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The Effect of Using Nanotechnology in Construction Processes Applied by BIM

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Abstract: **Artificial intelligence, programming, and cloud computing are the focus of attention and direction for students and workers in various applications of science these days. Building Information Modelling (BIM) is an example of one of these applications in the field of the construction industry. It has a great revolutionary impact on professionals' way of work, strategy of cooperation between construction parties, and business management. It is a practical approach that can manage the construction projects' life cycle activities and be used by the Architecture, Engineering, and Construction specialists (AEC) to ensure the projects' excellent quality, reduce cost, and facilitate communication among different contractors. And since the emergence of nanotechnology, it was employed in the field of building and finishing materials and has proven its great ability to improve and enhance the efficiency of building performance. Nanotechnology is becoming a future trend that is dreamed of by various participants in construction. The research aims to determine the role of nanotechnology in each stage of the construction project life cycle based on the RIBA plan of work classification. Then specify the degree of importance of each stage. This is achieved by exploring the opinions of field experts using an electronic questionnaire and evaluating the results using the Relative Importance Index (RII) analytical tool. Through this, the most important stages of the project that nanotechnology affects are identified and the role of BIM at these stages is determined to help stakeholders of construction projects using BIM in making decisions and evaluate the importance of project phases.**

Keywords: **Nanotechnology, Construction Process, Building Life Cycle, BIM, RIBA digital plan of work.**

I.INTRODUCTION

Building design and construction is a complex process that requires a tremendous amount of collaboration, management, and hard work. Building Information Modelling (BIM) is considered a digital revolution in the Architecture, Engineering and Construction (AEC) industry. It is the process of utilizing models created by the project team to improve coordination and scheduling while upgrading overall working quality and minimizing project risks [1]. It is applied with specific stages (Plan - Design - Construct and Operate) including the project's lifecycle. Each stage has its own requirements and outcomes. In addition to being an inclusive solution to construction challenges, BIM has been presented as a technology and process that can radically digitize the construction lifecycle, from inception to operation of an asset. The Royal Institute of British Architects (RIBA) have adjusted its processes to align with BIM with recommendations of functions needed to be delivered at the various lifecycle phases of facilities and produce (RIBA) Plan of works 2020.

Nanotechnology is the design, characterization, production and application of forms, mechanisms, and systems through controlled manipulation of shapes and dimensions at Nano scale that produces forms and systems with at least one improved or new property [2]. It makes changes to some building materials properties to improve current characteristics to be lighter, stronger structural sections, lower maintenance coatings, better cementing materials, and high-quality thermal insulation. For characterizing the engineering controls and for personal protection to reduce the risk to a minimum, nanotechnology must be connected by BIM process [3], [4]. This study tends to bridge this gap by introducing BIM definition and process framework, RIBA plan of work and its stages and finally nanotechnology and nanomaterials in the construction sector. Through the study, the mechanism of involving nanomaterials in the construction industry is regulated according to the RIBA classification of project phases. That comes with the aim to define the role of BIM that serves nanotechnology through these phases.

II.LITERATURE REVIEW

A. BIM Definition and Application Benefits

Building Information Modelling (BIM) is characterized as a process of generation and management of the "building data" during its lifecycle. In BIM, the building is analyzed into separate components including slabs, columns, roofs, walls, openings, etc. These components are defined architecturally and structurally with all needed information and predicted constraints, then shared between project team members [6]. Three main missions are provided by the BIM for AEC, visualization, coordination, and prefabrication.

Visualization: is the process which provides a better understanding about what the final product will look like and helps in making decisions about spaces aesthetics and functionality. It also helps in the field of good standard practice for the physical mock-up process and during bidding phase.

Coordination: including cooperation between the project team in the early stages. So that, the two-dimensional drawings provided by the architect are integrated with the three-dimensional drawings, especially in the fields of electrical and mechanical engineering and steel fabricators. Design errors are significantly reduced and the work to be done is fully understood better.

Prefabrication: It reduces site labor cost and time and increases accuracy in a good quality construction. BIM can provide this level accuracy by including the specifications, sequence, finishes, and the 3D visualization for each component. Prefabricated beam design would save enormous time, money, and effort compared with onsite beam design. Beams, roof structural tests, curtain wall prefabricated parts are all examples of prefabricated elements that BIM contributes to Pre-design and prefabrication of them [7].

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Table 1. BIM benefits different stakeholders' sectors. [7,8,9].

	Built Assets		Sectors		
	Delivery Phase	Use Phase	Design	Construction	Digital Management
Economic	- Savings 10% of time delivery	- Lower maintenance costs - Lower operations costs	- Save the design cost - Effective analysis cycles - Better production value	- Improve sector competitiveness - Grow export capability - Fewer changes in supply orders - Shorter construction time	-Grow digital services industry -Digital single market
Environmental	-Less site waste	- Optimize using operational energy -Assess whole life-cycle analysis - Improved operation and maintenance	-Effective prefabrication and more predictable field conditions -Enhanced basis for decision making - Errors and omissions reduction	- Resource efficiency - Circular economy	-Data infrastructure resource efficiency
Social	-Higher standard of health & safety -Improved public consultation and engagement	-Improve social outcomes (patient care, pupil learning)	-increased accuracy and improved quality	- Cleaner and safer jobs in construction - Attract next generation to the sector	-Data Security - Innovation in using digital design and construction applications

Table 2. BIM main data types [10, 11]

BIM Information	**The Employer's Information requirements (EIR)**	Technical	includes details of software platforms, definitions of levels of detail etc.
		Management	Deals with the management processes details to be adopted on the project through BIM.
		Commercial	is about details of BIM Model deliverables, timing of data exchange and definitions of information purposes
	BIM Execution Plan (BEP)	Identify	identifying the value of BIM and its uses during Project life cycle (PLC)
		Design	design the BIM execution process
		Define	define deliverables
		Develop	develop the infrastructure in the form of contract language, coordinates, naming procedures, communication procedures, technology, and quality control to support the implementation

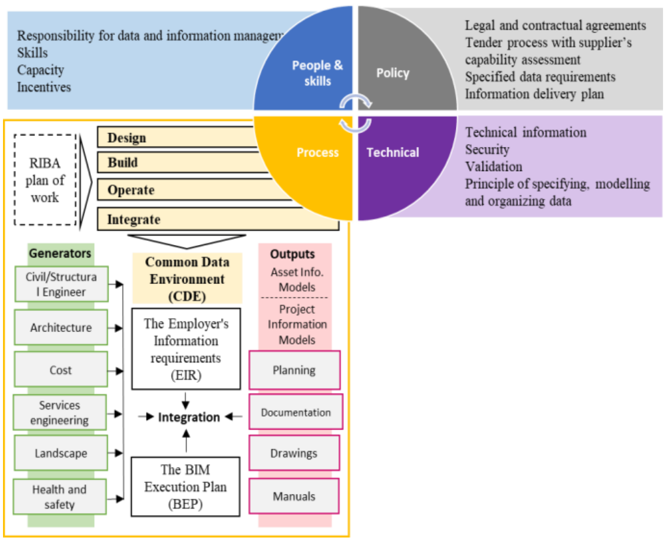

Figure 1. BIM Implementation cycle & process framework. [6, 9],

BIM presented many benefits either economic, environmental, or social to a project which is considered the main asset, and to the AEC sectors. Generally, BIM improves the design and implementation quality through all project phases [8], [9] as shown in Table 1.

B. BIM Process Framework Along Project Lifecycle

Raising the ability to get the right information, at a specific time and in an organized format is a key benefit of using BIM process. The success of this process depends on the performance of four connected parties. These parties include people and their skills, policy, technical, and the BIM core process [10]. The integration between The Employer's Information Requirements (EIR), and the BIM execution plan (BEP) helps in generating building information models of planning, documentation, drawings, and manuals as shown in Figure 1. The EIR referred to the needs of the client at each project stage while, BEP referred to the implementation strategy [11], as illustrated in Table 2.

C. BIM and RIBA Digital Plan of Work

For ensuring better information management within the BIM process, (RIBA digital plan of work) can be used. It is a systematic method for arranging works for construction projects during their life cycle. It was created by The Royal Institute of British Architects in 1963 and becomes the most used plan in the UK [6], [12]. It brings greater clarity to the different project stages for all stakeholders. RIBA divides the PLC into 8 stages. They can be combined with BIM levels as shown in Table 3 with a detailed clarifying for BIM stages which illustrated in Table 4 [13] and as shown in the successive tables from Table 5 to 12 according to RIBA actions and outcomes for each stage which all referred to Ref. [12], [14].

D. Nano Technology Definition and Scope of Applications

Nanomaterials (NMs) are those materials that have at least one dimension in the scale ranging from 1 -100 nanometers [4]. Consequently, these materials have properties or

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characteristics distinguished from others, where all materials behave differently at the nanoscale. The European Commission (EC) also defines them as materials that contain nanoparticles or nanofibers within their internal tissues. It is a slightly more specific definition than the definition of the International Organization for Standardization (ISO), which includes any materials that have internal structures on the nanoscale, including the presence of nanoscale holes, pores or nanofilms. It is usually associated with innovative ideas and unfortunately, with health risks. The uses of NMs have extended to the construction industry and have become necessary sometimes to improve the performance of various building elements [3], as shown in Appendix (1). The science that deals with the applications of these materials and supports its development acceleration is nanotechnology [4]. It has been approved that by the year 2025, up to 50% of building materials will be nanomaterials [15]. These currently used materials are classified into metal oxide nanoparticles and Carbon-based nanomaterials.

E. Nano Technology Through Building Life Cycle

Through buildings life cycle, it has been approved that the impact of nanotechnology appears in several stages like construction, operation & maintenance, and demolition. But the most evident one is the construction phase. Nanomaterials (NMs) are involved in all building systems whether structural, enclosure or mechanical systems as shown in Figure 2.

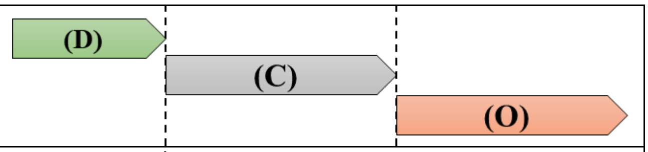
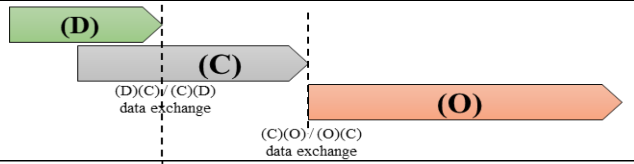
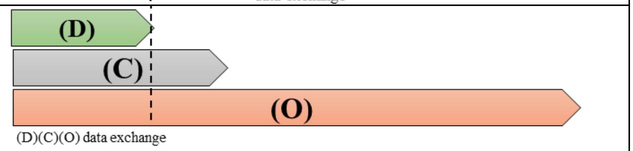
During these phases, workers are exposed to different nano particles, even MNMs or NEP [5]. These materials have an impact on public health and safety. About 75% of workers and employers in construction aren't aware of NMs usage procedures or risks, and the available information about these raw materials is usually lost or get lack as the information travels through the chain of users and different construction phases [5]. Consequently, potential Exposure flows and Scenarios (ES) in each process and NMs flow involved in these ES must be identified.

Table 3. Construction Projects Life cycle phases (PLC) according to RIBA plan of work

PLC phases	**Planning Phase(P)**		**Design Phase (D)**			**Construction Phase (C)**			**Operation Phase (O)**		
PLC sub-phases	P		D1	D2	D3	C1	C2	C3	O1	O2	O3
Counterpart RIBA Plan of Work stages	**Stage 0**	**Stage 1**	**Stage 2**	**Stage 3**	**Stage 4**	**Stage 5**		**Stage 6**	**Stage 7**		
	Strategic Definition	Preparation and brief	Concept design	Spatial Coordination	Technical design	Construction		Handover	In use		

P	**D1**	**C1**
Determining client needs, financial capacity, feasibility study, previous projects, site capabilities	conceptualization, programming, and cost planning	construction planning and detailing
	D2	**C2**
	architectural, structural and systems design	construction, manufacturing, and procurement
	D3	**C3**
	analysis, detailing, coordination, and specification	commissioning, as built and handover

Table 4. BIM effects in PLC phases [13].

BIM Stage 1: Object-Based Modelling Create single-disciplinary models for either design (D), construction (C), or operation (O), and exporting basic data such as openings schedules, concrete properties...etc. to apply coordination between 2D documentation and 3D visualizations.	
BIM Stage 2: Model-Based Collaboration Active collaboration and develop performed models after. collaboration applied within one or two PLC phases, like the Design -Design integration of architectural and structural models (DD), or the Design-Operations integration of architectural and maintenance work models (DO).	
BIM Stage 3: Network-Based Integration Create integrated models sharing collaboratively across PLC. This integration between models and documented data forms an overlap phase.	

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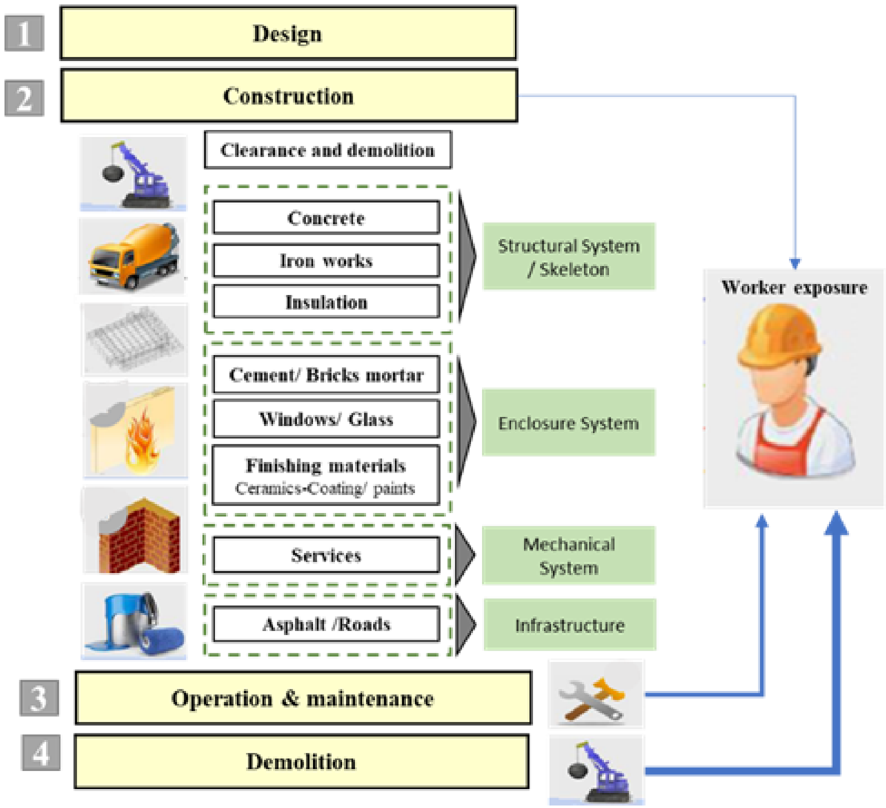

Figure 2. Nano Application in construction field through PLC [4,5]

Table 5. RIBA stage 0 and BIM related applications

Stage 0: **Strategic Definition**		
RIBA	Core Tasks	- Prepare Client Requirements - Understand business case including review of project risks and project budget - Review Feedback from previous projects - Undertake site appraisals
	Outcomes	Confirmation of client requirements
BIM	Objective	Collecting data from previous projects.
	Activities	Develop BIM adoption strategy.
	Deliverables	--

Table 6. RIBA stage 1 and BIM related applications

Stage 1: **Preparation and brief**		
RIBA	Core Tasks	-Prepare project brief including project outcomes and sustainability outcomes, quality aspirations and spatial requirements -Undertake Feasibility Studies -Agree project budget -Prepare Project Program -Prepare Project Execution Plan
	Outcomes	- Approval of project brief and confirmed that it can be accommodated on the site
BIM	objective	- Preparing project feasibility study. - Updating assigned budget based on concept design changes. - Definition of "as-is" condition.
	Activities	- Develop the EIR. - Model existing condition using 3D laser scanning.
	Deliverables	- Existing condition point cloud model.

Table 7. RIBA stage 2 and BIM related applications

Stage 2: **Concept Design**		
RIBA	Core Tasks	- Prepare an architectural concept that includes strategic engineering requirements and is aligned with the cost plan, project strategies, and outline specifications - Agree Project Brief Derogations - Undertake Design Reviews with client and Project Stakeholders -Prepare Stage Design Program
	Outcomes	- The architectural concept was approved by the client and matching with the project brief

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Follow Table 7. RIBA stage 2 and BIM related applications

BIM	objective	- Facilitate communication between the designer and the owner. - Successful visualization of the design to give clear decisions with minimum impact on project budget and duration. -Obtaining information about cost into a concept design parametric model. -Integrate site conditions and supply chain capabilities into the project. -Engaging other design disciplines and engineering requirements into the concept design stage. -Prepare sustainability strategy including energy analysis.
	Activities	- Develop BIM Execution plan BEP - Visualize the design intent to owner - Reflect cost information - Perform energy analysis.
	Deliverables	-VR models for the building - Parametric concept design model including architectural, structural, and building services. Preliminary 5D model (cost information model)

Table 8. RIBA stage 3 and BIM related applications

Stage 3: **Developed Design/ Spatial Coordination**		
RIBA	Core Tasks	- Practicing design studies, engineering analysis, and cost exercises to evaluate the architectural concept to utilize spatially coordinated design aligned to updated cost plan, project strategies, and the outline specification - Initiate Change Control Procedures - Prepare Stage Design Program
	Outcomes	Architectural and engineering information Spatially Coordinated
BIM	objective	- Facilitate the development of a coordinated design model. - Engaging the construction team in the design development. -Defining the LOD of BIM models.
	Activities	- Integrate buildability and maintainability considerations into design development
	Deliverables	- Coordinated and buildable design model. - Updated 5D model. - Preliminary Bill of Quantities (BOQ).

Table 9. RIBA stage 4 and BIM related applications

Stage 4: **Technical Design**		
RIBA	Core Tasks	-Develop architectural and engineering technical design -Prepare and coordinate design team Building Systems information -Prepare and integrate specialist subcontractor Building Systems information -Prepare stage Design Program
	Outcomes	- All design information required to manufacture and construct the project completed
BIM	objective	(The most complicated stage in the whole project lifecycle, based on the quality of previous stage) - Enriching BIM model with construction non-graphical information about construction sequence and methods. - Engaging construction team in the technical design. - Facilitate the coordination between procurement plans and construction sequence (4D model).
	Activities	- Integrate construction sequence into BIM model. - Provide Platform to enable site team to comment, inquire and navigate through BIM model.
	Deliverables	- 4D model (construction schedule information model). - Updated 5D model. - Coordinated procurement plan.

Table 10. RIBA stage 5 and BIM related applications

Stage 5: **Construction**		
RIBA	Core Tasks	- Finalize Site Logistics - Manufacture Building Systems and construct building - Monitor progress against Construction Program - Inspect Construction Quality - Resolve Site queries as required - Undertake Commissioning of building - Prepare Building Manual
	Outcomes	- Manufacturing, construction, and Commissioning completed
BIM	objective	- Facilitating the communication between site team and technical office. - Site coordination, Storage, logistics and labor management - Maintaining coordinated procurement process
	Activities	- Updating BIM Execution Plan (BEP). - Integrate procurement plan with construction sequence. - Provide Platform to enable site team to comment, inquire and navigate through BIM model. - 3D laser scanning of built elements.
	Deliverables	- As-built models. - Simulations of site logistics and construction sequence.

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Table 11. RIBA stage 6 and BIM related applications

Stage 6: **Handover**		
RIBA	Core Tasks	- Handing over the building in line with the usage strategy plan - Undertake review of Project Performance - Undertake seasonal Commissioning - Rectify defects - Complete initial aftercare tasks including final additions after occupancy assessment
	Outcomes	- Building handed over, Aftercare initiated, and Building Contract concluded
BIM	objective	- Enriching BIM model with FM non-graphical information.
	Activities	- Integrate COBie information into as-built models.
	Deliverables	- 6D asset model (FM- facilities management information model). - COBie sheet. It is specific information set in the form of a simple spreadsheet that offers consistent and structured information about an asset in post-occupancy facility management.
Note: Facility Management (FM) is an organizational function that integrates people, site, and the building process within the built environment to improving the quality of life. Construction Operations Building Information Exchange (COBie) is a modern data format, used to facilitate the handover process to building's owners.		

Table 12. RIBA stage 7 and BIM related applications

Stage 7: **In-Use**		
RIBA	Core Tasks	-Implement Facilities Management and Asset Management -Undertake Post Occupancy Evaluation of building performance in use -Verify Project Outcomes including Sustainability Outcomes
	Outcomes	- Building used, operated, and maintained efficiently
BIM	objective	- Learning from project experience
	Activities	- Extract data from BIM models and CDE records about overall project performance.
	Deliverables	- Quantitative data about cost, time, resources… etc.

Referring to the capabilities and contributions of nanomaterials, the application areas of their usage can be summarized as shown in Figure 3 and Table 13. These applications show the massive correlation between nanomaterials and green architecture as well as sustainability. They have been classified into (1), Develop Initial Planning, (2) Construction and insulation material advancement, (3) safety and security, (4) indoor quality, (5) material surface advancement, (6) energy generation and storage, (7) environmental impact control, in addition to (8) Adding technical values to the project [16].

F. Nanotechnology and BIM Construction Industry

Nanomaterial types and usage which have been identified in the field of construction industry and the coincidence of those uses through the PLC, need an organized tool to support its applications. BIM is going to perform its tasks of visualization, coordination, and prefabrication for these applications.

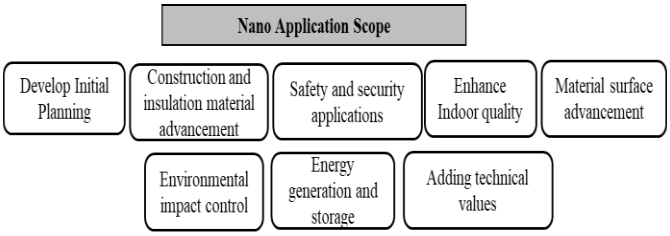

Figure 3. Nano Application in construction field through PLC

Table. 13 Application areas of Nanomaterials and BIM supporting tool. [5,17,18,19,20]

	Application scope	Nanomaterials functions	BIM supported functions	BIM process
1	Develop Initial Planning	Developed a best practice for health and safety during PLC.	Risk Prevention in selecting materials: Safe by Design for the design of MNMs or NEP [20]	Plan
			Risk Assessment:including sharing information about used MNMs through Material Safety Datasheets (MSDS) and defining potential Exposure flows and Scenarios (ES) with occupational exposure limits . According to Table 3 and future upgrades and Figure 4.	
			Risk Protection:using protective devices like respiratory protective devices, gloves, protective clothing	
			Design Risk Management Model (RMM) and intergrate it with any management system & choose suitable Toolkit	

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Follow Table. 13 Application areas of Nanomaterials and BIM supporting tool. [5,17,18,19,20]

	Application scope	Nanomaterials functions	BIM supported functions		BIM process
2	Construction and insulation material advancement	-Accelerate concrete hardening - High performance concrete - high performance steel with low carbon - Steel protective coats -High strength structural repair mortar - Thermal insulation blocks, thin panels and special paints -Open porous asphalt - UHPC for Bridges	visualization, coordination, and prefabrication		Build
3	Safety and security applications	-Fire protection by glazing - Bomb blasts protection by glazing	Recording products containing nanoparticles or nanofiber in the CDM health and safety file [15].		Design
			Disseminate information about properties and risks of MNMs through Material Safety Datasheets (MSDS) and Standards [5].		Design
			Design Risk Management Model (RMM) and integrate it with the management system		Operate
4	Indoor quality	-Temperature regulation -Antibacterial -Ease to clean -Air purification and quality -Fragrance capsules -Anti-fingerprint -Anti fogging	Natural ventilation system analyses	Estimation of the capacity for natural ventilation	Design
				Evaluation of various natural or mixed modes of ventilation strategies	Design
			Thermal comfort analyses	Simulation and optimization at the design stage	Design
				Monitoring comfort levels by integrating sensors	Operate
5	Material surface advancement	- Low-E coatings - UV protection -Solar protection -Anti-reflective -Dynamic glazing -Lotus-effect -Photocatalysis -Anti-graffiti -Scratch resistance	Solar radiation and lighting analyses	Solar radiation analyses for the exterior of buildings	Design
				Lighting-condition analysis	Design
				Point-by-point lighting simulation	Design
			Acoustics analyses	Acoustic performance simulation	Design
				Enhanced visual and audial effects of simulated acoustics	Design
6	Environmental impact control	-CO2 Emission &Recycling -Soiling, Staining and -Pollution Reduction	Carbon emission analyses	Carbon emission calculations	Design
				Design alternatives for carbon emission reduction	Design
7	Energy generation and storage	-Solar Glass -Thin Film Solar Cells -Semiconductor Devices -Quantum Dot Enhanced Cell -Electrical Energy by Paper Battery -Solid-state lighting	Energy performance analyses	Whole building energy analysis	Design
				Evaluations of different energy conservation measures	Design
				Feasibility evaluations of renewable energy	Design
				Fault detection and diagnostics of energy systems	Operate
8	Adding technical values	Smart Construction Equipment and knowledge management like using NEMS/MEMS*, automation, mechanical actuators, pumps, or motors, sensors.	System operation		Operate

III. METHODOLOGY

The study was divided into three sections. Through ***the first section***, identifying the BIM scope of work during projects lifecycle according to RIBA plan of work was discussed, after introducing the BIM definition and benefits across different project stakeholders. In the same way, nanotechnology, and its impact on the building construction industry through project life cycle were addressed. This comes after a brief on nanotechnology and its most prominent materials in construction issues. Finally, the research attempted to determine nanotechnology applications through BIM process.

While ***the second section***, as illustrated in Figure 4, includes joining the three triangle vertices to configure nanotechnology applications through BIM project supported by RIBA plan of work. By merging the outcomes from the first section, we can build the next configuration illustrated in Table 14.

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Table. 14 Merging nanotechnology applications with RIBA POW strategy [21],[22]

N	Nano technology applications through RIBA stages	PLC	BIM Role
Stage 0: Strategic Definition		Plan	Collecting and storing data from previous similar projects Risk Prevention in selecting materials: Safe by Design for the design of MNMs or NEP Recording nano products in the CDM health and safety file
1	Determine the need for using nanotechnology in the project according to client's needs"		
2	Analysis previous projects to evaluate the effectiveness of nanomaterials impact and study their strategic challenges		
Stage 1: Preparation and brief			
3	Determine the outputs of the use of nanomaterials, whether sustainable or quality outputs, and impact on the surrounding environment.		
4	Searching for nanomaterials and products available in the market		
5	Classification of products according to their applications or supporting functions and according to public health and safety.		
6	Selecting appropriate nanomaterials and products and confirming compatibility with environmental requirements like climate parameters, building style, and lifespan.		
7	Incorporating the cost of using nanomaterials into the project budget		
8	Introducing nanotechnology at the technical, management and commercial levels within the project program		
9	Studying the compatibility of the project after applying nanotechnology with the site		
Stage 2: Concept design		Design	Design Risk Management Model (RMM) and intergrate it with any management system & choose suitable Toolkit Preparing coordinated and buildable design model with (BOQ). Visualization, coordination, and prefabrication for nano products
10	Introducing nanotechnology in the concept of design in all parametric design models.		
11	Reviewing the structural and architectural design and complementary works after using nanomaterials.		
Stage 3: Spatial Coordination			
12	Studying the mutual effect between site conditions and the project after using nanotechnology		
13	Setting a policy and time for introducing nanomaterials in the construction and finishing stages.		
Stage 4: Technical design			
14	Completing all detailed project drawings and technical specifications that include nanomaterials as part of it.		
15	Completing the risk management plan resulting from the use of nanomaterials and calculating the exposure limits.		
16	Announcing the policy of dealing with nanomaterials in the implementation and operation phases to the team members		
Stage 5: Manufacturing & Construction		Build	Comparing potential Exposure flows and Scenarios (ES) with occupational exposure limits and activate protective devices Periodic audits, integration of nano products in COBie as-built models
17	Achieving the main benefits of using nanomaterials listed in Table 3 from 2 to 7.		
18	Inspection of construction quality		
19	Verify the occupational safety of workers and the work environment and take the necessary measures		
Stage 6: Handover close out			
20	Checking implementation quality of nanoproducts, applying environmental tests and monitoring procedures.		
21	Setting schedules for periodic maintenance work		
22	Approving plans for dealing with sudden accidents.		
Stage 7: In use		Operate	Verifying and documenting project outcomes
23	Activate implementation of maintenance and monitoring plans		
24	Evaluation of the impact of using nanotechnology on the project (were the expected benefits achieved?)		

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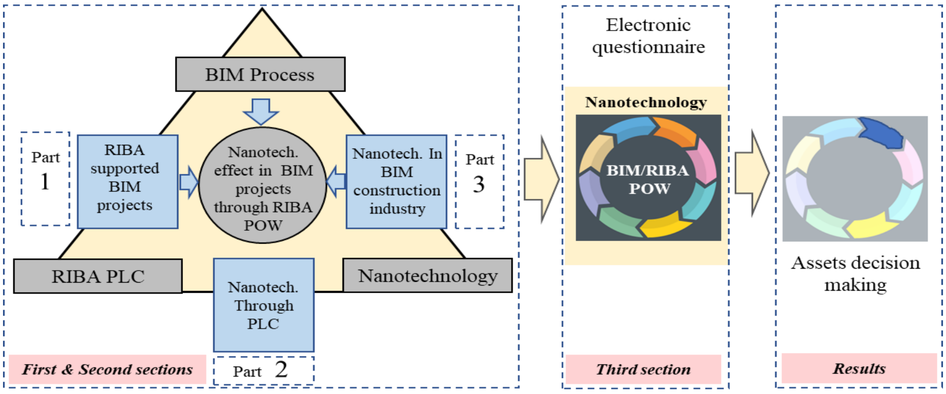

Figure 4. Research methodology

The third section, a baseline survey (electronic questionnaire) was designed based on the previous table to determine the most phases of the project in which the impact of nanotechnology is most prominent according to RIBA plan of work. Results will affect many design decisions while using nanotechnology in projects built with BIM system.

Multidisciplinary stakeholders (30 experts) involved in BIM projects with other architectural design interested in smart and nano materials (S&NM) were selected, then 30 electronic questionnaires were distributed as illustrated in Table 15.

The first part of the questionnaire evaluates the effect of nanotechnology through the four projects life cycle phases (plan, design, construct and operate), while the second part measures that effect according to RIBA plan of work which was classified as shown in Table 14 into 24 factors.

Subsequently, the results of the electronic questionnaire were collected and analyzed. Statistical analysis was applied using Relative Importance Index (RII). It gives weights to input factors and ranked them according to degree of importance using the next formula (1) [23], [24]:

$$RII = \frac{\sum w}{A*N} \qquad (1)$$

where, W is the sum of grades given to each factor by all respondents (ranging from 1 to 5), A is the highest grade (5), and N is the total number of respondents (30). This formula was entered into Microsoft Excel to facilitate final ranking giving the importance level ranges from 0 to 1 as shown in Table 16.

Given grades represent the level of agreement of the question which is measured using "Likert Scale" where: (Grade 5- EI) = Extremely important- (Grade 4- I) = important - (Grade 3-A) = Average- (Grade 2-NI) = Not important - (Grade 1- ENI) = Extremely not important. Global ranking of each factor (24 factors) is also calculated by multiplying the relative weight of the factor by the weight of the calculated weight of the PLC phase.

Standard Deviation (SD) is calculated to measure the amount of dispersion of the inputs, low values that tend to approach the mean indicate data closeness and balance [25].

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N}(x_i - \bar{x})^2}{N-1}} \qquad (2)$$

Table 15. The distribution of the electronic questionnaire to the experts

Participant	Number
BIM users	6
Engineers involved in S&NM	4
PhD. Architects	10
PhD. Structure engineers	10
Total	30

Table 16. RII Importance level ranges

The Relative importance index (RII) range	Importance level
0.00: 0.20	Low = L
0.21: 0.40	Medium low = M to L
0.41: 0.60	Medium = M
0.61: 0.80	Medium high = M to H
0.81: 1.00	High = H

Coefficient of Variance (CV) is also measured. It is defined as the ratio between the SD and the mean of values, expressing variability of sample dataset entered by respondents [26]. Low values indicate to more acceptable results as following: CV<10: very good, 10-20: good, 20-30: acceptable, and CV>30: not acceptable.

All SD values were near to the mean, and average of CV was 12.556, which means that respondents opinions were balanced and homogeneous.

IV. RESULTS

Results of the study is mainly related to the electronic questionnaire as illustrated in Table 17 and Table 18. Where, from the RII statistical analysis, and after verifying correlation and homogeneity of the dataset sample, it was found that the extent of interference of nanotechnology effect going through all PLC phases, as most experts consider that it affects the performance of each substage. The most important affected standard PLC stages and their corresponding RIBA plan of work phases are determined as following:

- Plan, design, construction, and operation is the resultant order for the effect of nanotechnology, while in RIBA stages, some details were added to these phases. Stage1 (Preparation and brief) comes first, then Stage 0 (Strategic Definition). Stages 3,4 and 5 come in the middle order, respectively. Finally stage 2 and 7.

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- According to global ranking, 50% of stage 0, 75% of stage 1, 50% of stage 3, 33% of stages 4 and 5 were from the top 10 of the affected substages by nanotechnology.
- Stage 7 totally has the largest part of the last 5 affected substages.

V.DISCUSSION

Regarding the electronic questionnaire results analysis, according to the project stages ranking presented in the last table, the role of BIM is highlighted in most prominent stages as following:

Through stage 0: BIM is relied upon to recall project models in which nanotechnology was used, analyze its elements and benefit from it. That gives an indication of the necessity of accurately recording project data and evaluating post-operational performance because it is considered an indicator of success.

Through stage 1: BIM is going to apply the safe design policy to health and the surrounding environment, and through the material data sheet that is recorded, the characteristics of each nanomaterial, operating considerations, maintenance needs, safety measures in case of sudden accidents are identified. In addition to Calculate and evaluate permissible exposure levels. The different uses of nanomaterials and their allocations are analyzed in this stage. The role of value engineering, which is managed and organized by BIM, also emerged.

Through stage 4: It is the most important part for (AEC), especially architectural designers where BIM models are visualized and coordinated including involved nanomaterials from all disciplines according to their field of use. It is the one in which special calculations are made, such as: Natural ventilation system analyses, Thermal comfort analyses, Solar radiation and lighting analyses, Carbon emission analyses, Energy performance analyses and others mentioned in Table 13.

Through stage 5, 6: Risk management plan is activated, exposure levels are monitored and compared to the permissible levels, with the necessary measurements being made at each implementation stage and upon final project submission compared with the COBie.

Through stage 3: Site conditions and determinants are added to the models that will be created in the fourth 4.

Table 17. The statistical analysis of the Electronic Questionnaire results- Part (1)-Integration of nanotechnology through PLC using BIM.

Code/N		EI	I	A	NI	ENI	Mean μ	Standard Deviation α	Coefficient of Variance cv	Relative Important Index RII	Importance level	Relative ranking
PLC	Plan	18	11	1	0	0	4.567	0.437	9.574	0.913	High	1
	Design	13	17	0	0	0	4.433	0.388	8.746	0.887	High	2
	Build	15	8	7		0	4.267	0.637	14.924	0.853	High	3
	Operate	12	8	10	0	0	4.067	0.668	16.427	0.813	High	4

Table 18. The statistical analysis of the Electronic Questionnaire results- Part (2)

	Code/N		EI	I	A	NI	ENI	Mean μ	SD α	CV	RII	Importance level	RR	GR	GR-mean	Stage rank
Planning Phase	Stage 0: Strategic Definition	1	9	14	7	0	0	4.067	0.569	13.993	0.813	High	2	14	8.5	2
		2	17	10	3	0	0	4.467	0.524	11.737	0.893	High	1	3		
	Stage 1: Preparation and brief	3	17	13	0	0	0	4.567	0.388	8.491	0.913	High	1	1	6.5	1
		4	15	11	4	0	0	4.367	0.553	12.657	0.873	High	5	6		
		5	19	6	5	0	0	4.467	0.597	13.367	0.893	High	3	3		
		6	13	15	2	0	0	4.367	0.473	10.834	0.873	High	5	6		
		7	16	10	4	0	0	4.400	0.557	12.658	0.880	High	4	5		
		8	4	14	12	0	0	3.733	0.532	14.249	0.747	Medium High	7	23		
		9	18	9	3	0	0	4.500	0.525	11.664	0.900	High	2	2		
Design Phase	Stage 2: Concept design	10	6	15	7	2	0	3.833	0.642	16.736	0.767	Medium High	2	24	18.5	7
		11	13	10	7	0	0	4.200	0.619	14.748	0.840	High	1	13		
	Stage 3: Spatial Coordination	12	8	16	6	0	0	4.067	0.532	13.081	0.813	High	2	21	15.5	6
		13	12	15	3	0	0	4.300	0.501	11.652	0.860	High	1	10		
	Stage 4: Technical design	14	12	18	0	0	0	4.400	0.383	8.712	0.880	High	1	8	11.6	3
		15	15	9	5	1	0	4.267	0.668	15.657	0.853	High	2	11		
		16	12	11	7	0	0	4.167	0.609	14.613	0.833	High	3	16		
Construction	Stage 5: Construction	17	10	18	2	0	0	4.267	0.449	10.517	0.853	High	2	17	14.3	4
		18	18	9	3	0	0	4.500	0.525	11.664	0.900	High	1	9		
		19	14	10	6	0	0	4.267	0.604	14.153	0.853	High	2	17		
	Stage 6: Handover close out	20	15	12	3	0	0	4.400	0.519	11.796	0.880	High	1	12	14.6	5
		21	13	14	3	0	0	4.333	0.508	11.733	0.867	High	2	15		
		22	13	13	3	1	0	4.267	0.604	14.153	0.853	High	3	17		
Operation	Stage 7: In use	23	12	15	3	0	0	4.300	0.501	11.652	0.860	High	2	22	21	8
		24	16	12	2	0	0	4.467	0.484	10.830	0.893	High	1	20		
	The average of (Coefficient of Variance)									12.556						

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Through stage 2: Includes evaluating the risk management plan within BIM.

Through stage 7: Ensuring the efficiency and safety of operation and display maintenance schedules, in addition to recording project details to become a database for another new project.

VI. CONCLUSIONS

Nanotechnology which deals with the smallest material particles and thus affects its properties is no longer a modern technology, it attracts many workers in the construction industry due to its outstanding effect in the field of improving construction and finishes materials, such as raising the capabilities of concrete, steel, insulation materials, paints, finishes, and restoration work for historical buildings. In addition to its distinguished additives in the field of glass, whether insulating light, heat, self-cleaning, fire resistance and breakability. Integration and inclusion of these materials in construction projects require special planning and arrangement of works. It begins with identifying the main needs and usage motivations, applying value engineering, as well as the implementation and operation phases. Therefore, the classification and arrangement of the importance of the role of nanotechnology in the various PLC using the RIBA classification is an effective indicator for all members involved in the construction industry for how to deal with each stage. In the relevant context, BIM supports these stages prominently, where it can also contribute to achieving the desired results of nanotechnology and organize the tasks in which nanotechnology is involved between architecture, engineering, and construction (AEC). Through the research, the importance of nanotechnology was studied in each stage of PLC and the role of BIM in those stages has been identified. The research verified the importance of initial stages represented in planning stage which corresponding with stages from 0 to 4 in RIBA plan of work compared to the design, construction, and operation stages, which reflects the importance of accurate initial data analysis.

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REFERENCES

[1] Florida International University, "Building Information Modeling (BIM)Standard & Guide", FIU BIM Specification, 2014.

[2] Papadonikolaki E., Leon M., Mohamad A., "BIM solutions for construction lifecycle: A myth or a tangible future?", 11th European Conference on Product and Process Modelling (ECPPM), Denmark, Vol.: 11, 2018.

[3] Mohamed H., "Applications of Nanomaterials in Architectural Design", International Journal on: Proceedings of Science and Technology, IEREK press, 2020. DOI: 10.21625/resourceedings. v2i1.740

[4] Mohajerani A., Burnett L., Smith J., Kurmus H., Milas J., Arulrajah A., Horpibulsuk S., Abdul Kadir A.," Nanoparticles in Construction Materials and Other Applications, and Implications of Nanoparticle Use", Maerials, 2019. 12, 3052; Doi:10.3390/ma12193052

[5] The Scaffold research, "Innovative strategies, methods and tools for occupational risks management of manufactured nanomaterials (MNMs) in the construction industry", European Community's Seventh Framework Program, Final Newsletter, September 2015

[6] The Institution of Structural Engineers, "An introduction to Building Information Modelling (BIM)", The Institution of Structural Engineers, 2021.

[7] The European Union," Development and advanced prefabrication of innovative, multifunctional building envelope elements for Modular Retrofitting and Connections (MORE-CONNECT)", The European Union,2014.

[8] Li Z., "The Application of BIM Technology in the whole Life Cycle of Construction Project", IOP Conf. Ser.: Earth Environ. Sci. 510 062004, IOP Publishing, 2020, Doi:10.1088/1755-1315/510/6/062004

[9] EU BIM Task group, "Handbook for the introduction of Building Information Modelling by the European Public Sector", The European Union, 2016.

[10] Kjartansdóttir I., Mordue S., Nowak P., Philp D., Snæbjörnsson J.," Building Information Modeling -BIM", Civil Engineering Faculty of Warsaw University of Technology, Warsaw, 2017.

[11] Messner J., Anumba C., Dubler C., Goodman S., Kasprzak C., Kreider R., Leicht R., Saluja C., Zikic N., "BIM Project Execution Planning Guide - Version 2.2", Computer Integrated Construction Research Program, Penn State, USA, 2020.

[12] RIBA working group, "RIBA Plan of Work 2020 Overview", RIBA, London, 2020.

[13] BIM framework, "Effects of BIM on Project Lifecycle Phases ", 2008. https://www.bimthinkspace.com/2008/11/effects-of-bim-on-project-lifecycle-phases.html (last accessed in December 2022)

[14] Amin K., Abanda F.," Building Information Modelling Plan of Work for Managing Construction Projects in Egypt", Journal of Construction in Developing Countries, 24(2), 23–61, 2019. Doi.org/10.21315/jcdc2019.24.2.2

[15] Gibb A., Jones W., Goodier C., Bust P., Song M., Jin J., "Nanotechnology in construction and demolition: Guidance for industry", IOSH Research Committee, Loughborough University, 2017.

[16] Abdellatif A.," Towards sustainable architecture with nanotechnology", Al-Azhar Engineering 11th International Conference, Cairo,2010.

[17] Gibb A., Jones W., Goodier C., Bust P., Song M., Jin J., "Nanotechnology in construction and demolition: what we know, what we don't", IOSH Research Committee, Loughborough University, 2017.

[18] Bozoglu J., "Nanotechnology Enabling BIM for Facility Owners", Presentation for Illinois Institute of Technology ,2012. DOI: 10.13140/RG.2.1.3179.6245

[19] Selem O., "Nanotechnology: Small materials for a big building", BIMarabia Magazine,36 issue,2020.

[20] Kraegeloh A., Suarez-Merino B., Sluijters T., Micheletti C.," Implementation of Safe-by-Design for Nanomaterial: Development and Safe Innovation: Why We Need a Comprehensive Approach", Nanomaterials 2018, 8, 239; doi:10.3390/nano8040239

[21] Bakir R., "Nanotechnology and Architecture: An Optimized Design Process Model", Sixth international conference in Nanotechnology in Construction NTC, 2014.

[22] Yusuf J., "Investigation into the adoption of Building Information Modelling (BIM) in architectural SMEs in the United Kingdom", The University of Salford - School of the Built Environment, MSc Building Information Modelling (BIM) and Integrated Design, 2014

[23] Tholibon D., Nujid M., Mokhtar H., Rahim J., Abdul Aziz N., Tarmizi A., "Relative Importance Index (RII) in Ranking the Factors of Employer Satisfaction Towards Industrial Training Students", International Journal for Asian Education IJAE, Vol. 2, No. 4, December 2021. Doi.org/10.46966/ijae. v2i4.187

[24] Rajgor M., Paresh C., Dhruv P., Chirag P., Dhrmesh B.," RII & IMPI: Effective techniques for finding delay in construction project", International Research Journal of Engineering and Technology (IRJET), Volume: 03 Issue: 01, 2016.

[25] Standard Deviation, https://www.cuemath.com/data/standard-deviation/ (last accessed in December 2022)

[26] CFI TEAM, "COEFFICIENT OF VARIATION", UPDATED 2022, HTTPS://CORPORATEFINANCEINSTITUTE.COM/RESOURCES/DATA-SCIENCE/COEFFICIENT-OF-VARIATION/ (LAST ACCESSED ON DECEMBER 2022)

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LIST OF ABBREVIATIONS

(BEP)	BIM Execution Plan	**(NMs)**	Nanomaterials
(BOQ)	Bill of Quantities	**NEMS**	nano-electromechanical
(BIM)	Building Information Modelling	**(PLC)**	Project life cycle
(CDM)	Construction, Design and Management Regulations for health & safety	**(RII)**	Relative Importance Index
(COBie)	Construction Operations Building Information Exchange	**(RIBA)**	Royal Institute of British Architects
(EC)	European Commission	**(RMM)**	Risk Management Model
(EIR)	Employer's Information Requirements	**UHPC**	Ultra-high-performance concrete
(ES)	Exposure flows and Scenarios	**UV**	Ultraviolet electromagnetic radiation
(FM)	Facility Management	**For analytical analysis**	
(ISO)	International Organization for Standardization	**(CV)**	Coefficient of Variance
(MSDS)	Material Safety Datasheets	**GR**	Global rank
MEMS	micro-electromechanical systems	**RR**	Relative ranking
(NEP)	Nano Enable Products	**(SD)**	Standard Deviation

Appendix (1) Table Nanomaterials Applications and Expected Benefit.

Nanomaterial	Application scope	Usage	Expected Benefit
Titanium dioxide (TiO2)	Window glass	used for heat, fire protection and self-cleaning surfaces.	absorbed UV fraction in sunlight to create reactive sites which have capability to remove bacterial and dirt on windows. Superhydrophilicity; anti fogging, fouling resistance
	solar cells		Non-utility electricity generation
	Coatings - Depolluting mortar (walls)	self-cleaning paints anti-fogging paints	maintain whiteness throughout the surface lifetime and reduced maintenance tasks duration
	Mechanical applications	water treatment	used as a photocatalyst producing reactive oxygen that may degrade other organics
	Road coating mortar	self-cleaning	applied on the road as a coating
	Cement	enhance durability	Rapid hydration: increase degree of hydration, self-cleaning - enhance durability and maintain whiteness throughout the lifetime of the construct.
Amorphous silica (SiO_2)	concrete	Self-compacting concrete	utilized as fillers to pack the pores and reinforce concrete; therefore, they can prevent concrete from weakening issue as abovementioned [9- 11]. Incorporating nanoparticles in fly ash as a cement replacement also enhanced the mechanical properties of concrete like fire resistant and flame-proofing
		enhance durability.	improve the surface properties of the material. Mainly in irregular formwork, some superficial cracks and porosities are produced which are caused by the contraction of the material and the quality of the surface is considerably reduced whereas the addition of this MNM avoids the apparition of these discontinuities
	Ceramics	Working as Coolant	light transmission, fire resistance
	Windows	Flame proofing anti-reflection	windows' coating control exterior light as it acts as an antireflective material, which contributes to energy conservation

Follow Appendix (1) Table Nanomaterials Applications and Expected Benefit.

Nanomaterial	Application scope	Usage	Expected Benefit
Nano clay (CNF) (May have toxic effects which are not apparent in the bulk material)	FR panels	Insulation panels	use in building walls, ceilings, floors, and roofs. They provide superior and uniform insulation. Different nano-powders are used as mass-ingredients in the technology of Structural Insulated Panels at different dosages up to 20% by weight to enhance Fire Retardant properties. The main nano clay reinforcements used are of hydrated sodium calcium aluminum silicate.[2]
	Bricks mortar		Compressive strength, increase surface roughness
	asphalt Road surface	Heavy duty surfaces	The asphalt doped by Nano clays or CNF has better barrier properties against the inclemency of the weather (high temperatures, rain…) or the transit of heavy motor vehicles, reducing for instance, the maintenance operations during their use.
Cellulose fibers (CellNF) (Toxic properties)	Insulation panels	improve insulation properties	for use in building walls, ceilings, floors, and roofs. One of the nanomaterials that can improve insulation properties

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Carbon nanofibers (CNFs)	composite materials	composite materials	Improve strength, stiffness, electrical conductivity, or heat resistance
Carbon nanotubes (CNTs)	Concrete		mechanical durability, crack prevention
	Ceramics		enhanced mechanical and thermal properties
	NEMS/MEMS,		real-time structural health monitoring
	Solar cell		effective electron mediation
`Iron oxide Fe2O3	concrete	enhance durability	increased compressive strength; abrasion-resistant., can be utilized as fillers to pack the pores and reinforce. concrete: therefore, they can prevent concrete from weakening issue as abovementioned
Copper/ Cu nanoparticles	steel	enhance durability	Weldability, corrosion resistance, formability
Silver nanoparticles	coating/painting	enhance Properties	Anti-bacteria coatings/ Biocidal activity

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