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Review Article

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Role of Nanotechnology in Building Smart Cities

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Abstract

Developing cities that are environmentally friendly, greener, and smarter is urgently needed due to the rising urbanization and resource scarcity. The concept of "smart cities" is crucial from the standpoint of the growing urban population and intelligently meeting demand. Nanotechnology is used in a wide range of industries, including manufacturing, agriculture, biomedicine, and military hardware. Nanotechnology can create smart cities by exploiting distinct nanomaterials for energy storage, smart building construction, infrastructure, smart textiles, environmental remediation, and nanoscale imaging innovations, just to name a few. The authors of this article have tried to offer insight into the ways that nanotechnology can be applied to the creation of smart cities.

Keywords

Nanotechnology, Smart-city, Nanomaterials, Urbanization

Introduction

We have experienced that the urbanization of society has increased exponentially in the past few decades. Everybody is moving toward the cities to earn their livelihood and good education. This rapid growth of the population has challenged the essentials such as food, clothes, energy, and land all around the world. Ensuring sustainable access to fundamental, smarter, and better amenities is essential for the population. Furthermore, it will be difficult to satisfy all the demands of the enormous population if the extraction of resources from finite sources, is also a key contributor to global climate change. Cities have exhausted their capacity for expansion, environment, and security concerning the current population. At the current time, more than 50% of the population is residing in urban settlements, and by 2030 it is expected to be more than 66% [1]. This situation has created undue pressure on the cities. Visionaries and town planners are finding the solution for low carbon emissions, a post-carbon economy, and improving energy efficiency. Cities are the major contributors to climate change. Cities cover only 2% of the earth's space consume more than 78% of the available world energy and emit around 60% CO_2. Significant energy consumption and numerous connected devices in recent years have drawn the attention of the authorities to find a solution. To answer this problem, developing smart cities is the smart solution. Smart cities are modern areas whose purpose is to serve the needs of industries, institutions, and the population. Smart city technologies are in terms of availing services like infrastructure, energy consumption, and other resources. The basic features of smart cities consist of smart transportation systems, smart traffic light systems, smart buildings, smart homes, smart schools, smart energy, smart industries, smart offices, smart environments, and smart waste management depicted in figure 1.

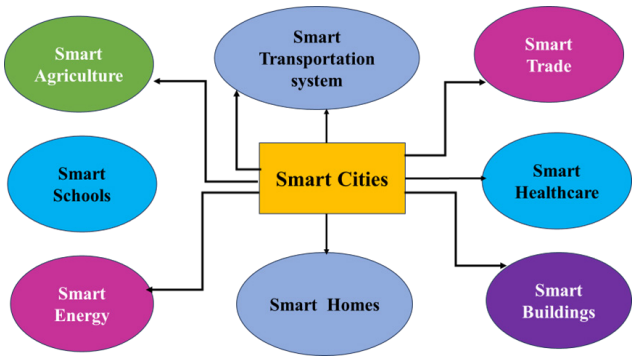

Figure 1: Different fields of smart cities.

Nanotechnology is one of the emerging fields of science useful for developing smart cities. The field of nano-science concentrates on the study, measurement, control, and production of materials at the nanoscale scale. The word nano means very small, the size ranges between 1 to 100 nanometres (nm) length on the scale, Nanotechnology is used to control the one billionth of the meter [2]. In the scientific field of nanotechnology, materials, and structures' impacts and functions are being tried to be controlled. With exceptional sensitivity and accuracy, nanotechnology has the power to regulate and characterize substances and structures on the nanoscale. A typical material's structure may be altered through nanotechnology, or entirely new materials and devices may be developed. Numerous industries, including those in the fields of medicine, the environment, agriculture, transportation, aerospace, materials, manufacturing, electronics, computers, and energy have benefited from the development of nanotechnology. Even while nanotechnology research has had some success, some significant problems remain to be resolved. The gadgets employed in the fabrication process, the fabrication methods, and the testing of nanostructures are among these difficulties. Nanomaterials are classified into 0D (amorphous), 1D (amorphous), 2D (amorphous), and 3D (crystalline) [3]. The classification of the nanomaterials based on their dimension is explained in table 1. Nanomaterials have a large surface area and are extremely flexible, light, conductive, and resilient. We can create materials with incredible capabilities thanks to nanoparticles, which are useful in every aspect of daily life.

Table 1: Categorization of nanomaterials on size [4].

S. No.	Class	Nature	Examples
1	0D	Crystalline	Single crystal-like or polycrystalline nanoparticles
2	1D	Amorphous or crystalline	Nanotubes, nanowires, nanofibers, nanorods
3	2D	Amorphous or crystalline	Nanofilms, dendrimers, nanolayers, nanotextured surfaces or thin films, nanocoating, etc.
4	3D	Crystalline	Quantum dots, fullerenes, nanoparticles, nanocrystals, colloids, nanoshells, nanorings, etc.

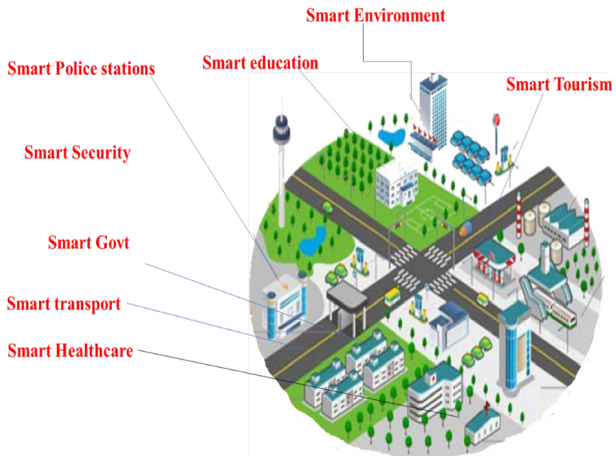

Figure 2: Modern smart city component.

Components of Smart Cities

In this section, the components of a smart city are discussed as shown in figure 2.

Smart homes

Smart homes are the most prominent part of smart cities, as citizens can avail the facilities using the concept of Internet of Things [4]. The important feature of smart homes is automation. The core objective of automation is to minimize the human effort. The equipment at home is controlled remotely. The automation system works on wireless technologies that have several advantages over wired technology. Smart homes have made human life easier through automation [5]. The nanomaterial TiO_2 is used as a membrane, hydrophilicity, photocatalyst, adsorbent, interior and exterior paint pigment, thin film on glass windows, climate control, sensors, and more [6].

Smart schools

Smart school is one of the areas of smart cities. Smart schools are integrated through computing devices with sensors, smartphones, and other systems to cloud computing with the association of the IoT. Smart school will make easier the monitoring of children and the provision of information regarding their whereabouts in the school setting for teachers, parents, and schools as users. It is suggested that student monitoring be done via an IP-based CCTV system that can identify and detect persons. The technology can make face identification verification issues easier to handle with the support of beacon chips used for student identification. When using beacon chips and transmitter signals, a generic technique known as fingerprinting is utilized to locate items. This enables the location of a student's face to be determined based on the user's position. Then, using a combination of fingerprinting methods and facial recognition data from the camera, the face verification process is carried out [7].

Smart transportation systems

Smart transportation systems are the much-needed system of smart cities. The improvement of stainless steel's mechanical and thermal properties by oxide nanoparticles that are uniformly spread on the material. By nanoengineering cementitious materials like steel and concrete, one can increase the tensile strength of roads and transportation while also lowering the cost [8].

Smart energy

Scientists are more interested in producing clean, efficient, and economical energy from renewable sources of energy since nanotechnology has applications in both traditional and alternative energy sources to meet the enormous need for energy. Energy is one of the critical factors that must be addressed if smart cities are to be developed. The nanomaterial ZnO is used to photocatalyst greenhouse gas emissions.

Smart environment

The ecology will be directly impacted by the expansion of metropolitan areas with high population increases. Consequently, it is crucial to keep an eye on and remove environmental pollutants. Several photocatalysts, including TiO_2, SnO_2, and ZnO, can be utilized with nanomaterials to detect water pollutants and cure water pollution. For effective water filtration, a molybdenum disulfide membrane containing nanopores can be used [7].

Smart textiles

Smart textiles are made of fabrics that are built to include technology that provides the wearer with better functionality. These fabrics may connect to different devices, transmit signals, transform into other valuable resources, and protect the wearer from ecological hazards, among other functions. To create wearable textiles that can track health, safety, and healthy lifestyles, research into the production of these materials has risen significantly.

Smart agriculture

The excessive use of fertilizers and pesticides has decreased the productivity of soil as well and the excessive use of these is very harmful to humans. Numerous solutions are offered by nanotechnology for issues in the agricultural sector. Advanced biosensors and nanoparticle or nanochip materials are highly useful in agriculture. The regulated and gradual delivery of agrochemicals and nutrients to plants is facilitated by nano-mediated fertilizers, herbicides, and insecticides. Ag, ZnO, and TiO_2 nanoparticles are very beneficial for treating plant diseases [6].

Smart health care

To diagnose and treat diseases, nanotechnology is helpful. Nanoparticles are excellent host mediums for marking the right medications for different types of cancers. These new techniques aid in focusing treatment on cancerous cells or organs while preserving the effectiveness of healthy tissue.

Smart building

Innovative approaches for the creation of smart structures for modern facility-enabled cities are made possible by nanotechnology. Advanced nanomaterials and nanotechnology can help with building design and more environmentally friendly materials while also increasing energy efficiency. By incorporating nanosized TiO_2, SiO_4, clay, and Al_2O_3 particles into cement, numerous unique cement composites are created [6].

Role of Nanotechnology in Smart Cities

In this section, the role of nanotechnology in different types of components of smart cities is discussed. The relationship between nanomaterials, Nanotechnology and smart cities is presented in figure 3.

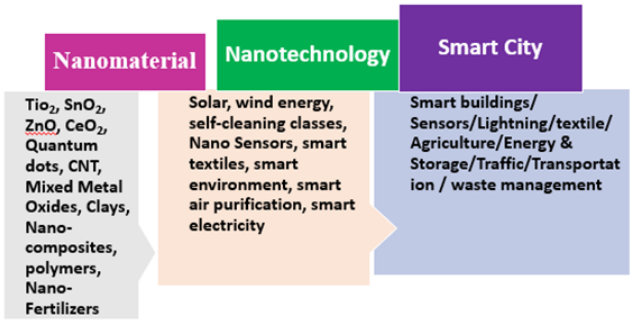

Figure 3: Role of nanotechnology in smart cities.

In agriculture

Nanotechnology applications are also being created to increase crop yield and soil fertility. Magnetic nanoparticles may clean up contaminated soil, and nano-sensors could keep an eye on crop and animal health. The development of "lab on a chip" technologies may also have a big impact on underdeveloped countries. The primary purpose of fertilizer in agriculture is to supply the full complement of macro and micronutrients that soil typically lacks. Fertilizer is necessary for 35-40% of crop yield; however, some types of fertilizer can have a direct impact on plant growth [9]. Nanotechnology can be a source for finding a more intelligent technique to get around all these drawbacks. Since fertilizers are the primary issue, creating nano-based fertilizer would represent a new development in this technology area. These inorganic fertilizers are delivered to offer the three primary components, nitrogen, phosphorous, and potassium in similar quantities. Fertilizers are sprayed in numerous methods, either on soil or through leaves, even in aquatic habitats.

In Internet of Nano-Things (IoNT)

For the moving messages from a distant room to the nano-hubs based on electromagnetic nanonetworks, End-to-end unshakable quality in nanonetworks and the IoNT needs to be ensured. The construction of the previously unseen machinery for future nanomachines is currently the focus of many professionals. Because of the novel characteristics of the nanoscale and the structure of nanonetworks, the data and correspondence society must provide novel arrangements for correspondences. Among the promises expected from the IoT field are unique nano-receiving wire designs, nanoscale channel models, data encoding as well as adjustments for nanoscale systems, and protocols for nanonetworks. The majority of IoNT investigations focus on biomedical applications [10].

In 5G wireless communication

Mobile wireless communication technology is a 5G technology, which will be widely accessible in the market. It has appealing qualities. When accessing the data, there is

no traffic and a high bit rate. Since nanotechnology is used to create 5G technology, it will benefit a variety of vocations as well as our society. Based on mobile communication, nanotechnology, and all IP networks, the 5G technology will aid in fostering the connection between individuals operating in diverse industries. It is a technological advancement that is intelligent and can operate on a nanoscale. There will be more opportunities with 5G technology [11].

In power grid system

Smart power grids are thought of as the monitoring, integrating, and intelligent control of all the components of the current electrical power system. The fundamental purpose of the smart grid is to use the existing infrastructure to supply the rising electricity demand. The primary foundation of a smart grid is the integration of distributed resources into the electrical grid. Power electronics play a crucial role in regulating the smart grid. It is a representation of the grid's regulated devices [12]. The field of nanotechnology tries to regulate the impacts and usefulness of materials and structures. With exceptional sensitivity and accuracy, nanotechnology has the power to regulate and characterize materials and structures on the nanoscale.

In smart textiles

Smart textiles are designed to support various functions of smart cities like transmission of signals to different smart devices. To create wearable textiles that can track wellbeing, protection, and beneficial lifestyles, research into the production of these materials has risen significantly. By altering diverse features including water-repellence, self-cleaning, antimicrobial, and UV protection, coating nanoparticles on the outside of textiles improves their functioning and usefulness [13].

Smart health care

To diagnose and treat diseases, nanotechnology is helpful. Nanoparticles make excellent host mediums for marking the proper medications for different types of cancers. These new techniques aid in focusing treatment on cancerous cells or organs while preserving the effectiveness of healthy tissue.

Sustainable development approach

The breakthrough in nanotechnology has a favourable impact on architecture. One of the most effective contemporary approaches to creating sustainable buildings with high functional efficiency is the use of nanotechnology. Nano architecture is a field that deals with structure and building by using nanomaterials like SiO_2, items, or even nano-shapes. Nanotechnology provides techniques that can support the sustainable development of structures having fire retardant and mechanical properties, etc. [14].

Conclusion

In this paper, the various aspects of nanotechnology used in the development of smart cities are discussed. The different nanomaterials such as nano-polymer, nano-porous materials, NPK, zeolites, nanosensors, metal oxides and their applications in the development of smart city components are discussed. The uses of nanomaterials can improve the efficiency of construction and can improve the design and performance. Nanomaterials can be widely used in the development of medical scans and drugs that can be used for the treatment of critical diseases. The full development of smart cities in different smart city components still faces several obstacles that must be overcome.

Acknowledgements

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Conflict of Interest

No potential conflict of interest was reported by the authors.

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