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Sustainability of Development and Application of Nanomaterials in Healthcare within Hospital Settings

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Abstract - *Healthcare has been one of the largest worldwide challenges. Since a recognised solution to the pandemic has not developed, all countries around the world have had to devise self-adopted methods promoting different ways to conduct a series of clinical analyses on cases. Hence, it has become very difficult to generate the number of people who were infected, treated, or deceased. Global application of nanomaterials in epidemiological healthcare represents a pivotal approach that may serve an essential purpose to the problem in case of holds the potential to address not only current pandemic challenges but also to mitigate the impact of unforeseen outbreaks of diverse diseases proactively. This study endeavors to contribute nuanced perspectives and discerning insights regarding the judicious application of healthcare nanomaterials within the ambit of pandemic hospital interior design. The primary objective is to discern the efficacy of integrating these nanomaterials, considering their inherent antimicrobial and antiviral properties, in order to fortify safety measures and cultivate an environment that is both secure and conducive to the wellbeing of all stakeholders, encompassing healthcare practitioners and patients alike. The envisaged outcome is an informed discourse on the pragmatic incorporation of healthcare nanomaterials, delineating a path towards a healthcare milieu that is inherently safer and more supportive during pandemic scenarios. The research findings concluded that there had been a considerable upward increase in the number and level of adoption of healthcare nanomaterials in the pandemic in the hospital space. Consequently, this study provides comprehensive process instructions for any fatal virus through the detailed process and diagrams. Hence it is highly recommended to use the content as part of any guidelines that would be required to fight against any current or future pandemics.*

Keywords –*Healthcare, Nanomaterials, Design, Hospital strategies.*

1. Introduction

In the contemporary landscape of healthcare, the escalating challenges posed by pandemics underscore the imperative to rethink and fortify the design of hospital interiors [1,2]. The recent proliferation of infectious diseases, marked by their rapid global dissemination, necessitates a paradigm shift in our approach to healthcare facility design [3,4]. In this context, the infusion of nanomaterials into the architectural fabric of pandemic-ready hospitals emerges as a novel and promising avenue, holding the potential to not only optimize healthcare delivery but also safeguard the health and safety of patients and healthcare professionals alike [5,6]. Nanotechnology, functioning at the nanoscale, empowers the manipulation and utilization of materials at molecular and atomic dimensions. The distinctive properties inherent to nanomaterials, including heightened surface area, augmented reactivity, and enhanced mechanical strength, have ushered in a transformative era across diverse scientific domains. Within the healthcare sector, the integration of nanomaterials into hospital interior design stands out as a groundbreaking initiative with far-reaching implications for infection control, patient care protocols, and overall environmental resilience. The integration of nanomaterials in healthcare represents a significant advancement, particularly in medical diagnostics, treatment, and patient care. Despite their potential, the use of nanomaterials in hospital interior design, especially regarding sustainable development, remains underexplored. While most research focuses on biomedical applications like drug delivery, imaging, and tissue engineering, there is a notable gap in studies on their role in enhancing the sustainability of healthcare facilities [7]. This research addresses this gap by examining how nanomaterials can improve hospital interiors' sustainability. Potential benefits include better air quality, reduced microbial contamination, and increased energy efficiency. Hospitals face increasing pressure to adopt sustainable practices due to environmental concerns and regulations. However, traditional materials and design strategies often fall short in balancing high-performance, hygienic environments with sustainability goals. Nanomaterials offer a promising solution to these challenges, yet their practical application and long-term impacts are not well-documented.

This study focuses on the sustainable development of nanomaterials in hospital interior design, an area less studied than their medical uses. Previous research has primarily noted the antimicrobial properties and environmental benefits of nanomaterials individually. This research seeks to provide a comprehensive analysis of how these materials can be systematically integrated into healthcare design to achieve combined benefits for sustainability and patient wellbeing. The goal is to offer a holistic understanding of the benefits and challenges of using nanomaterials in hospital interiors, laying the foundation for future studies and practical implementations in sustainable healthcare design.

Furthermore, the utilization of nanomaterials in hospital architecture represents a conscientious approach to environmental integration. The fine-tuned properties of nanomaterials enable the creation of structures that harmonize with their surroundings, fostering a symbiotic relationship between the built environment and the natural world. This holistic approach not only contributes to the overall sustainability of healthcare facilities but also aligns with contemporary architectural aspirations for environmentally responsive design [7,8].

This research aims to bridge the existing gap between the realms of nanotechnology and hospital architecture, endeavouring to craft environments that not only boast aesthetic appeal but also exhibit functional robustness in the face of infectious threats. The incorporation of nanomaterials holds promise for curtailing pathogen transmission, optimizing the functionality of medical equipment, and fostering sustainable solutions tailored to the exigencies presented by pandemics. This introductory paper segment lays the groundwork for a comprehensive exploration into the intersectionality of nanotechnology and healthcare design, underscoring the urgent need for innovative solutions amid global health crises. Subsequent sections of this academic endeavor will delve into specific applications of nanomaterials in pandemic hospital interior design, offering nuanced insights into how these advancements can reshape the contours of healthcare infrastructure, ushering in a safer, more adaptive healthcare milieu and the specific objectives of this paper are:

- Assess the long-term durability and resilience of nanomaterial-infused design elements within hospital interiors.
- Evaluate the antimicrobial properties of nanomaterials utilized in hospital interior design to ascertain their effectiveness in mitigating the spread of infections.
- Consolidate the findings into a set of comprehensive guidelines and recommendations for the sustainable implementation of healthcare nanomaterials in pandemic hospital interior design.

2. Materials and Methods

The advent of nanotechnology in the 21st century represents a pivotal and indispensable technological stride, meriting attention for its transformative implications across various domains. Particularly noteworthy is the discernible promise embedded within the distinctive properties and attributes of nanomaterials, particularly as they align with environmental considerations, thereby rendering them pivotal in the realms of architecture and interior design [9]. A myriad of supplementary applications of nanomaterials is observable and strategically designed to augment material qualities in the pursuit of enhancement, longevity, and ease of maintenance. Among these applications are notable functionalities such as self-cleaning mechanisms inspired by the Lotus Effect and Photocatalysis, air purification, anti-fogging technologies, thermal insulation leveraging materials like Aerogel, temperature regulation through Phase Change Materials (PCMs), solar and UV protection, fire resistance, anti-graffiti coatings, anti-reflective coatings, antibacterial treatments, anti-fingerprint technologies, scratch resistance, and abrasion resistance [10,11].

Of particular significance is the incorporation of nano-based air-purifying materials in healthcare facilities, where indoor air quality is often compromised by the presence of fungi, bacteria, and viruses [12]. These contaminants are typically propagated due to inadequate ventilation and excessive heating. The accumulation of CO_2 further exacerbates the issue, resulting in various complaints from patients, staff, and visitors alike [13]. Recognizing the pivotal role of daylight in the recuperation of patients and the overall mood and comfort of occupants, the deployment of UV and solar protection glass panels is imperative [14].

These panels not only filter harmful ultraviolet radiations that can adversely affect both building materials and human health, especially that of patients but also facilitate the intake of sufficient sunlight [15]. By addressing these considerations, the integration of nanomaterials in healthcare facilities emerges as not only a sustainable choice but also one that exerts a profound healing influence on the environment for patients, staff, and visitors. This paradigmatic shift reduces reliance on natural resources and contributes to energy conservation, particularly in the realms of heating, cooling, and lighting systems. Consequently, the convergence of nanotechnology and healthcare infrastructure underscores a synergistic relationship, promising multifaceted benefits and affirming the centrality of nanomaterials in shaping the future of architectural and interior design paradigms.

Within the context of this research, a sample of functional medical centers in Istanbul has been identified and selected as the case study. Specifically, Kolan Hospital, situated in Istanbul, has been chosen to investigate nanotechnological applications within interior spaces, with a focus on the deployment of nanomaterials in patient rooms. This selection aims to provide a comprehensive yet focused examination of the utilization and properties of deployed nanomaterials in the healthcare environment.

The rationale behind choosing this method lies in its capacity to offer a broad perspective while yielding closely connected outcomes related to hospital spaces. The primary objective of the case study is to quantify the nature of hospitals in Istanbul, with a particular emphasis on assessing the materials employed in the design of patient rooms. This includes an examination of the essential properties of nanomaterials, their specific locations within the design, and the quantity in which they are used. Additionally, the study aims to evaluate the efforts undertaken to address the effects of pandemics within society. The necessity to assess hospitals constructed over an extended period, which are still operational alongside those of the current generation, is paramount. This dual evaluation seeks to gain insights into their inherent capabilities to respond effectively to pandemic cases. The choice of the case study also facilitates the identification of various hospital characteristics, informing the planning and design criteria for new modules with a focus on nanotechnology.

In the case of Kolan Hospital, two specific inquiries are posed:
(i) Is the measurement and quantification of technological growth accurate and appropriate?
(ii) What trends and relationships emerge between high and low-tech areas within the hospital setting?

These inquiries aim to critically examine the assessment of technological advancements and explore the dynamics between high-tech and low-tech areas within the hospital environment. The findings from these inquiries will contribute to a deeper understanding of the role of technology in healthcare spaces, specifically focusing on nanotechnological applications and their implications for patient rooms.

2.1. Requirements of Nanomaterials Implementation in Interior Architecture

The incorporation of nanomaterials within architectural design necessitates materials characterized by optimal performance and durability while simultaneously upholding standards of safety and environmental sustainability. Compatibility with established construction methodologies, along with the scalability of manufacturing procedures, stands as a pivotal factors to be addressed. Moreover, considerations pertaining to cost-effectiveness are imperative in determining the feasibility of nanomaterial integration. Adherence to regulatory frameworks, fostering interdisciplinary collaboration, and promoting awareness regarding the capabilities of nanomaterials constitute essential facets for their effective implementation in architectural practice. Attending to these requisites empowers architects to harness the potential of nanomaterials in fostering sustainable and pioneering architectural solutions [16]. In the 21st century, nanotechnology has emerged as a pivotal technological advancement, showcasing remarkable potential across diverse fields, including architecture and interior design. Notably, the distinctive properties and environmental benefits inherent in nanomaterials underscore their profound promise in these domains. A wide array of supplementary applications of nanomaterials has been observed, each strategically aimed at enhancing material qualities for the betterment of long-term use and maintenance. These applications encompass self-cleaning mechanisms inspired by the Lotus Effect and Photocatalysis, air purification systems, anti-fogging coatings, thermal insulation utilizing Aerogel, temperature regulation through Phase Change Materials (PCMs), solar and UV protection measures, fireproofing solutions, anti-graffiti coatings, anti-reflective surfaces, antibacterial treatments, anti-fingerprint technologies, as well as scratchproof and abrasion-resistant coatings. Each of these functionalities serves to augment the performance and durability of architectural materials, offering innovative solutions to contemporary design challenges [10,11,17].

2.1.1. Self-Cleaning Qualities

The Lotus effect stands as a prominent method in surface design, leveraging nanomaterials to achieve self-cleaning attributes. Inspired by the hydrophobic properties of lotus leaves, surfaces with nanostructured features mimic their water-repellent wax coating. This nanostructured architecture prompts water droplets to bead up and roll off, effectively cleansing organic dirt upon descent. Such surfaces find optimal application in areas prone to water contamination, such as building facades and bathrooms [18].

Photocatalytic self-cleaning entails surfaces coated with titanium dioxide (TiO2) nanoparticles, imbuing them with super-hydrophilic properties that minimize cleaning frequency. Upon exposure to sunlight, TiO2 catalyzes reactions that break down organic contaminants, which are subsequently washed away by rainwater. This technology is particularly suitable for outdoor contexts like facade design and glass patios .Distinguishing itself from self-cleaning functions, Easy-to-clean (ETC) surfaces possess water-repellent properties, albeit with notable differences from the Lotus effect and photocatalytic surfaces. ETC surfaces exhibit smoother microscopic textures, lacking adhesive properties and facilitating the formation of water droplets that easily run off. These characteristics render ETC coatings applicable to various indoor and outdoor environments [19,20].

2.1.2. Air Purifying Qualities

The integration of air-purifying nanomaterials represents a significant advancement in the improvement of air quality, both indoors and outdoors. Notably, the efficacy of this system hinges upon the proportional implementation of these products relative to the volume of the environment they are intended to treat, with direct exposure to air being essential for optimal functionality. Key applications of air-purifying technologies predominantly manifest in paints and textiles, offering a promising avenue for widespread adoption and impact in diverse settings [21].

2.1.3. Anti-Fogging Qualities

Anti-fogging nanomaterials are comprised of ultra-thin coatings of nanoscale titanium dioxide. These coatings exhibit heightened surface energies and increased moisture attraction capabilities. By virtue of their hydrophilic nature, they facilitate the formation of an ultra-thin moisture film on surfaces, thereby preempting the formation of water droplets that typically lead to surface spots. Instead, the moisture settles as a transparent film, rendering the surface fog-free and clear.

Particularly well-suited for indoor applications, such as bathroom mirrors and glass panels, these coatings offer effective mitigation against fogging issues. Furthermore, they find utility in glass surfaces within air-conditioned spaces situated in tropical climates, where they prevent clouding upon the introduction of outdoor air into enclosed environments [22].

2.1.4. Insulation Qualities

Nano Thermal Insulation, also known as nanogel, is a type of Aerogel renowned for its exceptional thermal insulation properties. It primarily comprises air (approximately 95-99.9%) and silicon dioxide. Noteworthy is its dual functionality as both a thermal and sound insulator, rendering it suitable for various applications including exterior environments like facade panels and interior spaces such as conference areas within office buildings. The fundamental aim driving the development of such nano-based products is the enhancement of energy efficiency, ultimately contributing to the reduction of operational expenses in constructed systems and bolstering sustainability efforts [23].

Moreover, Phase Change Materials (PCMs) represent a pivotal approach to temperature regulation within built environments. Composed primarily of paraffin and salt hydrates, PCMs are capable of storing latent heat and effectively modulating indoor temperatures. Their integration provides not only thermal insulation benefits but also mitigates unwanted air infiltration and exfiltration. Notably, minute paraffin globules, ranging from 2 to 20 nm in diameter, are encapsulated within sealed plastic sheeting, facilitating their injection into conventional building materials. This characteristic underscores their applicability in both new constructions and retrofitting endeavors, thereby embodying a versatile solution for achieving optimal indoor climate control and energy management [24]. Table 1 describes the Nano thermal.

Table 1. Descriptions of common materials used in nano thermal

Material	Properties	Features
Aerogel	Hydrophobic surfaces	- It is used for windows because of its transparency. - Lightweight. - Very effective insulation.
Vaccum Insulated Panel	Hydrophilic surfaces.	- It has a highly slim profile. - Fits in narrow spaces for novel builds. - High performance for thermal insulation.
Nansulate	Hydrophobic	- Non-toxic. - Composing a thin layer for insulation. - High resistance against microbiological attack. - Smooth surfaces, which featured reducing the attraction of the surface.

2.1.5. Anti-Reflective Qualities

In contemporary construction practices, there has been a noticeable surge in the adoption of anti-reflective glasses, driven by their ability to capitalize on augmented solar transmission resulting from broadband spectral de-reflections. This trend underscores a growing recognition of the benefits associated with these glasses within the industry [25]. A key innovation in this realm is the development of transparent nano-scalar surface structures characterized by the presence of minute 30-50nm silicon dioxide (SiO_2) balls. These structures not only offer a novel approach to anti-reflective solutions but also present a cost-effective and highly efficient alternative. The versatility of these products extends to various architectural applications, including but not limited to patios, glass atriums, glass cabinets in exhibition design, and treatment rooms within hospital environments. Particularly in healthcare settings, where the controlled dissemination of sunlight is crucial, such glasses prove invaluable, especially in specialized spaces requiring radiation containment. This emerging technology holds significant promise for advancing both architectural design and environmental functionality within built environments [26].

2.1.6. Antibacterial Qualities

In the context of antimicrobial strategies, the utilization of silver nanoparticles has emerged as a promising avenue to combat microbes and bacteria that commonly proliferate on object surfaces. This approach involves modifying surfaces with antibacterial nanoproducts to thwart the emergence of new bacterial colonies. By incorporating anti-stick functionalities, the likelihood of bacterial growth is significantly reduced [27]. A notable advantage of antibacterial nanomaterials is their capacity to diminish the necessity for chemical disinfectants while concurrently streamlining cleaning protocols. Within the domain of interior design, virtually all interior surfaces, including walls, floors, ceilings, furniture, and various textures, are amenable to being coated with antibacterial nanosurfaces [28]. Healthcare centers represent particularly conducive environments for the deployment of these products. Such facilities often harbor harmful bacteria, and the presence of vulnerable patients heightens the imperative for stringent antimicrobial measures. Thus, the integration of antibacterial nanosurfaces offers a proactive approach to safeguarding against microbial threats within healthcare settings while concurrently mitigating the reliance on traditional disinfection methods.

2.1.7. Scratchproof and Abrasion-Resistance Qualities

In response to the common issues of wear and tear experienced by materials from activities like walking, cleaning, and scrubbing, nanotechnology has introduced transparent scratchproof Abrasion-Resistance coatings. These coatings represent a significant advancement in material protection, offering resilience against corrosion and abrasion across various substrates such as wood, metal, and ceramics. In architectural contexts, the availability of scratch-resistant stainless steel coatings, whether transparent or colorful, adds a layer of durability while maintaining the aesthetic integrity of materials [29]. It is pertinent to acknowledge, however, that while these nano-based coatings enhance scratch resistance, they do not provide immunity against significant mechanical impacts, such as those caused by keys or other damaging implements. Despite this limitation, their application signifies a noteworthy stride in extending the longevity and visual appeal of architectural materials.

2.2. Analysis of Nanomaterials in Optimization to Sustainability

Nanomaterials play a pivotal role in enhancing sustainability and efficiency in structural construction [30]. Their integration offers several benefits:

- Strength and Durability: Nanomaterials strengthen construction materials, making structures more resilient and longer-lasting.
- Lightweight Construction: They enable the creation of lightweight yet sturdy materials, reducing material usage and enhancing earthquake resistance.
- Energy Efficiency: Nanomaterials improve insulation, reducing heat transfer and energy consumption for heating and cooling.
- Self-Healing Properties: Some nanomaterials can autonomously repair cracks and damage, extending structural lifespan and reducing maintenance needs.
- Environmental Impact Reduction: Nanomaterials can remove pollutants from air and water, lessen greenhouse gas emissions, and decrease material waste.
- Resource Efficiency and Recycling: They promote efficient resource usage and enable easier recycling, contributing to sustainable practices in construction.

Overall, nanomaterials offer versatile solutions for sustainable construction, though careful consideration of potential risks is necessary [31].

2.3. Air Quality and Pandemic

Maintaining a good quality of air that flows in and out of a built environment or apartment space can go a long way in reducing the level of contamination which can be transmitted and contacted through air. However, it is essential to note that this does not prevent people from contracting the pandemic. But the Centres for Disease Control (CDC) or health organizations in different nations across the world have arrived at measures that, if practiced religiously, including the use of face masks, filtration, and social distancing, can greatly lessen the probability of its contamination within an enclosed space [32].

The use of air cleaners and other HVAC filters is to rid the air that circulates within a room of the pollutants it harbours. Filtering and subjecting indoor air to cleaning will aid in eliminating contaminants and other substances that likely serve as carriers of microorganisms, an example being the virus-carrying particles. It is, however, essential to know that if there is to be effectiveness in the use of air filters in space, for it to eliminate microorganisms, it must possess pores which will only allow the passage of particles smaller than the size of microbes (i.e. ranging from 0.1 - 1 micrometre) [33].

2.4. Nanotechnology and its Potential Applications in Interior Architecture

John M. Johansen, an architect, discusses the potential of nanoarchitecture in integrating new technologies with architectural design [34]. He highlights several key points:

- Humanizing Technology: Nanoarchitecture can create designs that better engage human senses, making technology more humane.
- Custom Material Design: Nanoarchitecture enables the design of unique materials beyond traditional ones like wood, concrete, and glass.
- Dynamic, Growing Buildings: Conceptualizing architecture as a "growing" environment suggests buildings evolving according to different codes, leading to responsive architecture.
- Personalized Spaces: Nanoarchitecture allows for personalized spaces, offering occupants greater flexibility and choice in their environments.
- Harmonizing with Nature: Nanoarchitecture brings architectural design closer to nature, fostering synchronous harmony between buildings and the environment.
- Demand-Driven Evolution: Good design, driven by demand, contributes to the evolution of nanomaterials and nanoproducts. Materials/products meeting demand become established, while others fade from the market.

Johansen's reflections underscore the transformative potential of nanoarchitecture in redefining the contours of architectural practice, fostering human-centric, sustainable, and responsive built environments that resonate harmoniously with both human occupants and the natural world.

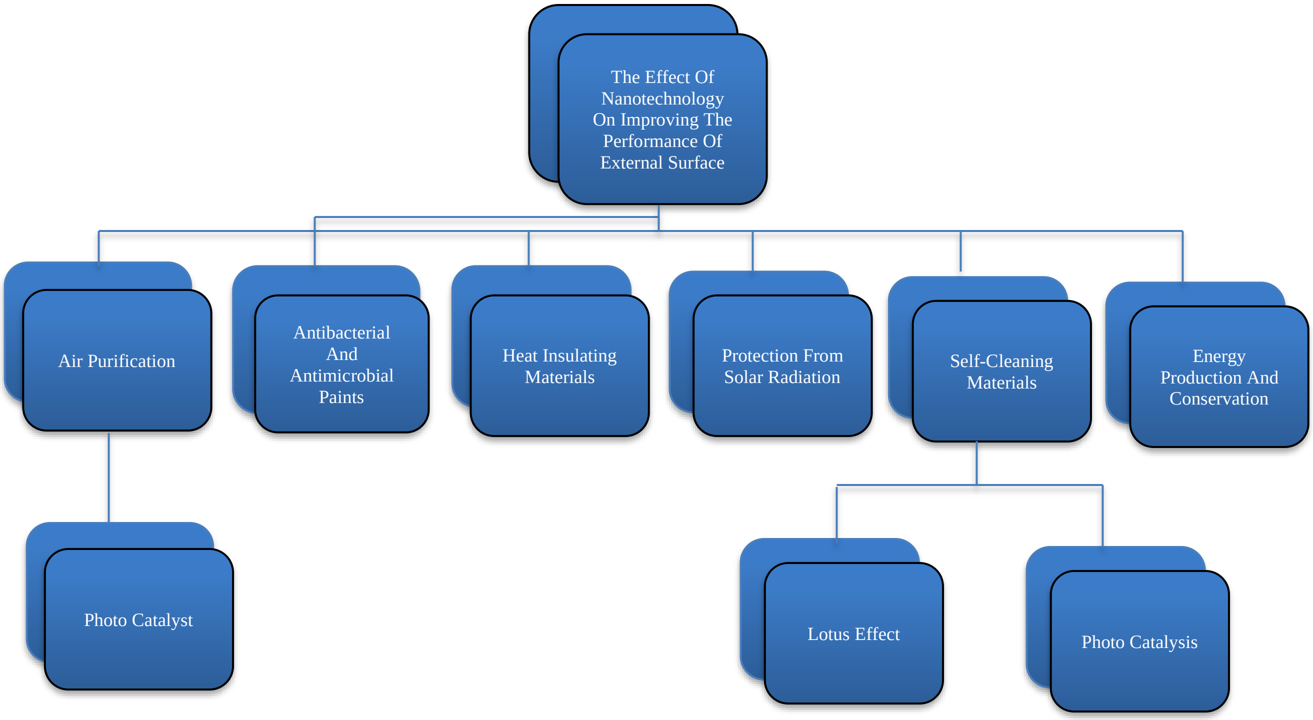


Fig. 1 The impact of nanotechnology applications on buildings

Further, nanotechnology has emerged as a pivotal domain facilitating the development of various applications tailored to enhance energy utilization efficiency, particularly within the realm of building infrastructure [35]. Fig. 1 elucidates the multifaceted contributions of nanotechnology toward mitigating escalated energy consumption in buildings, primarily through augmenting lighting efficacy, refining insulation materials, fortifying coatings, and facilitating diverse applications aimed at bolstering energy efficiency.

2.5. Description of the Case Study

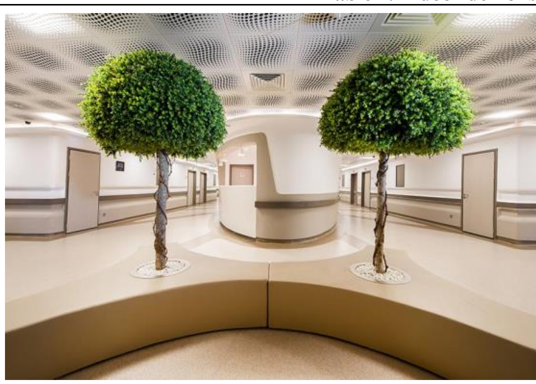
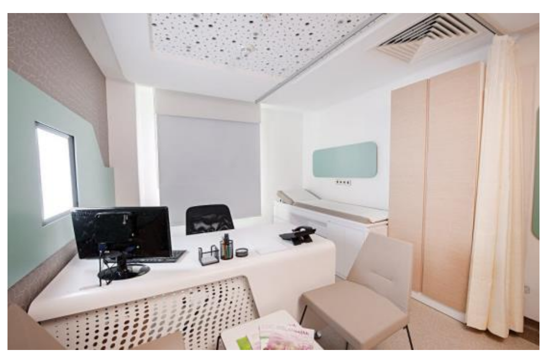
In the bustling urban landscape of Şişli, Istanbul, stands Kolan Hospital, a beacon of healing and rejuvenation. Renowned for its cutting-edge medical services and compassionate patient care, Kolan Hospital transcends the conventional healthcare paradigm by intertwining modernity with tranquillity. Situated amidst the vibrant pulse of the city, Kolan Hospital emerges as a sanctuary, offering a serene and therapeutic environment for patients seeking solace and restoration. At the heart of Kolan Hospital lies a commitment to excellence in healthcare delivery. Specializing in cardiology, pediatric cardiology, general surgeries, heart and vascular surgery, internal medicine, and ophthalmology, the hospital stands as a testament to medical innovation and expertise. Bolstered by a team of dedicated medical professionals, Kolan Hospital epitomizes the pinnacle of medical excellence, where each patient is treated with unwavering attention and care. Beyond its clinical prowess, Kolan Hospital distinguishes itself through its avant-garde interior design, meticulously crafted to evoke a sense of calm and wellbeing. Embracing the principles of modernity and sustainability, the hospital's architecture seamlessly integrates with its natural surroundings, fostering a harmonious coexistence between humans and the environment. Within its walls, patients, staff, and visitors alike are enveloped in an oasis of comfort and tranquility, where healing begins the moment one steps through its doors. Central to Kolan Hospital's ethos is a steadfast commitment to the holistic wellbeing of its occupants. Every facet of the hospital's design is meticulously curated to promote health and wellness, from its ergonomic furnishings to its eco-friendly initiatives. By prioritizing patient, staff, and visitor comfort, Kolan Hospital emerges not only as a beacon of healing but also as a bastion of hospitality and compassion.

In essence, Kolan Hospital stands as a testament to the transformative power of healthcare design. By seamlessly integrating modern medical technologies with sustainable and healthy environments, the hospital redefines the patient experience, transcending the boundaries of traditional healthcare delivery. As a cornerstone of healing in Şişli, Istanbul, Kolan Hospital exemplifies the convergence of innovation, compassion, and architectural excellence, setting a new standard for healthcare facilities worldwide. Figure 2 shows the Kolan Hospital building.

The Kolan Hospital, situated in Şişli, boasts a comprehensive infrastructure tailored to meet the exigencies of modern medical care. With a capacity of 174 beds, 6 operating rooms, and specialized units, including internal surgical, coronary and cardiovascular surgery intensive care, as well as a neonatal intensive care unit equipped with 31 incubators, the hospital stands as a pivotal institution within the healthcare landscape. Spanning across an impressive 20,000 m² indoor area and housing over 40 departments, the facility caters to a diverse array of medical needs [36]. Notably, the architectural composition of Kolan Hospital Şişli, meticulously crafted by Zoom Office in 2013, embodies a paradigm of innovative design principles. The core ethos underlying this architectural endeavor is the integration of cutting-edge technological materials, notably nano-based materials, alongside natural and composite elements. This symbiotic amalgamation serves to metamorphose the conventional hospital structure into an immersive healing environment reminiscent of a "flora" Table 2 presents the indoor demonstration of the Kolan Hospital building.

Fig. 2 Kolan hospital building

Table 2. Indoor demonstration of the Kolan Hospital building

 **a. A corridor connecting the patient wards**	 **b. A typical multi-bed ward section**
 **c. Patient bed-room ward**	 **d. Consulting room**

The conceptualization of a healing space characterized by a botanical metaphor, where patients find solace and tranquility amidst their therapeutic journey, underscores the holistic approach adopted by design. By leveraging advanced materials and design strategies, the hospital transcends its functional role to become a sanctuary that fosters not only physical recovery but also psychological wellbeing. This architectural narrative underscores the pivotal role of design in healthcare environments, where the built environment assumes significance beyond its utilitarian functions.

In transforming the physical space into a therapeutic milieu, Kolan Hospital Şişli epitomizes the convergence of technology, nature-inspired aesthetics, and compassionate care, thereby redefining the contours of contemporary healthcare architecture.

Table 3. Matrix of use of materials in the interior architecture of patient rooms at Kolan

Finishing Elements	Walls	Paint water-borne	-	+	-	-	-	+	-	+	-	-	-	+	-	-	+	-	-
		Wallpaper	-	+	-	-	+	+	-	-	-	+	-	-	-	+	-	-	-
		Wood laminate strip	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Glass	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Floors	PVC	-	+	-	+	+	+	-	+	+	-	-	-	-	-	-	-	-
	Ceiling	Wood laminate strip	-	+	-	-	+	+	-	+	+	-	-	-	-	+	-	-	-
		Plasterboard	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Finishing Elements (Bathroom)	Walls	Marble	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Marble	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Floors	Marble	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Ceiling	Paint water-borne	-	+	-	-	-	+	-	+		-	-	+	-	+	-	-	-
Furniture and Fixtures	Immobile	Acrylic zenith unit	-	+	+	+	+	+	-	+	+	+	+	-	-	+	-	-	+
		Metal laminate zenith unit	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Wood laminate strip wardrobe unit	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Acrylic bench	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Wardrobe acrylic unit	-	+	+	+	+	+	-	+	+	+	+	-	-	+	-	-	+
		Laminate door finish	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Mobile	Curtains	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Fabric	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Chair with artificial leather	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Patient-bed	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Wood laminate strip desk	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Wall protection type	-	+	+	+	+	+	-	+	+	+	+	-	-	+	-	-	+
Furniture and Fixtures (Bathroom)	Immobile	Closet set stainless steel	-	+	+	+	+	+	-	+	+	+	+	-	-	+	-	-	-
		Shower set stainless steel.	-	+	+	+	+	+	-	+	+	+	+	-	-	+	-	-	-
		Mirror 6mm	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Acrylic sink	-	+	+	+	+	+	-	+	+	+	+	-	-	+	-	-	+

As delineated in Table 3, the integration of natural and composite materials, alongside nano-based innovations such as wallpaper endowed with antibacterial and scratch-resistant attributes, nano-based PVC finishing characterized by antibacterial, easy-to-clean, and anti-fingerprint qualities, as well as nano-based laminate finishing imbued with antibacterial, easy-to-clean, fire-resistant, and scratch-resistant properties, has been effectuated within the confines of the patient room under scrutiny. Regrettably, the absence of air-purifying capabilities represents a conspicuous lacuna in this particular instantiation. This omission not only precipitates a dearth in indoor air quality but also engenders a reliance on artificial ventilation systems, the deployment of which often precipitates heightened energy consumption and an attendant augmentation in maintenance outlays. It is imperative to underscore that such systems may be deleterious to patient wellbeing, as they necessitate the periodic replacement of filters; neglecting this imperative maintenance measure can precipitate heightened indoor pollution levels, with deleterious ramifications for patient health. Furthermore, in juxtaposition to the predominance of natural materials characterizing the finishing elements within patient bathrooms, the procurement team has opted for nano-based furniture comprising acrylic components, affording commendable antibacterial, easy-to-clean, and fire-resistant properties. As encapsulated in Table 3, this departure from convention underscores a strategic commitment to furnishing the patient room with furniture possessing common attributes such as antibacterial, easy-to-clean, anti-fingerprint, and wear-resistant qualities.

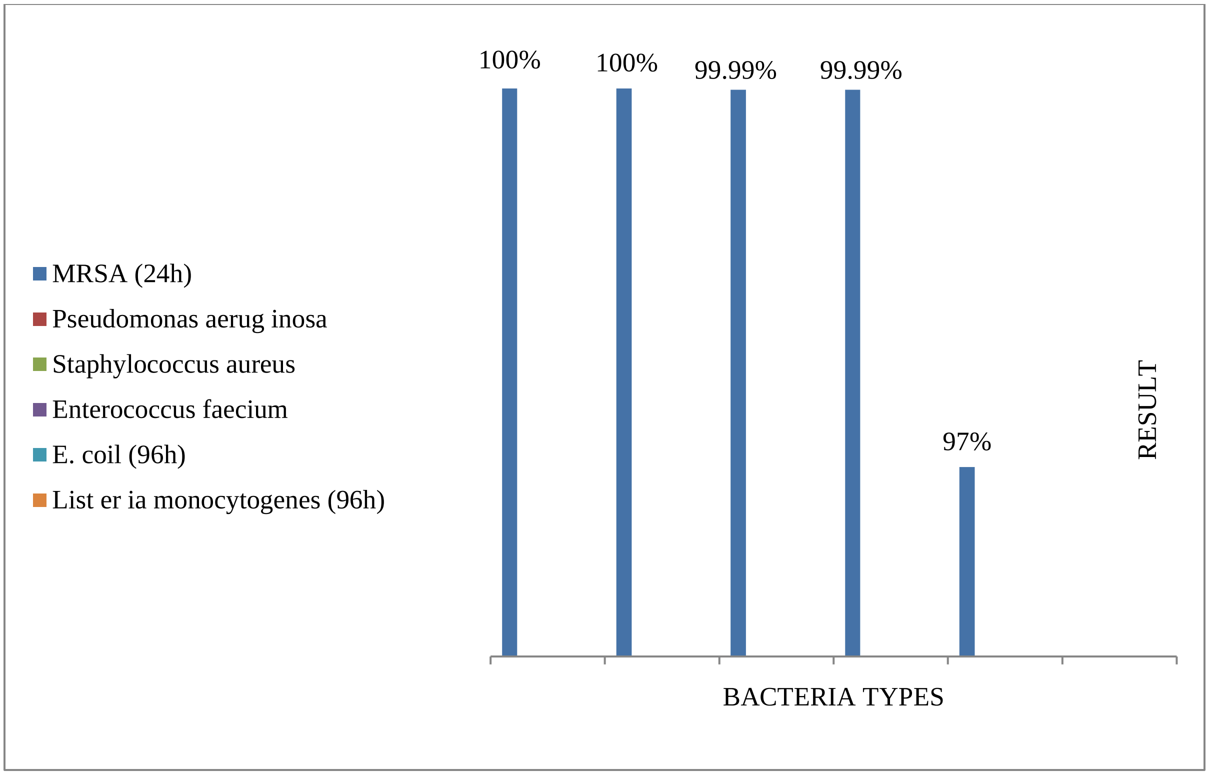


Fig. 3 The impact of applying Nano-coating to inhibit bacteria on surfaces

According to the findings from tests conducted by the Institute for Hospital Hygiene and Infection Control, nano-coating emerges as the most effective solution for combating bacteria, as depicted in Figure 3.

Integrating nanomaterials into hospital interior design presents a revolutionary method for enhancing functionality, sustainability, and patient wellbeing. This study explores the use of nanomaterials to improve various elements of hospital interiors, including temperature regulation, UV and solar protection, fire resistance, anti-graffiti properties, anti-reflective qualities, and anti-fingerprint capabilities. A thorough analysis, supported by data, will elucidate the benefits and challenges of these materials, offering a comprehensive understanding of their potential in sustainable healthcare design.

Temperature Regulating Qualities: Nanomaterials such as Phase Change Materials (PCMs) and nano-enhanced thermal insulators can substantially enhance thermal management in hospital interiors. PCMs absorb, store, and release thermal energy, contributing to stable indoor temperatures. Research indicates that integrating PCMs into building materials can decrease temperature fluctuations by up to 5°C, resulting in a 10-15% reduction in energy consumption for heating and cooling. Experimental data show that walls embedded with PCMs maintain indoor temperatures within the comfort range (20-24°C) more effectively than traditional walls, particularly during extreme external temperature changes.

UV and Solar Protection Qualities: Nanomaterials like titanium dioxide (TiO_2) and zinc oxide (ZnO) nanoparticles offer superior UV protection and solar control when used in coatings and films. TiO_2 nanoparticles can block up to 99% of harmful UV radiation, protecting interior surfaces and reducing cooling loads by minimizing solar heat gain. Tests of nano-enhanced solar control films reveal a reduction in indoor temperatures by 2-4°C, leading to significant energy savings in HVAC systems.

Fireproof Qualities: Nanomaterials such as nano-silica and nano-clay can enhance the fire resistance of building materials by improving thermal stability and promoting char formation. These materials can increase the fire resistance of building components by up to 30%, delaying ignition and reducing flame spread. Fire tests on nano-enhanced wall panels show a 50% increase in time-to-ignition and a 40% reduction in peak heat release rate compared to standard panels.

Anti-Graffiti Qualities: Nanocoatings with hydrophobic and oleophobic properties prevent graffiti from adhering to surfaces, facilitating easier cleaning and maintenance. Silane-based nanocoatings create a protective barrier that repels water and oil, preventing paint and other substances from sticking to treated surfaces. Field tests indicate that graffiti removal time is reduced by 70-80% on surfaces treated with anti-graffiti nanocoatings, with minimal damage to the underlying material.

Anti-Reflective Qualities: Nanomaterials such as silica nanoparticles can be used to create anti-reflective coatings that reduce glare and enhance visibility in hospital settings. Anti-reflective nanocoatings can decrease surface reflectance by up to 90%, improving the clarity of displays and reducing eye strain for patients and staff. Optical performance tests show that treated glass surfaces exhibit less than 1% reflectance, compared to 8% for untreated glass, significantly enhancing visual comfort.

Anti-Fingerprint Qualities: Nanocoatings with oleophobic properties prevent fingerprints and smudges from adhering to surfaces, helping maintain cleanliness and hygiene. Fluorinated silane-based nanocoatings repel oils and moisture, reducing the visibility of fingerprints on high-touch surfaces. Laboratory tests demonstrate a 60-70% reduction in visible fingerprints on treated surfaces, with performance sustained over multiple cleaning cycles.

3. Results and Discussion

3.1. The Application of Novel Nanomaterials in Interior Architecture

3.1.1. The Application of Nanometer Self-Cleaning Antibacterial Coatings and Finishing Materials

The realm of nanotechnology is actively engaged in the exploration of integrating self-cleaning antibacterial properties into coatings and finishing materials, which represents a significant area of research and innovation [37]. One notable application of nanotechnology in this domain involves enhancing the insulation properties of paints by incorporating nano-sized cells, pores, and particles. This integration serves to limit thermal conduction paths, thereby improving insulation efficiency. Presently, such paints find utility in corrosion protection under insulation due to their hydrophobic nature, effectively repelling water. Additionally, nanoparticle coatings demonstrate superior adhesion and transparency compared to traditional methods, particularly when applied to stone-based materials.

Nanometer-scale self-cleaning antibacterial coatings hold great promise for improving hygiene and reducing infection risks in healthcare settings. Surfaces endowed with photocatalytic properties possess an inherent antibacterial effect by decomposing organic substances in dirt [38]. The utilization of silver nanoparticles, renowned for their antimicrobial characteristics, facilitates the production of surfaces tailored to be antibacterial or germicidal.

The advantages of antibacterial nanosurfaces include targeted bacteria destruction, reduced reliance on disinfectants, and enhanced hygiene practices, particularly in healthcare environments. Silver nanoparticles enable the creation of surfaces specifically designed to combat bacteria and germs, whether through ultra-thin coatings or materials infused with the particles, presenting a robust alternative to antibiotics. Otherwise, exposure to light triggers the formation of TiO2 on surfaces where hydrophilic and lipophilic phases coexist, resulting in remarkable super amphiphilic properties at the nanometer scale. In industrial settings, the production of antimicrobial powder for coatings facilitates the formulation of bactericidal paints. When applied to building materials such as sanitary ware, indoor surfaces, equipment, and hospital environments, these coatings exhibit sterilization and cleaning capabilities. Nano TiO2 particles absorb shortwave radiation below 400nm wavelength during illumination, leading to electron excitation and the formation of electron-hole pairs, which subsequently transfer energy to the surrounding medium through photochemical and catalytic reactions.

The leaves of Lotus plants exhibit a remarkable feature whereby they are coated with minute wax crystals, measuring approximately 1nm in diameter, effectively repelling water. This phenomenon, commonly referred to as the Lotus effect, is widely recognized as a leading strategy for engineering surfaces using nanomaterials. The self-cleaning behavior characteristic of such surfaces is typically achieved through the utilization of hydrophobic surfaces with nanostructured attributes, as depicted in Figure 4. These surfaces draw inspiration from the natural design of Lotus flower leaves, which integrate nanoscale surface roughness along with a water-repelling wax composition. This effect can be deliberately engineered or replicated using nanocomposite materials comprising nanoparticles embedded within a polymeric matrix.

Another method employed in the creation of self-cleaning textiles involves leveraging the photocatalytic properties of specific nanoparticles, presenting a mechanism distinct from the renowned 'lotus effect'. Typically, formulations containing TiO2 or ZnO nanoparticles are applied as finishes or coatings to imbue textiles with self-cleaning capabilities [40]. The efficacy of TiO2 photocatalysis is contingent upon its crystal structure, particularly the Anatase grade, which exhibits remarkable photocatalytic activity against dyes and pollutants. Upon exposure to light energy surpassing the band-gap threshold, electrons within the valence band of nano-TiO2 and nano-ZnO undergo excitation, transitioning to the conduction band while generating electron-hole pairs in the valence band. In the presence of atmospheric oxygen, these excited electrons instigate the formation of oxygen free radicals (O2) by cleaving oxygen molecule bonds. Concurrently, electron holes in the valence band react with ambient moisture to yield hydroxyl free radicals (OH). Subsequently, these hydroxyl and oxygen free radicals catalyze the decomposition of organic compounds such as stains, dyes, microbes, and pollutants via oxidation and reduction reactions, respectively. The schematic representation of TiO2 photocatalysis is delineated in Figure 4.

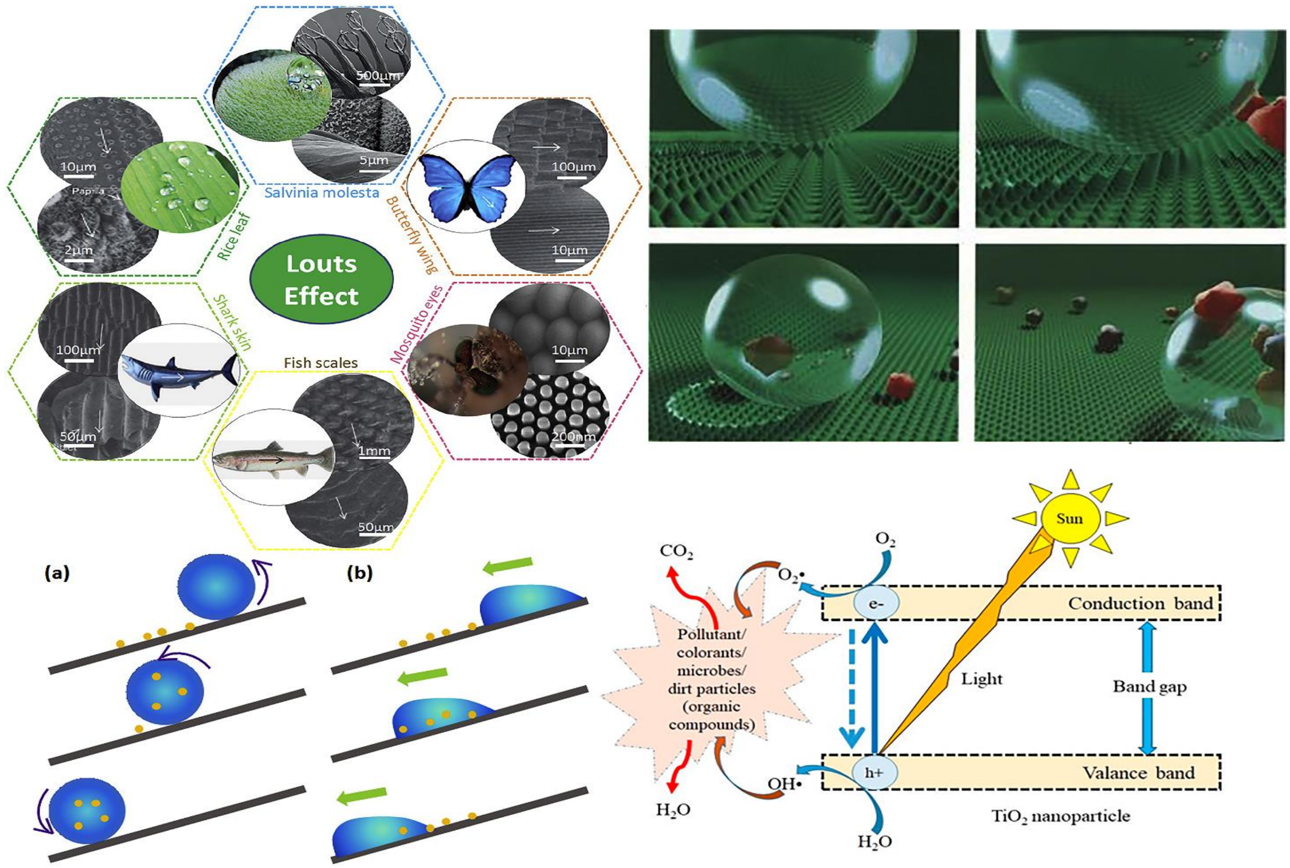


Fig. 4 Understanding how the Lotus-Effect operates and comprehending the photocatalytic mechanism of TiO2 nanoparticles [39]

Below is how the management process development nanomaterials healthcare in hospitals;

- The emergence of nano-coating paint, exemplified by Lotusan from Sto painting, showcases advancements in surface technology. Lotusan employs silicon nanoparticles to create a self-cleaning micro-structured surface, offering features like anti-graffiti and UV protection. Its application on the Commercial Building in Pula, Croatia, demonstrates long-lasting dirt resistance. Despite its efficacy, Lotusan's cost and environmental impact raise concerns. Its reliance on UV exposure also limits indoor use. Therefore, while promising for urban settings, its suitability requires careful consideration based on context and environmental factors [41].
- The application of nano-coatings to ceramics within hospital interiors presents a multitude of advantages. These coatings afford enhanced protection, cleanliness, and durability to ceramic surfaces, attributes of paramount importance in environments where hygiene is of utmost concern, notably within hospital settings. In the selection process of nano-coating for ceramic surfaces in hospital interiors, meticulous consideration of various factors is essential. These factors encompass the specific requirements inherent to the hospital environment, the characteristics of the ceramics undergoing treatment, and the durability and performance metrics of the coating under consideration. Collaboration with reputable suppliers and manufacturers specializing in healthcare-grade nano-coatings is indispensable to ensure compliance with requisite safety, efficacy, and performance standards within hospital contexts [42]. Furthermore, meticulous attention to surface preparation and application methodologies is pivotal in achieving the desired outcomes and optimizing the benefits of nano-coatings within hospital interiors.
- Nano-coatings applied to metal surfaces within hospital interiors play a pivotal role in maintaining cleanliness and safety standards. These coatings offer enhanced protection, cleanliness, and durability to metal surfaces, which is particularly vital in environments mandating stringent hygiene protocols, such as hospitals. The selection of an appropriate nano-coating for metal surfaces in hospital settings necessitates consideration of several factors, including the specific environmental demands of the healthcare facility, the characteristics of the metal substrate, and the performance attributes of the coating. Furthermore, the adoption of proper surface preparation and application methodologies is imperative to optimize results and capitalize on the advantages of nano-coatings in hospital environments [43].

- The process of nano-coating floors within hospital interiors entails the application of a thin layer of nanomaterials onto the surface of the flooring material. These coatings bring forth a myriad of benefits, including heightened protection, improved cleanliness, enhanced durability, resistance to stains and chemicals, antibacterial properties, and environmental friendliness [44]. By creating a cleaner, safer, and more durable environment, nano-coatings support the wellbeing of patients, staff, and visitors within hospital settings while concurrently mitigating maintenance costs and environmental impact.
- Fabrics imbued with antibacterial properties are designed to feature hygienic surfaces with self-cleaning capabilities. These textiles are infused with silver nanoparticles, serving as potent antibacterial agents whose efficacy is amplified at the nanoscale. Consequently, they possess the ability to neutralize a wide array of harmful bacteria. These advanced textiles offer increased cost-effectiveness, durability, energy efficiency, and environmental compatibility compared to conventional options. They find application in pillows, bedding, and various fabric products to mitigate bacterial proliferation. Moreover, nanotextile fibers can release aromatic substances, with nanocontainers absorbing odors or dispersing antimicrobial agents to inhibit bacterial growth. Utilization of ceramic nanopowders and fiber-polymer nanocomposites in finishing processes renders textiles fireproof, waterproof, or self-cleaning. Furthermore, decorative fabrics can be crafted utilizing nanoparticles with optical properties capable of altering color, akin to cosmetics [45]. Additionally, the integration of optical fibers into fabrics enables emitted light to fluctuate in response to physiological changes in the human body, effectively transforming them into medical monitoring devices.
- The application of nano-coating technology in wallcoverings represents a significant advancement in surface protection and functionality. Nano-coatings, consisting of nanoscale protective layers, are pivotal in enhancing the durability, antimicrobial efficacy, and maintenance ease of wall surfaces. Their utilization promises benefits, including resistance against scratches and stains, facile cleaning procedures, and augmented aesthetics. Employed through specialized application techniques, nano-coatings also address environmental concerns with reduced Volatile Organic Compound (VOC) emissions [45]. Moreover, ongoing research endeavors aim to refine nano-coating technology, envisioning tailored functionalities and heightened performance in diverse environmental contexts.
- Photocatalytic self-cleaning technology implemented in hospital interiors employs titanium dioxide (TiO_2) as a catalyst to break down organic compounds upon exposure to light, thus enhancing cleanliness and reducing pathogen transmission. These surfaces exhibit super-hydrophilic characteristics stemming from oxygen gaps present on the TiO_2 surface. In this mechanism, accumulated dirt is disintegrated and remains loosely adhered to the surface, subsequently washed away by a water film. The efficacy of this process relies on the presence of UV light, oxygen, and air humidity, thereby reducing maintenance demands in hospitals [46]. The decreased necessity for detergents contributes to diminished environmental pollution and reduced material degradation. Activation of the photocatalytic reaction necessitates exposure to UV light, which is readily available in natural daylight. Essentially, organic dirt on material surfaces undergoes decomposition facilitated by a catalyst, typically titanium dioxide, extensively utilized across various products. At a nanoscale level, titanium dioxide loses its white appearance, becoming transparent while exhibiting hydrophilic properties. Common applications of photocatalytic surface coatings include glass or ceramic facade panels and membranes. However, it should supplement rather than replace traditional cleaning methods for comprehensive infection control and patient safety. Figure 5 shows the management process of photocatalytic self-cleaning.

3.1.2. The Application of Nanotechnology in Air-purifying Indoors and its Healthcare Sustainability

The incorporation of nanomaterials presents a promising avenue for enhancing air quality by effectively mitigating unpleasant odors and pollutants, as highlighted in the realm of Sustainable Environment practices (See Figure 6). While nanotechnology does not serve as a substitute for ventilation systems, it significantly contributes to the enhancement of air quality by chemically breaking down odorous compounds into harmless constituents [47]. This process involves molecular breakdown, resulting in the emission of steam and carbon dioxide. The air-purifying characteristics inherent in nanomaterials offer substantial advantages for both indoor and outdoor environments. Furthermore, air-purifying curtain materials can integrate antibacterial properties, representing a dual-functional innovation [47]. The adoption of air purification technology is progressively gaining traction, particularly in the textile and paint industries. Antibacterial nanometer materials, encompassing series such as TiO_2, Ag, Cu, and ZnO, are commonly amalgamated with ceramic glazes or incorporated within ceramic surface layers. Such materials find extensive application in the production of antibacterial ceramic glaze tiles and sanitary ceramics, primarily used for decorative purposes in spaces like kitchens, bathrooms, and toilets. Moreover, the addition of far-infrared ceramic powder during the manufacturing process of antibacterial ceramics enables the creation of composite antibacterial health ceramics. These ceramics emit infrared radiation, thereby promoting microcirculation within the body, augmenting blood flow, and fortifying resistance against colds, diseases, and the aging process.

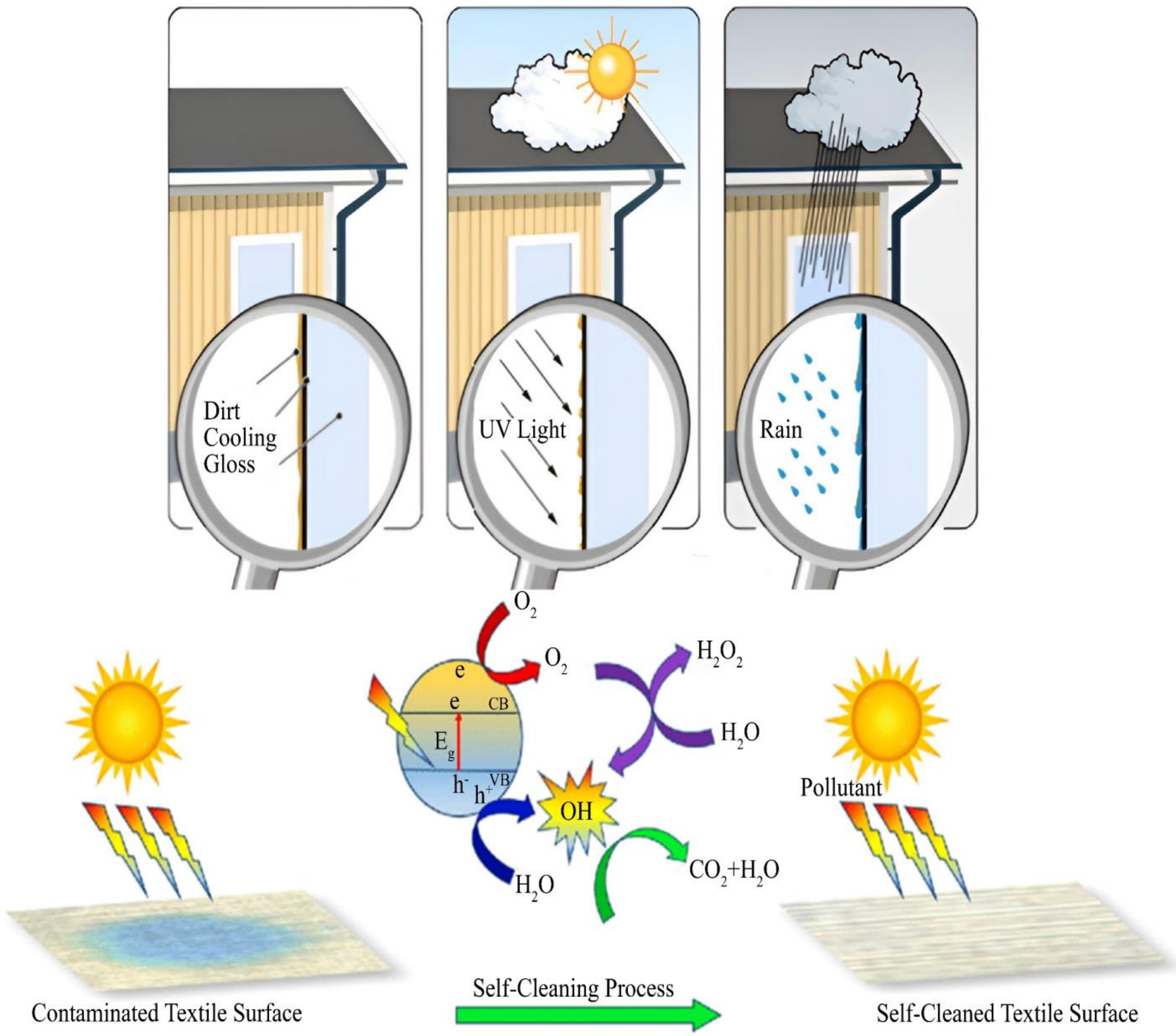


Fig. 5 Management process of photocatalytic self-cleaning technology applied in the hospital [46]

As depicted in Figure 6, nanomaterials offer several advantages, including manageable working conditions, minimal reliance on sophisticated equipment, and cost-effectiveness. The APN technology emerges as a highly promising solution for elevating air quality, particularly in hospital settings and urban environments. Its efficacy is particularly notable in confined spaces, rendering it a preferred option. Undoubtedly, there will be a growing global acknowledgment of the significance of APN technology in the years to come.

The most compelling argument advocating for the integration of nanotechnology in architecture centers around its potential to significantly enhance energy efficiency. Nanotechnology offers a novel technological avenue to address climate change and mitigate greenhouse gas emissions in the foreseeable future. Its application in construction is closely tied to the principles of sustainability, which encompass social, environmental, and economic dimensions.

Nanotechnology serves as an enabling force, unlocking a wide array of material functionalities and performance enhancements while simultaneously fostering new avenues for sustainability within the construction sector [48]. On one hand, nanotechnology enables the utilization of natural resources in a more efficient manner, allowing for the attainment of specific characteristics or properties with minimal material consumption. Additionally, it addresses critical energy challenges in buildings, including consumption and generation, as well as water treatment, among other areas.

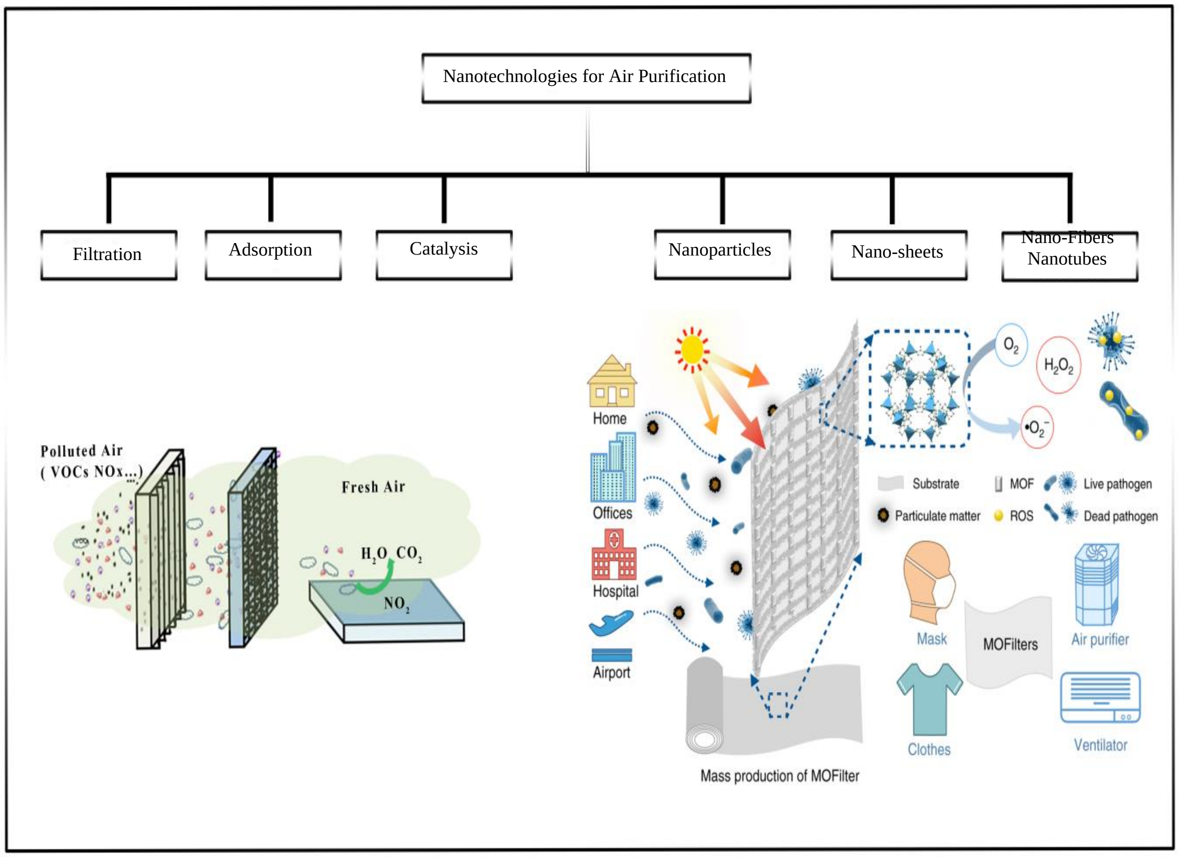


Fig. 6 Technologies used in healthcare to purify air using nanomaterials [47]

Sustainability, in its essence, entails the ability to meet the needs of the current global population without compromising the ability of future generations to meet their own needs. The distinctive attributes of nanomaterials significantly influence the pursuit of sustainability objectives, aiming to maximize benefits for both humanity and the environment while maintaining economic viability. Nanomaterials contribute to the creation of lighter, more compact, and resilient buildings, thereby reducing construction costs and preserving land for the benefit of future generations. This approach emphasizes the importance of maintaining natural materials and landscapes, such as mountains, plains, and forests, in alignment with the overarching concept of sustainability. Table 4 elucidates the advantageous implications (T) and potential drawbacks (F) of integrating Nano Technology into hospital infrastructure. This analysis draws upon a comprehensive review of pertinent literature conducted within the scope of this study. The table initiates with an examination of sustainability pillars encompassing economic, social, and environmental dimensions, which collectively inform the overarching assessment. Notably, the adverse impact of Nanotechnology appears to be negligible, underscoring the predominantly positive outcomes associated with its application. Of particular significance is the commendable ability of Nanomaterials to mitigate energy loss by facilitating temperature regulation within the interior environment while requiring minimal energy input for maintenance. This underscores the efficacy of Nanomaterials in averting energy wastage, thus contributing positively to sustainability efforts within hospital settings.

The comprehensive evaluation presented in Table 5 underscores the prevalence of positive effects, as demonstrated by the significantly higher positive scores and measures compared to negative ones. This highlights the crucial role of Nano Technology within the scope of this study. The summarized findings in Table 4 are succinctly referenced in Table 5, offering an overarching assessment of Nanomaterials applied in hospital construction. The results, expressed in percentages, provide a condensed overview of the outcomes outlined in Table 4. Positive effects are predominant at 71.1%, while negative effects amount to 19.2%, with 9.5% deemed ineffective. The substantial prevalence of positive effects at 71.1% outweighs the combined negative and ineffective aspects, underscoring the significant efficacy of Nano Technology in hospital design and management.

Table 4. Analysis of nanomaterial criteria standards for buildings

S/N	Nanomaterial's Types	Positive Effect (T)	Negative Effect (F)
Nano coating	Powered light Works with natural UV Fluorescent light High performance Environment friendly Decomposition of endotoxin	-Improves IAQ (indoor air quality). -Reduces using of toxic chemicals. - Reduces the risk of surface bio-contamination. - Reduces the time of cleaning and disinfection process.	- can easily enter the body and interact with cells and tissues in ways larger particles cannot. Some studies suggest that certain types of nanoparticles could have toxic effects on the body.
Nanoparticle types	Silica nanoparticles Carbon nanotubes Aluminium oxide nanoparticles Clay nanoparticles Iron oxide nanoparticles Copper nanoparticles	- Improve reinforcement in mechanical strength. - Rabid hydration. - Increased compression strength. - High self-cleaning. - Mechanical durability. - High crack prevention. - Increased serviceability and compression ability. - Increased surface roughness. - High abrasion resistance. - Increased compressive strength. - Reduce weldability and corrosion resistance formability	- Breathing in tiny particles could have a negative effect on our lungs. - Difficulties in production and experience needed in terms of usage. - Meaning standards are not fully clarified
Insulations coatings	Color and reproducible paints Self-cleaning Scratch resistance Photocatalytic effect and antimicrobial Fire retardant UV protection IR absorbing	- Prevent crack formation. - Enhanced resistance to fading. - Dirt and water repellent. - Anti-graffiti protection. - Protection against fungi and algae. - Enhanced scratch resistance.	- Nanoparticles could accumulate in organism's overtime, and we are unaware of the long-term effects. - Human health and the environment have not been fully determined. - Control and repair methods are needed.

Table 5. Test analysis matrix criteria for the effect of nanotechnology

Effect of the Nano Technology																				
S/N	**Criteria**	Powered light	Works with natural UV	Fluorescent light	High performance	Environment friendly	Decomposition of endotoxin	Silica nanoparticles	Carbon nanotubes	Aluminium oxide nanoparticles	Clay nanoparticles	Iron oxide nanoparticles	Copper nanoparticles	Color and reproducible paints	Self-cleaning	Scratch resistance	antimicrobial	Fire retardant	UV protection	IR absorbing
1. Optimizing the space consume		T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T
2. Energy consumption		T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T
3. Energy and loss prevention		T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T
4. Minimizing the cost of transportation		T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T

5. Minimizing resource consumption	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T
6. Reduce work cleaning time	T	T	T	T	T	T	T	T	T	T	F	F	F	F	F	F	F	F	F
7. Keep maintaining average indoor	F	F	F	F	F	F	F	F	F	F	T	T	T	T	T	T	T	T	T
8. Reduce minimal environmental gas	T	T	T	T	T	T	T	T	T	T	T	T	T	T	F	F	F	F	F
9. Reduce chemical substance usage	T	T	T	T	T	T	F	F	F	F	F	F	F	T	T	T	T	T	T
10. Long lifespan	F	F	F	F	F	F	T	T	T	T	T	T	T	T	T	T	T	T	T
11. Ease of application	T	T	T	T	T	T	T	T	T	T	T	T	F	F	F	F	F	F	F
12. Reducing the need for repair	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	F	F
13. Increase indoor air quality	T	T	T	T	T	T	T	T	T	T	T	T	T	F	F	F	F	F	F
14. Prevents the spread of bacteria	T	T	T	T	T	T	T	T	T	T	T	T	T	T	F	F	F	F	F
15. lighting using reflective Nano	T	T	T	T	T	T	T	T	T	T	T	T	T	T	O	O	O	O	O
16. High brightness and efficiency,	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	F	F	F	F
17. Reduce costs of cooling a room	T	T	T	T	T	T	T	T	O	O	O	O	O	F	F	F	F	F	F
18. Energy saving	T	T	T	T	T	T	T	T	T	T	T	T	T	T	F	F	F	F	F
19. Required colour filtering	T	T	T	T	T	T	T	T	T	T	O	O	O	O	O	O	O	O	O
20. Effects on human health	T	T	T	T	T	T	T	T	T	T	O	O	O	O	O	O	O	O	O
21. Observe on Nanoscale	T	T	T	T	T	T	T	O	O	O	O	O	O	O	O	O	O	O	O
22. Recyclable and reusable	T	T	T	T	T	T	T	T	T	T	T	T	F	F	F	F	F	F	F

4. Conclusion and Recommendations

Nanotechnology has emerged as a promising avenue for producing hygienic products that are both safe for human health and environmentally friendly. It is increasingly recognized as a potential solution to environmental challenges, particularly those associated with building construction. This study specifically focuses on exploring the effects of nanotechnology on the performance of finishing materials in hospital environments. Through the use of nanocomposites, nanotechnology has the potential to enhance various aspects of interior design in hospitals, including aesthetics, light filtration, thermal and sound insulation, and overall environmental quality. These enhancements have been supported by studies and tests evaluating the performance of nanomaterials within interior spaces. The advent of nanotechnology holds significant promise for revolutionizing building performance, energy efficiency, and sustainability in construction projects. Consequently, nanoarchitecture is poised to become a defining architectural trend of contemporary times, contributing to the creation of a more sustainable society. In today's context, where energy conservation, cost efficiency, environmental stewardship, and the responsible use of natural resources are paramount considerations for sustainability, the role of nanotechnology and nanomaterials in architecture and design cannot be overstated. The integration of nanotechnology into architectural practices aims to achieve advanced efficiency and functionality in spatial solutions. Architects and interior designers are encouraged to familiarize themselves with the benefits of using nanomaterials and their potential impacts on human health and the surrounding environment. This understanding will enable informed decision-making and promote the responsible application of nanotechnology in design endeavors.Future research can be achieved at the intersection of three axes (Resilience-Mitigation, Maintainability-Improvement, and Changeability-Transition) that enable hospital buildings to Survive, Evolve, and Thrive and will be conducted on patients' perceptions and opinions about the capacity of existing hospitals to handle current and future pandemics, and six key trends will inform the future design of hospitals: pandemic preparedness, climate resilience, connectivity with the rest of the healthcare ecosystem, flexibility, digital transformation, and patient centricity.

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