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Review Article

Harnessing Nanomaterials for Indoor Air Quality Improvement and Sustainable Architecture

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Abstract

The quality of indoor air is of great importance to inhabitants as its pollution incur great health risks, also leads to compromise of the sustainability of built environments, lending credence to the urgent need for innovative lasting solutions that would enhance air quality without reducing the standard of sustainable architecture principles. Nanomaterials through the emergence of nanotechnology in this fourth industrial revolution have led to the production of nanoparticles with unique physico-chemical properties greater than the parent materials. These particles that are a thousand times smaller than a micron have offered transformative potential in this domain. This review explores the role of nanotechnology in improving indoor air quality (IAQ) and advancing sustainable architectural practices. The mechanisms through which metallic nanoparticles improves indoor air quality are unprecedented. Nanoparticles such as photocatalytic Titanium Dioxide (TiO_2) nanoparticles and adsorptive agents like graphenso e and carbon nanotubes which are capable of removing pollutants like particulate matter, bioaerosols and volatile organic compounds (VOCs) indoors. Also, antimicrobial silver and zinc oxide nanoparticles which are potent against mycotoxigenic fungi; their antifungal potentials help in reducing moulds exospores in indoor air thus improving its quality. The integration of these materials into building components, such as paints, coatings, and structural elements to mention a few are discussed within the confines of architectural sustainability, air purification and quality. With the interplay of IAQ improvement and sustainable architecture, this article exemplifies nanotechnology's role in innovation toward healthier, greener indoor environments and further advocates for innovation and collaborations across disciplines in this area.

Keywords: Architecture; Indoor-air-quality; Nanotechnology; Nanoparticles; Sustainability; Mycotoxigenic; Mould; Limitations

Abbreviations

The profound impact residential or commercial building has over its occupants can never be over emphasized. Where a man lives say a lot about his health beyond the confines of appearance or composure. The air he breaths in comes from his ambience, and if the ambience air is polluted so is the health of the man. According to Pekdogan [1] indoor air quality and the occupants comfort in the building are intertwined, and are categorized into four conditions which are indoor air quality, thermal comfort, acoustic and visual comfort, be that as it may, indoor air quality takes precedence [1].

For healthy living, man needs good indoor air quality which starts from sustainable architecture of the building he resides. It is of paramount importance that architects take indoor air quality seriously and as human-centered design approach, taking into consideration air filtration, ventilation system, regulation, humidity and temperature [1,2]. Materials used in construction of a house will always be one of the determining factors of the indoor air quality in such building. Building materials made from radioactive component or indoor appliance that radiates remain a silent killer in many houses both in developed and third world countries. For decades now, many building materials have been improved to tackle the challenges facing sustainable construction [3,4] but with little attention to health risks they incur when it comes to indoor air quality (Table 1), as increased health complications and fatality rate have been associated with indoor air pollution yearly both in developed and under developed countries around the world.

Innovative building materials	Types	Form of pollution to indoor air	Health risk	Ref
Engineered wood product	Wood fibers or strands glued together with adhesives to form a structure	Volatile Organic Compounds (VOC), formaldehyde.	Respiratory tract lesions and irritations, nausea, fatigue, carcinogen	[4,5]
Recycled aggregates	Aggregates formed from demolition and construction waste e.g. asphalt, bricks and concrete.	Radon, ammonia	Lung cancer, aggravation of respiratory diseases, irritation	[5,6]
Bio-based materials	Materials derived from renewable green sources like microorganisms, plants and animals. Samples include -Mycelium- based composite (MBC),-Hempcrete,-Self-heating concrete (making use *Bacillus lentus, Bacillus pasteurii* and *Bacillus sphaericus* bacteria)	Toxic microorganisms secondary metabolites, mycotoxigenic fungi (moulds) exospores as humidity above 95% and temperature may enhance mould growth.	Allergy, infections	[7,8]
Recycled plastics	They are found in roofing, deckings and fencing.	Phthalates	Irritation, carcinogen	[3,9]
Paints and coatings	Conventional paints, low VOC paints	Volatile organic compounds (VOC)	Irritations, respiratory tract lesions, carcinogens	[5]

Conventional building materials versus Nanomaterials

These innovations in building materials actually solved lots of construction problems but not much have been solved in area of indoor air pollution. The release of volatile organic compounds, phthalates, radon to mention a few from these materials have been reported and their adverse effect on man are far more detrimental over time than their good. On the evidence of the growing indoor air pollution challenge all over the world there is a need for a lasting solution. As the world is advancing more into fourth industrial revolution, one of the cutting edge innovation that cross across virtually all areas is nanotechnology [10,11].

According to Oladipo and Ogunsona [12] nanotechnology is the science that deals with the manipulation of matter at atomic level. Through nanotechnology it is evident now that atoms can be manipulated and controlled on a scale of 1 to 100 nanometer. The versatility and reactivity of nanomaterials have made their applications pivotal in sustainable architecture. As reported by Dhir., *et al*. [13] and Alia and Kharofab [10] nanomaterials have been known to improve the functionality and efficiency of building materials while minimizing the negative impact the building material might have on the environment as illustrated in Table 2.

While other innovative building materials, such as advanced composites and recycled aggregate have contributed to sustainable practices [5,6], nanotechnology (nanomaterials) offer pivotal and versatile advantages. Nanoparticles high reactivity at atomic level allows them to neutralize contaminants at the any level be it microbial or chemical [16], which is a feat lacking in most innovative materials [10,11]. Additionally, nanomaterials provide unprecedented thermal insulating properties, reducing energy consumption for cooling and heating while being lightweight and easy to integrate into architectural designs [16-18,26-29]. Another innovative advantage of nanomaterials is their ability to enhance the functionality and durability of surfaces through nano-coatings [20,21,23,27,30]. These coatings provide self-cleaning properties by repelling dirt and water, thus reducing the maintenance challenges and prolonging the lifespan of such materials. In contrast, many innovative materials lack such multi-functional qualities, often requiring additional enhancement to achieve similar effects [21,31-34]. Furthermore, the production of nanomaterials are more sustainable, as their highly efficient and lightweight qualities

Building materials	Effects on indoor air quality and architectural sustainability	Nano- technologically improved building materials	Indoor air quality enhancement and architectural sustainability potentials	Ref
Concrete	Emits more than 1.5 billion tons of CO_2 (accounting for more than 7% of total CO_2 emissions, ranking second in greenhouse gas emissions)	Nano-Silica concrete (SiO_2)	More densified, robust and compact. Reduction in materials needed for constructions water proof	[14,15]
		Photocatalytic self-cleaning concrete (Titanium dioxide nanoparticles)	Environmental pollution cleansing and photocatalytic properties. Resistant to dust accumulation Long term sustainability enhancement	[14,15]
Glass	Unchecked radiation of heat and Ultra violet rays from the sun. Dirt and moulds exospores accumulations.	Glass enhanced with Heat-insulating nanomaterials	Heat transfer reduction, sustainability boosting through energy consumption reduction thus cooling the interiors.	[16-18]
		Titanium dioxide nanoparticles Self- Cleaning glass	Washing of the glass surface with raindrops containing dirt or spilled water won't leave a trace of deposition	[16-18]
		Silica nanoparticles fire-protective glass	Fire resistant	[19]
		Tungsten oxide nanoparticles electrochromic glass	Reduces the passing of sunlight by turning into blue colour when electricity of around 3 voltage is applied	[16-19]
Paints and Coating	Emission of volatile organic compounds, Environmentally Persistent Free Radicals (EPFR)	Zinc Oxide self- cleaning enamel paint	Self-cleaning	[20,21]
		Titanium dioxide nanoparticles coating	Antifouling and self-cleaning, little chemical effect	[21,22]
		Silver nanoparticles and biocide acticide emulsion paint	Increased abrasion and hiding power, inhibited the growth of black yeast (*Aureobasidium pullulans*)	[21,23]
		Silica nanopowder	Improved toughness, aging resistant, wear resistant	[25]
		Hybrid Magnetic Graphene Oxide (HMGO) paint	Antibacterial activities against pathogenic *Escherichia coli* and *S. typhimurium*	[21,25]

Table 2: Conventional building materials versus Nanomaterials in construction.

help reduce the quantity of material needed for a given construction application, as a result minimizes energy inputs and waste [16,28,35]. In this dispensation of sustainable architecture, nanomaterials are making significant impacts. Nanoparticles/nanomaterials integration into building designs allows for innovations for example nano-enabled solar panels with enhanced efficiency [16-18], which can seamlessly blend into façades and support renewable energy adoption. Similarly, nano-enhanced coatings/paintings can reflect infrared radiation, thus help to reduce indoor temperatures and lower energy demands for cooling [16]. These applications not only enhance sustainable architecture but also in alignment with global efforts to achieve green building certifications and reduce carbon emissions.

Some limitations of nanomaterials in construction

It will be shallow, having reviewed the importance of nanomaterials over conventional building materials in construction, not to discuss the risk associated with the usage of nanomaterials in building over time. Despite the pivotal and sustainable properties and applications of nanomaterials in building construction, the usage of these materials are meant to be well studied and researched within the confines of health and environmental safety before considering their usage in construction, because it has been reported that some nanomaterials pose health risk when being exposed to over time [36-38]. For instance, silica nanoparticles have been reported to be highly important in enhancing the durability and mechanical features of concrete but its indiscriminate usage in high dosage could result in agglomeration of the nanoparticles which could eventually compromise the durability and mechanical features of the concrete eventually, features which might have been conferred on the materials by the nanoparticles at first [38]. Furthermore, some nanomaterials have been reported to generate free radicals and some are carcinogenic [36] while some metallic nanoparticle have been reported to be highly toxic to the respiratory system when inhaled [38-40].

Silica nanoparticles has been reported to affect human's health over exposure. Silica nanoparticles exposure and inhalation has been associated with lung malfunction and illness [40]. Carbon nanomaterials have been reported to be cytotoxic [41]. Titanium and Barium sulphate nanoparticles exposure have been associated with inflammation and cancer in man [36], silver, Ferric oxide and Tungsten nanomaterials have been associated with reduced cell proliferation and death [42]. Furthermore, nanomaterials could be the answer to many challenges facing construction and building habitability but still, economic barriers restrict wild usage of nanomaterials, For instance, nano-silica concrete, despite its pivotal importance in construction, it is not economical and accessible in many developing countries [37]. The exorbitant prices of nanomaterials could be as the result of specialized processes involved in the synthesis/production and requirements like quality control.

Approaches to mitigate the limitation of nanomaterials usage in sustainable building and indoor environment

The feat of nanomaterials could be flawless and rise more above limitation in sustainable architecture and indoor air quality improvement through the development of better dispersion techniques to check nanoparticles agglomeration, also implementation of strict safety protocols on nanomaterials usage will definitely mitigate health risks. Also employing green method of synthesis will reduce health and environmental risk while reducing production costs and accessibility. The conduction of more research on the potential health and environmental risk associated with nanomaterials is of great importance as it still seems like we are still scratching the surface of nanotechnology, there is still more to discover. It is noteworthy that the limitations associated with nanomaterials do not in any way negate their pivotal potential, but rather emphasize the need for well-researched approach and caution in their usage in construction and more. Through the conscious acknowledgment and mitigation of these challenges, this dispensation can achieve cutting edge innovations within the confines of harnessing the potentials of nanomaterials in construction while mitigating the risks, ultimately contributing to more sustainable buildings and healthier indoor environments.

Conclusion

Nanotechnology (nanomaterials) is a groundbreaking innovation in the fields of sustainable architecture and indoor air quality. Nanomaterials air purification potentials and multifunctional properties distinguish them from known innovative building materials. As new researches continue to unlock nanomaterials full potential in sustainable architecture and indoor air quality improvement, nanotechnology are focused to play a pivotal role in creating more sustainable, healthier, and technologically advanced built environments. Nanotechnology adoption marks an unprecedented turning point toward addressing the challenges of modern urban living and environmental conservation.

Bibliography

1. Pekdogan T. "Evaluating the Impact of Building Materials on Indoor Air Quality: A Critical Analysis". *Sakarya University Journal of Science* (2024).
2. Astolfi A and Pellerey F. "Subjective and objective assessment of acoustical and overall environmental quality in secondary school classrooms". *The Journal of the Acoustical Society of America* 123.1 (2008): 163-173.
3. Iluyomade TD and Okwandu AC. "Innovative materials in sustainable construction: A review". *International Journal of Science and Research Archive* 12.1 (2024): 2435-2447.
4. Okwandu AC., *et al*. "Sustainable architecture: Envisioning self-sustaining buildings for the future". *International Journal of Management and Entrepreneurship Research* (2024).
5. Wagdi D., *et al*. "Materials Selection for Improved Indoor Air Quality in Residential Buildings: a Pre-occupancy Assessment". (2015).
6. Al-Taie A., *et al*. "Recycled aggregate blends for backfilling deep trenches in trafficable areas". *Construction and Building Materials* 401 (2023): 132942.
7. Andrew JJ and Dhakal H N. "Sustainable biobased composites for advanced applications: recent trends and future opportunities–A critical review". *Composites Part C: Open Access* 7 (2022): 100220.

8. Zerari S., *et al*. “The potential impacts of using bio-based building materials on human health and wellbeing”. *E3S Web of Conferences* 436 (2023): 01006
9. Feng X., *et al*. “Occurrence and human health risks of phthalates in indoor air of laboratories”. *Science of The Total Environment* 707 (2020): 135609.
10. Alia RA and Kharofab OH. “The impact of nanomaterials on sustainable architectural applications smart concrete as a model”. *Materials Today: Proceedings* 42 (2020): 3010-3017.
11. Alhmoud SH. “Sustainability of Development and Application of Nanomaterials in Healthcare within Hospital Settings”. *International Journal of Civil Engineering* 11.6 (2024): 79-97.
12. Oladipo IC and Ogunsona SB. “The Utilization of Agro-Waste: A Nanobiotechnology Point of View”. *Recent Advances in Biological Research 5. B P International* (2019).
13. Dhir R., *et al*. “Sustainable Construction Materials: Sewage Sludge Ash”. Woodhead Publishing (2017).
14. Mohajerani A., *et al*. “Nanoparticles in Construction Materials and Other Applications, and Implications of Nanoparticle Use”. *Materials (Basel)* 12.19 (2019): 3052.
15. Topçu İB., *et al*. “Self-Cleaning Concretes: An Overview”. Journal of Cement Based Composites 1.2 (2020): 6-11.
16. Usama K and Hendm M. “A Proposed Strategy to Evaluate Nanomaterials in Construction to Boost Sustainable Architecture”. *Civil Engineering and Architecture* 10.7 (2022): 3206-3226.
17. Khandve P. “Nanotechnology for building material”. *International Journal of Basic Applied Research* 4 (2014): 146-151.
18. Nasiol. “What is Nano Coating? Is It Really Important?” (2022).
19. Health I.o.O.S.a. Nanotechnology in Construction and Demolition Guidance for industry; Loughborough University (2017).
20. Solano R., *et al*. “Preparation of modified paints with nanostructured additives and its potential applications”. *Nanomaterials and Nanotechnology* 10 (2020): 1–17.
21. Olawore AS., *et al*. “Enhancing Functionalities of Paints with Nanoparticles: A Review”. *Nano Plus: Science and Technology of Nanomaterials* 2 (2021): 97-119.
22. Nyamutswa LT., *et al*. “Light conducting photocatalytic membrane for chemical-free fouling control in water treatment”. *Journal of Membrane Science* 604 (2020): 118018.
23. Asafa TB., *et al*. “Physicomechanical properties of emulsion paint embedded with silver nanoparticles”. *Bulletin of Material Science* 44.7 (2021): 1-11.
24. Hai LH. “The effect of SiO2 nanoparticles in polyurethane paint formulation on metal surfaces”. *International Journal of Science and Research Archive* 3.1 (2021): 031– 036
25. Arun T., *et al*. “Facile synthesized novel hybrid graphene oxide/cobalt ferrite magnetic nanoparticles based surface coating material inhibit bacterial secretion pathway for antibacterial effect”. *Materials Science and Engineering C* 104 (2019): 109932.
26. Ahou Akbar Haghıghat and Emine Görgül. “Emergence of Nanomaterials in Interior Architecture of Healthcare Domain”. *International Journal of Architecture and Urban Studies* 1.2 (2016): 48-58.
27. Marco Valente., *et al*. “Geopolymers vs. Cement Matrix Materials: How Nanofiller Can Help a Sustainability Approach for Smart Construction Applications A Review”. *Nanomaterials* 11.8 (2021): 1-34.
28. Ajit B. “Self-Cleaning Materials”. *Advanced Materials* (2022): 359-394.
29. Shashwat S., *et al*. “A Review on Bioinspired Strategies for an Energy-Efficient Built Environment”. *Energy and Buildings* (2023): 296.
30. Yongqiang Li., *et al*. “Highly Transparent and Scratch Resistant Polysiloxane Coatings Containing Silica Nanoparticles”. *Journal of Colloid and Interface Science* 559 (2020): 273-281.
31. Mann S. “Nanotechnology and Construction”. 2006, Nanoforum-European Nanotechnology Gateway: Institute of Nanotechnology, (2006).
32. Jesse T Jacob., *et al*. “The Role of the Hospital Environment in Preventing Healthcare-Associated Infections Caused by Pathogens Transmitted through the Air”. H*ERD: Health Environments Research and Design Journa*l 7.1 (2013): 74-98.
33. Aryatama R., *et al*. “Microbiology Indoor Air Quality at Hospital during the Covid19 Pandemic”. *Jurnal Kesehatan Lingkungan* 12.1 (2020): 89-92.
34. Denver P Linklater., *et al*. “Current Perspectives on the Development of Virucidal Nano Surfaces”. *Current Opinion in Colloid and Interface Science* 67.10 (2023).

35. Sadia Afroz., *et al*. "Self-Cleaning Textiles: Structure, Fabrication and Applications". F*undamentals of Natural Fibres and Textiles* (2021): 557-597.

36. Skocaj M., *et al*. "Titanium dioxide in our everyday life; is it safe?" *Radiology and Oncology* 45.4 (2011).

37. Huseien G F., *et al*. "Sustainability of nanomaterials based self-healing concrete: An all-inclusive insight". *Journal of Building Engineering* 23 (2019): 155-171.

38. Khan K., *et al*. "Nano-Silica-Modified Concrete: A bibliographic analysis and comprehensive review of material properties". *Nanomaterials* 12.12 (2022): 1989.

39. Zoroddu MA., *et al*. "Toxicity of nanoparticles". *Current Medicinal Chemistry* 21 (2014): 3837-3853.

40. Liu JY and Sayes CM. "A toxicological profile of silica nanoparticles". *Toxicology Research* 11.4 (2022): 565-582.

41. Jia G., *et al*. "Cytotoxicity of Carbon Nanomaterials: Single-Wall Nanotube, Multi-Wall Nanotube, and Fullerene". *Environmental Science and Technology* 39.5 (2005): 1378-1383.

42. Hussain S M., *et al*. "In vitro toxicity of nanoparticles in BRL 3A rat liver cells". *Toxicology In vitro* 19.7 (2005): 975-983.