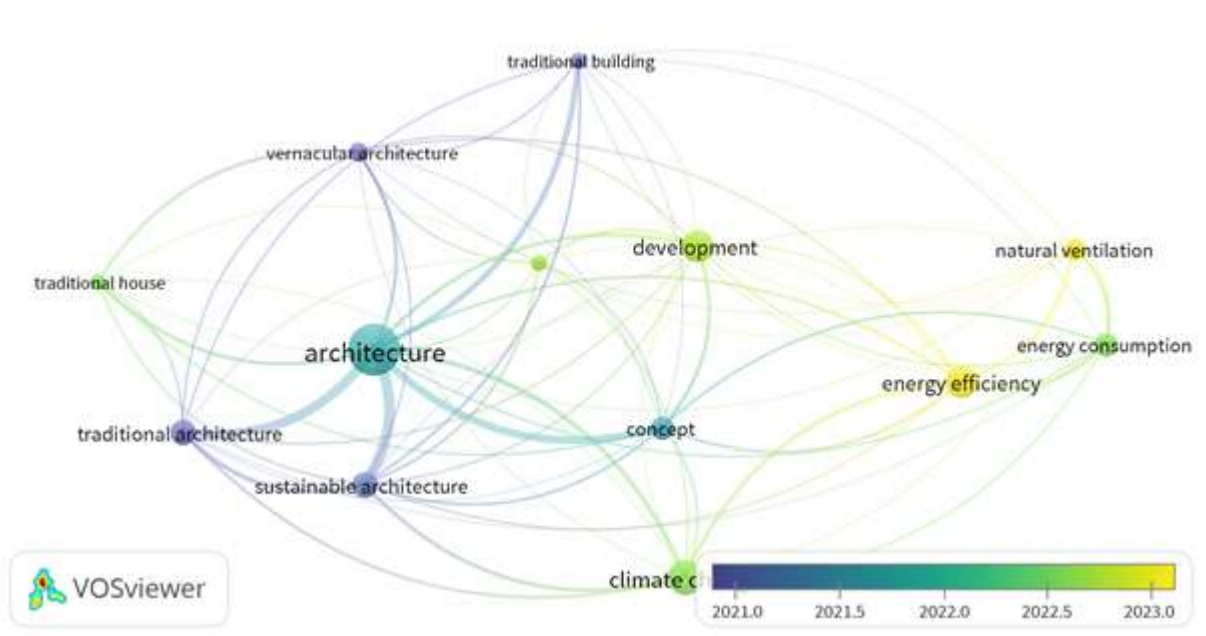

Figure 2. Results of Bibliometric Analysis – Overlay Visualization.

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4.2.1 Clusters and Keywords Based on Color

- **Blue to Purple (2021 - 2022):**
  - Keywords in blue to purple, such as architecture, traditional architecture, and traditional building, indicate that this theme has emerged earlier in the research. This shows that architecture and concepts related to traditional architecture are the basis or initial focus in discussions related to sustainable architecture.
  - Keywords such as traditional house and sustainable architecture are also in this color zone, indicating that concepts of sustainability in traditional architecture have been a topic of interest since the beginning of the research.
- **Green (2022 - 2022.5):**
  - Keywords such as development, vernacular architecture, and climate change are in the green range. This shows that these topics are increasingly being discussed around 2022. Development and climate change emerged as a response to the need to develop architectural concepts that are able to face the challenges of climate change.
  - Concept is also in this cluster, suggesting that concepts related to sustainable architectural development began to receive greater attention during this period.
- **Yellow (2022.5 - 2023):**
  - Yellow keywords such as energy efficiency, energy consumption, and natural ventilation are newer topics in the research, especially from 2022 to 2023. This indicates an increased focus on energy efficiency in buildings to reduce energy consumption and environmental impact. This trend is likely driven by an increased awareness of the importance of energy efficiency in more sustainable architectural design.

4.2.2 Cluster Analysis

- **Traditional Architecture Cluster (Blue-Purple)**
  - Key words: architecture, traditional architecture, traditional building, sustainable architecture
  - This cluster focuses on the theme of architecture that uses traditional principles in the context of sustainability. With the keywords that appear earlier, this cluster shows that traditional architecture has long been an important topic in sustainability research because of its ability to adapt to the environment and use local materials.
- **Concept Development and Climate Change Cluster (Green)**
  - Key words: development, vernacular architecture, climate change, concept
  - This cluster highlights efforts to develop a vernacular architectural concept that is adaptive to climate change. The development and concept positions show that there is a push to develop a sustainable architectural concept that takes local wisdom into account.
  - The presence of the keyword climate change emphasizes the importance of climate change adaptation in modern architectural design. This indicates that more and more research is paying attention to how architectural design can reduce environmental impacts.
- **Energy Efficiency and Natural Ventilation Cluster (Yellow)**
  - Key words: energy efficiency, energy consumption, natural ventilation

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- This cluster is one of the latest trends in research, where the focus is shifting to the technical aspects of energy efficiency in buildings. Natural ventilation, as one of the methods to reduce energy consumption in modern buildings, is becoming a major concern. This demonstrates that attention to sustainable architecture extends beyond the conceptual level to practical implementation, which has a direct impact on building energy consumption.

- **Key Conclusions from Visualization**
  - The Evolution from Traditional Architecture to Energy Efficiency: From this visualization, it can be seen that research initially focused on traditional architecture and its sustainability, then evolved towards developing architectural concepts that are responsive to climate change. Finally, recent research has focused heavily on technical aspects, such as energy efficiency and energy consumption management.
  - Shifting Focus in Sustainability Context: The yellow color of energy efficiency and natural ventilation signifies the growing trend to reduce energy consumption in modern buildings. This indicates that research is increasingly prioritizing energy-efficient building design as a primary means of achieving sustainability in architecture.
  - Integration of Vernacular Architecture Concept: The existence of vernacular architecture as part of a green cluster shows an interest in developing local architectural concepts as sustainable solutions. This suggests that local wisdom from traditional architecture is considered a crucial element in creating more environmentally friendly buildings.

  Thus, this visualization helps us understand that research in the field of sustainable architecture has evolved from understanding and exploring traditional architecture, to a focus on developing concepts that are responsive to climate change, to the technical aspects of reducing energy consumption in modern buildings.

4.3 Results of Bibliometric Analysis – Density Visualization.

This image is a density map visualization of the results of bibliometric analysis using VOSviewer. This density map illustrates the distribution of terms or keywords that frequently appear in related literature. The brighter the color of the area (yellow or bright green), the higher the frequency density of the keyword occurrence, indicating that the keyword is often discussed or has a significant influence in this research field.

PROCEEDINGS OF THE INTERNATIONAL CONFERENCE OF GRADUATE SCHOOL ON SUSTAINABILITY (ICGSS)

9th International Conference on Sustainability (ICoS9)
University of Merdeka Malang, November 9th, 2024
https://jurnal.unmer.ac.id/index.php/icgss

E-ISSN:
2721-13988

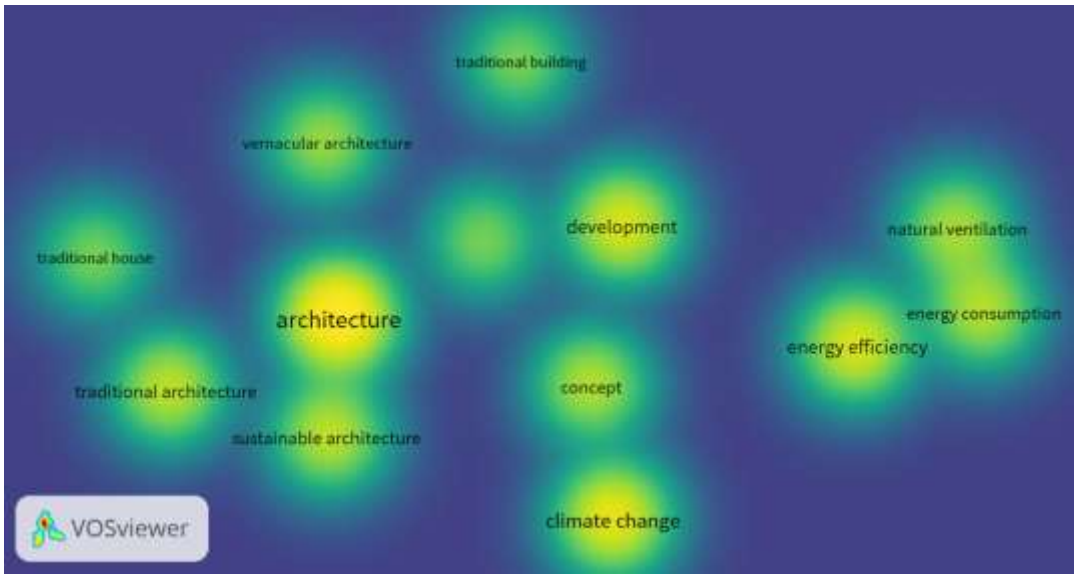

Figure 3. Results of Bibliometric Analysis – Density Visualization.

4.4 Detailed Explanation Based on Density Map

4.4.1. High-DensityDensity Primary Keywords

- **Architecture**: Located in the center of the map with a very bright color, indicating that this term is most often discussed in the literature. This indicates that the concept of architecture is the core or basis of this research, becoming the central focus of the discussion on sustainability.
- **Energy Efficiency and Climate Change**: This keyword also has a fairly high density, which means that there are many studies that relate architecture to energy efficiency and climate change. This suggests a significant interest in the technical aspects of energy efficiency and climate change adaptation as part of sustainable architecture.
- **Development**: This word also has a high density, indicating that many studies discuss how the concept of development relates to sustainable architecture. This can include innovations or adaptations in building design for sustainability.

4.4.2. Medium to High Density Keywords

- **Vernacular Architecture and Traditional Building**: These words are in bright green, indicating that there is a lot of research that addresses vernacular architecture and traditional buildings in the context of sustainability. This indicates an interest in how traditional architecture can provide insights or solutions for more environmentally friendly building design.
- **Energy Consumption and Natural Ventilation**: Both of these terms are located in the bright green area, indicating a significant focus in the research. There is considerable attention on how energy consumption in buildings can be minimized, and how natural ventilation can support this goal.

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4.4.3. Lower Density Keywords

- **Traditional Architecture, Traditional House, and Sustainable Architecture**: These words are in the bluish green area, indicating that although they are included in the discussion, their intensity or frequency is lower compared to the main keywords. This indicates that there is a steady but less intense focus on how traditional architecture and sustainable architecture concepts are used as approaches that support sustainability goals.

4.4.4. Key Conclusions from Density Map

- **Research Focus on Energy Efficiency and Climate Change**: The light on energy efficiency and climate change shows that these topics are top priorities in recent research. This indicates that sustainable architectural design is now more focused on reducing environmental impacts through energy efficiency and climate change adaptation.
- **The Role of Traditional Architecture as Inspiration**: The density of keywords such as vernacular architecture, traditional building, and traditional house shows that there is an effort to explore local wisdom as inspiration in creating more sustainable buildings.
- **Concept and Development Approach in Sustainable Design**: The density of concepts and developments indicates that discussions related to the development of sustainable design concepts are an important part of this field. There is interest in developing new concepts or improving existing ones to achieve greater efficiency and sustainability.

Overall, this density map illustrates the research focus shifting from a purely exploratory approach to traditional architecture to a more technical focus on aspects and development concepts aimed at enhancing sustainability.

5 Conclusion

The following is a discussion and analysis of the results of the three VOSviewer visualizations that have been provided, from the perspective of an experienced academic and researcher in architecture who focuses on sustainability issues:

5.1. Network Visualization

In this network visualization, there is a strong connection between several key terms, including "architecture," "energy efficiency," "climate change," "vernacular architecture," and "traditional building." The term "architecture" appears as the core of the network, indicating that this topic is a major focus in the reviewed studies. From the perspective of sustainable architecture research, this connectivity suggests that researchers are examining how architectural concepts can be integrated with sustainability efforts, particularly in relation to energy efficiency and climate change mitigation.

On the other hand, the strong association between “vernacular architecture” and “traditional building” suggests an interest in more traditional approaches to building design as an inspiration for sustainability. These studies likely demonstrate how traditional architecture, utilizing local materials and techniques, can minimize environmental impact. This connection reflects an

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important perspective in modern architectural research, namely, how traditional principles can be adapted to meet today's sustainability demands.

5.2. Overlay Visualization

The overlay visualization provides insight into the temporal evolution of the terms used in the research. Based on the color gradients in this visualization, it is evident that several concepts have emerged and gained more attention in the 2022-2023 period, including "energy efficiency," "natural ventilation," and "energy consumption." This suggests a shift in research focus from simply exploring the basic concepts of sustainable architecture to a more technical approach, with the primary goal of optimizing energy efficiency in buildings.

Keywords such as "climate change" and "energy efficiency," which are on the lighter side of this overlay, indicate topics that remain relevant and have been discussed in recent years. This reflects a response to the growing urgency of the global climate crisis, where architecture plays a crucial role in reducing carbon emissions and enhancing energy efficiency. From the perspective of a journal editor, this trend highlights the need for more empirical research that examines the practical implementation of energy-saving technologies in various types of buildings, including both traditional and modern structures.

5.3. Density Visualization

The density map visualization shows a denser area of research concentration, with the term "architecture" emerging as the main center, marked by the brightest color, indicating that this term is discussed most frequently in the literature. This confirms that architecture is the foundation of this research, both in theory and in practice, in the context of sustainability. Around "architecture," other terms such as "climate change," "energy efficiency," "development," and "vernacular architecture," are seen to have a relatively high density. This reflects the focus on the interaction between architectural design and global environmental issues, with energy and climate change as the main challenges facing the architecture industry.

In sustainable architecture research, this approach is significant because it highlights two main approaches: the adaptation of traditional concepts that have proven efficient in utilizing local resources, and the application of modern technologies to optimize energy efficiency. From a theoretical development perspective, the results of this density map demonstrate the potential to develop a framework that combines these two approaches, thereby producing architectural solutions that are not only energy-efficient but also consider local values and long-term sustainability.

5.4. General Conclusion

These three visualizations present a fairly holistic research landscape, where the focus of sustainable architecture research is divided between the application of traditional architectural principles and the use of modern technologies for energy efficiency. As the urgency of climate change increases, research is showing an increase in more detailed technical approaches, such as energy efficiency and natural ventilation, indicating that the field of architecture is not only focused on aesthetics and comfort, but also on environmental impact and long-term sustainability.

As an academic and editor, these results underscore the need to enhance cross-disciplinary collaboration among architects, energy engineers, and environmental experts. It also presents an opportunity for research publications that examine the implementation of sustainability

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technologies in local contexts, which can help enrich the literature with case studies from diverse countries and cultures.

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