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The Role of Nanotechnology in Achieving Sustainable Architecture

Mahdi Aliyari
Department of Architecture, Islamic Azad University, Shabestar Branch, Shabestar, Iran

Abstract
Given the significant growth of the world's population, several serious issues have arisen, including pollution, economic challenges, and environmental problems. To address these environmental issues, many construction experts are actively seeking new flexible techniques. In this context, nanotechnology emerges as a critical field aimed at enhancing the efficiency of the built environment and plays a vital role in addressing prominent future challenges. The nanotechnology revolution has had a positive impact on architecture. The use of nanotechnology is considered one of the most successful modern methods for achieving sustainable buildings with high operational efficiency. This study aims to examine the role of nanotechnology in achieving sustainable architecture through a descriptive-analytical approach. The findings of this research include the advantages of nanotechnology in the construction and improvement of building quality, the enhancement of material quality, energy savings, and consequently sustainable architecture and environmental sustainability. Additionally, it explores strategies for energy conservation in buildings and achieving sustainable architecture using nanomaterials and technology.

Keywords: Sustainable architecture, nanotechnology, nanomaterials, environmental

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Introduction

The environment, with all its components, is a blessing from the Almighty Creator for humanity. It is mankind's responsibility to utilize it wisely and live in the cities they inhabit, without causing damage or corruption. However, with the changing of ecosystems, depletion of natural resources, and environmental pollution, the current global trend demands efforts to restore ecological balance. Therefore, the concepts of sustainability and sustainable development have emerged to meet the needs of the present generation without compromising the ability of future generations to meet their own needs. This requires social participation that is no longer separate from the urgent environmental issues that have attracted global attention in recent decades (Johansen and Princeton, 2002).

The global challenge faced by policymakers and decision-makers is the same challenge that construction specialists encounter. Architects, in particular, play a significant role in making architectural decisions that have a clear impact on the environmental and economic future of communities. Today, various terms dominate the world, including green architecture and environmentally sustainable technological design. While these terms may seem diverse, they collectively strive to achieve a balance between human needs on one side and the preservation of natural resources, reduction of environmental pollution, and mitigation of the risk of depleting non-renewable energy resources on the other.

Sustainability has produced various definitions and concepts; however, the most comprehensive one ensures that our current capacity to meet our needs does not negatively impact the ability of future generations to meet theirs. Consequently, the application of sustainability and sustainable development in architecture has shifted from an academic consideration to a fundamental mission for advanced and major industrial countries in the architectural field.

Our architectural structures' inability to fulfill their role in achieving comprehensive sustainability is evident. The increasing rate of energy consumption in cooling and heating processes in buildings has reached unprecedented levels in recent years. This does not align with the rising rate of energy production in Iran and has exacerbated the energy crisis in recent years.

Therefore, due to a lack of awareness about nanotechnology in construction processes in Iran—driven by building owners' urgent need to reduce initial costs despite rising operational costs—and a lack of understanding in architectural education regarding the importance and role of pre-fabrication processes for buildings, and their potential for significant energy savings in our public and educational buildings, we are compelled to investigate the role of nanotechnology in achieving sustainable architecture. This study aims to identify key principles for achieving comprehensive sustainability, with a special focus on environmental aspects and the impact of nanotechnology on various architectural spaces.

Theoretical Foundations

- **Sustainability: A Pioneer in Environmental Responsibility**

The first environmental conference that called for sustainability was held in the early 1970s. Its recommendations emphasized the importance of conserving and interacting with the environment. Since then, environmental conferences have continued to support sustainability. As global environmental problems worsened, this concept evolved to achieve conservation and sustainability goals. Modern architectural systems now share part of their environmental responsibility (Raafat, 2013).

In the early 1970s, various environmental and economic problems emerged worldwide, including the depletion of energy resources, raw materials, and water sources due to human activities and

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economic processes aimed at improving human living standards. The close relationship between development and the environment became evident, leading to several international conferences that clarified the relationship between development and the environment. The concept of environmental development encompasses various aspects and is not limited to specific fields or sciences. It represents the entire world, both present and future.

Figure (1) Humanitarian needs according to priorities (Ihab Mahmoud Okba, 2006)

- **Sustainable Development: A Dual Approach**

The Concept of Needs: This includes efforts to ensure an adequate standard of living for all individuals. According to Maslow's hierarchy of needs, it ranges from basic needs such as food, water, and clothing to secondary needs that vary based on age, gender, social status, and occupation (Attia MM, 2014).

- **Sustainable Development Goals**

The sustainable development system consists of three fundamental dimensions that represent its main pillars. Any imbalance in these dimensions affects the primary goals of sustainable development (Figure 2). These dimensions are:

- Environment
- Economy
- Society (Figure 2)

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Figure (2) Sustainable Development Goals (Ihab Mahmoud Okba, 2006)

For sustainable development to succeed, these dimensions need continuity and integration due to the close relationship between the environment, economy, and social welfare levels. The concept of sustainability is to maintain the environment in good condition for future generations, without pollution, ecosystem degradation, or resource depletion. This can be achieved through the implementation of various tools to attain sustainable development across its different dimensions (Badran, 2005).

The environmental dimensions of sustainability include achieving environmental sustainability through waste reduction and environmental emissions, minimizing negative impacts on human health, and avoiding the use of toxic materials (Badran, 2005).

- **Principles of Sustainable Architecture**

Sustainable architecture is based on a set of principles aimed at creating and utilizing healthy built environments. These principles rely on resource efficiency and environmental design. They can be clarified through the following elements:

- Resource Reduction - Decrease resource consumption.
- Resource Reuse - Reuse of resources.
- Resource Recycling - Use of recyclable resources.
- Environmental Protection - Protection of nature.
- Toxin Disposal - Proper disposal of toxins and pollutants.
- Economic Life Cycle- Apply full life cycle costing.

These principles are the foundations that must be considered to achieve sustainable architecture. They primarily rely on resource efficiency in energy, water, building materials, and other resources through strategies that emphasize good use, conservation, and waste management for recyclable resources. Additionally, they emphasize care for, protection of, and pollution prevention of the environment by designing buildings that are harmonized with their surroundings, preventing harm to it, and striving to create better indoor environments that provide comfort for occupants (Helwa, 2006).

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- **Strategies for Achieving Energy Efficiency**

Energy efficiency in buildings is achieved through the implementation of an integrated strategy aimed at optimizing energy consumption and use in construction processes. It also includes the use of renewable energy resources, as outlined in the following points:

1) Energy Consumption Optimization:
   - Efficient use of energy in buildings in all forms, such as cooling, heating, and lighting, through environmentally friendly designs that harmonize with the surroundings.
   - Optimal use of passive solar design considering orientation, shape, window placement, and selecting suitable site elements to meet the building's consumption needs.
   - Use of high-efficiency building coverings by selecting appropriate wall, roof, and other materials to achieve insulation, efficiency, and durability requirements.
   - Reducing harmful emissions from non-renewable energy sources (such as oil and coal) (Vale et al., 1997).
2) Use of renewable energy sources:
   - Integrating renewable energy sources into building design, such as daylight for natural lighting, passive solar design, and solar water heating.
   - Using photovoltaic cells to generate electricity from clean solar energy, integrating wind turbines for energy production, and utilizing biomass for energy production in buildings (Figure 3).

Figure (3) Wind power and biomass energy generation turbines (arabiaweather.com)

Nanotechnology

Nanotechnology goes beyond nanoscience, aiming to transform the fundamental knowledge regarding the new properties of materials and goods to enhance existing products or propose entirely new ones (Fouad, 2012).

It is clear that nanotechnology fundamentally deals with the application of knowledge derived from nanoscience. Smart cities are gradually becoming a reality, developing pilot projects in many parts of the world (Amsterdam, Dubai, Helsinki, San Diego, San Francisco, Spain). By mid-century, many of our cities will reach reasonable levels of "intelligence" (Pelin, 2009).

Nanomaterials are not only useful for minor needs such as roofs and facades. They also expand some design possibilities for both sustainable design strategies and architects (Pelin, 2009). Nano building materials are intelligent for achieving energy efficiency and environmental comfort. As shown in Figure 4, we consider the use of nanotechnology in various buildings in the city center.

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Building Type	Urban Services
Entertainment	Stadium/Park
Religious	Islamic Centers
Social	Orphanage
Cultural	Cultural Centers
Management	Governmental
Health	Specialty Hospitals
Educational	Universities
Economic	Shopping Center
Residential	Residential Areas

Figure (4) Some of the main services in the city center that use nanotechnology

This research highlights the goals of nanotechnology, its factors, and case studies for such buildings in the city center, as well as the potential for applying this technology in other buildings on the outskirts of the city.

- **Technology Compatibility Goals**

A. User Welfare and Safety:
- Comfort
- Health
- Safety
- Indoor Environmental Quality
- Quality of Life
- Interaction with the building and other users.

B. Creating Long-Term Value (Pacheco-Torgala and Jalali, 2011):
- Longevity and Sustainability
- Enhanced Image
- Modern Components at Low Cost
- Suitable for various uses and users (residential, commercial, administrative, cultural, etc.) tailored to market needs.
- Cost-effectiveness
- Compatibility with the environment and contributing to it by:
- Maintaining connections with the surrounding environment (other buildings, neighborhoods);
- The harmless and yet positive impact of the building on the environment.
- Energy Efficiency.

C. Functional Efficiency:
- Flexibility, multifunctional and polyfunctional spaces (Nakib, 2010).

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- Efficient physical and virtual communication (Figure 5).

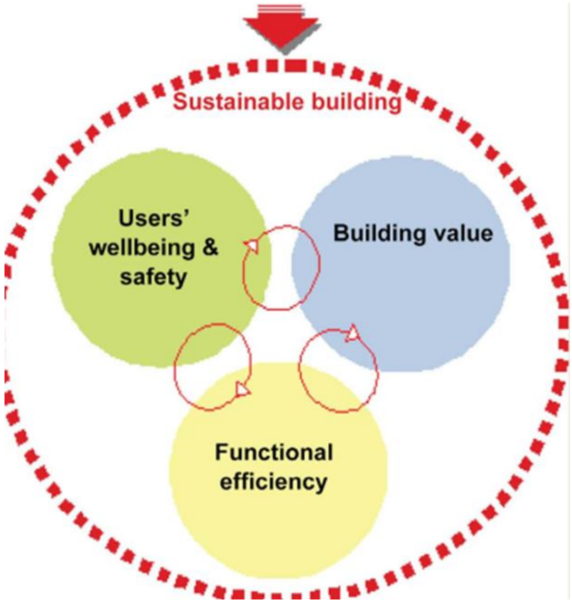

Figure (5) Goals of Technological Compatibility. Source: Fayzeh Nakib, Technological Compatibility, An Approach Towards Flexible and Sustainable Architecture (International Conference on Technology and Sustainability in the Built Environment, Riyadh, 2010)

Nanotechnology and Sustainable Architecture

Some essential principles that must be followed for a building to be considered sustainable design and architecture include: increasing the durability and lifespan of the building, saving energy and materials, avoiding environmental destruction, and protecting natural and building resources, among others. On the other hand, the profession of architecture and the construction industry face a vast array of materials and resources. In fact, materials form the core of the building, and their impact on the environment cannot be overlooked. Among the achievements of nanotechnology in this field are materials that reduce energy consumption and increase the lifespan of structures. Generally, nanotechnology enables effective actions towards the protection of natural resources and the environment by enhancing the efficiency of tools and materials used in various sectors, as well as reducing the consumption of raw materials and energy; all of these factors constitute an effective step towards achieving sustainable design. (TanaZian and Sarbanghali, 2015).

- Nanomaterials

The field of nanotechnology has developed at three different levels: nanomaterials, nano-devices, and nano-systems. Currently, the nanomaterials level is the most advanced among the three, as nanomaterials are significant in scientific research and commercial applications due to their size-dependent physical and chemical properties (Williams, 2007).

With the increasing emphasis on the need to achieve a balance between various demands for improving environmental performance and the aesthetic and trendy aspects of future building materials, ensuring alignment with the functional properties and needs of materials becomes essential.

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Nanotechnology has the ability to transform the fundamental characteristics of materials and address structural challenges, paving the way for the creation of new materials with innovative properties that enhance both efficiency and durability. Thus, the idea of nanoscale design emerged, leading to a revolution in the industry. In fact, nanotechnology involves the combination and bonding of conventional microparticles to produce nanomaterials for various applications. Generally, materials with particle sizes in the range of 1 to 100 nanometers are referred to as nanomaterials.

- **Case Studies**
  - **Residential Buildings**

    Nano-House is a new type of super-efficient home that uses new materials developed through nanotechnology. Hydro-House utilizes natural airflow and seawater to cool and humidify the greenhouse (Figure 6). Seawater evaporates on the greenhouse facades, increasing humidity as air passes into the green house. The smart section is in the structural columns, which also serve as supports for the growing shelves (Omar, 2015). When it rains, fresh rainwater flows down the cylindrical columns from the roof.

Figure (6) Nano houses as a new type of super-efficient energy homes.

  - **Torre De Especialidades, Manuel Gea Gonzalez Hospital**

    Prosolve was chosen by the hospital partly due to its antibacterial and anti-pollution effects, as well as its memorable visual complexity in form, addressing the issue of urban air pollution. According to recent studies on this technology, the facade of the Torre de Especialidades reduces pollution equivalent to that produced by 1000 cars per day (Figure 7).

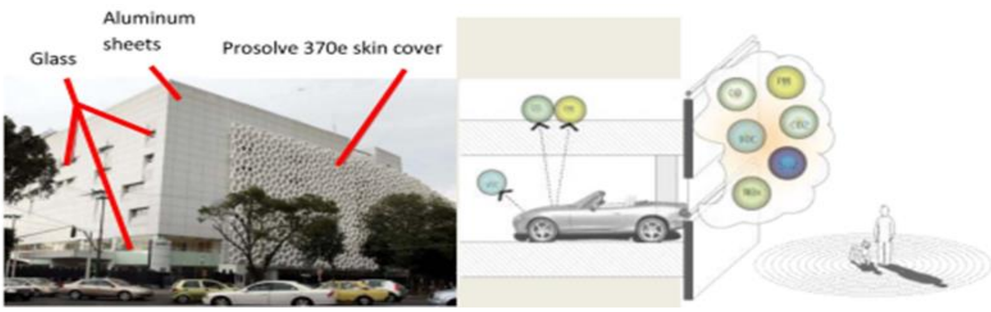

Figure (7) Manuel Gea Gonzalez Hospital using conventional TiO2 (Prosolve370e — beautiful decorations, decorative facades that "eat" pollution - "incredible smog-eating building" - CNN).

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- **Memorial Church of the Day of Freedom, Rome, Italy**
  This church is located in an urban area close to residential space. The design of this church was shaped in response to the disorder of its site. Three curved shell structures with equal radii define the overall shape and form of the building. The semi-transparent glass skylights between the shells also determine the pattern of light entering the interior space of the church. The concrete structure of this church incorporates nanoparticles with self-cleaning properties. The photocatalytic surface of the shell facades keeps them white and reduces surrounding environmental pollution (URL 3) (Figure 8).

Figure (8) Memorial Church of the Day of Freedom (URL 3)

Results

Exploring and understanding the dimensions of sustainability is the true starting point for achieving a precise description and understanding of the nature of sustainable design. Environmental, social, and economic sustainability cannot be achieved separately. To enhance environmental quality, economic prosperity, and social justice, all three aspects must be considered simultaneously.

There are five fundamental principles that have been adopted in many sustainable building assessment systems to define their criteria and assessment elements. These principles include site sustainability, water consumption efficiency, energy and atmospheric protection, indoor environmental quality, and resource conservation.

The philosophy of sustainable design implicitly includes achieving ecological and green design. The goal of sustainable design goes beyond environmental aspects; it also considers social and economic factors, such as responsible social use and designing to meet human needs. Therefore, green design and environmentally compatible design are elements of the sustainable design system.

The forms of materials result from various construction methods and can include nanoparticles, nanospheres, tubes, fibers, wires, and nanocomposites. The integration of nanotechnology materials with architecture involves using these materials in the context of construction and building, classified based on their physical properties or functional behaviors (self-cleaning,

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antibacterial, self-healing, thermal insulation, smart features) or external appearance (textures, colors, adhesives, fabrics). Both physical and visual characteristics can coexist simultaneously.

The use of nanomaterials as an additional technology in construction and building significantly contributes to achieving higher rankings in global building assessment systems that reflect environmentally friendly and sustainable buildings. Nanomaterials, due to their ability to modify the physical and mechanical properties of construction materials, help provide innovative solutions with notable environmental and economic effects throughout the short and long-term lifespan of a building. They also assist in achieving speed, precision, and safety in construction.

Overall, nanotechnology is driving significant scientific progress in solving many environmental issues, improving conditions, and particularly reducing energy consumption across humanity. The application of nanotechnology in the construction industry, especially in materials and resources, can be an effective step in advancing sustainable architecture goals. Since the aim of sustainable architecture is to save energy, reduce non-renewable resources, enhance and extend the lifespan of structures, decrease environmental pollution, and lower costs, it is expected that using nanotechnology in architecture and assisting in the production of materials with these specified characteristics and applications will lead to more economical production of materials while also reducing the extraction of natural resources.

Conclusion

Nanotechnology building products offer many advantages and benefits in the construction process, contributing to economic development. The applications of nanotechnology in architecture can vary widely from the early stages to the final completion and throughout the lifespan of the building (Leena et al., 2017). We need architects, scientists, and technologies to address any new regulatory controls that may be required.

Therefore, this research recommends that adopting and following nanotechnology approaches in a sustainable manner for energy conservation, resource reduction, and avoiding environmental risks is both essential and urgent. This will help achieve economic development and a sustainable future.

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