

# Sustainable and Green Architecture Industrial Technology: Challenges and Future Directions

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**Abstract**—Sustainable design plays a pivotal role in addressing environmental and social concerns within the field of architecture. This concept involves the integration of sustainability principles throughout the architectural design process, encompassing social sustainability, sustainable materials and construction methods, and sustainability assessment. Architects can create structures that demonstrate environmental consciousness, optimize resource use, promote social inclusivity, and preserve cultural significance by incorporating these fundamental principles. However, the successful implementation of sustainable architecture faces several challenges. These challenges include limited awareness among professionals, resistance to change in the industry, complexities in integrating sustainability, and budget constraints. Overcoming these hurdles necessitates comprehensive education, government support, adherence to regulations, technology utilization, and economic incentives to encourage the adoption of sustainable design techniques. Despite these challenges, the field of sustainable architecture holds significant potential for further advancement. Opportunities for exploration include integrating emerging technologies like artificial intelligence and machine learning, applying sustainable architectural principles in urban planning, advancing sustainable materials and construction methods, considering social sustainability, and developing comprehensive frameworks for holistic sustainability assessment. By advancing knowledge and innovation in these areas, sustainable architecture can contribute substantially to creating a more sustainable built environment. Architectural professionals, through collaboration, interdisciplinary approaches, and a commitment to long-term sustainability, have the potential to play a crucial role in shaping a sustainable future for urban areas and communities.

**Keywords**—environmental consciousness, interdisciplinary collaboration, social inclusivity, sustainable architecture, urban planning.

## I. INTRODUCTION

### A. Definition of sustainable architecture

Sustainable architecture refers to a design methodology that emphasizes the utilization of renewable energy sources, environmental consciousness, efficient management of energy, water, materials, and space, as well as the safeguarding of occupants' health and comfort throughout a

building's lifespan [1]. The objective is to establish constructions and implement procedures that demonstrate environmental responsibility and resource efficiency [2]. According to [3], sustainable architecture encompasses not only ecological considerations but also incorporates economic and social dimensions of sustainability.

Waterfront usage is shown in Fig. 1, for instance. Hence, it was imperative to capitalize on the advantages associated with using waterfront areas. Several students in this study [1] proposed several ideas involving different types of pedestrian pathways, seating installations, observation areas, and waterfront spaces. These interventions aimed to seamlessly incorporate these elements into the neighborhood, contributing to social sustainability in multiple ways. In addition, certain students have put forth alternative routes or centralized locations for other modes of transportation, such as harbors or cycling stations. This would facilitate an expansion in the user base of the website, so rendering it advantageous for addressing social sustainability concerns.



Fig. 1. Waterfront design concept for green architecture

The objectives of sustainable design encompass several aspects, such as energy efficiency, land preservation, water management, material conservation, and environmental safeguarding [2]. The primary objective of this approach is to prioritize energy and ecological conservation within the

design of the built environment, ultimately leading to a reduction in overall well-being or the potential depletion of resources for alternative purposes over an extended period [4]. The early stages of the architectural design process are also taken into consideration in sustainable architecture, with a focus on integrating sustainability concepts [5].

In addition to the ecological factors, sustainable architecture also incorporates the social and economic dimensions. The objective is to construct structures that facilitate a pleasant residential environment, promote educational advancement, generate employment prospects, enrich local communities, and safeguard public health [3]. The successful implementation of sustainable design necessitates the incorporation of methods that encompass these principles, accompanied by a meticulous evaluation procedure [5].

The scope of sustainable architecture extends beyond any one geographical area or cultural setting. The architectural designs that prioritize sustainability are influenced by various factors such as climatic circumstances, cultures, and traditions [6]. The proposed solution facilitates the development of organic habitats and the design of environmentally adaptive architecture [7].

In its entirety, sustainable architecture encompasses a comprehensive methodology that takes into account the ecological, financial, and societal dimensions of sustainability. The primary objective of this approach is to develop structures and implement procedures that demonstrate environmental responsibility, optimize resource utilization, and emphasize the welfare of inhabitants throughout a building's entire lifespan.

#### *B. Importance of sustainable architecture in addressing environmental and social challenges*

The incorporation of sustainable architecture is of paramount importance in effectively addressing both environmental and social concerns. Social sustainability is a crucial aspect in the attainment of sustainable design, as highlighted by Ref. [8]. The concept of social sustainability centers around the development of constructed surroundings that foster the enhancement of individuals' welfare, and fairness, and the establishment of harmonious social relationships [8]. The incorporation of social issues into architectural design has the potential to enhance communities and enhance the well-being of individuals [8].

In conjunction with the pursuit of social sustainability, sustainable architecture also includes the mitigation of environmental concerns. The objective of this approach is to mitigate the adverse environmental effects of buildings by the integration of energy-efficient design solutions, utilization of renewable materials, and reduction of resource consumption [9]. According to Ref. [9], sustainable architecture advocates for the utilization of renewable energy sources, such as solar and wind power, to mitigate greenhouse gas emissions and address the challenges posed by climate change. Furthermore, it underscores the importance of optimizing water utilization and safeguarding natural resources.

In addition, it should be noted that sustainable architecture plays a crucial role in facilitating the shift towards a more sustainable built environment, as highlighted by Ref. [9]. The study acknowledges the extended durations and entrenched impacts of current infrastructures and aims to enhance design

and governance methodologies to foster the development of environmentally sustainable buildings and cities.

#### *C. Purpose of the paper: to provide guidelines for architects to incorporate sustainability principles in building design*

The objective of this article is to furnish architects with complete guidelines about the integration of sustainability concepts within the realm of building design. The paper endeavors to provide architects with the necessary knowledge and tools to design environmentally responsible buildings by utilizing a variety of authoritative references. The cited sources encompass a range of topics within the field of sustainable architecture, including life cycle assessment, eco-labeling, passive solar design, and green building methods. Through the process of synthesizing many resources, this study provides practical guidance about energy-efficient design techniques, the utilization of renewable materials, and the mitigation of resource consumption. The primary objective of this article is to enable architects to have a central role in tackling environmental issues and advancing sustainable development through their design choices.

## II. GUIDELINES FOR SUSTAINABLE ARCHITECTURE

### *A. Introduction, implementation, and evaluation of sustainability principles in different phases of architectural design*

The incorporation, execution, and assessment of sustainability concepts throughout all stages of architectural design are crucial in the development of environmentally conscious and resource-efficient structures. Incorporating sustainability principles commences by imparting architecture students with a broad theoretical understanding of sustainability and the multifaceted elements of sustainable design [10]. This entails the integration of professional design tools and transdisciplinary workshops or seminars facilitated by green building consultants to enhance students' proficiency in implementing sustainable design solutions.

Incorporating sustainability concepts within architectural design necessitates carefully considering multiple facets at each stage of the design process. Ref. [5] propose the establishment of guidelines to effectively address resource efficiency, waste management, optimization of indoor environment quality parameters, and pro-environmental education. Furthermore, the incorporation of the notion of adaptive reuse within the design framework can serve to facilitate the preservation and sustainable utilization of natural resources [11]. The incorporation of sustainability principles also encompasses the utilization of inner space elements, which takes into account a comprehensive and interconnected design framework to attain a modern and environmentally conscious interior design [12].

According to Ref. [5], the examination of sustainability principles in architectural design can be accomplished by employing project-based learning methodologies and evaluating the adherence to sustainability criteria. According to Ref. [13]. The assessment procedure might encompass quantifying the influence of pedagogy on students' capacity to incorporate sustainable design principles into their projects. Assessment of teaching methods' efficiency and the degree of sustainable aspects integration can be conducted through several means, such as student feedback, course evaluations, questionnaires, and colloquiums.

To foster ecologically sustainable practices, it is crucial to incorporate sustainability concepts into many stages of architectural design, including the introduction, implementation, and evaluation phases.

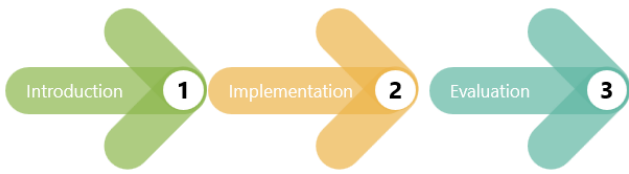


Fig. 2. Phases to adverse environmental effect

According to Fig. 2, it can be seen that by integrating these concepts, architects can make valuable contributions towards the development of resource-efficient structures that foster well-being and mitigate adverse environmental effects. The incorporation of sustainability ideas within architecture education and design practices is of paramount importance in constructing a built environment that is more sustainable.

### B. Consideration of social sustainability in the decision-making process

Including social sustainability in the decision-making process is an imperative element of sustainable design. The concept of social sustainability centers around the development of constructed surroundings that foster the enhancement of individuals' welfare fairness and the establishment of harmonious social relationships [8]. The inclusion of social sustainability principles within the decision-making process necessitates a thorough comprehension of the social aspects of architecture and the seamless integration of these factors across the various design stages.

The incorporation of sustainability into the architectural design process is crucial to ensure that building solutions make a positive contribution to sustainable development [5]. Modifying architectural pedagogy to prioritize the three fundamental aspects of sustainability, namely economic, social, and environmental issues, has been identified as a key area of focus. By incorporating social sustainability principles into their decision-making process, architects can enhance the quality of life for both current and future generations.

The incorporation of social sustainability into architectural design necessitates the consideration of multiple elements. The promotion of inclusion and accessibility in the design of spaces is crucial to suit the different demands and abilities of users [1]. Additionally, this process entails the establishment of environments that cultivate social interaction, community involvement, and a feeling of inclusion [14]. The integration of historical and cultural preservation into the design process is crucial for the maintenance of social links and collective memory.

The assessment of social sustainability in architectural design can be accomplished using a range of methodologies. This may involve evaluating the effects of design choices on the welfare of society, the involvement of the community, and the advancement of social fairness [8]. The input of users and stakeholders can yield useful insights regarding the efficacy of the design in achieving social sustainability objectives [15]. Furthermore, the utilization of post-occupancy evaluations can serve the purpose of identifying potential

areas of enhancement and providing valuable insights for informing subsequent design choices [16].

In summary, the incorporation of social sustainability within the decision-making framework is crucial in the pursuit of establishing sustainable architecture. Architects have the potential to create buildings that foster well-being, inclusion, and social cohesion by incorporating concepts of social sustainability. This entails altering architectural education, integrating social sustainability considerations across the many phases of design, and assessing the influence of design choices on social outcomes. Architects have the potential to enhance the quality of life for individuals and communities by emphasizing social sustainability in the design and construction of built environments.

### C. Examination of vernacular architecture and its contribution to sustainability

Vernacular architecture encompasses the customary construction methods that have developed organically by regional climate conditions, cultural influences, and the availability of local resources. The artifact encapsulates the accumulated wisdom and expertise passed down over multiple generations, integrating enduring sustainable design principles that have proven their efficacy over time. This essay investigates vernacular architecture and its noteworthy contribution to the concept of sustainability. Through a comprehensive analysis of multiple studies and research endeavors, this investigation aims to elucidate the sustainable attributes and methodologies utilized in vernacular architecture while emphasizing their pertinence in present-day sustainable design approaches.

Climate-responsive design refers to the practice of designing buildings and structures that take into account the local climate conditions and aim to optimize energy efficiency and occupant comfort. Vernacular architecture exemplifies a profound comprehension of regional climatic variables and employs design solutions that effectively address them [17]. According to Ref. [18], empirical research has demonstrated that vernacular buildings possess a remarkable capacity to successfully accommodate and respond to severe environmental circumstances, thereby serving as exemplars for the development of sustainable design methodologies.

Vernacular architecture enhances energy efficiency and lowers dependence on mechanical systems through the integration of passive design strategies, including orientation, shading, natural ventilation, and thermal mass [19]. Fig. 3 shows that utilizing a climate-responsive design strategy effectively reduces energy consumption and enhances the overall sustainability of the constructed environment.

The utilization of vernacular architecture is predicated upon the utilization of materials that are readily accessible within the local vicinity, mitigating the necessity for long-distance transportation and subsequently limiting the environmental impact associated with construction activities [20]. According to Ref. [21], the utilization of natural and renewable resources, such as timber, earth, stone, and thatch, mitigates environmental consequences, fosters local economies, and safeguards cultural heritage. Moreover, vernacular architecture frequently integrates customary construction procedures that necessitate lower energy consumption and resource utilization in contrast to contemporary construction approaches [22].

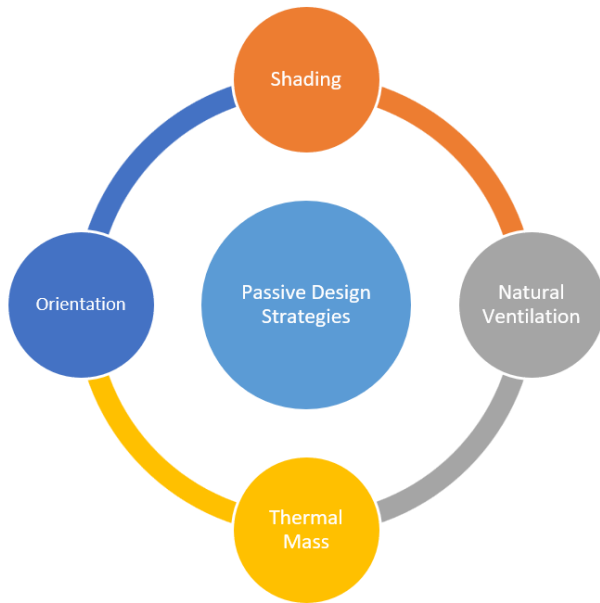


Fig. 3. Passive Design Strategies [19]

Prioritizing local materials and resources enhances sustainability by reducing embodied energy and promoting a circular economy. Vernacular architecture exhibits a profound connection to communities' social and cultural framework. According to Ref. [23], the local population's ideals, traditions, and lifestyles are reflected in it. The architectural composition of vernacular structures frequently emphasizes fostering social cohesion, promoting community participation, and cultivating a distinct feeling of place. Vernacular architecture has a significant role in enhancing communities' well-being and social sustainability by establishing environments that facilitate social interaction and develop a sense of belonging. In addition, vernacular architecture plays a significant role in the conservation of cultural heritage and the maintenance of local identity, both of which are integral aspects of sustainable development [24].

According to Philokyprou et al., vernacular architecture has a notable level of adaptation and resilience in response to fluctuations in external conditions [25], the utilization of design ideas and construction techniques in vernacular buildings facilitates adaptability and the ability to undergo modifications during their lifespan. The inherent adaptability of structures enables them to effectively address changing demands and obstacles, hence decreasing the necessity for demolition and subsequent reconstruction. Vernacular architecture, with its adherence to the principles of flexibility and resilience, fosters long-term sustainability and mitigates waste within the constructed environment.

The analysis of vernacular architecture elucidates its noteworthy impact on sustainability. Vernacular architecture provides useful insights for contemporary sustainable design methods by including climate-responsive design, utilizing local materials and resources, promoting social and cultural sustainability, and emphasizing adaptability. By integrating the wisdom and knowledge inherent in vernacular architecture, architects, and designers have the potential to develop buildings that exhibit not only environmental responsibility but also social and cultural sustainability. The examination and admiration of vernacular architecture have the potential to stimulate inventive approaches that

effectively tackle the urgent sustainability issues inside the constructed surroundings.

#### D. Architectural professionals' needs and preferences for sustainable building guidelines

Incorporating sustainable building norms is crucial in fostering sustainable architectural practices since it caters to the demands and preferences of architectural professionals. To include sustainability concepts in the decision-making process, it is important to comprehend the distinct requirements and preferences of architectural experts. Numerous research has been conducted to investigate these demands and preferences, providing valuable insights into the essential factors to be considered in developing sustainable building guidelines.

The integration of sustainability concepts in the early stages of the design process is a key priority for architectural professionals [5]. This entails evaluating preventative and passive approaches in contrast to active techniques, with a focus on enhancing energy efficiency and diminishing dependence on mechanical systems. Architectural experts widely acknowledge the significance of decisions made during the design phase for a structure's long-term sustainability and performance.

According to Ref. [26], architectural professionals have increasingly favored the adoption of Building Information Modeling (BIM) and virtual reality technology for sustainable design. These technologies facilitate the evaluation of sustainability aspects, such as life cycle assessment and cost analysis, in a more thorough and streamlined manner for architects. Building Information Modeling (BIM) enables the seamless incorporation of sustainability factors across the many stages of design and construction, hence enhancing the quality of decision-making and fostering effective collaboration among the different parties involved in a project [27].

The significance of social and cultural sustainability in building design is also emphasized by architectural experts [28]. The individuals acknowledge the necessity of establishing environments that foster inclusiveness, encourage active participation within the community, and prioritize the overall welfare of individuals. This includes examining infection prevention and control measures within public buildings, safeguarding cultural assets, and maintaining local identity. Architectural practitioners understand that sustainable architecture extends beyond just environmental considerations and embraces a broader scope that includes social and cultural components.

In addition, it is worth noting that architectural experts have a predilection for sustainable design approaches that employ indigenous resources, foster circularity, and provide cost-effective housing alternatives [29]. The individuals acknowledge the significance of mitigating the environmental consequences associated with construction activities by employing renewable and biobased products. Architectural experts place significant importance on the affordability and reproducibility of sustainable housing solutions.

In summary, the requirements and inclinations of architectural professionals regarding sustainable building guidelines encompass a range of factors. These factors include the early incorporation of sustainability principles, the adoption of Building Information Modeling (BIM) and virtual reality technologies, considerations for social and

cultural sustainability, and the utilization of local materials and affordable housing solutions. Through a comprehensive awareness and deliberate consideration of these aforementioned needs, the promotion of sustainable architecture can be successfully achieved, resulting in the development of structures that exhibit a high degree of environmental conscientiousness, social inclusivity, and cultural significance.

### III. IV. CHALLENGES AND FUTURE DIRECTIONS

#### A. *Obstacles in the implementation of sustainable architecture*

The presence of many challenges during the implementation phase of sustainable architecture can impede the extensive integration of sustainable design techniques. A notable challenge that architecture professionals face is the limited awareness and comprehension of sustainable design principles [1],[30]. Many professionals may have not been sufficiently educated or trained in sustainable architecture, resulting in a restricted comprehension of the advantages and methodologies linked to sustainable design.

One further challenge that hinders progress within the architectural sector is the prevailing reluctance to embrace change. The integration of sustainable design concepts may face resistance from traditional design processes and established standards due to the need for a fundamental change in thinking and approach [31]. Furthermore, a dearth of incentives or regulatory frameworks may exist, which may hinder the adoption of sustainable design methods by architectural experts, hence posing a challenge in prioritizing sustainability within their projects [32].

The issues associated with sustainable architecture are often attributed to its intricate and multidisciplinary nature. Implementing sustainable design necessitates a comprehensive methodology that considers many issues, including but not limited to energy efficiency, materials selection, and social impact. The challenge of architectural experts to integrate these concerns and balance opposing demands can be intricate [33]. In addition, the absence of universally accepted protocols and resources for sustainable design poses challenges for practitioners in effectively adopting and incorporating sustainable principles. The challenges in sustainable architecture and its recommendations are served in Table 1.

As described in Table 1, the adoption of sustainable architecture can be significantly impeded by financial limitations. According to Ref. [32], implementing sustainable design methods and technology may involve more initial expenses, which can discourage clients and developers from allocating resources to sustainable projects. Adopting sustainable design approaches may be impeded by the perceived greater costs and uncertainties surrounding the return on investment.

In summary, the challenges encountered throughout the execution of sustainable architecture encompass a dearth of knowledge and comprehension, opposition to alteration, intricacy, and multidisciplinary aspects of sustainable design, as well as economic limitations. To surmount these challenges, it is important to possess a comprehensive education and training, receive regulatory assistance, establish standardized rules and tools, and foster a transformative shift in the mindset prevalent within the architectural sector.

TABLE 1  
CHALLENGES IN SUSTAINABLE ARCHITECTURE

Challenges in Implementation	Recommendations for Overcoming Challenges
Limited awareness and comprehension among professionals	<ul style="list-style-type: none"> <li>- Comprehensive education and training programs</li> <li>- Promoting awareness through public campaigns</li> <li>- Incentivizing sustainability through governmental support and economic incentives</li> </ul>
Reluctance to embrace change	<ul style="list-style-type: none"> <li>- Foster a transformative shift in mindset</li> <li>- Demonstrate economic benefits through cost-benefit analyses</li> <li>- Establish regulatory frameworks and incentives to encourage adoption</li> </ul>
Complexity and multidisciplinary nature of sustainable design	<ul style="list-style-type: none"> <li>- Utilize interdisciplinary collaboration</li> <li>- Develop standardized rules and tools</li> <li>- Balance conflicting demands through thorough research and informed decision-making</li> </ul>
Financial limitations	<ul style="list-style-type: none"> <li>- Explore cost-effective sustainable design strategies</li> <li>- Showcase the long-term benefits of sustainable architecture</li> <li>- Offer financial incentives for sustainable projects</li> </ul>

Architectural professionals possess the potential to assume a crucial role in the advancement of sustainable design and the establishment of a built environment that exhibits environmental responsibility and social benefits through the identification and resolution of these difficulties.

#### B. *Potential for further research and development in sustainable architecture*

The realm of sustainable architecture presents extensive prospects for future research and development, presenting many options for progress within the discipline. An area of inquiry that warrants attention is the incorporation of nascent technologies, such as artificial intelligence and machine learning, within the context of sustainable architecture design processes [5]. These technologies possess the capacity to enhance energy efficiency, optimize material choices, and augment buildings' overall sustainability performance.

An additional avenue for investigation may involve examining the implementation of sustainable architecture principles within the framework of urban planning and design [34]. Urban areas encounter distinct sustainability issues, necessitating the use of inventive strategies to foster the development of cities that are both sustainable and conducive to human habitation. Research endeavors could be undertaken to explore various strategies to achieve sustainable urban development. These strategies may encompass the conceptualization and implementation of green spaces, efficient transit systems, and resilient infrastructure.

In addition, it is worth exploring the field of sustainable materials and construction approaches in further research. Investigating alternative materials, such as biobased and recycled materials, has the potential to mitigate the environmental consequences associated with construction activities. Furthermore, the progression of construction techniques, such as the utilization of prefabrication and modular construction, has the potential to augment the efficacy and ecological soundness of the building procedure.

Further research is necessary in the domain of integrating social sustainability within the context of sustainable architecture. It is vital to comprehend the societal ramifications of architectural design and the various manners

in which structures might enhance communal welfare and foster inclusiveness. Research endeavors could be undertaken to investigate various tactics aimed at establishing socially sustainable places, facilitating community involvement, and mitigating social inequities within the realm of architectural design.

Future research endeavors may prioritize the advancement of all-encompassing sustainability evaluation frameworks and methodologies that can effectively evaluate the environmental, social, and economic aspects of buildings [35]. These frameworks offer architects and designers standardized approaches to evaluating and comparing the sustainability of their projects. Furthermore, studies must delve into the life cycle ramifications of buildings, encompassing their operational energy consumption, embodied carbon emissions, and possibilities for adaptive reuse or deconstruction. The future and potential research direction can be seen in Table 2.

TABLE 2

## FUTURE DIRECTIONS IN SUSTAINABLE ARCHITECTURE

Areas for Future Research and Development	Potential Research Directions
Incorporation of nascent technologies in sustainable architecture	Explore applications of artificial intelligence and machine learning in enhancing energy efficiency, material optimization, and overall sustainability performance
Sustainable urban planning strategies	Investigate strategies for sustainable urban development, including green spaces, efficient transit systems, and resilient infrastructure
Advancements in sustainable materials and construction methodologies	Research alternative materials such as biobased and recycled materials; explore construction techniques like prefabrication and modular construction
Integration of social sustainability	Study societal impacts of architectural design; develop tactics for creating socially sustainable places, fostering community involvement, and addressing social inequities
Development of comprehensive sustainability evaluation frameworks	Advance holistic evaluation frameworks to assess environmental, social, and economic aspects of buildings; delve into life cycle analysis to understand operational energy consumption, embodied carbon emissions, and potential for adaptive reuse or deconstruction

In summary, the realm of sustainable architecture exhibits extensive and multifaceted prospects for future investigation and advancement. Potential research areas encompass the amalgamation of nascent technologies, the establishment of sustainable urban planning strategies, the advancement of sustainable materials and building methodologies, the incorporation of social sustainability, and the formulation of complete frameworks for sustainability evaluation. Through the progression of knowledge and innovation in these domains, sustainable architecture has the potential to further develop and make significant contributions towards the establishment of a more sustainable built environment.

## IV. CONCLUSION

In summary, sustainable design is pivotal in effectively resolving environmental and social concerns. The concept involves incorporating sustainability concepts across several stages of architectural design, encompassing the examination of social sustainability, the utilization of sustainable materials and building methods, and the assessment of sustainability outcomes. By integrating these fundamental concepts, architects can conceive and construct edifices that exhibit

environmental consciousness, optimize resource utilization, foster social inclusivity, and uphold cultural significance. Nevertheless, the successful execution of sustainable architecture encounters numerous challenges. The factors contributing to the challenges faced in implementing sustainable practices within the architectural field encompass a limited level of awareness and comprehension among professionals in the discipline, a notable reluctance to change prevalent within the sector, intricacies associated with integrating sustainability considerations, and budgetary limitations. To surmount these challenges, it is imperative to possess a comprehensive education and training, have governmental backing, adhere to established rules, and utilize appropriate technologies, as well as receive economic incentives to foster the adoption of sustainable design techniques.

Notwithstanding these limitations, there is significant potential for further exploration and advancement in sustainable architecture. Potential avenues for further investigation encompass the assimilation of nascent technologies, such as artificial intelligence and machine learning, within the realm of sustainable design methodologies, the utilization of sustainable architectural principles in the domain of urban planning and design, the advancement of sustainable materials and construction methodologies, the incorporation of social sustainability considerations, and the formulation of comprehensive frameworks and tools for assessing sustainability holistically.

Through the progression of knowledge and innovation in these domains, sustainable architecture has the potential to develop further and make significant contributions towards the establishment of a more sustainable built environment. Architectural professionals possess the potential to significantly contribute to developing a more sustainable future for urban areas and communities through their emphasis on collaboration, interdisciplinary methodologies, and dedication to long-term sustainability.

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