Nanotechnology and its Role in Product Sustainability

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Abstract:
The research revolves around activating the role of modern technologies as a solution for developing products to achieve sustainability. Nanotechnology is considered one of the most important technologies that work on developing material properties and creating new materials. The problem addressed by the research is the failure to achieve sustainability in the design of some products due to the prevalence of many commonly used traditional products made from environmentally harmful materials and production methods that do not meet sustainability standards and represent a burden on the environment that is difficult to address. The research discussed the concept and importance of sustainability in product design, the historical development of material use in product design, and the development of new material properties in product design. It also discussed nanotechnology, nanomaterials, and their impact on developing product properties. Can new materials be used through nanotechnology to develop products and support them with properties that achieve sustainability? The research also aims to demonstrate how sustainability can be achieved in product design by transforming environmentally harmful traditional products into sustainable products by replacing harmful materials with new nanomaterials. It sheds light on the role of nanotechnology and the resulting nanomaterials in achieving sustainability in product design by developing their properties.

Keywords:
Product development, Sustainability, Nanotechnology, Nanoproducts, Sustainable products

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Introduction:
The research revolves around developing products and directing designers to focus on development processes to achieve product sustainability. The problem lies in the proliferation of many traditional and commonly used products that are manufactured from environmentally harmful materials and production methods. Therefore, there has been an increased focus on modern technology as a means of achieving sustainability in products. Nanotechnology is one of the most important modern technologies that has great potential for achieving sustainability goals. This technology involves manipulating materials at the nanometer level, allowing the creation of materials with improved properties and functions. The research focuses on developing traditional products by integrating newly developed materials using nanotechnology and the properties that these materials have added to the products to achieve sustainability. Nanomaterials play a crucial role in developing traditional products to produce more sustainable alternatives. Nanomaterials have unique physical and chemical properties that allow them to enhance the functions of traditional products, making them stronger, more durable, and resistant to damage and corrosion. By integrating nanometer technology in the development of industrial products, energy consumption efficiency can be improved, waste can be reduced, and environmental impact can be minimized.

Problem Statement:
Sustainability of products is one of the most important trends that designers should focus on in product development processes. The problem lies in the failure to achieve sustainability in the design of some products due to the prevalence of many conventional products that are commonly used, which are manufactured from materials and production methods that are environmentally harmful, and do not meet sustainability standards, posing a burden on the environment that is difficult to address.

Aims and Objectives:
The research aims to:
1- Demonstrate how sustainability can be achieved in product design by transforming traditional products with negative environmental impact into sustainable products through the replacement of harmful materials with newly developed nanomaterials.
2- Highlight the role of nanotechnology and the resulting nanomaterials in achieving

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sustainability in product design through the enhancement of their properties.

Hypothesis and Methodologies:

1- If it is possible to develop traditional products by replacing their materials with innovative nanotechnology materials, this will contribute to increasing the rates of achieving sustainable principles for these products.
2- Environmental problems can be addressed, and the sustainability rates of traditional products can be increased by replacing traditional materials with innovative nanotechnology materials.

The study has adopted the descriptive analytical Method for studying the problem and achieving research hypotheses.

Research Importance:

1- Emphasizing the importance of integrating modern technologies as a solution to develop products to achieve sustainability.
2- Activating the role of nanotechnology in the process of product development to achieve sustainability.
3- Utilizing modern technologies to achieve product sustainability.
4- Directing designers to focus on nanotechnology in developing the properties of traditional products to work towards achieving sustainability.

First: sustainability in product design

Achieving sustainability has become a global trend, and its applications in all areas of life are now necessary to meet present needs while preserving the right of future generations to natural resources and sources of energy. Sustainability means continuity, and applying the concept of sustainability in all aspects of life has become an inevitable necessity. Therefore, it is important to focus on how to consider sustainability in the product design process and emphasize the importance of the impact of designers' decisions on the environment. Proper utilization of available resources and technology in a balanced manner helps to meet the needs of humans in the present and future. Since the design process and decisions made by designers affect the environmental, economic, and social future, it is important to focus on the importance of the materials used in executing products in general.

The term sustainability has been used since the 1980s to refer to human sustainability on planet Earth. This led to the most common definition of sustainability and sustainable development, as defined by the United Nations Environment and Development Commission in 1987, which states that "sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs." During the 2005 World Summit, it was agreed that achieving this requires balancing social, environmental, and economic demands, which are the three pillars of sustainability. This view can be expressed using three overlapping areas that indicate that the three pillars of sustainability do not exclude each other but rather enhance each other. Sustainability is also defined as "improving the quality of human life while living within the carrying capacity of the supporting ecosystems." As a concept, sustainability means the continuity of interaction between society and the environment, and it is a concept that calls for attention to the future of humanity and the preservation of the environment that provides human continuity. Therefore, it enhances life in a way that allows others to meet their needs in the present and future, and applying this concept to all areas of design, planning, and economics. It also means using natural resources in the best possible way while preserving and maintaining them. (Abdul Kareem, 2019)

Sustainability is the ability of natural systems to achieve continuity over time, and the designer can achieve it by directing design, construction, and spatial structure thinking and methods. Sustainability also emphasizes the use of future technologies in sustainable design. The term sustainability means the ability to maintain a certain balance. Therefore, the application of the philosophy and concept of sustainability comes at the top of the global concerns, which forced designers to reassess and study what is known as "Environmentally Conscious Design". (Naseer, 2017)

Sustainable design is a term used to describe the use of sustainability principles in designing and developing commercial and industrial products. It aims to provide social and economic benefits while protecting public health, providing well-being, and safeguarding the environment from harmful emissions throughout the life cycle of the product. (Abdulhamid, 2018) American designer and architect William McDonough strongly advocates for this concept, pointing out the designer's ability to design materials, systems, companies, products, buildings, and communities capable of continuous improvement over time. (Abouelsoud, 2019)

The aim of sustainable product design is to develop greater environmental awareness in products and design processes. Applying sustainable product design involves a specific framework to consider environmental issues and challenges to traditional design and manufacturing practices. This is especially important given the worldwide tendency to ignore environmental impacts during product design and development. The challenge of sustainable design is to change traditional design and manufacturing practices to more effectively incorporate environmental considerations in both products and design processes. This requires changing existing practices, even though it may be difficult for existing products and processes. The general goals of sustainable future have been identified as follows:

- Reducing the use of non-renewable resources or minimizing it.
- Managing renewable resources to ensure sustainability.
- Reducing toxic and other harmful emissions in the environment, including those that contribute to greenhouse gas emissions, with the aim of eventually eliminating them. (Abouelsoud, 2019)

There is a significant impact of industrial products on the environment in all aspects, as their production, distribution, use, and disposal involve many processes and resources that affect the balance of natural systems. Studies indicate that 80% of the environmental impacts of a product during its life cycle are determined by the decisions made during the design process. Therefore, the design stage is the most promising moment for the product to overcome environmental problems. (Mohammed, 2019)

As the wrong choice of raw materials for industrial products can cause a disturbance to the ecosystem and the principles of sustainability, leading to harmful environmental, health, economic, and social effects, as well as wasting natural resources, it is essential for designers to be aware of the most important sustainable raw materials, production, manufacturing, and packaging processes to help them move towards cleaner production and sustainable industrial products. Eco-friendly materials are known as those that do not harm humans or the surrounding environment during their extraction, manufacture, or use, and they do not pollute the indoor environment because they are made of natural materials. Choosing renewable materials, natural decomposable materials, and calculating the minimum amount of energy and effort used, all achieve sustainability in the product design process (Kamel, 2016)Sustainable materials are defined as those used in manufacturing and take into account the three environmental, social, and economic considerations, and may be non-natural materials, but they must be ensured to be non-toxic, i.e., not harmful to the environment or the health of living organisms. The more local the materials, the more sustainable they are, and they should be low in energy consumption, waste, cost, and socially acceptable. The considerations for choosing sustainable materials include:

- Natural materials: as they are renewable and do not cause harm to the environment if managed properly.
- Durable materials: with a long lifespan that require less maintenance and contribute to reducing solid waste. They can also be reused.
- Recyclable materials: contributing to environmental protection by avoiding or minimizing pollution through waste management strategies based on clean production technologies, recycling, and environmentally sound waste disposal.
- Non-toxic materials: to prevent pollution and ensure the safety of living organisms. They do not emit any toxic emissions during their lifecycle, either during or after production, and are biodegradable, ensuring public health and environmental safety.
- Limited energy consumption: using materials that consume less energy during the manufacturing process, as they are easy to shape and manipulate with minimal energy.
- Local materials: using local materials reduces transportation costs. (Ahmed & Hassanein, 2022)

The concept of sustainability, from the perspective of designers and manufacturers, involves working better with less, not just for today but for tomorrow as well. This requires a deep and comprehensive understanding of the product lifecycle and its impact on business, environment, and society. This clearly means that sustainability is not just about "doing the right thing" for the environment or society. It is also about doing the right thing entirely, in order to make the situation balanced. (Abouelsoud, 2019)

1. Sustainability Patterns in Design:

Design sustainability patterns refer to the different approaches and strategies that designers use to create environmentally sustainable products and systems. These patterns are based on the principles of sustainable design, which aim to reduce the impact of human activities on the planet and promote a more sustainable society. Some common sustainability patterns include:

1.1. Design for Disassembly:

Refers to a design approach that allows the product to be easily disassembled and reassembled, enabling the use of its parts in another product, recycling some of its parts, or replacing damaged parts with new ones, and reusing it again after the end of its life cycle. The process should be simple and inexpensive, which helps to increase economic value and reduce environmental impact through reuse and recycling. (Abdulhamid, 2018)

1.2. Cradle to Cradle:

This approach is based on the idea that every product should be a source of input for another system at the end of its life cycle, rather than becoming waste. The process should be cyclical rather than linear, just like in nature. When the life cycle of a living organism ends, it becomes a source of food for another organism. Similarly, a product should not become waste at the end of its life cycle but should become a source of input for another product. Sustainability is achieved throughout the product's life cycle, starting from its design process to its end-of-life disposal. (Abdulhamid, 2018)

2. Product life cycle

Understanding the product life cycle is important for product designers because it allows them to identify stages where they can reduce the environmental impact of their product. By considering the entire life cycle of the product during the design process, designers can create products that are not only functional and aesthetically pleasing, but also environmentally sustainable. The product life cycle can be divided into four stages: design, production, use, and end-of-life. (Abu Ghneimah, Mustafa, & El-Saadani, 2023)

2.1. Design Stage:

This stage is responsible for about 80% of the environmental emissions that occur during the product life cycle, as the designer is responsible for selecting environmentally friendly materials that do not deplete or harm the environment after the end of their life cycle. The designer is also responsible for determining the most appropriate production methods that do not consume high amounts of energy. The end of the life cycle determines the fate of the product after its assumed lifespan, and this is done after sufficient study of available materials and a comparison between them and different manufacturing processes to determine the most appropriate and least environmentally and economically damaging process.

The aspects that the designer considers during the design process to produce a sustainable product are as follows:

- Material efficiency: reducing the amount of material required to build the product.
- Use of environmentally friendly materials, such as relying on bio-plastics instead of plastics derived from petroleum.
- Efficiency in use, which means designing the product to consume fewer resources during the operation period, such as reducing the energy used to operate an electrical product.
- Using biodegradable or recyclable materials, where the design process prepares for the recycling point from the beginning of the design process when selecting the product's materials.
- Reuse, where products are made up of materials that can be reused.
- Energy, where the product uses clean energy, whether during its use or in the manufacturing stage.
- Safety, meaning that the product is not toxic during use or in its manufacturing stages, and no harmful emissions are released into the environment.
- Social impact, meaning that the product and all its parts and materials are under operating conditions that do not harm the workers or the community in any way.

2.2. Production stage:

It is the stage that causes the most pollution in the product life cycle, despite its short duration. It produces waste that is airborne due to the chemical compounds resulting from the manufacturing process. It also produces solid and liquid waste, which are often disposed of by burning, burying, or discharging into rivers and seas. Therefore, it is essential to identify clean production methods that are not polluting and do not deplete resources, or to rely on clean energy sources. Additionally, proper and healthy methods must be available for disposing of the resulting waste without harming the environment or future generations.

2.3. Use stage:

This is the longest period in the product life cycle, and it lasts until the end of its assumed lifespan. Extending the useful life of the product reduces waste at this stage, and this can be achieved by designing the product to be easily disassembled and reassembled, thus facilitating the replacement of faulty parts.

2.4. End-of-life stage:

After the assumed lifespan of the product ends, it becomes waste that burdens the environment. However, there are several ways to avoid this, including:

- Reusing the product: This can be achieved by designing the product for reuse and making it easy to disassemble and reassemble, so that its parts can be repaired by the manufacturer and reused for the same purpose.
- Recycling the product material: This involves using the product material after the end of its assumed lifespan, i.e., recycling it for use in another manufacturing process.

Second: Product Development:

In the past, humans used to live in the ancient environment, and their design strategy was based on the available resources in that environment such as wood, stones, and other raw materials. Over time, human thinking evolved in terms of manufacturing raw materials by extracting chemical elements from the earth and adding them in proportions to make the raw material that provided designers with a broad base of materials. This broad base of raw materials and their different characteristics gave designers, prior to the industrial revolution, the ability to design products based on the available raw materials and production technology. Designers focused on the functional aspect of the product, making these products more durable with a longer lifespan.

The emergence of plastic had a significant impact on product design, as many parts of products made of metal materials were replaced with plastic materials, achieving ease of production in addition to their lightweight. Due to the development of human life, needs and desires diversified, leading to a variety of design trends to meet these needs, resulting in a diversity of products. The environment faced the problem of disposing of damaged or broken parts of these multiple products, leading to the emergence of modern design trends such as environmental design with its various design approaches and the adoption of the cradle-to-cradle design principle, which is based on the closed life cycle principle in nature. The goal of these trends is to preserve the environment and design environmentally friendly products. The most important design principles of these trends include knowing the properties of each material before using it, and how to dispose of it after use without harming the environment and humans, using sustainable and renewable environmentally friendly materials, and ensuring the optimal lifespan of the product. (Hashem & Alsindioni, 2015)

The design process is considered a complex process where industrial designers face many technical and engineering challenges, especially the complex mental processes of choosing appropriate design materials. Optimal material selection is the starting point for solving many problems related to building the design form, and in some cases, this concept is not enough to consider the final considerations for selecting suitable materials, as the result may be that the optimal choice falls on materials that are difficult to find or obtain. Three cultural variables have occurred as a result of modern technology, which accompanies the end of the twentieth century and the beginning of the third millennium, in which materials play a prominent role. The first of these variables is the move away from the design and production of heavy and large products and the shift to designs with small sizes and weights, sometimes with precise dimensions, in proportion to human use. The second of these variables is narrowing the gap between the values of natural-looking products and those produced industrially. The third is the avoidance of using materials that cannot be renewed, and this variable began to flourish after technological research methods increased. (Awad, 1992)

The raw materials used in engineering product design have evolved over different ages according to the environment in which humans lived. When humans first appeared on Earth, they only found stones from the mountains and rocks around them, so they made most of their tools like cooking utensils or spearheads for defense and hunting from stones. They also used wood from various trees and plants. Therefore, this era was called "The Stone Age" due to the use of stone materials as primary raw materials. Humans later discovered bronze and made their tools, statues, and decorative vessels from it, so this era was called "The Bronze Age." Until humans discovered copper, copper alloys spread in all tools during that period, even in weapons such as swords and spears, and this era was called "The Copper Age."

Metallic materials have evolved since the Stone Age, where humans used stones and rocks to make their tools such as cooking pots and hunting weapons. Then, they discovered bronze and made tools, statues, and decorative objects from it, leading to the Bronze Age. Later on, they discovered copper, and copper alloys were used in all tools, including weapons like swords and axes, leading to the Copper Age.

Metallic materials continued to evolve until the pre-industrial revolution period, where each type of metal raw material was divided into types and grades to be prepared for use in products that can withstand stress and be easily shaped according to their metallurgical properties. Interest in metallic materials grew due to the requirements of the machines that emerged during the Industrial Revolution.

Plastic materials are one of the most important materials used in modern tools, and the origin of plastic materials can be traced back to the 19th century after the discovery of nitrocellulose. In 1865, Parkes Alexander attempted to use this material to produce synthetic ivory. In 1916, the first heat-molded powder was produced, and since then, the phenolic product industry has expanded greatly. The first heat-molded plastic material was named "Bakelite," and this name became widespread worldwide. Due to the depletion of the properties of traditional materials over centuries, science has turned to searching for new materials with different characteristics and properties that can be used in functional technologies for products.

Therefore, in the modern era, new materials have emerged, called smart materials, and these materials have appeared and developed with the advancement of nanotechnology. This scientific field has enabled the control of the granular structure of raw materials, giving them novel properties or improving their traditional properties.

These materials can respond differently to various conditions and take different reactions depending on their characteristics. As a result of the emergence of these novel properties of such materials in the industrial field, this has pushed the wheel of innovation and invention to employ these materials in novel functions known as smart functions. (Nafea, 2018) Additionally, the diversity of materials entails a significant difference in their properties and quality, but modern materials have common properties that can be summarized as follows:

1- Design Characteristics

Modern materials assist innovation through their new skills and specifications that help designers achieve their creative ideas. To this end, many manufacturing companies embrace the creative potential of artists from various disciplines and link them to huge technological achievements and diverse scientific experiences to offer a contemporary product that is characterized by modernity and contemporaneity. Modern and innovative designer visions allow for solutions that are freer and more independent of the conditions imposed by the standards and technical requirements of traditional materials, which required the use of materials with a specific structure and shape. (Al-Amayreh, 2015)

2- Technical Features

Many of the recently introduced materials in design are linked to the developments in this field. Machines are no longer operated manually, but are linked to computers that move them based on commands and coordinates stored by the designer. They can draw, engrave, sculpt, cut, and turn with precision that is almost miraculous compared to manual work

3- Expressive and Philosophical Features

As modern products tend to reduce thickness and weight, designers have benefited from these new materials.

4- Environmental Characteristics

With the beginning of the second half of the twentieth century, many governments became aware that the increasing consumption of many natural resources began to pose a great threat to the environment. Wood and marble are at the forefront of those materials, and the reckless cutting of forests raises many question marks about the importance and role of plant cover in the process of preserving the environment. It was necessary to search for new resources to compensate for the significant shortage in the needs of global markets for such materials. The research took two directions: the first is the search for alternative industrial materials to natural materials, and many modern materials have emerged. The second is the recycling of materials." (Mohammed D. Y., 2013)

Modern technologies, especially nanotechnology, have dominated various aspects of life in this era, and materials design is one of the fields that has been affected by it. By utilizing its capabilities in producing new materials or improving the properties of certain materials, this has led to a precise improvement of many materials, including wood, which has gained new qualities and features that contributed to the development of design and the existence of solutions and alternatives that were not previously known. In addition, nanotechnology has provided the design field with multiple and diverse capabilities due to its advanced properties for construction systems and design materials, it has provided new environmental solutions that helped improve design and reduced economic costs. This technology has contributed to an advanced design by using modern technology, new materials, and advanced scientific methods. Understanding the science of nanotechnology and its applications opens up promises and prospects for improving everything it produces, as this technology seeks to develop materials and process them through the use of new technology and advanced scientific methods provided by this technology, and nanotechnology is one of the main components of nanotechnology, it has gained great importance during the past ten years as an alternative to materials and substances, becoming environmentally friendly, producing particles of very small sizes in all fields. (Ibrahim, 2020)

Third: Nano-technology:

Nano-technology is one of the latest developments in technological and scientific advancements in recent years. Understanding the science of nano-technology and its applications in product development, manufacturing methods and production is essential. This technology aims to develop and process materials, reduce resource consumption significantly and provide alternatives to rare raw materials or those with harmful environmental impacts. It also contributes to avoiding the use of highly toxic or environmentally harmful materials.

1- Nano:

The term "nano" linguistically refers to the word derived from the Greek word "nanos," which means "dwarf" or something extremely small. (Mehran, 2014) It refers to technology that relies on extremely small materials. The German Federal Association for Education and Research has defined nanotechnology as the restructuring and reformation of materials at the structural and molecular levels to add some practical properties to them. (Imam, 2013)

2- Nanoscience:

There are many definitions of nanoscience as a result of its integration with many other fields. Below are some of these definitions:

- The science that deals with the study of the structure and properties of materials at the nanometer scale. (Al-Habshi, 2011)
- The science that is concerned with the study, classification, determination of chemical, physical, and mechanical properties of nanomaterials, with the study of phenomena that arise from the miniaturization of their sizes. (Al-Eskandarani, 2010)
- The science that is concerned with precise and complete control over the production of materials by controlling the interaction of molecules involved in the reaction, with the guidance of these molecules through the production of a specific substance. This type of interaction is known as "molecular manufacturing." The materials produced using this science are called "nanomaterials" which can be built and designed in multiple and different shapes. (Mehran, 2014)
- The study of the ability to control the state of matter at its atomic and molecular scale. (Farid, Abu Ghazala, & Al-Shami, 2015)

3- Nano Technology

Nano Technology is a technology that involves reducing the size of material particles to be less than one hundred nanometers, which is the smallest unit of measurement that humans have been able to measure so far. When materials are manufactured at the nano scale, the chemical and physical composition of the raw materials used in the manufacturing process play an important role in the properties of the resulting nano material. There are two methods for producing nano-sized materials:

- The first method is Top-Down, where building units are reduced to the nanometer level.
- The second method is Bottom-Up, where building units are enlarged by introducing individual atoms or molecules into reactions to form chemical and biological materials, and then introducing these materials into the building of nano-sized components, as shown in (Figure 1). (Al-Ashmaawi, 2016)

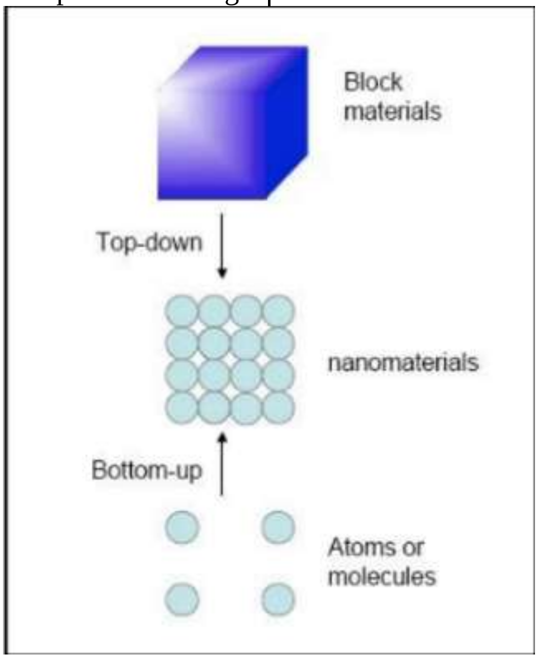

Figure 1, Illustrates methods for producing nanoscale materials (Al-Ashmaawi, 2016)

Nanotechnology focuses on engineering functional systems at the atomic level. When dealing with materials at the nanoscale, physical, chemical, and biological properties may differ from those of materials tested at larger scales. Nanotechnology can alter materials at the most fundamental levels to enhance their properties, such as strength, durability, heat absorption, and heat conduction. (Sherif, Khalil, & Ahmed, 2017) Nanotechnology is defined as the technology that deals with individual atoms and molecules that make up materials, using precise tools to build and operate a smaller set of materials repeatedly until reaching the desired size. It is also the technology that is concerned with designing and manufacturing materials and machines at the nanoscale. It is a set of tools, techniques, and applications related to manufacturing a particular structure and assembling it using extremely small scales. In general, this technology aims to apply the science of nanotechnology to create and produce useful tools, techniques, inventions, and products that are characterized by their extremely small size and low cost, which does not exceed the raw materials and energy used in the manufacturing process of these tools and products. (Mehran, 2014)

4- Historical overview:

Nanotechnology is a field in science and engineering that focuses on studying matter at the nanoscale, typically at the level of atoms and molecules. Although the study of phenomena at the nanoscale has been carried out for several centuries, the term "nanotechnology" was first used in 1974 by the Japanese researcher Norio Taniguchi. He said that "nanotechnology is based on processes of separation, merging, and reshaping of materials using a single atom or molecule" (Mehran, 2014). Since then, advances in microscopy, computing, and other scientific and technological fields have enabled scientists and engineers to study and modify materials on smaller scales. In 1991, Professor Sumio Iijima of Meiji University in Japan discovered "carbon nanotubes," which are thin cylindrical tubes with diameters of only a few nanometers, made of graphene sheets. These tubes have exceptional structural and thermal properties that make them lighter than aluminum and five times stronger than steel. The industrial application phase of this technology began in 2014, where nanomaterials were used in the production of Malaysian rubber, resulting in improved specifications by adding small amounts of nanomaterials, making it more durable than steel by a factor of 100 and six times lighter. (Fadel & Alkhalef, 2021)

5- Principles that distinguish nanotechnology: (Al-Habshi, 2011)

There are many principles that distinguish nanotechnology from the technologies we know, and the following table presents the most important principles and their benefits:

Table 1, The main principles that distinguish nanotechnology and its benefits

The principle	The advantage
1- The ability to control the movement of individual atoms and rearrange them.	The ability to build any material in the universe, because the atom is the basic unit of matter.
2- The physical and chemical properties of a material at the nanoscale differ from the properties of the same material at the natural size.	Discovering unique properties of materials that can be utilized in many inventions and practical fields.
3- The field of nanotechnology relies on principles of physics, chemistry, biology, electrical engineering, and electronics.	Science connects and encourages everyone, regardless of their scientific specialization, to enter and collaborate in the field.
4- The ability to control atoms in manufacturing materials and machines, purifying them from impurities, and eliminating defects.	"The properties of materials and machines become better, as they become smaller, lighter, stronger, faster, cheaper, and consume less energy."
5- Nanotechnology relies on scientific research that can be applied to useful inventions and applications.	Science fiction turns into reality.

6. Nanomaterials

Nanomaterials can be defined as "an advanced class of materials that have dimensions or at least one dimension ranging between 1 to 100 nanometers. Due to their small size, nanomaterials exhibit behavior that is different from that of conventional bulk materials that have dimensions larger than 100 nanometers, and they possess unique and distinct properties that are not found in conventional materials. Nanomaterials can be of organic or inorganic origin, natural or synthetic, and they include all known conventional materials and elements, such as metals and their alloys, semiconductors, oxides, metals, polymers, and so on, which are used as building blocks for the production of nanomaterials. The shapes of nanomaterials can vary depending on the method of production and can be in the form of spheres, tubes, fibers, wires, or flakes as shown in (Figure 2)." (Sabry, 2020)

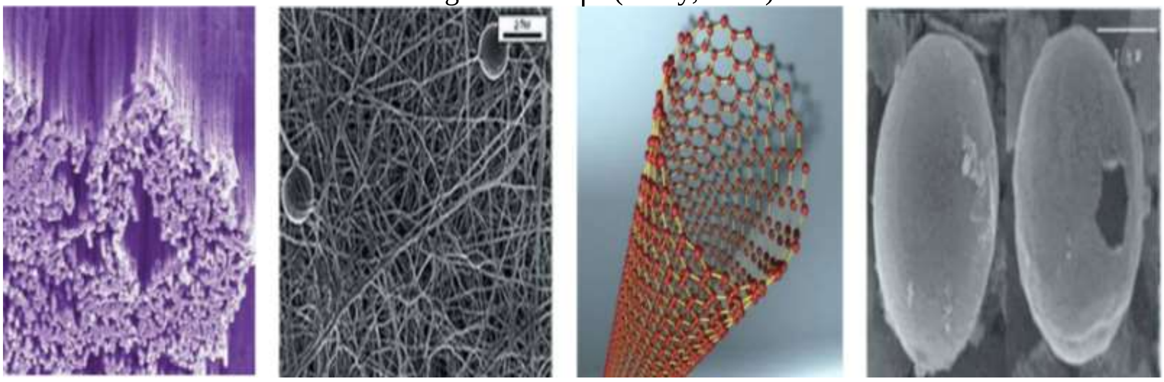

Figure 2, Nanomaterials forms (Sabry, 2020)

6.1. Classification of Nanomaterials:

Nanomaterials are usually classified according to their size, geometric structure, and chemical composition. Nanomaterials vary greatly and include atoms, wires, fibers, colloidal particles, and much more. These materials are classified according to the type of elements and chemical bonds they are composed of. This classification is used to study the properties of nanomaterials and understand the effects of size, shape, and chemical composition on these properties. The classification aims to categorize nanomaterials according to their common and unique properties, which helps in understanding the effect of nanostructure on material properties and improving their applications. In addition, classification is used in the design and development of nanomaterials to improve their performance and various applications. The importance of classification lies in identifying the nanomaterials that are suitable for specific applications and understanding the effect of chemical and geometric structure on material properties. Thus, the performance and applications of nanomaterials can be improved to a greater extent. Nanomaterials can be classified based on their dimensions in space as follows: (Mehran, 2014)

- Mono-dimensional nanomaterials: These are materials that have one dimension within the range of less than 100 nanometers, such as thin films used for coating surfaces.
- Bi-dimensional nanomaterials: These are materials that have two dimensions ranging between 1 and 100 nanometers, such as single and multi-walled carbon nanotubes, nanowires, and nanofibers. These structures possess unique chemical, physical, and mechanical properties.
- Tri-dimensional nanomaterials: These are materials that have three nanoscale dimensions, each ranging between 1 and 100 nanometers, such as nano shells and Bucky Balls, as well as nanoparticle powders.

6.2. Properties of Nanomaterials:

Nanomaterials have unique properties that make them different from traditional materials with the same chemical composition and size. For example, nanomaterials have a much larger surface area than larger-sized materials, which makes them more reactive and able to interact with other materials. Nanomaterials also have different mechanical, thermal, electrical, and optical properties, which vary depending on the type and size of the nanomaterials. Nanomaterials also have distinctive electrical properties, as they can be conductive or insulating depending on several factors, such as particle size and the chemical composition of the nanomaterial. Nanomaterials are capable of reacting more strongly to light, infrared radiation, sound waves, and others, which can be used in many optical, medical, and electronic applications. Additionally, nanomaterials are able to store energy with high efficiency and improve the mechanical properties of materials. They are also sensitive to external conditions such as temperature, humidity, radiation exposure, and others. Therefore, the use of nanomaterials provides exciting opportunities for applications in many different fields. (Figure 3) illustrates the properties of nanomaterials. (Sabry, 2020)

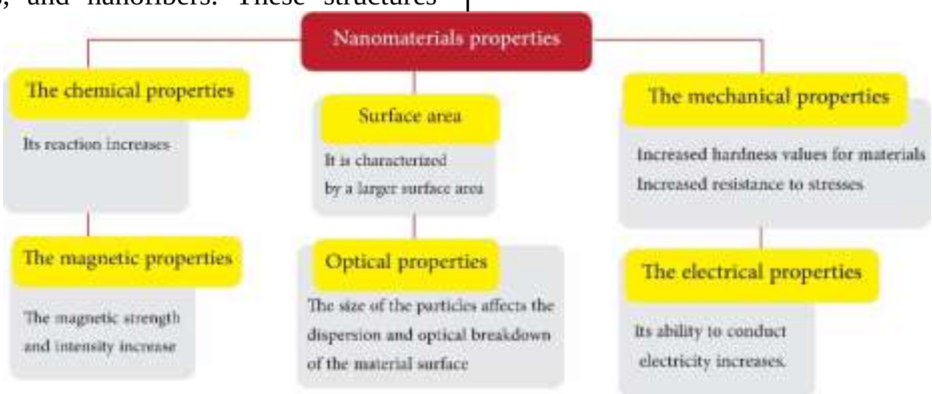

Figure 3, Properties of Nanomaterials

The properties of nanomaterials differ from traditional properties due to a set of reasons, which are: (Al-Habshi, 2011)

- Particle size: The properties of materials such as conductivity and color do not change with size, except when the size reaches the nanometer scale, in which case the properties change. For example, natural silicon is considered a dark material that does not emit light, but when its size is 1 nanometer, it emits blue light, and when it is 3 nanometers in size, it emits red light.
- Particle shape: The properties of a nanoscale particle depend on its shape, whether it is spherical, tubular, hexagonal, or other shapes.

- Particle composition: The type and number of atoms or molecules that make up the nanoscale particle.
- Degree of aggregation: Some nanoscale particles have widely spaced atoms or molecules, while others have densely packed ones, and the difference in the degree of aggregation between particles causes changes in properties.
- Distribution: The distribution of atoms or molecules inside the particle may be regular or irregular, stable or unstable. For example, silicon particles are evenly distributed in a solution, but after leaving it for several days, their distribution becomes irregular and they settle to the bottom, so the solution no longer emits light.
- Quantum confinement: Some materials are confined to two dimensions, so electron movement is in one direction, while others are confined to one dimension, so electron movement is in two directions.

6.3. Nanotechnology-produced materials

Scientists rely on nanotechnology to produce many innovative materials with unique properties that did not exist before. Nanotechnology is based on two basic principles. The first principle is to improve the properties of materials. For example, porcelain is a hard material because the space between its sand particles is relatively large, which reduces its cohesion. Through nanotechnology, those components can be rearranged in a very cohesive manner to produce porcelain stronger than steel that can be used in construction or car manufacturing, among other applications. The second principle is to completely change the properties of a material when it is broken down into finite particles. This relies on rearranging and controlling the particles and atoms. An example of this is diamond and coal (graphite). Both are made up of a stacked series of carbon atoms, but the geometric arrangement differs in the two materials. (Sabry, 2020)

Nanomaterials are characterized by physical, chemical, and mechanical properties that distinguish them from traditional materials with larger particles. They possess properties that cannot be found in traditional materials. For example, the optical properties of gold change in the nanoscale. Pure gold, which has a particle size of about 311 nanometers in its natural state, is known for its golden yellow color. However, if its particle size is reduced to less than 21 nanometers, it becomes colorless and transparent. As the particle size decreases further, its color changes to green, then orange, and then red, causing a change in particle diameter and light scattering. (Mehran, 2014)

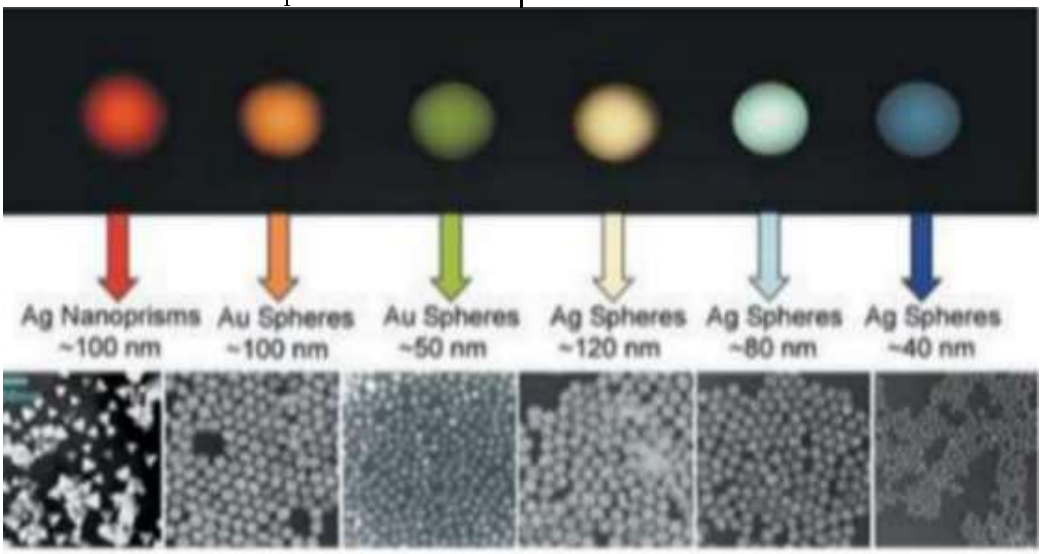

Figure 4, Changing the optical properties of gold in the nanoscale size (Mehran, 2014)

6.4. Applications of Nanomaterials:

Nanotechnology is a rapidly advancing field that focuses on developing materials and devices at the nanometer level. Nanomaterials are materials that have at least one dimension in the range of 1-100 nanometers and exhibit unique and novel properties not observed in traditional materials. Thanks to these unique properties, nanomaterials have found applications in various fields including medicine, electronics, energy, environmental improvement, and others. The small size and large surface area of nanomaterials make them highly active, allowing for increased efficiency in various applications. Additionally, their properties can be precisely controlled, making them highly desirable for many applications. The applications of nanomaterials are expanding rapidly and hold great promise in addressing many of the challenges facing society today, such as sustainable development and environmental protection. The following are some examples of applications of nanomaterials in different fields:

Table 2, Metallic rubber material and its applications

Material Name	Description of the material	Applications
Metallic rubber (Sabry, 2020)	It is a new material that combines the elasticity of rubber and the strength of metal. It combines the conductivity properties of metal with the malleability of rubber.	It has been used in many advanced products that are characterized by innovative properties such as lightweight, foldability, fracture and impact resistance. It has been used in the manufacturing of artificial limbs, high-efficiency robots, and computer devices as shown in (figure 5).

Figure 5, Applications of Metal Rubber in the field of computers. (Sabri, 2020)

Table 3, Graphene Material and its Applications

Material Name	Description of the material	Applications
Graphene (Sabry, 2020)	Discovered in 2004, it is a single layer of graphite carbon atoms stacked in a hexagonal shape resembling a honeycomb as shown in (Figure 6) . It is characterized by: . Being a thin material, with a thickness of a single atom, lightweight, strong, and harder than diamond. It is transparent, but it can absorb light. . It is impermeable to gases and liquids except for water. . It is a good conductor of heat and electricity. . It is flexible and can be folded.	Graphene has several anticipated applications, as shown in (Figure 7) which demonstrates solar cells, and (Figure 8) which demonstrates batteries as one of its potential applications.

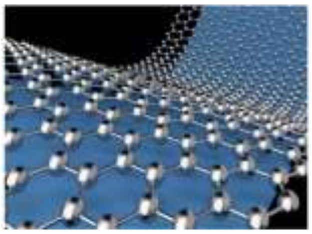

Figure 6, Illustrates the atomic structure of graphene.

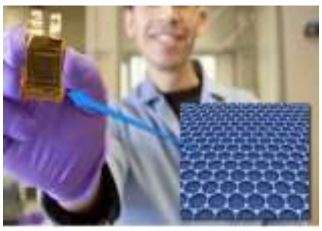

Figure 7, Illustrates solar cells, which are one of the anticipated applications of graphene.

Figure 8, Illustrates batteries as one of the anticipated applications of graphene

Fourth: Utilizing the properties of nanomaterials in the sustainability of some products

Nanomaterials have become an encouraging tool for developing sustainable products, thanks to their unique physical, chemical, and mechanical properties. They can improve the performance, durability, and efficiency of many products, leading to increased interest in various fields such as renewable energy, electronics, and transportation. In this context, this study explores how the properties of nanomaterials can be leveraged to enhance the sustainability of different products, specifically how the use of nanomaterials can lead to the development of more efficient and environmentally friendly products.

Traditional materials have been the basis for building many products over the centuries, but with the rapid development of nanotechnology, nanomaterials have become increasingly common as an alternative to traditional materials. Unlike traditional materials, nanomaterials have unique properties at the nanometer scale that enable them to significantly improve their performance and functions in various applications. Traditional materials are limited in strength and durability, while nanomaterials are characterized by high strength and hardness due to their small size and increased surface area. In addition, the optical, electronic, and thermal properties of nanomaterials surpass those found in traditional materials. Traditional materials include many of the materials used in everyday applications, such as metals, plastics, and ceramics. These materials often consist of large particles or atoms, while nanomaterials consist of small groups of atoms or particles, and are characterized by unique properties due to their small size. Nanomaterials can be designed to achieve specific properties and functions, such as enhanced strength, electrical conductivity, or improved chemical reactivity.

Nanomaterials possess properties that contribute to achieving sustainability in products. For example, nanotechnology can improve the durability and strength of products, reducing the need for replacement and ultimately decreasing waste. Nanomaterials can also be used to create energy storage devices and convert it into more efficient devices, reducing the environmental impact of energy production. They can also be used to create lightweight but strong materials, reducing weight and energy consumption for mobile vehicles such as cars, planes, and ships. These examples illustrate how nanomaterials can be used to achieve sustainability in products. Nanomaterials have become a fundamental trend in achieving sustainability in product design. Nanomaterials can be produced using sustainable methods such as green chemistry and renewable energy sources, helping to reduce their environmental impact and making them a more sustainable option.

Nanomaterials are also used to create sustainable packaging solutions that reduce waste and promote product preservation. Integrating nanomaterials into product design provides a great opportunity to improve the sustainability of manufacturing processes and produce environmentally friendly products. Nanomaterials can also extend the lifespan of everyday products in various ways. One of the most important is enhancing their durability and strength, allowing them to resist corrosion and damage over a long period of time. Additionally, nano coatings can be used on fabrics to improve their stain, water, and UV resistance, thus extending their lifespan. Furthermore, nanomaterials can improve product performance, making them more efficient and reducing their need for maintenance or replacement. For example, nanoparticles can be used in lubricants and coatings to reduce friction and wear, resulting in longer-lasting and more reliable products. The above highlights the ability of nanomaterials to provide many methods for extending the lifespan of everyday products, reducing waste, and improving sustainability. (National Nanotechnology Initiative, 2023)

The use of nanomaterials has led to new possibilities for achieving sustainability in product design. Table 3 illustrates a comparison between a traditional kettle (Figure 9) and another made using nanomaterials (Figure 10). The comparison shows the difference between using traditional materials and nanomaterials in product manufacturing. Understanding the benefits and limitations associated with both traditional and nanomaterials allows for the identification of opportunities to create more sustainable products that meet the needs of consumers while reducing their impact on the environment. How can nanomaterials improve product characteristics, and how can this improvement affect sustainability?

Table 4, A comparison between a traditional material-based kettle and another kettle based on nanomaterials

Comparison points	**Traditional Product**	**Modern Product**
Name and description	A kettle made using traditional materials	A kettle made using nanomaterials
Shape	 Figure 9, Illustrates a household product made with traditional materials (a kettle)	 Figure 10, Illustrates a foldable kettle, which is one of the applications of metallic rubber in household products. (Sabry, 2020)
Materials	Non-renewable materials such as plastic and metal	A nanomaterial called metallic rubber, which is a blend of metal and rubber.

Comparison points	Traditional Product	Modern Product
Properties.	- Less efficient heating compared to the kettle manufactured using nanomaterials. - Heavier weight than the kettle manufactured using nanomaterials. - Does not have any special features to reduce energy consumption or increase efficiency.	- Metallic rubber has a higher surface area, resulting in faster and more efficient heating. - Lighter in weight than the traditional kettle, making it more convenient for handling and transportation. - High thermal conductivity allows for more efficient heat transfer within the kettle, resulting in reduced energy consumption and harmful emissions.
The expected lifespan	Traditional kettles are susceptible to corrosion over time, leading to rust, damage, and a shortened lifespan.	Kettles manufactured using nanomaterials are characterized by high durability and strength, leading to an increased product lifespan and a reduction in the need for frequent replacement and waste.
Sustainably aspects	Traditional kettles are made of materials that are not easily recyclable, such as plastic, which contributes to waste and pollution. Additionally, traditional kettles are prone to corrosion over time, leading to rust, damage, and shortened lifespan, thus increasing waste production.	- Increasing the product's lifespan and reducing the need for frequent replacement and waste generation due to their high durability and strength. - Reducing maintenance costs and environmental impact of material production and disposal thanks to their corrosion resistance, high strength, and lightweight. - Reducing energy consumption through the high thermal conductivity of the metal rubber used in their construction.

The comparison illustrates how the use of nanomaterials instead of traditional materials can lead to significant environmental improvements in the product. Nanomaterials provide unique properties such as increased strength, durability, and high thermal conductivity, which leads to improved efficiency and longer-lasting products. In addition, it reduces the use of materials, as the enhanced properties of nanomaterials require lesser amounts of materials to achieve the same performance as traditional materials. This leads to reduced waste and sustainable use of resources. Therefore, the use of nanomaterials contributes to creating a more sustainable future by improving the efficiency and lifespan of products, reducing waste, and consuming fewer resources.

Fifth: Results:

1- Nanomaterials are considered one of the most important options for developing traditional products into advanced modern products through their contribution to increasing the quality and efficiency of products, reducing their size, increasing their durability and effectiveness, reducing waste, reducing environmental impact...etc.

2- Nanotechnology is already being used in various industries such as energy, transportation, healthcare, and consumer goods, to develop sustainable products with improved properties and reduced environmental impact.

3- The industrial designer's awareness of what nanotechnology and nanomaterials are contributes to integrating these materials into products and creating sustainable and advanced products.

4- Nanomaterials offer alternatives with multiple properties, whenever their size and ways of forming their particles are controlled, which makes them a fertile material for development and scientific research.

5- Nano technology contributes to transforming environmentally harmful materials or waste into useful, harmless materials with advanced properties, which supports products and contributes to achieving sustainability and preserving the environment.

6- Nanotechnology contributes to transforming local raw materials into nanomaterials with properties like limited materials and raw materials that are imported, which supports the economy of countries and contributes to preserving limited raw materials and resources.

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