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Review

The Relation between Environmental Risk Analysis and the Use of Nanomaterials in the Built Environment Sector: A Circular Economy Perspective

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Abstract

Nowadays, the challenge of climate change and “ecological transition” is substantially an “energy challenge” for every city, which is supposed to become as “energetically self-sufficient” as possible. The construction sector is one of the main contributors to the effects of climate change, starting from the production of materials to the use phase of buildings to their demolition. Recent innovations in sustainable/circular design are related to using “new materials." According to this perspective, nanomaterials are becoming an increasingly widespread practice in various sectors. Nanomaterials are considered very innovative materials able to solve different problems related to buildings' structural and energy efficiency due to their small size. However, the future challenge is to understand whether these materials can be considered “green" from their production stage since risks to human health have been found in both the manufacturing and use and disposal stages. In this regard, an abacus of the most commonly used nanomaterials in the construction industry is defined. Simultaneously, were identified the negative environmental impacts related to the use of these materials, to propose possible solutions to reduce/mitigate them. Therefore, from this analysis, it emerged that a possible solution could be to move to the “industrial biosynthesis process" for producing nanomaterials, according to the circular economy principles. However, this process must always be combined/supported by "Environmental Risk Analysis (ERA)," an evaluation tool capable of identifying and mitigating the adverse negative environmental impacts. The paper concludes with the consideration that new materials for the built environment should be functional and " beautiful," particularly when they are to be used for reuse projects in historic buildings.

Keywords

Nanomaterials; built environment; circular economy, environmental risk analysis; bio-synthesis; life cycle assessment

1. Introduction

Climate change problems are generated mainly due to greenhouse gas emissions from human activity. The built environment sector contributes to climate mutation through the extraction of raw materials for producing materials, for the use of each one, for the buildings use of electricity and water, maintenance interventions, so at all life cycle of the building until its dismantling. For example, in Europe alone, buildings and the construction sector are responsible for 36 percent of annual CO_2 emissions, 40 percent of energy consumption, and 50 percent of raw material extraction [1].

The European Commission launched different programs to enhance the sustainability of the built environment sector. Among them, the "European New Green Deal" highlights that the sustainable and circular regeneration/realization of buildings plays a fundamental role in maximizing the objective of decarbonization and resource conservation by 2050 [2].

The "Renovation Wave Action" (European Commission, 2021) states that "green buildings" can help fight climate change and improve daily life conditions by enhancing the energy performance of buildings [3].

Instead, the "European New European Bauhaus" proposes a "new sustainable and circular movement" to make "green" the built environment sector through the use of renewable energy, bio-materials, reuse of waste materials, and the protection and conservation of biodiversity [4].

The circular economy has 114 definitions in the literature [5]. According to the circular economy theory, nothing in nature is waste, and everything can be used as a resource [6].

A definition of the circular economy, for example, may be intended as "the restructuring of industrial processes to support ecosystems through the adoption of ways to enhance resource efficiency through recycling and minimizing emissions and waste" [7].

A circular economy generally aims to rely on renewable energy, reduce, track, and eventually eliminate hazardous chemicals [6]. Specifically, circular economy in a built environment suggests that designers should understand that the "design choices" determine the asset's durability and adaptability. In this perspective, it is necessary to think about the entire building life cycle through the definition of specific actions.

One of the most significant problems in the construction industry is related to materials procurement, which is tied to the linear approach to using natural resources. Materials are purchased, used, and finally disposed of as waste.

In this light, the new materials should be designed to be durable, repaired, recycled, and reused, so that the feedstocks that make them up last as long as possible.

For this reason, the attention is focused in this paper, particularly on using nanomaterials in the construction sector designed according to the circular economy principles. Nanomaterials (ENM) are very diffused for various applications: biomedical and healthcare, environment, textile industry, agriculture, electronics, energy, and construction and building sectors [8]. However, recent literature shows that during during the production stage of nanomaterials, negative impacts can be generated on "**human health**".

This paper has realized an abacus of the most used nanomaterials for the built environment sector. Simultaneously, were identified the negative environmental impacts related to the use of these materials, to propose possible solutions to reduce/mitigate them.

So, the first aim of this paper is to identify nanomaterials utilized in the construction sector (section 2). Then, a Swat Analysis was performed to identify the advantages, disadvantages, possibilities, and risks of using these materials (section 2).

Subsequently, possible solutions (that may represent the novelty of the present study) have been identified to mitigate the negative impacts generated by the production/use of nanomaterials.

Therefore, from this analysis, it emerged that a possible solution could be to move to the "industrial biosynthesis process" for producing nanomaterials, according to the circular economy principles. But this process must always be combined/supported by "Environmental Risk Analysis (ERA)," an evaluation tool capable of identifying and mitigating the adverse negative environmental impacts. (section 3). The paper ends with a conclusion and recommendations (section 4) (Figure 1).

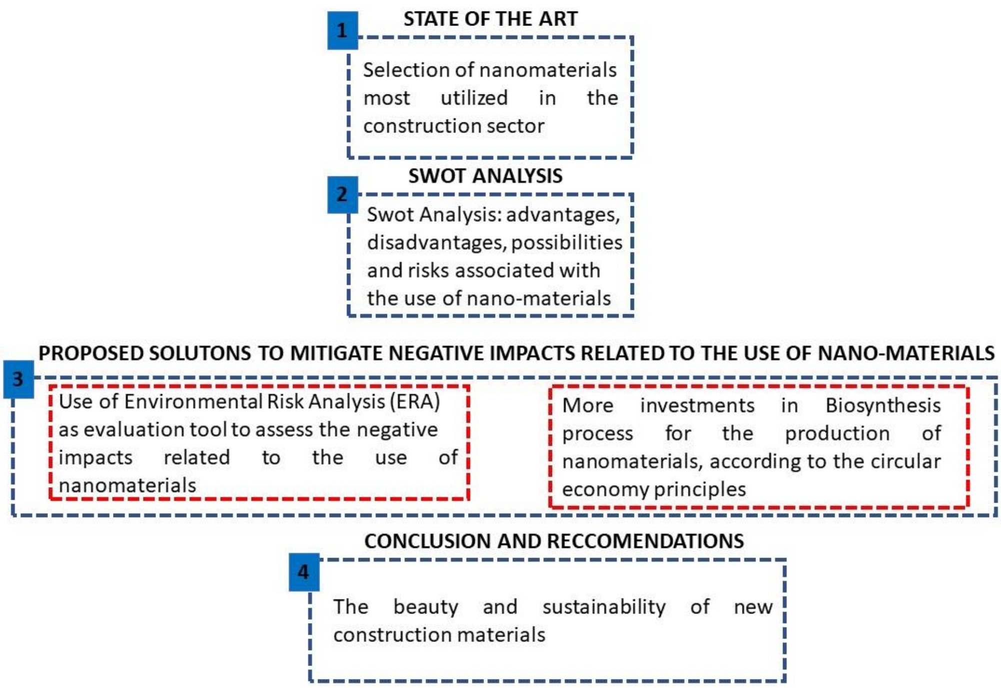

Figure 1 The methodological workflow.

2. Nanomaterials in the Built Environment Sector

The use of nanotechnology and nanomaterials are becoming a reality increasingly consolidated for sustainable innovation in the construction sector. These materials are generally used to improve the properties of concrete, plaster, glass, tiles, insulating metals, paints, etc. Nanomaterials are used in different industrial sectors: automotive, sensors, electronics, medicine, pharmaceuticals, and built environment, for the energy saving and for making consumer goods.

When exposed to environmental stimulation and external stresses (such as changes in temperature, electric and electromagnetic fields, light, etc.), nanomaterials can rapidly change their structure and properties.

European Commission defines nanomaterials as a natural product or a product containing particles in an untied state either as an aggregate or agglomerate [9]. Lopez-Alonso et al. (2020) say that nanotechnology plays a key role in technological innovation, including in the construction sector [10]. An exponential increase is expected in their application, although this has been hampered by the current uncertainty regarding the potential effects on human health and the environment [10].

The regulatory framework for producing and utilizing nanomaterials has not yet been fully developed and agreed upon. In addition, there is no information on specific management measures and evaluation tools to evaluate the specific negative impacts. For these reasons, it is necessary to define a “non-complex protocol” as a preventive tool [10].

In this light, in a recent report, OECD reminds manufacturers that nanomaterials should be realized by respecting the physical-chemical standards and providing suitable toxicological and ecotoxicological information about the products [11]. A study by Mohajerani et al. (2019) remarks that titanium dioxide, carbon nanotubes, silicon dioxide, copper, clay, and aluminum oxide are the most widely used nanoparticles in the construction industry [12].

In this section, an abacus of the most commonly used nanomaterials in the construction industry was made through an analysis of specific scientific literature (Table 1).

Table 1 The classification of nanomaterials for sustainable built environment.

Material	Use	References
Aerogel Thin-film insulation Thermal insulation: Vacuum insulating panels (VIPs) Temperature regulation: Phase changing materials (PCMs) Plasters Paints	Thermal insulations (double-glazed windows, walls, facades, roofs	[13-17]
Self-cleaning coatings: Lotus-effect and photo catalysis Easy to clean –ETC Anti-fogging UV and solar protection	Coatings	[13-17]

Anti-graffiti coatings Anti-reflective coatings Anti-fingerprint coatings Scratch-resistant coatings Anti-corrosion coatings Antimicrobial coatings Moisture resistance coatings Fire-proof coatings Floors Ceramic coatings		
Light emitting diodes - LEDs Organic light emitting diodes - OLEDs	Lighting	[13-17]
Inorganic silicon solar cells Organic thin-film solar nanotechnologies Photovoltaic windows	Solar energy	[13-17]
Concrete Steel Wood Nano-beams	Structural materials	[13-19]
Glass Roofing Drywall Plastics Polymers	Non-structural materials	[13-17, 20]
Switches Handles Mirrors Bathroom fittings Tables Upholstery Laundries Sensors	Furniture	[13-17, 19]

As shown in Table 1, nanomaterials used in the built environment can be used as insulating materials, coatings, for lighting, structural and non-structural materials, as supplies, and finally, to improve the energy performance of buildings.

Contemporaneously to the classification of nanomaterials for the construction sector, have been identified the strengths, weaknesses, opportunities, and threats related to their use in the always-to-built environment sector shown in Table 2.

Table 2 Swot analysis.

Strengths	**Weaknesses**
- Thermal and mechanical efficiency Performance and drivability - Reliability and durability - Reducing material weight - Faster response time - Are materials that prevent energy loss and capable to conserves energy - Reduce natural resource consumption - small dimensions in comparison with classic materials - long lifespan - prevent the spread and formation of bacteria - reusable and recyclable	- Expensive in their production - Cost effectiveness - Absence of protocols and legislation - Creation of new toxins and pollutants - Loss of jobs in the manufacturing industry - Collapse of some markets - Difficult to clean - Some unknown effects - Economical balance
Opportunities	**Threats**
- Recyclability - Environmentally friendly - Aesthetics - Application in different sectors - New properties and functions compared to traditional materials - Significant demand for the production of nanomaterials - Improving the culture of interaction between business and science on the introduction of innovative products - Reduction of transportation costs - Increase the use of renewable energy	- Risks to human health - Toxic effect - Pulmonary granulomas fibrosis and inflammation - Distribution to other organs, including as the central nervous system - Skin penetration - potential for brain entry via olfactory neurons in the nasal epithelium - potential for greater toxicity than micron-sized particles

Therefore, as previously anticipated, there are different benefits and weaknesses related to using nanomaterials for the built environment.

Ray et al. (2009) argue that among the benefits of nanomaterials production, the first positive factor is related to the dimensions of the small material; its physical and chemical properties are very different concerning the traditional materials [21].

The most important benefits in the built environment sector are related to their insulation properties. The product's dimensions are very small and can be easily adapted to any type of façade, masonry or reinforced concrete [16]. The installation is fast and implies a strong reduction of thermal bridges and prevention of fungal microorganisms/ molds and moisture. They are materials that also respond very well to corrosion and fire resistance [21].

Furthermore, a study by Amendola et al. (2016) reads that particular materials, such as pentode, associated with nano-structuring methods, can improve the seismic properties of buildings [22].

Also, Experimental Modal Analysis (EMA) is a powerful aid to the seismic design of new structures and a useful tool for the structural identification of existing structures [23].

Regarding the weakness and threats, different studies say that the population is increasingly exposed to certain toxic effects caused by using these materials [10, 13, 15, 16, 21].

Manufactured nanomaterials could enter the environment through various sources, including solid or liquid waste from manufacturing plants and air emissions [21].

Nanomaterials have the potential to pollute soil and move into surface and groundwater when they fall to the ground. Wind or rainstorm runoff can introduce particles from solid waste or accidental spills into aquatic systems [21].

Large-scale environmental releases could occur due to spills connected to the transportation of manufactured nanomaterials from manufacturing facilities to other locations, deliberate releases for environmental purposes, and diffuse releases related to wear and erosion from everyday use [21].

Specifically, for the construction sector, during the manufacturing phase of nanomaterials, operations including coating, compounding, and inclusion can release nanoparticles into the environment. Inhalation exposure by workers at work can potentially result in respiratory health issues [11]. Also, during the building demolition, exposure to nanoparticles may become uncontrollable (e.g., wrecking balls). The leftover debris is intermingled during the random crushing, making it challenging to separate the wastes related to nanomaterials later [11]. Sorted demolition waste is transported to landfills, which may be a frequent source of nanomaterial releases into the environment. Generally, when buildings are damaged, worn down, or abraded over a building's lifetime, whether natural or manufactured, the environment may become exposed to particle releases [11].

Additionally, burning or incineration could release nanomaterials into the atmosphere, and rainfall could encourage disintegration or leaching into soil and natural rivers. Due to present analytical limitations, characterizing such emissions over the long term is particularly difficult [11].

Therefore, in the next paragraph, a series of operational solutions have been proposed to reduce the negative effects related to the production and use of nanomaterials for the construction sector.

3. Environmental Risk Analysis (ERA) and Nanomaterials Production

Analyzing the scientific literature review discussed in the previous section, it may emerged that Environmental Risk Analysis is an assessment tool capable of predicting and mitigating the negative impacts generated by using nanomaterials in the construction sector. For this reason, in this paragraph, an in-depth investigation has been made into the papers that support this thesis using the Vos Viewer software. It is a tool for constructing and visualizing bibliometric networks; it can create a map of the scientific landscape of a specific research field. The software uses Scopus, Web of Sciences, Lens, and PubMed data to realize this map. In this paper, the data was extracted from the Lens.org platform.

The keywords used for the research on Lens have been “Environmental Risk Analysis, nanomaterials, and the built environment." Lens platform has identified 150 papers about this topic. The research was done within a time limit from 1990 to 2022, and only scientific journals, books, and conference proceedings were selected. The software identifies four research topics that researchers are investigating. The first one is related to the innovation in construction materials, the environmental and health implications, and the sustainability of new materials. The second and third cluster is about decision analysis, governance communication, and risk perception related to nanomaterials. Cluster four is related to database management systems and Environmental Risk Analysis as the most widely used tool for assessing environmental impacts (Figure 2: Vos Viewer elaboration).

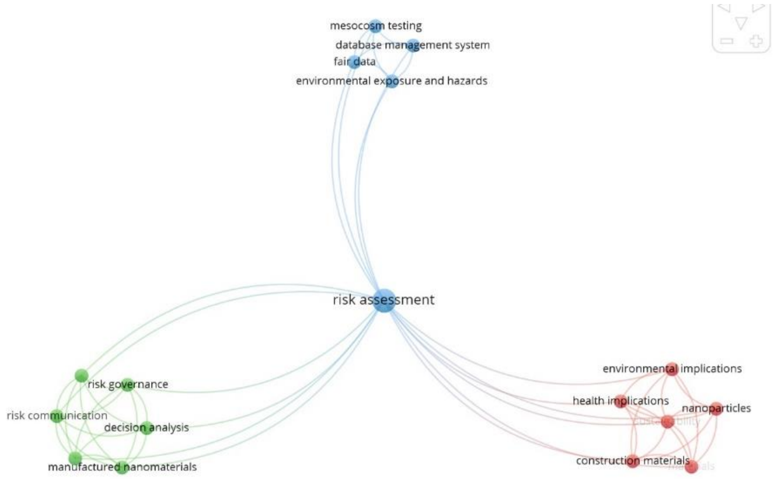

Figure 2 Vos Viewer elaboration map. Source: Vos Viewer elaboration.

As previously stated, among these 150 papers that were analyzed, those in which reference is made to the ERA as an evaluation tool capable of mitigating the negative impacts produced by using nano-materials in the built environment.

Wanting to define the ERA evaluation tool, Jørgensen et al. (2005) define it as a process of assigning magnitudes and probabilities to the adverse effects of human activities. The process involves the identification of hazards (e.g., releasing toxic chemicals to the environment) by quantifying the relationship between an activity associated with emission to the environment and its impacts [24].

McIntosh (2017) argued that Environmental Risk Analysis is currently used in various contexts, from engineering to analyzing the possibility and impact of component failure to assessing social risks brought on, for instance, by customers' antisocial behavior. Risk assessment has increased in popularity over the past few decades as a method for analyzing environmental issues that result from human activity [25].

Different scientific studies have stated that results of many “Environmental Risk Analyses” related to nanomaterials are often common, i.e., linked to safe handling and exposure control of workers producing such materials in factories [21, 24-32]. Due to their small size and high surface area to volume ratio, some ENMs can easily enter the body, accumulate in tissues, and potentially cause damage, therefore, dangerous to human health [10]. For example, carbon nanotubes (CNTs) have been reported to induce reactive oxygen species (ROS) [20] and pulmonary effects [12]. Toxicological studies have also shown that nanometric titanium dioxide (TiO_2) particles have the potential to induce cytotoxically [26-29], genotoxic [30, 31], and inflammatory effects [28, 29].

The most negative effects are related to the chemical compositions of nanomaterials and the combination with others components.

Buitrago et al. (2022) state that because it is currently done material-by-material, risk evaluation of nanomaterial processes is lengthy and laborious. For (new) nanoparticles, safety data sheets are infrequently accessible, and even when they are, they frequently lack nano-specific information. Measurements or exposure estimates are challenging tasks requiring expensive, high-end equipment and specialized knowledge [29].

In almost analyzed papers, it is stated that thanks to the use of ERA, it is possible to define appropriate Safe-by-Design solutions (SbD) that allow for intrinsically safe nanotechnology products. These solutions need to be validated throughout the life cycle of products, giving particular attention to preserving and optimizing performance attributes related to their specific functionality, production techniques, safety, environmental sustainability, cost/benefit ratio, and regulatory and standardization requirements.

According to Aksel et al. (2017), while the risk management of ENMs receives significant attention, there is still limited understanding of how to select optimal risk management measures to control and mitigate risks associated with exposure to ENMs [30].

For this reason, it is necessary to use appropriate evaluation methods to facilitate the production of nanomaterials, but they should be transparent and comprehensible tools for risk assessment and management [31, 32].

Therefore, the Environmental Risk Analysis process is necessary to evaluate risks to which people, the environment, and other living species are exposed. This is necessary regardless of whether the toxicology of the chemical(s) making up the nanoparticle is well established or not.

According to European Commission (2021), depending on the conditions of manufacture, formulation, use, and final disposal, a risk assessment of nanoparticles may need to be addressed to define:

- Safety of workers during nanoparticle manufacture;
- The security of customers using nanoparticle-containing products;
- Safety of local human populations due to the chronic or acute release of nanoparticles from production and/or processing facilities [33].

Aksel et al. (2017) also argue that there are two ways to reduce the risk from NMEs:

- Control of the risk by modifying the properties of ENMs while maintaining their original characteristics and functionality;
- Control exposure by reducing the release of ENMs from industrial processes or consumer products or by limiting the exposure of workers and consumers to ENMs using administrative measures and behavioral guidelines [24].

Therefore, it is necessary to carry out appropriate administrative checks to see whether the guidelines for the production of these materials have been complied with, to ensure the use of protective equipment by the workers who make these products, and to strengthen continuous checks by the engineers who follow the production of these materials.

To make operative an ERA, there are different evaluation tools and software: Leopold matrix, Hazard and Operability study (HAZOP), Knowledge-based HAZOP, Fault Tree Analysis (FTA), Event Tree Analysis (ETA), Process mapping, Failure Mode and Effect Analysis (FMEA), What-if analysis, and Checklists), Life Cycle Assessment and so many others [32].

Among these tools, Life Cycle Assessment (LCA) is considered the evaluation tool most used to perform an ERA. More in general, LCA is a methodology used to evaluate the environmental impacts of a product, process, or service during its life cycle [30].

Salieri et al. (2018) have asserted that Life cycle assessment (LCA) has been acknowledged for more than ten years as a useful methodology for methodically assessing the potential environmental effects of manufactured nanomaterials over their entire life cycles [32].

Through Life Cycle Assessment (nota UNI EN ISO 14040:2006), an overall balance of impacts can be obtained to guide the appropriate choices of materials in architectural design [32].

In conclusion, the European Committee for Standardisation underlined that the Life Cycle Assessment technique is the evaluation tool (CEN/TS 17276: 2018 Nanotechnologies - Guidelines for Life Cycle Assessment - Application of EN ISO 14044:2006) that enables the assessment of a nanomaterials product's environmental performance throughout its whole life cycle [32].

3.1 The Bio-synthesis Industrial Process to Make "Green" Nanomaterials

European Commission launched different action plans and legislation related to using nanomaterials for the construction sector.

A recent European Union Observatory (EUON) report reads that nanomaterials should be designed circularly [33]. Specific nanomaterials are available for water treatment and recovery of various chemicals and valuable metals.

The industry's transformation to a more sustainable and environmentally friendly circular economy was assisted by the "European Industrial Strategy" published in 2020. For the future development of Europe, the Strategy identified nanomaterials as the main enabling technologies [34].

Green nanotechnology is currently focused on enhancing the sustainability of nanomaterials at the production, usage, recycling, and other waste management operations in addition to the clean and sustainable synthesis of nanomaterials [35].

For example, the Safe by Design (SbD) approach, addressed by EU policy, has recently been applied to nanomaterials to enhance their resilience [36]. SbD gathers a series of guiding principles for product design that aims to identify, estimate, minimize, and reduce risks and uncertainties to people and the environment across the material's or product's life cycle and along its whole value chain [36].

The safety of the product/material is ensured by reducing any potentially hazardous properties while maintaining its functions. Safe production also ensures occupational, process, and environmental protection (for example, using green synthesis to produce nanomaterials). Finally, safe use and end-of-life management, including recycling and disposal, are significant factors in the SbD process [37].

So, the challenges of recent research are to understand what are the better strategies to enhance the "nanomaterials green production," called "the green chemical," to adapt to the principles of the new Green Deal (2011) and the Sustainable Development Goals (2015). Analyzing the scientific literature, it is also indicated that to make "sustainable" the production of these materials, it is necessary to think at an evolution/change of their production, for example, through the use of fungi, yeast bacteria, viruses, algae, plants and biomolecules [38].

According to Saratale et al. (2018), utilizing various bio-reducing agents throughout the biosynthesis process results in nanoparticles with various sizes, shapes, and bioactivities [39].

In the EUON document was made a list of nanomaterials that can be produced through bio-synthesis: gold, silver, zinc, titanium dioxide, iron, palladium, platinum, cerium, copper, selenium, zirconium, silicon, cadmium, nickel, quantum dots, uraninite [39].

According to the principles of circular economy, specific waste materials such as cowhide, goatskin, pig bristles, oil palm leaves, fruit peels, fish scales, rice husk, goose feathers, natural hair, waste corn residue, goldfish scales, chicken eggshell membrane, cherry calyces, corncob sponge, waste sawdust, rice husk, banana fibers, peanut shells, waste coffee grounds, and sugarcane bagasse should be used to make this biosynthesis process operational [39].

However, to improve efficiency and produce nanomaterials with the required size, shape, and monodispersity, bio-synthesis still needs to be optimized for parameters including pH, temperature, reaction time, and growth media [40].

Elegbede and Lateef (2020) say that biological technique, which is a major element of green nanotechnology, has expanded in the last decade to biosynthesize nanoparticles due to a wealth of a wide range of biological resources such as fungi bacteria [41, 42] plants [43, 44], as well as metabolites of arthropods [45-49] and enzymes [50-52].

Furthermore, “green synthesis” and the “biotechnology” have received unparalleled attention due to their reliability, economic effectiveness, reduced chemical use, eco-friendliness, simplicity of the processes, and better biocompatibility of nanomaterials that are produced by biosynthesis [48, 52, 53].

Construction is one area where this biotechnology is being tested However, this technology is just used in biomedicine, drug-gene delivery, cosmetics, the environment, food and feed, the chemical industry, single electron transistors, electronics, light emitters, the space industry, energy science, nonlinear optical devices, mechanics, agriculture, remediation, and photo-electrochemical applications [54-57].

For example, among the green construction materials already being treated using nanotechnology is wood, particularly used in construction and which, thanks to compounds based on specific nanoparticles, can improve its resistance to moisture and other external agents. Specifically, these are treatments capable of creating invisible protection on wooden surfaces, making them water-repellent and oil-repellent, repelling water and external contaminants such as dirt, oil, grease, and dust, and preventing problems related to humidity, the growth of moss and fungus, and insects such as woodworms and tea moths.

Bozoglu and Karacar (2015) state that it is possible to make green materials such as concrete ceramics solar cells, concrete ceramics window glass, concrete, steel, coating, and painting [56].

Soutter (2012) says that materials such as fly ash, slags, and other waste materials from the industry have been used as fillers in cement production. As well as providing a good way to reuse this high-volume waste, cement using these materials has often demonstrated improved mechanical properties, better abrasion resistance, and other benefits [57].

Mishra et al. (2018) analyzed the literature about bio-nanomaterials and their engineering applications [52]. They define biopolymers as polymeric biomolecules consisting of monomeric units, generally joined covalently to create larger molecules. The term “bio” suggests that these are, in fact, naturally degradable materials derived from living micro-organisms [58].

Biopolymers, for example, are a general term for materials based on synthetic pathways generated from biological resources, such as plant oils, sucrose, lipids, resins, proteins, amino acids, etc. (due to their natural compositions) [55]. Significantly, these properties make biopolymers active molecules in vivo. Typically, biopolymers are a variety of plastics made from sustainable biomass sources, such as maize starch, pea starch, vegetable oil, and others [58, 59].

Khalaj et al. (2020) stated that the "green synthesis" described in the literature could not achieve the goals of sustainable development regarding the economic aspect, which call for highly effective, environmentally friendly, economical, and socially acceptable products [60]. This is because the focus has primarily been on the green synthesis's technical requirements and the intended use of the nanoparticles rather than on economic concerns that could adversely impact the production of such materials. Moreover, neither the environmental impact of the established procedures nor their social acceptability has been thoroughly addressed in the academic literature [60]. Therefore, further investigation into biologically created nanoparticles for sustainable development is required.

4. Conclusion and Recommendations

Sustainable development proposes a radical change in lifestyles. Resources and materials are scarce due to the linear economy model, which has led to the intensive exploitation of all the planet's resources. In this context, classical industrial technologies are contrasted by alternative technologies that seek to rebalance the environment.

In this scenario, using nanomaterials in the construction sector is becoming increasingly a reality. However, several obstacles to certifying their sustainability are related to the lack of adequate regulations. It is necessary to do much research before using nanomaterials in the built environment is successful. Nanomaterial production causes different negative environmental impacts during their life cycle (extraction, production, and disposal). In particular, they are produced through different methods, which include physical, chemical, and biological processes. The first two methods are the ones that cause different environmental contaminations and a large number of toxic by-products using a large amount of energy.

Green chemistry, according to researchers, offers the best chance for progressing nanotechnology in a sustainable future. Green chemistry refers to designing chemical processes and products in a way that minimizes or eliminates the use of hazardous materials across the product's entire life cycle. Green nanotechnology can actively affect the design of nanomaterials and products by reducing or eliminating pollution during the production of nanomaterials [60].

Also, the use of evaluation tools is fundamental to support the use of new technologies in the construction sector. In particular, Environmental Risk Analysis is a specific evaluation tool capable of guiding the entire process for applying nanomaterials in the built environment sector. Through the support of these evaluation tools, all the negative impacts can be assessed in the ex-ante phase of each project. Through this pre-assessment phase, the designers can also limit the amount of embodied energy produced for the construction, operation, and disposal of any building.

Using nanotechnology in architecture, urban planning, and engineering will influence the choice of building materials and bring about real change. The future will probably be "nanoarchitecture," i.e., the meeting point between nanotechnology and architecture expected to revolutionize the world of building heritage [60].

The future aim of this research is to reflect on the realization of bionanomaterials for the built environment sector, using waste materials on a territorial scale and, in particular, from local agricultural production waste. In conclusion, it is necessary to consider the "beauty" of the future materials for the built environment; one should consider their efficiency and aesthetic quality [61].

Fusco Girard states that the circular model promotes new forms of architecture through innovative technology to create new spaces. New forms of ecological regeneration, energy recovery, and waste management are the matrix of original and creative architectures that combine the old and the new in a creative synthesis [61].

Author Contributions

M.A. developed the research method, literature review and analysis, manuscript organization and coordination. F.F. developed literature about the innovative materials for the reuse of existing buildings, the manuscript draft and revisions. Both authors have read and agreed to the published version of the manuscript.

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Competing Interests

The authors have declared that no competing interests exist.

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