REVIEW ARTICLE

Investigation and Application of Nanomaterials in Sustainable Architecture

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ABSTRACT

The review article seeks to highlight current developments in the investigation of nanotechnology in sustainable architecture. Nanotechnologies play an important role in architectural design. In fact, building materials combined with nanotechnology developed smaller, with work better than current materials. Some of the developments on the application of nanotechnology on sustainable architecture comprise the improvement of the durability and strength properties of concrete; production of self-cleaning surface, glass, thermal and *moisture* nano-insulation. Any alteration at the nanoscopic level of concrete, ceramic, glass and surfaces and its constituent influences its behavior, including its strength, durability and self-cleaning characteristics. In fact, nanotechnology further influences architecture and design and even design ideas in the world by introducing new materials and how to use energy. Sustainable architecture can be achieved by using materials produced from nanotechnology correctly. The unforeseen consequences of the development of this technology should also be considered.

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1. Introduction

In recent years, various technologies are applied to generate more comfort, security and cost savings, particularly in the consumption of energy resources. Nanotechnology is one of the new technologies for which a very bright future is predicted and the scope of impact of this technology has been so wide that it is said that this technology can affect most aspects of human future life and therefore use the approach [1]. It is very important to be suitable for this phenomenon and to have sufficient knowledge of different fields of its applications. In this technology, by synthesizing materials at the nanometer scale, it is possible to control the intrinsic properties of materials, including chemical composition and melting temperature. Significant advances in various fields from engineering to medicine as well as the provision of suitable materials and heating and cooling equipment have become possible by this science [2].

Today, sustainable architecture in all relevant fields is one of the current issues in the world of architecture, in which nanotechnology can play a significant role, especially through building materials and consumables [3]. In fact, the role of this technology in the production of materials and materials with greater strength, lighter and cheaper than current materials, how to make materials and the materials more resistant to climate change such as acid rain and corrosion caused by chemical reactions, cold and heat.

Antibacterial and self-cleaning nanoceramics and surfaces that are used in final coatings as glazes are also very effective in strengthening; Thin, insulated glass with very high resistance, hardness and smart against weather changes; concrete only with high flexibility, lighter and stronger, and at the same time insulating against water and moisture and transmitting natural light; steels resistant to decay and corrosion, etc. All these phenomena show only close and accessible perspectives of this technology. Nanotechnology also plays a significant role in the construction industry, with steel, glass and concrete industries playing the largest role. The application of nanoparticles in the construction industry, the most important of which are titanium oxide carbon nanotubes, generally increases the mechanical properties of the samples in the main structures and in the joinery section, the application of nanocoatings in the interior and exterior of buildings is of special importance. They repel water and minimize dirt absorption, making the facade UV resistant. These coatings cover surfaces such as cement, brick, pottery, ordinary stone, tile, marble, wood, ceramic, glass, steel and concrete. Construction of reinforced concrete, self-repairing, self-cleaning, self-cleaning glass, fire-resistant and energy-controlling ? result in energy savings. The use of nanoscale paints that prevent bacteria from penetrating office and residential buildings. Hospitals, etc., giving them a long life, a bacterial-free environment, and a non-dirty and degradable nature are other important applications of nanotechnology in the construction industry.

In this review article, we define the recent applications of different nanomaterials that affect the aspects of sustainable architecture. In sections 2, 3 and 4, the definition of nanomaterials, types of nanomaterials and the role of nanotechnology are discussed. Then the review focuses on the applications of nanomaterials in sustainable architecture (Section 5 and their subsections). Finally, Section 6 draws conclusions on the current state-of-the-art in the field, and future direction.

2. What are Nanomaterials?

Nanotechnology implied as the technology that deals with the synthesis of materials that are measured from 1 to 100 nanometers. Nano is neither a substance nor an object, but only a scale. Nanomaterials are materials that have at least one of their dimensions on a scale of 1 to 100 nm. Decreasing the particle size by the nanometer causes changes in their physical and chemical properties [4].

The history of nanoparticles dates back to many years ago. Their first use was in Chinese glazes. In a Roman cup called the Licergus Cup, gold nanoparticles were used to create different colors of the cup according to the way the light radiated. The first nanotechnology was ignited in 1959 by Richard Feynman, and experts such as Peter Edon introduced this superior technology in architecture [5].

3. Application of Nanotechnology

Nanotechnology has changed the lives of human society. This emerging technology has been incorporated into many knowledge and achievements, and researchers have achieved significant results. This technology, along with two other major developments in genetics and information technology will mark the fourth wave of the industrial revolution. Nanotechnology is a phenomenon that has found its way into all scientific trends, to the extent that over the next decade, the superiority of processes will depend on this evolution. Nanotechnology is another step towards developing powerful tools for building metropolises and anti-gravity halls. Nanotechnology has additional applications in the pharmaceutical and medicinal industries alike delivery systems. After particle sizes are wont to nanometer, the possessions affected through this decrease are their response to light. This outcome managed the creation of nanoglues with significant applications in optoelectrics manufacturing as a whole [6, 7]. Table 1 lists various uses of nanotechnology in different fields.

The uses of nanotechnology in civil engineering comprise nanoscale additives in boring grimes, as a means of cumulative the drawing from reservoirs, in order to the construction of catalysts in the gas, and petrochemical productions, in order to the manufacture of nanocoatings that are resistant to eclipse, scrape, heat, to improve energy efficacy, in the manufacture of nanosensors, to decrease pollutants, besides progress technologies [8].

4. Types of nanomaterials

The nanoscale occurs between 1 and 100 nm. In fact, materials with at least one dimension below one micron but larger than one nanometer can be measured as nanomaterials [4]. The most classification of nanomaterial is made according to their dimension, as zero-dimensional (0-D), one-dimensional (1-D), two-dimensional (2-D), and three-dimensional (3-D), as shown in Figure 1. The division of different materials can be done based on their structure, properties, applications and even dimensions. Nanomaterial classification based on their dimensions is one of the most interesting divisions. These four types of nanostructures have significant differences both in terms of synthesis and production methods, as well as in terms of properties and applications [13]. Electrical, optical, and magnetic properties of these nanomaterials are very different and as a result, each of them will have unique applications [14].

1D and 2D nanostructures can be showed for high electrochemical properties than 0D nanostructures. As shown in Figure 2, 1D and 2D nanostructures have large surface area than 0D nanoparticle (NP). Active materials with 1D or 2D nanostructures show various exclusive appeal, and they have been widely studied in order to high-performing electrodes in energy storage and conversion systems. While 2D nanomaterials have great surface areas. 1D nanomaterials display the lower surface area however they are comparatively stable [15].

Table 1. Application of nanomaterials in different fields

Applications	Discription	Ref
medicinal and pharmaceutical	• Production of biosensor systems for the detection of diseases and analytes • Application in drug and gene delivery • Production of artificial tissues compatible with the body • Better health care using nanometer equipment inside the body	[4, 9]
Environment	• Decreased consumption of materials and energy • Production of solar energy	[10]
Agriculture and Food	• Application in fertilizer compounds by nanoscale coatings, or nanomaterials	[8]
Civil engineering and information technology	• Potential for faster and smaller computers with greater memories than current technologies	[11]
Architecture	• A great effect on construction materials and their properties • Reduce the high costs of construction and maintenance of structures	[12]

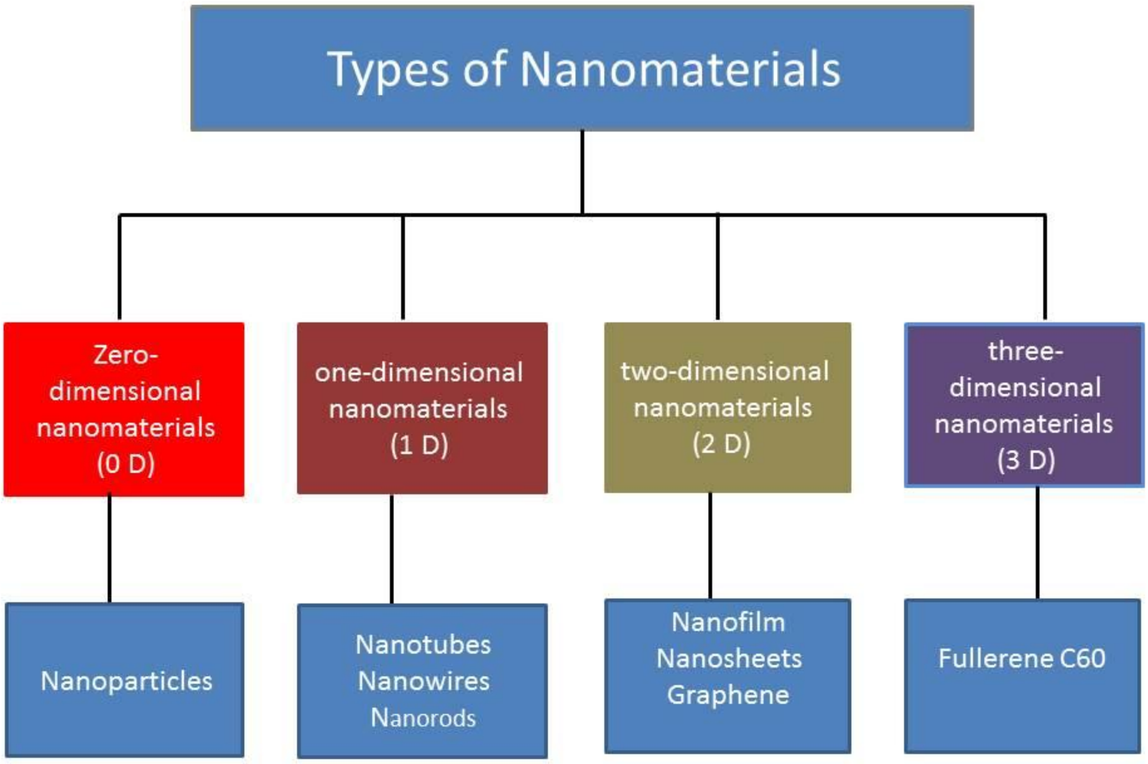

Figure 1. The overview of different nanomaterials in this article

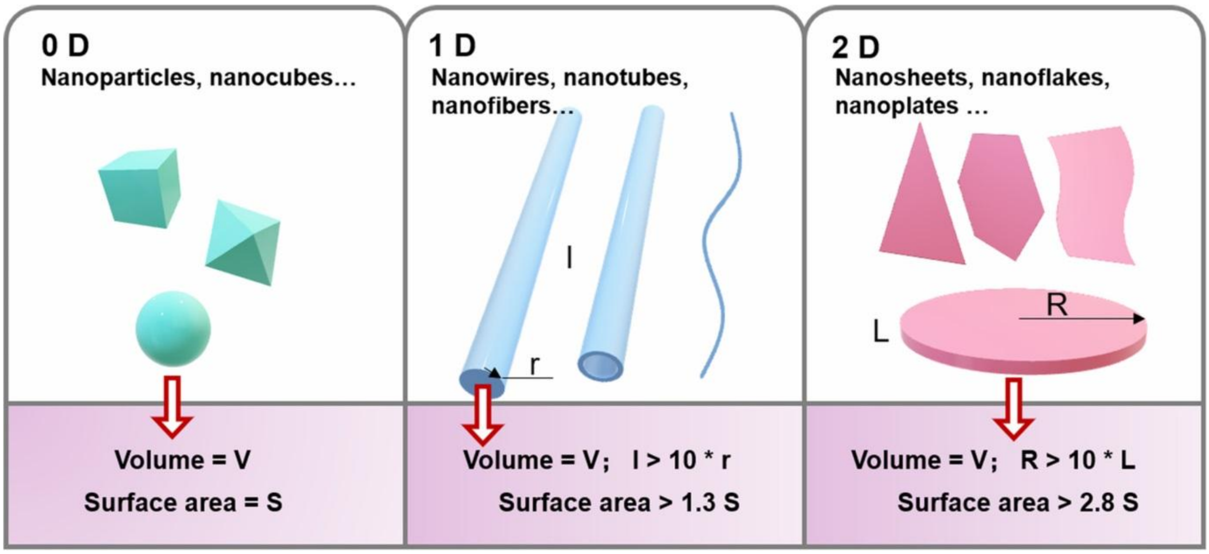

Figure 2. Schematic illustration of the 0D, 1D and 2D nanostructured materials. The surface areas of 1D and 2D nanostructures are greater compared to 0D- dimensional nanoparticles, if the same volume *V* is preserved [15]

4-1- Zero-dimensional nanomaterials (0 D)

In this type, all the dimensions of the nanoparticles are in the nano range. Nanoparticles, as a 0D dimensional nano materials, do not have dimension outside the 1 to100 nm [16]. Nanoparticles can be showed in various shapes, and their small scale tempts an alter in essential properties [17]. This properties can be establish in the quantum dots, which are nanocrystalline particles comprising a few hundred atoms. Quantum dots can be applied in the design of road reflectors that will show incident light [18]. Magnetic NPs can be applied to identify specific biological entities, including diseases and microorganisms [19]. The use of Zero-dimensional nanomaterials in architecture will existent new chances to solve limitation and lead the construction architecture and structure to an optimal level through refining meaningfully the nature of building structure and efficacy and the way buildings relate to the environment.

4-2- One-dimensional nanomaterials (1D)

1D nanomaterials, are materials in which one or two dimensions are on a nanometer scale and no longer on a nanometer scale; or one dimension is outside the nanoscale. One-dimensional nanostructures are divided into several categories depending on parameters such as dimensional ratio, and include nanorodel, nanowire, and nanotube. This nanomaterials can be used as surfaces and thin films in chemistry and electronics [20].

Nanotubes and nanowires have one long axis, and a cross-section that is within the 1-100 nm range. Carbon nanotubes (CNTs) are mechanically very strong materials. Nanotubes are much more powerful than steel and are therefore used to increase strength in many composites [21]. Another application is the production of CNTs fibers, which can be used for a variety of applications. By incorporating these fibers into building materials, their mechanical properties will improve. With the use of carbon nanotubes and the production of various composites, the properties of building materials can be improved. A single-wall CNTs has well electrical and mechanical properties. A multi-wall CNTs, has semiconductor properties, such as GaN, SnO2, and nanowires of ZnO, which are pretty to the microelectronic industry [18, 22].

Metallic nanowires (NWs) as one-dimensional nanomaterials (1D) have been studied due to good mechanical flexibility and good thermal and electrical conductivity. This nanomaterials can be measured as engineering materials due to their good behavior [23]. In recent years, study into NWs has fortified development technologies in different areas, such as energy-efficient *buildings*, electrochromic devices, and flexible transparent conductive films.

4-3- Two-dimensional nanomaterials (2D)

In two-dimensional nanomaterials (2D), two dimensions are outside the nanoscale. This type of materials shows nanofilms, nanosheets, nanocoating, graphene, and nanolayers. This type of nanomaterials is deliberated as the thinnest nanomaterials according to their dimensions and thickness on nanoscale. There are layered structure by strong bonds and weak van der waals among layers in 2D nanomaterials. One of the applications of 2D nanomaterials is to enhance the antibacterial effect according to the large surface area and easy surface operation, as well as intimate interactions with the bacterial membrane. [24, 25].

4-4- Three-dimensional nanomaterials (3D)

Three-dimensional nanomaterials (3D) are materials that are not kept to the nanoscale in any dimension. This type of nanomaterials can comprise nanotubes, powders, nanowires, and nanotubes [2]. 3D nanomaterials can applied in construction applications including structural reinforcements, and high efficient lubricants [26].

5-1- Application of nanomaterials in Nano-coatings

In recent years, *nanoparticles* have been added to coatings to progress their mechanical and chemical properties [27]. Nanocoatings are types of thin films that are chemically or physically applied to different surfaces and have a thickness of less than 100 nm. Nanocoatings are often very transparent due to their very low thickness and are composed of nanoscale particles in their structure and are used for various mechanical, chemical and optical properties [28]. Nanostructured materials in coatings are defined as one-dimensional, two-dimensional and three-dimensional nanometer shapes. Conventional structures therefore include coatings containing particles, nanowires, nanorods, nanotubes, and nanofibers [29]. Nanotechnology and nanocoatings used in building materials can be used for glass, stone, wood, steel, ceramic, brick, tile, cement and concrete surfaces, etc., and for various applications such as corrosion-resistant coatings, coatings anti-scratch, self-cleaning, hydrophobic, and gas detector. Studies on nanocoatings have shown that their properties in many cases are significantly better than conventional coatings. Nanocoatings have greater coefficient of thermal expansion, and hardness and more resistance to abrasion, corrosion, and erosion compared to micrometer coatings.

5-1-1- Self-cleaning surface and glass

The self-cleaning process includes several solutions such as hydrophobic, and the process of photocatalysis is important. In fact, self-cleaning does not mean that there is no need to clean at all, in fact, in this process, the distance between cleaning becomes longer. Tiles and ceramics are among the most widely used building materials that can be used in different parts of a building. If hydrophilic surfaces are used, these surfaces will remove the chemical structure of the contaminants in the presence of light under the process of photo catalysis. Coatings made of titanium dioxide (TiO_2) nanoparticles are known for their ability to perform light-dependent activities due to their self-cleaning behavior, which increases with increasing size and increasing the ratio of surface area to volume. Different types of oxide semiconductors, including TiO_2 [30], ZnO [31], Cu_2O [32], etc. have been extensively applied in the field of photocatalysis.

TiO_2 could become the metal for architectural applications in world. Japan is the first country that has made an effort to apply this nanomaterial in architectural uses [33]. However various countries such as USA, have also stared applying this field, although, its application in developed country such as India is still restricted. Titanium has become of competitive building material, which can be combined with a plenty of refined ore and raw is needed in order to an enhanced obtainability of the material for large scale apply in building industry. Construction materials with TiO_2 photo catalyst display acts of self-cleaning, air purification, self-water purification and antibacterial action [34].

Air pollution is one of the greatest important factors that damage the facade of buildings, the use of self-cleaning materials in combination with paints of the building facades, can be effective in maintaining facade of the building for a long time [35]. The catalytic procedure as an oxidation procedure could be applied as assay in order to degradation of hazardous materials on building facades. In a study, it was suggested that TiO_2 be used instead of painting the entire building to preserve the building appearance. In this study, three types of dyes were mixed with TiO_2 and the coatings were coated on smooth strophomy sheets. These coated sheets were covered with black and white stains. TiO_2 oxidized most of the pollutants that covered the flat sheet after exposing these plates to waterfalls and the UV. Therefore, it can be expected that the mixture of paint components and TiO_2 is strong. Here, the electrons can transfer into the paint components and reduce the chance of recombination of the electrons /h+. O_2 can be adsorbed on the surface of TiO_2-paint and reacts with the electrons in order to form the O_2 radicals. This O_2 radical adsorbed the pollutant on the TiO_2 surface. The produced OH through TiO_2, oxides the adsorbed pollutant on the surface of the sheet. Figure 3A showed the appliance of photo-catalytic activities of TiO_2 inside the painted surfaces.

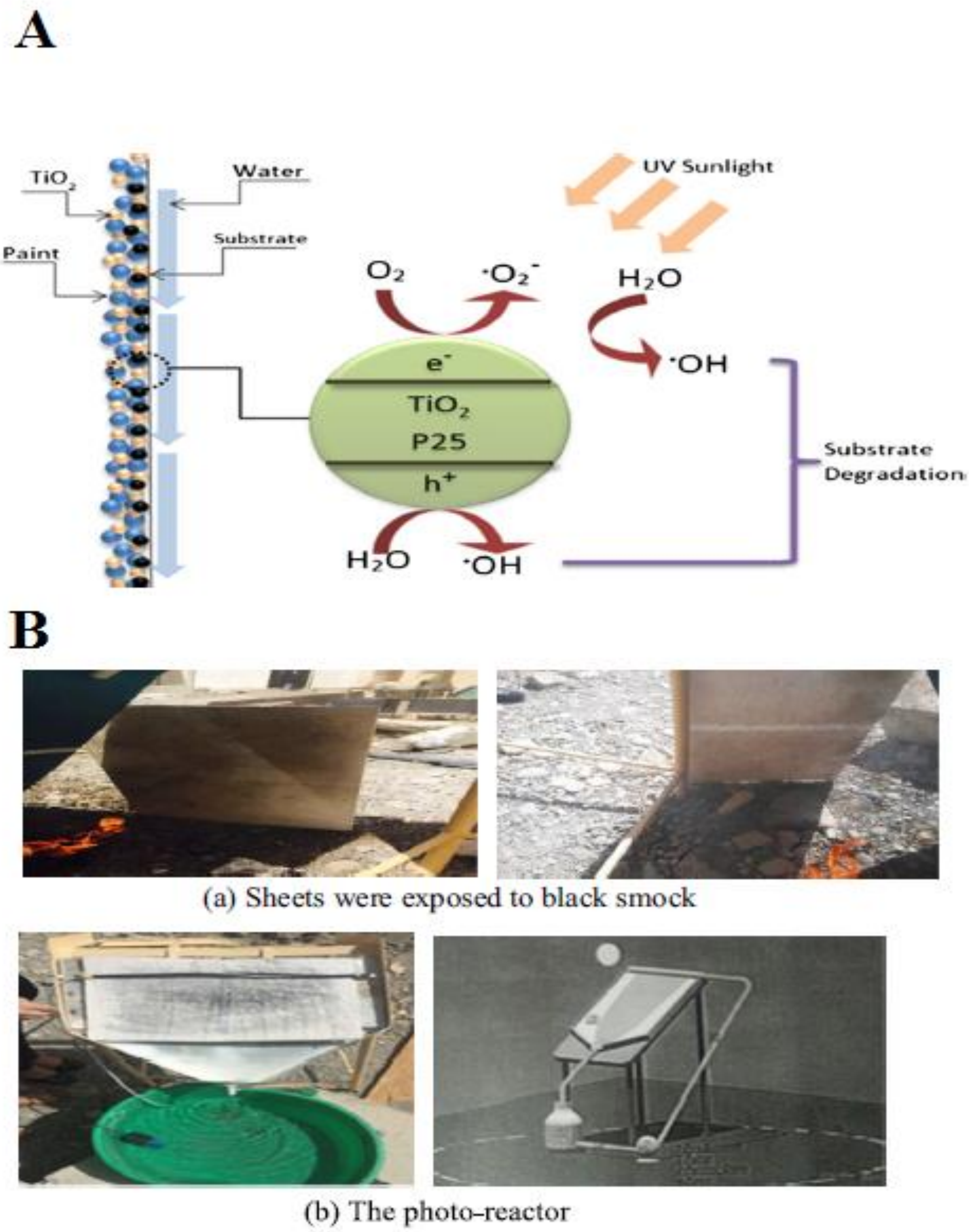

Figure 3. Schematic illustration of the mechanism of photo-catalytic activities of TiO_2 inside the painted surfaces (A);and experimental photos and systematic diagram (B) [35]

In addition to TiO_2 nanoparticles, other nanoparticles such as ZnO oxide (ZnO cadmium), SiO_2, and zirconium (sulfide) (CdS), are used. Among photocatalytic materials, ZnO attracts significant nanomaterials interest according to its photo electronic and chemical properties. ZnO is considered through a wide band-gap like anatase TiO_2, suitable location of conduction, and low cost

[36]. ZnO is incorporated in the coating in order to improve the hydrophobicity. In a study, researcher showed that the polyvinylidene fluoride (PVDF)-based self-cleaning coating improved by ZnO nanoparticles on aluminum panels through improving the level of hydrophobicity [37]. Hikku et al. prepared Ag-doped ZnO nanoparticles synthesized through a facile gel-combustion assay with self-cleaning properties. Self-cleaning coating is synthesized by 1 % SDZO, and the photo-catalytic degradation of solution through SDZO nanoparticles is spectroscopically tracked using UV-Vis spectroscopy. As a result, the rate of degradation of 1 % SDZO nanoparticles is obtained greater compared to other samples under UV light [38].

5-1-2- Antibacterial and antimicrobial nano-coating

The nano-products used for this purpose are in the form of coatings and paints containing special nanoparticles that adhere to the surface of traditional materials. In some other methods, nanoparticles are used in combination with traditional materials. The use of antibacterial coatings on tiles, ceramics and surfaces and their use in hospitals and clinics can prevent the spread and transmission of pathogenic bacteria and prevent the spread of disease among people [39, 40]**.** Silver nanoparticles, ZnO, CuO, TiO_2 and nickel oxide (NiO) have strong antimicrobial properties. This material is capable of eradicating the most of microbes and bacteria [41].

The anti-microbial properties of nanoparticles such as ZnO and TiO_2 according to their photocatalytic activities. Figure 3 showed the photocatalytic procedure happening on the self-disinfecting surfaces [42]. TiO2 has been broadly studied as photo catalyst based on its ability to create surface reactive oxygen species (ROS). ROS produced from photo catalysts can inactivate pathogens through destroying macromolecules [43]. TiO_2 nanoparticles with a size of about 5 nm were applied to functionalize glass slides and glass microfiber filters. The biofilm-forming *Staphylococcus aureus* and *Pseudomonas putida* grew on TiO2-functionalized surface. UV light irradiation for 2 hours causes damage to the bacterial cell membrane by production of ROS radicals, and the decrease of cell viability was over 99 % for TiO_2 on glass surfaces. In fact, this study showed the significance of bacterial colonization during dark surface and the problems in eliminating the bacteria biofilms (Figure 3).

The antimicrobial potential of ZnO can according to creation of ROS, release of zinc ions and cell membrane destruction. The mechanisms depend on the properties of ZnO nanoparticles. Valenzuelaet al. developed a sol-gel method to synthesis ZnO suspensions with size of 100–300 nm for producing electrosprayed coatings. A low-cost scalable Electrospray technique has the ability to convert droplets into solid particles to produce a thin coating. These electrosprayed coatings showed antibacterial activity in contrast to *Staphylococcus aureus*, with >99% decrease in the number of cultural cells. Antibacterial activity is due to the production ROS on the surface of ZnO coatings and Zinc ions. These photoactive coatings reserved various surfaces free from microbial colonization [36]. One of the most significant properties of ZnO nanoparticles is their capacity to escape biofilm formation of pathogenes on historical buildings [44]. Some microorganisms are involved in the process of biodeterioration and changes in the properties of materials, which is one of the important factors in the destruction of cultural heritage along with other factors for instance climate. In 2020, Schifano et al. showed the antimicrobial activities of ZnO-nanorods (Zn-NRs) and graphene nanoplatelets decorated with Zn-NRs (ZNGs) were assessed in contrast to the Achromobacter spanius and

Arthrobacter aurescens on stones and surfaces.

Silver nanoparticles (AgNPs) have important properties, especially according to their antimicrobial activity, against wide ranges of bacteria [45]. Ag-incorporated titania coatings can prevent biofilm formation of S. epidermidis by regulating the expression levels of related genes (icaR and icaA for S. epidermidis). Ag-nanoparticles were arranged on Ti surfaces to progress a delivery platform for controlled release of Ag nanoparticles. These levels have the ability to regulate the expression of genes associated with biofilm creation in order to reduce bacterial adhesion and bacterial growth [46] (Figure 4). Table 2 showed the examples of various nanomaterials with anti-microbial properties.

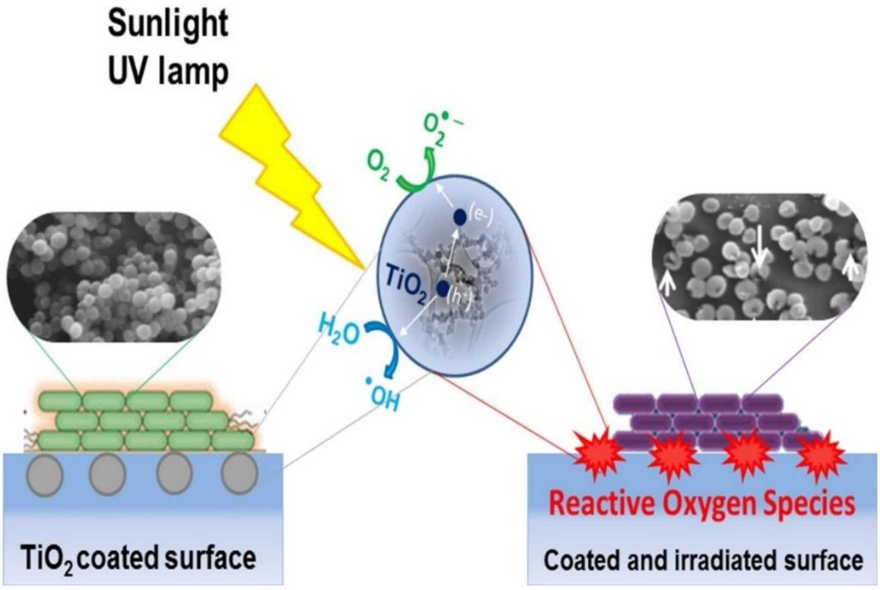

Figure 3. Schematic illustration of self-disinfecting TiO_2 coated surfaces [42]

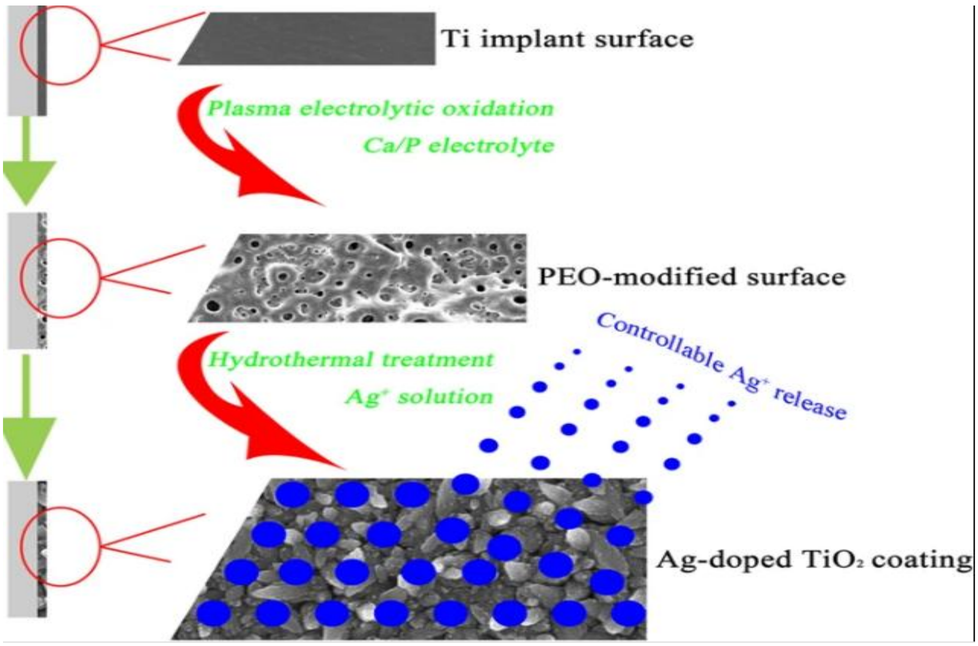

Figure 4. Schematic illustration of the fabrication procedure for the Ag-doped TiO2 coating [46]

Table 2. Examples of nanomaterials with anti-microbial properties

Types of nanomaterials	Types of pathogenes	Ref
TiO_2	P. putida, S. aureus	[42]
Silver	S. aureus, Shigella flexneri, S. pneumonia	[47]
ZnO	L. monocytogenes, E. coli O157:H7, *Bacillus subtilis*	[48]
Graphene oxide	S. aureus, E. coli	[49]
Selenium dioxide	S. aureus, Proteus mirabilis, P. aeruginosa	[50]
Gold nanopaticles	*Corynebacterium pseudotuberculosis*, S. pneumoniae	[51, 52]

5-2- Application of nanomaterials in nano-insulations

In sustainable architecture, one of the important solutions is decreasing the consumption of the fossil fuels. Studies have shown that buildings worldwide are able to account for 32% of final energy consumption and one third of direct CO_2 emissions and particulate matter in 2012 . In fact, this high energy consumption could be due to a lack of insulation. Poor heat and humidity and low air conditioning efficiency. As a result, the commitment of countries to reduce energy consumption and greenhouse gas emissions to increase the energy efficiency of buildings has increased in recent years, and more than 50% of the current global building stock will continue to be in 2050 [53].

There are different common thermal insulation materials, such as rock wool, polystyrene and fiber glass. However, these materials have various disadvantages, including poor structural strength, low deformation resistance, and non-biodegradable in the environment. The use of nanomaterials with very low thermal conductivity can be architecturally interesting because the use of nano-insulating materials (NIMs) to reduce wall thickness while maintaining insulating properties can be used as an important strategy in the path of sustainable construction [54]. The use of nano insulating products in the building envelope is deliberated to customary insulation materials. The analysis demonstrations that their apply in structures is an actual solution to progress the thermal presentation of the envelope, permitting to resolve the purposes of energy consumption decrease [53]..

Aerogel is an ultralight material of superior thermal and acoustic insulation belongings. The basic material is silica, with a particularly low thermal conductivity. Then synthesis of aerogels based on chrome, aluminum, and carbon aerogels were developed. Since of vacuuming air, the coefficient of thermal conductivity is 0.0010 W/mK, and has a thermal tolerance of 500 °C. Aerogels are also used as a good sound insulating material. With these properties, this material can be used as a highly durable, hydrophobic and anti-flammable material in buildings. However, compared to other common materials, it has a higher cost [55]. By adding nanogels to other systems, materials with high thermal insulation properties can be made depending on the percentage of aerogels, which varies from 80-95 %. These plasters have water resistance properties, and are also resistant to microbial agents due to their mineral composition. They are also used as sound insulation due to their porous structure [56].

Some of other nanomaterials that can be applied in order to building purposes are CNTs, TiO_2, silicon dioxide, and etc. The applications of these nanomaterials as a composite with other materials, and their action as thermal insulations will be improved to get an effective use of energy [57-59].

Nanocomposites have been widely reported in thermal insulation and conduction. Polymer-based nanocomposites show the low weight and low cost, as well as worthy corrosion resistance that make them in order to composites to be applied for thermal insulation. In fact polymer nanocomposite indications improve the properties of polymer itself. Insulating polymeric nanocomposites with great thermal conductivity have pronounced potential in order to apply as thermal-management materials in optoelectronics. However, current composite materials need a large amount of electrically conducting fillers. Flexible nanocomposite films with linear densely packed BN structures (LDPBNs) show a thermal conductivity of 1.5 W/mK [60].

Polyurethane (PU) is one of the most versatile polymers with high compatibility and thermoplastic properties. In a study, thin thermal building insulation material using PU-clay nanocomposite *via* solution intercalation method was developed. These PU nanocomposite showed the probable to absorb more water and this properties may help benefits in making thermal building insulation material [61].

Researcher used an environment-friendly and low-cost material for example date pits (DP), as an effective thermal insulator material for buildings. Date pits are described through water insolubility and stability, and high mechanical strength. Synthesized DP nanoparticles in this study, displayed a semi-homogenous mixture of DP0S50E with no detected changes. The thermal conductivity of the DP0S50E obtained 0.26 W/mK, and it showed the lowest thermal diffusivity. As a result, DP0S50E polymer can be applied as a coating material for buildings with a thickness of 10 mm. This polymer is efficient in using 6% energy and eliminating CO_2 emissions through 6% , and is able to decrease the cost of energy used in existing buildings [62].

However, there is a need for thermal and acoustic insulation to reduce energy waste at all industrial applications and processes are in great demand and much effort is needed to make greater use of nanotechnology for this purpose.

5-3- Application of nanomaterials in concrete and cement

Concrete is used as one of the significant materials in the construction industry. Natural pozzolanic powder is added to concrete to increase durability, reduce the cost of concrete production and reduce environmental pollution caused by cement production which reduces the strength in the early ages of concrete. Recently, the applications of nanoparticles for progressing the properties of concrete have attracted the attention of numerous researchers in concrete technology. According to the role of nanomaterials in improving the bulk properties, they can be suggested in producing the concrete [63]. Nanoparticles can make a filler result through refining the intersectional zone in cement and creating more bulk concrete [64]. Nanotechnology can improve the properties of the concrete and help to get a faster setting times and thinner products [65].

Silica is one of the most important materials that can be applied in the manufacture of concrete [66]. Other nanoparticles such as titanium oxide, carbon tube and nano-alumina can be used in nanoconcrete [67, 68]. In a study, Qing et al. [69] showed that adding nano silica to concrete compounds can increase the performance of concrete. Due to their suitable size, these nanoparticles can act as good filler in concrete. The micro-cavities in the concrete can be compacted and provided a neat concrete microstructure. Another advantage of these nanoparticles is that they control resistance by controlling the ratio of water to cement.

Some studies have shown that the addition of nano-silica in a specific dose can increase and improve the resistance of HSC and also these particles can act as a substitute for cement. Considering the reduction of 20 to 30% of cement content by nano-silica, it can be concluded that this material can act as a suitable alternative to cement. In some countries, silica is also used in the concrete industry [70].

Carbon nanotubes (CNTs) are 1D nanomaterial with a hollow structure which can be categorized as single-walled carbon nanotubes (SWCNTs) and multi-walled carbon nanotubes (MWCNTs). The length and diameter of these nanoparticles are about 50 μm with an aspect ratio larger than 1000 [71]. Various researches have been carried on the role of nanoparticles in concrete applications, for example, cement-based materials comprising 0.036 wt.% and 0.018 wt.% and 0.036 wt.% MWCNTs were synthesized and cohesion of them were assessed after several days of aging. The results showed that adding of 0.036 wt.% CNTs enhanced the cohesion through 24% and 19%, respectively, and causes the enhanced shearing resistance [72].

CNT in ultra-high performance concrete (UHPC) has the property of flexibility which can increase flexibility and strength as well as improving the UHPC tensile and compressive capacity. The steel reinforcing section can be replaced with CNT, which allows additional loads to be carried. In fact, it is believed that by replacing steel in UHPC, lighter and lighter sections can be created, reducing construction time and cost. However, due to the high cost and scarcity of CNT resources, interest in using CNT in UHPC has decreased [73, 74].

In one study, the compressive and tensile strength of CNTs in concrete was investigated. In this study, CNTs with size 2 were used. Also, several mixes were equipped, with 0.01%, 0.02%, and 0.03%, CNTs through weight of cement, along with a control mix without CNTs. The outcomes showed that the addition of CNT can increase the compressive, tensile and bond strength of specimens compared to control. Also, SEM analysis for control samples and CNTs exhibited that CNT samples have a good structure compared to the control sample and CNTs can act as a bridge among microcracks [75].

Titanium oxide (TiO_2) is the happening oxide of titanium. Addition of TiO_2 to the cement can be caused the manufacture of acoustic baffles [76]. Addition of TiO_2 to concrete, in addition to its effect on self-cleaning properties, can also increase the strength of concrete for example, the act of concrete increases resistance in concrete. Mainly, these effects are delivered through TiO_2 in UHPC and concrete according to TiO_2 that is capable of acting as glass layer outside the concrete. Its function is that in order to improve the performance, TiO2 in concrete can form a fiber-reinforced system. Refining the hydration gel through acting as fiber pay to the strength improvement and more durable concrete [77].

Other researchers described the improvement of concrete microstructure by using TiO_2, which improved its mechanical strength. In this study, concrete samples with different weight ratios of TiO_2 were examined and compressive strength was also investigated. According to Table 3, the strength of cement is inversely proportional to the weight ratio of TiO_2 at different *temperature*s. Here, strength of concrete first increases and then decreases with increasing weight ratio of TiO_2. In this assay, when the weight ratio of TiO_2 nanoparticles is 2%, the strength of concrete spreads the extreme rate. Furthermore, the concrete with TiO_2 nanoparticles reached an extreme compressive strength that was 7% greater compared to the non-added nanoparticle concrete [78].

5. Conclusion and Future direction

In recent years, developments have led to negative effects on the environment. Therefore, the issue of sustainability and in the architecture, the issue of sustainable architecture has been proposed, which seeks to minimize the negative environmental effects of buildings in order to increase productivity and moderation in the usage of materials and energy. Therefore, nanotechnology is one of the newest technologies in the world, which is actually the science of controlling matter at the molecular scale. Nanomaterials can progress the mechanical belongings of Portland cement. SiO_2 nanoparticles progress the compression strength of Portland based concrete. Nanomaterials including TiO_2, silica, CNTs, zinc oxide, and graphene give good results in order to Portland cement based concrete. The nanotechnology based systems are stronger than outmoded systems and are eco-friendly materials. After this, the nanomaterials will be replaced with bricks and the provisional materials will not be applied. Novel carbon-based nanomaterials can be applied to make most buildings safer. There is also a need for smart appliances in order to the design and construction of buildings with self-cleaning surface, colored coatings, and light-sensitive appearance. For thermal insulation, polymer nanocomposites are outstanding nanocomposites in order to these ends.

These components are able to communicate with users and are changing. In general, the pervasive impact of nanotechnology on human life and how it relates to the environment and buildings is inevitable and unimaginable. Therefore, nano-based materials should gradually replace traditional materials in order to create enormous delivery in the construction industry. On the other hand, providing architectural designs based on the morphological structure and nano-cells will be an antidote for today's form-based buildings.

Table 3. Strengths of concrete at various temperatures [78]

Entry	**Weight ratio of TiO2**	**20 C**	**155 C**	**-20C**	**-40C**
1	0%	36	31	49	49
2	2%	39	34	60	64
3	4%	34	31	56	65
4	6%	37	33	51	65

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