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ديسمبر 2022
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تصدر عن كلية الهندسة وكلية الحاسبات والمعلوماتية – جامعة ذمار
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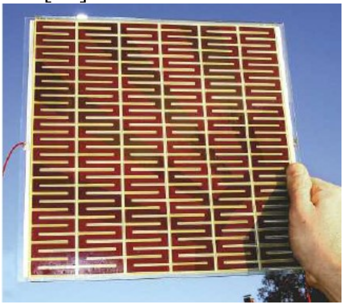
#	Name of Nanotechnology	Uses	Brief Description
	nanoparticles in dye solar cells		charge separation [29].  Prototype of a dye solar cell module for decorative applications in glass facades [29].

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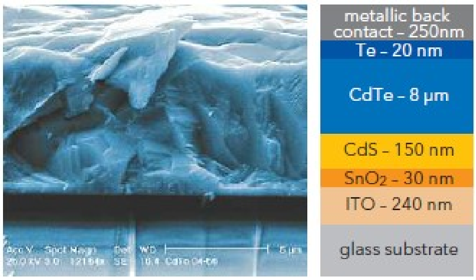
			CO2 as a solvent, the use of organic solvents is also avoided. In addition, the method has numerous advantages [26].
N_22	The Hypucem	[I]	Hybrid Polyurethane Cement, for example, is rigid foam, fire and water resistant combined within a single material [33].
N_23	The Pilkington Activ	[W]	It is self-cleaning glass that uses a 15 nm thick transparent coating of microcrystalline titanium dioxide. The coating is applied by chemical vapor deposition [26].
N_24	NT thin-film	[W]	NT helps to improve the properties of glazing, especially the heat gain and loss, by thin-film coatings, thermo-chromic, photochromic and electro-chromic technologies [27].
N_25	Thin- layer solar	[S]	 Electronic microscopic photo and schematic of a cadmium telluride thin-layer solar [29].
N_26	TiO2-DDA hybrid film	[C]	This is a very high-tech coating that is especially designed for glass. Micro-nano-structured super-hydrophobic film was obtained by incorporating titania nanoparticles and dodecylamine. The sol-gel processing parameters and the concentration of DDA in the film were optimized to prepare super-hydrophobic surfaces [37]. 
N_27	Titanium dioxide	[S]	Dye solar cells use titan dioxide nanoparticles doped with dye molecules (e.g. different ruthenium complexes) for

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#	Name of Nanotechnology	Uses	Brief Description
			sales towards glass facades as well as low energy buildings. According to their webpage they are "reinventing the window" and are "building with energy in mind" [26].
N_17	Quantum dots, such as CdSe	[L]	A quantum dot is a closely packed semiconductor crystal comprised of hundreds or thousands of atoms, and whose size is on the order of a few nanometers to a few hundred nanometers. Changing the size of quantum dots changes their optical properties [40].
N_18	SGG Aquaclean	[W]	Aqaclean has been developed to diminish cleaning costs and pollution of window. This material is not coated on the glass but burned in, the water cannot get a grip on the surface and the windows stay clean [41]. Both photoactive and hydrophilic are applied by chemical vapor deposition [26].
N_19	Silicon nanocrystalline ink	[S]	A technology that has the potential to greatly reduce the cost of silicon-based solar cells [27]. 
N_20	SunClean	[W]	SunClean self-cleaning window glass uses a coating of titanium dioxide, applied by a patented process [26]. The SunClean glass metal oxide coating is bonded to the surface of the glass during the manufacturing process and is extremely durable. However, during and after construction, the glass should be protected from spills, runoff, and over-spray from common building materials. Caulking, lubricants, and paints should be promptly removed [42].
N_21	Super-critical CO2	[A]	Supercritical carbon dioxide has a combination of liquid and gas-like properties that makes it an attractive solvent for wood impregnation purposes – both from technical and environmental points of view [43]. By using this method, the use of chemicals per m3 wood is significantly reduced compared to conventional methods, and the use of heavy metal salts and boric acid is avoided. By using supercritical

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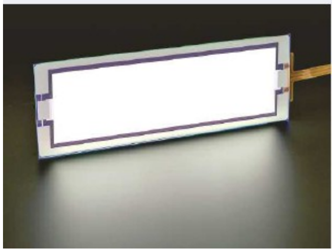
#	Name of Nanotechnology	Uses	Brief Description
			  The further development of OLED will also depend on nano-technological innovation, which concern, inter alia, the optimization of the field carrier material, succession and thickness of layers, application of dopants and the purity of the materials used [29].
N_15	Photocatalytic paints	[C] [A] [L]	These products are natural with no VOC compounds. The photocatalytic paint is supplied in powder form. It is processed and shipped dry for maximum cost savings in compliance with LEED standards for the Green Industry. Self-cleaning photocatalytic paint is based on the natural minerals containing calcium carbonite and titanium dioxide [39]. 
N_16	PRO TEC 7	[W] [S]	PRO TEC 7 is being patented by PRO TEC windows. PRO TEC continues to develop custom-made solutions collaborating with architects and construction companies in several countries. They have especially orientated their

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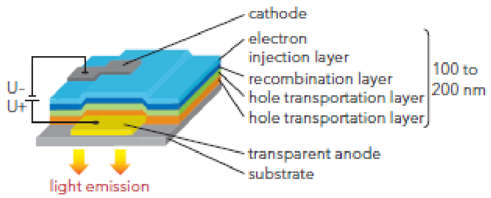
#	Name of Nanotechnology	Uses	Brief Description
	film		infrared light and heat while transmitting visible light [32].
N_10	Nano Films	[C] [S]	Nano films are materials that have two non-nano dimensions. The films are so thin that their thickness is within the 1-100nm range. The most recent nano-films are just a few molecules thick, having been built up by self-assembly, i.e., atom-by-atom or molecule-by-molecule [36].
N_11	Nanostructured Anti-reflection Layers	[S]	 Antireflection coating [29].
N_12	VELUX	[C] [W]	Nanotechnology has long been an aspect of interest to VELUX because it plays an important role among a number of their suppliers and in the components of their products. VELUX is among the Danish companies with quite a varied interest in nano-technologies [26].
N_13	Neat Glass	[W]	Titanium dioxide layer less than 10 nm thick applied by magnetron sputtering [26].
N_14	Organic Light-Emitting Diodes (OLED)	[L]	Organic light-emitting diodes describe the phenomenon that thin layers semiconducting organic materials are capable of emitting light under application of an electric field (electro luminescence) [29].  Schematic structure of an OLED [29]

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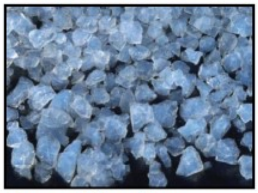
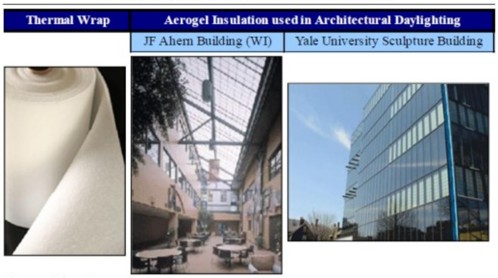
#	Name of Nanotechnology	Uses	Brief Description
N_05	Three ultra-thin Aspen aerogel insulation product lines Cryogel®, Pyrogel®, and Spaceloft®	[I]	The Spaceloft® line ranging from 5 mm to 10 mm in thickness is targeted to residential and commercial building applications. It can be applied to interior and exterior walls, framing, floors, and roofs [28].
N_06	Cabot (CBT-NYSE)	[C] [I] [L] [S]	Cabot has developed aerogels that offers ultra-low thermal conductivity (Rvalue of 9.6 per inch); Cabot produces aerogel particles [28]. Cabot Corp. AEROGEL PARTICLES  *Source: Cabot Corp.* A Thermal Wrap aerogel blanket. Its thickness ranges from 3.5 mm to 8 mm, with operating temperatures between -200°C and roughly 125°C (for continuous heat, 160°C for peaks) [28]. A SELECTION OF CABOT'S AEROGEL SOLUTIONS  *Source: Cabot Corp.*
N_07	CNTs (Carbon Nano-Tubes)	[C]	CNTs can kill Echerichia coli bacteria. In their experiments, roughly 80 % of these bacteria were killed after one hour of exposure [30].
N_08	Cork and Carbon nanotubes	[I]	Cork and carbon nanotubes melded into one single material composites with nanostructured components and integrating these composites as building materials [31].
N_09	Hüper Optik's nanoceramic	[W]	It does not incorporate dyes or metals but rather is embedded with titanium nitride beads that block UV and

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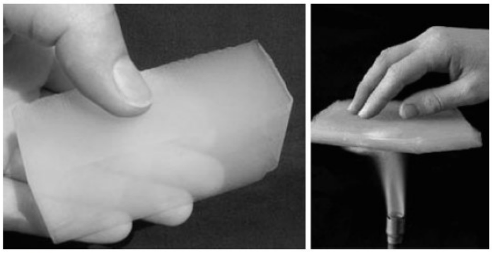
Appendix I: A Brief description of the identified most common 27 nanotechnologies used in non-structural elements of buildings

#	Name of Nanotechnology	Uses	Brief Description
N_01	ActiFloor	[A]	The idea is to make floors which are depolluting and thereby improve the indoor climate as well as being easy-to-clean. Photo-catalytic nano-particles are integrated in the matrix of the upper layer. As far as Photocat is concerned, the product is the first of its kind in the world [26].
N_02	Aerogel	[I]	Aerogel is a highly porous solid material with extremely low density with large, open pores, and highly specific surface area [27]. 
N_03	AR-surface	[W]	AR-surface is a nano-porous structure of approx. 100 nm thicknesses on both sides of the glass. The chemical systems remain in a closed loop and no harmful waste is imposed on the environment [26].
N_04	Aspen Aerogels	[I]	The company's technology converts standard aerogels into a flexible aerogel blanket reinforced with non-woven fiber batting the company's technology and converts standard aerogels into a flexible aerogel blanket reinforced with non-woven fiber batting [28]. 

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http://papers.cumincad.org/data/works/att/acadia05_058.content.pdf [Accessed in November 2016].

[29] Wolfgang, L. "Application of nanotechnology in the energy sector", HA Hessen Agentur GmbH, Volume 9 of the series Aktionslinie Hessen- Nanotech of the Hessian Ministry of Economy, Transport, Urban and Regional Development, Germany (2008).

[30] Inman, M. "Bug-pooping surfaces promise clean surfaces", NewScientist.com, 22 August 2007, available online: http://www.newscientist.com [Accessed in October 2016].

[32] Residential Window Films, https://huperoptikusa.com/residential/[Accessed in Dec 2016].

[33] Leone, M. F. "Nanotechnology for Architecture. Innovation and Eco-Efficiency of Nanostructured Cement-Based Materials", Leone MF (2012).

[34] Carmody, J., Selkowitz, S., Lee, S. e., Arasteh, D. and Willmert, T., W. W. Norton & Company, New York, "*Window Systems for High-Performance Buildings*", (2004).

[35] Nanocrystalline Silicon/Silicon Inks, A Nano Market - White Paper, (April 2008), available online: http://nanomarkets.net/images/uploads/NMNanocrystallineSilicon.pdf [Accessed in December 2016].

[36] Kotov, N. "MRS Bulletin". Dec. 992-997 (2001).

[37] Risø National Laboratory, "NanoByg: A survey of nano-innovation in Danish construction", available online: http://www.risoe.dk/rispubl/ reports/ris-r-1602.pdf [Accessed in October 2016].

[38] Febriyanti, E. and Kartini, I. " Self Cleaning Hydrophobic Glass TiO2-Dodecylamine Hybrid Film", Proceedings of The 1st Annual International Scholars Conference in Taiwan (2013).

[39] http://www.ecogreen-plus.com/Pages/PhotocatalyticPaint.aspx [Accessed in Dec 2016].

[40] Nanotechnology White Paper, Science Policy Council U.S. Environmental Protection Agency Washington, DC 20460 EPA 100/B-07/001 (2007).

[41] https://materia.nl/material/aquaclean/ [Accessed in Dec 2016].

[42] http://www.bfrich.com/wp-content/uploads/2014/06/Caring-for-Sun-Clean-Glass.pdf [Accessed in Dec 2016].

[43] http://www.superwood.no/Files//Images/Certifikater/Superwood_report_Feb_14.pdf [Accessed in Dec 2016].

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[15] Omar, O. M. E. "NanoArchitecture and Global warming". M.Sc. Thesis, Architecture Department, University of Alexandria, Egypt (2012).
[16] El Mograby, Y. M. S. "Nanotechnology and its Impact on Architecture in Construction Methods and Finishing Materials". M.Sc. Thesis, Architecture Department, Cairo University, Egypt (2013).
[17] Metwaly, M. M. A. "Nano-Era A New Prospect for Achieving Architectural Sustainability", M.Sc.Thesis, Architecture Department, Cairo University, Egypt (2013).
[18] Saleh, M. M. "Green Nanotechnology as A Language for A Futuristic Architecture", M.Sc. Thesis, Architecture Department, Cairo University, Egypt (2013).
[19] Ibrahim, S. M. "Nanotechnology as an Approach to Green Architecture", M.Sc. Thesis, Architecture Department, Cairo University, Egypt (2014).
[20] Mohamed, A. S. Y. "Nano-Innovation in Construction – A New Era of Sustainability", 2015 International Conference on Environment And Civil Engineering (ICEACE'2015), Pattaya, Thailand, (2015).
[21] Saad, A. A. E. "Nano Technology Impact on Buildings Envelope to Reduce Energy", M.Sc. Thesis, Architecture Department, Cairo University, Egypt (2014).
[22] Ali, M. A. M. "Applications of Nanotechnology on Glass and its Impact on Energy Efficiency in Office Building", M.Sc. Thesis, Architecture Department, Cairo University, Egypt (2014).
[23] Larsson, N. "Building performance assessment", SB Method and SBTool (2010).
[24] Feifer, L. "Sustainability Indicators in Buildings: Identifying Key Performance Indicators. PLEA 2011 proceedings", 786 (2011).
[25] Sustainability Performance Assessment and Benchmarking of Buildings (SuPerBuildings) Conclusions about the need for development of sustainability indicators and assessment methods. SuPerBuildings Project Deliverable 2.1. (2010).
[26] Andersen, M., Sandén, B. and Palmberg, C. "Green Nanotechnology in Nordic Construction, Eco-innovation Strategies and Dynamics in Nordic Window Value Chains", Nordic Innovation Centre project number: 06242, (2009).
[27] Sev, A. and Ezel, M. "Nanotechnology Innovations for the Sustainable Buildings of the Future", World Academy of Science. *Engineering and Technology International Journal of Civil, Environmental, Structural, Construction and Architectural Engineering*, Vol:8, No:8, (2014).
[28] Nano-Technology and the built environment: The transition to green infrastructure, Crystal Research Associates, LLC& Livingston Securities LLC, (2011).
[31] Daveiga, J. and Ferreira, P. "Smart and Nano Materials in Architecture, ACADIA05: Smart Architecture, available online:

engineered Nano-materials that are embedded in the urban fabric, that is, the dynamic, spatially-agglomerated complex of activities, buildings, infrastructures, technical devices, and ecosystems that comprise the contemporary metropolis.

REFERENCES

[1] Daryoush, B. and Darvish, A. "A Case Study and Review of Nanotechnology and Nanomaterials in Green Architecture". *Research Journal of Environmental and Earth Sciences* 5(2): 78-84, (2013).

[2] Soltani, M. "Review of nanotechnology application in the construction industry". *Mon. J. Nanotech.*, No. 122, (2007).

[3] Wiek, A., Guston, D., van der Leeuw, S., Selin, C. and Shapira, P. "Nanotechnology in the City: Sustainability Challenges and Anticipatory Governance". *Journal of Urban Technology*, Vol. 20, No. 2: 45–62 (2013).

[4] Asadifard, R. "An Overview of some of the Applications of Nanotechnology". The Presidential Office of Technology Cooperation, Nanotechnology Studies Committee, Iran. (2004).

[5] Elvin, G. "Nanotechnology for Green Building". *Green Technology Forum*. (2007).

[6] Williams, D. E. FAIA and Publishers, John Wiley and Sons Inc., Hoboken, New Jersey. "Sustainable Design: Ecology, Architecture and Planning". (2008).

[7] Droege, P. "Climate Design: Design and Planning for the Age of Climate Change". ORO Edn., Reyes Station, CA, (2010).

[8] Kibert, C. J. John Wiley and Sons, Hoboken, New Jersey. "*Sustainable Construction: Green Building Design and Delivery*". 2nd Ed. (2008).

[9] Leydecker, S. Springer Science & Business Media, Birkhäuser, Berlin, Germany, "*Nano Materials in architecture, Interior architecture and Design*", (2008).

[10] El-Samny, M. F. "Nano-Architecture: Nanotechnology and Architecture", M.Sc. Thesis, Architecture Department, University of Alexandria, Egypt. (2008).

[11] Michael, F. A., Paulo J. F., Daniel L. S. Elsevier Ltd., UK. "*NanoMaterials, Nano-Technologies and Design, An Introduction for Engineers and Architects*", (2009).

[12] Mohammed, A. A. S. "Nanomaterial's in Architectural Engineering -Their Applications and Their Characteristics in Buildings". M.Sc. Thesis, Architecture Department, Cairo University, Egypt. (2014).

[13] Fahmey, M. H. M. "Nanomaterials & Architecture - Sustainable Architecture", M.Sc. Thesis, Architecture Department, University of Alexandria, Egypt. (2010).

[14] Fouad, F. F. "NanoArchitecture and Sustainability", M.Sc. Thesis, Architecture Department, University of Alexandria, Egypt (2012).

insulation, window chain, lighting, and solar energy. Furthermore, this paper offered an extraction-based analysis of the roles and potentials of these nanotechnologies towards achieving green and sustainable architecture. These are in addition to providing brief description on each of these nano-technologies. The developed matrix and structured knowledge on selected nano-technologies pave the road for architects and building engineers to better select from these nano-technologies to achieve sustainable and green architecture in the design and construction of buildings.

However, there is a need to advance from predication-based estimation of the opportunities offered by nanotechnologies to more concrete evaluation of the actual impacts of nanotechnologies applications on building construction and about their economic, ecological and social impacts. This will provide evidence-based results of the actual impacts of nanotechnology on sustainability. This opens a wide door for future research on this regard. Furthermore, the issue of ensuring the sustainability of nanotechnology materials is by itself of great concern in future research in terms of ensuring through evidence-based evaluation that nanotechnology materials are resource-efficient, consistent and inherently safe. Another important direction of future research on nanotechnology and sustainability is the life cycle analysis of adopting nanotechnologies since it could be economically feasible and profitable in the short-term but its significant contribution to the sustainability of buildings over the long run needs to be thoroughly investigated. While many proposed nanotechnologies are projections of isolated applications, set only marginally in the urban context, the impact of nanotechnologies on sustainability at the urban level needs to be further articulated while considering the debate argued by Wiek et al [3] on urban nanotechnologies viewed as products, structures, and processes using

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#	Name of Nanotechnology	Uses	Major Concerns of Sustainable and Green Architecture													
			Environmental						Economic					Social		
			Energy	Materials	Climate Change	Ecology	Water	Waste	Manage. & Maint.	Lifecycle Costs	Adaptability	Process Quality	Innovation	Comfort& Health	Accessibility	Safety & Security
	nanocrystal															
N_20	SunClean	[W]							X							
N_21	Super-critical CO2	[A]										X				
N_22	The Hypucem	[I]							X							
N_23	The Pilkington Activ	[W]	X						X	X						
N_24	NT thin-film	[W]	X						X		X			X		
N_25	Thin- layer solar	[S]														
N_26	TiO2-DDA hybrid film	[C]							X							
N_27	Titanium D	[S]	X							X						

CONCLUSION

This paper offers a guide to architects and building engineers to select the most appropriate nano-technologies for achieving sustainable and green architecture that is developed on prediction-based estimation of the opportunities offered by these nanotechnologies. Also, the paper provided a structured and tabulated knowledge on the multiple uses of the most common and selected 27 nano-technologies used in the non-structural elements of buildings including coatings, adhesives,

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			Energy	Materials	Climate Change	Ecology	Water	Waste	Manage. & Maint.	Lifecycle Costs	Adaptability	Process Quality	Innovation	Comfort& Health	Accessibility	Safety & Security
	Aspen															
N_06	Cabot	[C] [I] [L] [S]								X	X		X	X		
N_07	CNTs	[C]												X		
N_08	Cork and CNT	[I]							X	X						
N_09	Hüper Optik	[W]												X		
N_10	Nano Films	[C] [S]	X						X							
N_11	Nanostructured ARL	[S]							X	X						
N_12	VELUX	[C] [W]	X									X	X			
N_13	Neat Glass	[W]							X							
N_14	Organic LED	[L]	X									X				
N_15	Photocatalytic paints	[C] [A] [L]			X					X				X		
N_16	PRO TEC 7	[W] [S]	X						X	X	X		X	X		
N_17	Quantum dots	[L]	X													
N_18	SGG Aquaclean	[W]							X							
N_19	Silicon	[S]								X						

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27 nanotechnologies extracted in Table 3 was induced with reference to the major issues of sustainability listed in Table 2. Such mapping is used to establish the matrix of the roles and potentials of nanotechnologies in achieving sustainable and green architecture as developed and illustrated in Table 4. This developed matrix in Table 4 offers a starting point for architects and building engineers to select the most appropriate nano-technologies based on their desired outcomes in terms of major concerns of sustainable and major architecture; then Table 3 offers to them the specific and detailed potentials of these nano-technologies in achieving sustainable and major architecture; and Appendix I provides the brief description associated with available visualization for these nano-technologies.

Table 4: Matrix for mapping of roles and potentials of the selected 27 nanotechnologies to the major issues of sustainability architecture (Source: Authors).

#	Name of Nanotechnology	Uses	Major Concerns of Sustainable and Green Architecture													
			Environmental						Economic					Social		
			Energy	Materials	Climate Change	Ecology	Water	Waste	Manage. & Maint.	Lifecycle Costs	Adaptability	Process Quality	Innovation	Comfort& Health	Accessibility	Safety & Security
N_01	ActiFloor	[A]							X					X		
N_02	Aerogel	[I]					X				X					
N_03	AR-surface	[W]				X	X									
N_04	Aspen Aerogels	[I]												X		X
N_05	Three ultra-thin	[I]							X		X					

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#	Name of Nanotechnology	Uses	Potentials and impacts in achieving sustainable and green architecture
N_25	Thin- layer solar	[S]	• Provides potentials for cost reduction in the manufacturing of solar cells due to materials savings • Low- temperature processes • Integrated cell isolation • High automation level in series production • Improvements of the rear reflectors for which usually metal layers (e.g. silver) are used, for example through the application of photonic crystal or non-metal nano-layer systems to further increase the light yield in the substrate. • Apart of silicon, materials combinations of opper/indium/gallium/sulphur/selenium (CIGS- cells) as well as III-V semiconductors (e.g. gallium arsenide) are applied, which allows efficiencies up to 20% [29].
N_26	TiO2-DDA hybrid film	[C]	• The hybrid films showed sufficient stable retention of hydrophobicity for four weeks outdoor and at high humidity environment (RH >90%). Thus, this work can provide development of new approach to creation of transparent super-hydrophobic films on the basis of TiO2-DDA hybrid materials. • Nano TiO2-DDA hybrid film showed maximum WCA of 155.5° [38].
N_27	Titanium dioxide nanoparticles in dye solar cells	[S]	• Application possibilities at diffuse incidence of light (e.g. for internal application) as well as the transparency and color design possibilities of cells, which open up interesting architectural application perspectives. • Dye solar cells are cheap manufacturing processes through screen printing [29].

A GUIDE FOR SELECTING THE MOST APPROPRIATE NANOTECHNOLOGIES IN NON-STRUCTURAL ELEMENTS OF BUILDINGS

At the early stages of design and construction process and before completing tender documents for construction bidding, it will be extremely useful to architects and building engineers to have the opportunity to appropriately select the nanotechnologies that can assist and contribute to achieving and/or improving the level of buildings towards green and sustainable architecture. Accordingly, there is a need to simplify this selection process in the form of a guide that has various tiers of knowledge to be used as required and needed. Therefore, the mapping of roles and potentials for each of the selected

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#	Name of Nanotechnology	Uses	Potentials and impacts in achieving sustainable and green architecture
N_19	Silicon nano-crystalline ink	[S]	• Could make flexible solar panels as much as ten times cheaper than current solutions. Their silicon process lends itself to low cost and high efficiency [35].
N_20	SunClean	[W]	• Low maintenance glass [36].
N_21	Super-critical CO_2	[A]	• The wood is completely impregnated and can be processed without exposing un-impregnated wood; the method enables the impregnation of wood species such as spruce that cannot be impregnated using traditional methods; and the wood may be used immediately after the impregnation since the process leaves neither large amount of water nor solvents in the wood [26].
N_22	The Hypucem	[I]	• The Hypucem: excellent thermal insulation properties (λ = 0.025-0.040 W/mK) and thermal mass (it can be manufactured with different densities: 200-400- 750 kg/m3). • The material shows both the properties of an autoclaved aerated concrete (breathable, lightweight, with good compressive strength, fire resistance, good compatibility with mortars and plasters) and the properties of a polymer foam (thermal and acoustic insulation, ease of installation and processability) [33].
N_23	The Pilkington Activ	[W]	• This Self-Cleaning Glass is characterized by high photo-catalytic properties, chemical stability and low price. • Offers additional features like solar control and low emissivity. • Low maintenance glass [28]
N_24	NT thin-film	[W]	• Thin film coatings are spectrally sensitive surface applications for window glass. They filter out infrared light to reduce heat gain in buildings. • Self-cleaning surfaces, which were the first architectural applications of NT. These surfaces are made by applying thin nano-coating films and painting. • A nano-coating on or integrating nanoparticles into the surface layer of the substrate, such as concrete walls. A drawback of self-cleaning coatings is that they require sunlight for activation, reducing their effectiveness indoors [27]. • As an alternative for indoor applications, coatings using layered double metal hydroxides and air-cleaning nanocrystals can be applied to indoor surfaces to improve the indoor climate and reduce ventilation requirements, thereby improving the building's energy efficiency [37] . • Thin film coatings utilizing SiO_2 and TiO_2 nanorods can control exterior reflectivity. These coatings have the lowest reflectivity ever reported [36]. • Applications can also be activated by a heating element in the window, making it operate like other switchable glazings, but this tends to be less energy efficient [36]. • Cutting out excess sunlight that creates glare and overloads the cooling system [34].

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#	Name of Nanotechnology	Uses	Potentials and impacts in achieving sustainable and green architecture
			can be less than 1 mm thick [29].
N_15	Photocatalytic paints	[C]	• Photocatalytic paints determine an extra cost of about 10-12%, while in the case of paving blocks the cost increase compared to a traditional asphalt is approximately of 15% [33].
		[A]	• Photocatalytic paving blocks for road resurfacing has been tested, resulting in a reduction of NOx values, especially at head height, in the order of 40% [10]. • Photocatalytic paving blocks have shown how the use of such technology avoids the blackening due to exhaust gases and reduce the concentration of pollutants from 30% to 40% [33].
		[L]	• Since the photocatalytic action is activated by solar radiation, this will be provided by the integration of a new lighting system with UV lamps and special self-cleaning glasses reduced cost of maintenance operations along time [33].
N_16	PRO TEC 7	[W]	• Has a very high insulation property. • The U-value for the total window structure is as low as 0.51 W/m^2K, which puts the window well ahead of the tighter new specifications introduced in the upcoming building regulations. • The frame appears sleek letting in a large amount of light. PRO TEC also produces integrated façade systems without double frames. • The composite window is 20% more expensive than traditional windows, but the total cost of ownership is far less than for a traditional window giving the energy prices [26]. • Applications can also be activated by a heating element in the window, making it operate like other switchable glazings, but this tends to be less energy efficient [26]. • Thin film coatings utilizing SiO_2 and TiO_2 Nano-rods can control exterior reflectivity. These coatings have the lowest reflectivity ever reported [26]. • Cutting out excess sunlight that creates glare and overloads the cooling system [34].
		[S]	• Looking at the energy balance, it is an energy plus window. • Producing up to 11kW/m2. The energy performance of the window can be increased by up to 60% compared to traditional modern low energy windows [26].
N_17	Quantum dots, such as CdSe	[L]	• Quantum dots can be used in the design of road reflectors and any other reflective surface that will be exposed to incident light. • Because electrons in a quantum dot are confined to widely separated energy levels, as particle size decreases, the dots emit only one wavelength of light when excited. Thus, CdSe Nano-crystals in solution, exposed to incident light, emit radiation of a particular color [31].
N_18	SGG Aquaclean	[W]	• Low maintenance glass [33].

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#	Name of Nanotechnology	Uses	Potentials and impacts in achieving sustainable and green architecture
			infrared rejection and 99% UV rejection, increases the shatter resistance of glass, and has shown to be up to 13°C cooler than unprotected glass [32].
N_10	Nano Films	[C]	• Nanofilms are used as a surface treatment when composition or/and mechanical properties need to be altered, or as coatings when a different material is deposited to create a new surface. • Nanofilms are stable and able to cover larger areas. • Once applied, they are easy to manipulate using standard processes and tools. • Potential applications of Nanofilms include the development of scratch-resistant plastic coatings, low friction coatings, and materials with a very low or negative refractive index [31].
		[S]	• Nanofilms are useful in the solar energy area [31].
N_11	Nanostructured Anti-reflection Layers	[S]	• A relatively low-cost method of increasing energy yields of solar cells. • Solar collectors are the application of anti-reflection layers for flat glass based on a Nano-porous coating of silicon dioxide. • The porosity allows the adjustment of the effective refraction index between glass and ambient air, which helps reduce reflection losses of glass panes of usually 8% to 2%. • It is possible to increase the annual heat yield of solar collectors by 10% [29].
N_12	VELUX	[C]	• VELUX contributes to developing different nano-technological surface coatings for wood, metal protection and plastic “NanoPaint” to encapsulate the biocide and thereby obtain a possible controlled release of the biocide. • The effect of this controlled release of biocide is expected to affect the lifetime of the paint film leading to a more durable paint [26].
		[W]	• VELUX offers three-layer insulating glass, however there is not much difference in the energy performance of good low-E two-layer insulating windows and three-layer insulating glass, especially if the windows are located properly towards south and west and a total energy balance calculation is made. • The shift from the dark U-value towards a total energy balance perspective is hence seen as an important parameter to VELUX [26].
N_13	Neat Glass	[W]	• Low maintenance glass [26].
N_14	Organic Light-Emitting Diodes (OLED)	[L]	• The diffuse and thus glare-free light emission of the lighting surface allows the realization of new kinds of illumination concepts, e.g. illuminated wall at home. • Plays a decisive role especially for the designers. • The OLED technology allows the manufacturing of a high-efficiency flat luminous source with continuously adjustable brightness, which offers any possible shade of color and which

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#	Name of Nanotechnology	Uses	Potentials and impacts in achieving sustainable and green architecture
N_06	Cabot (CBT-NYSE)	[C]	• Cabot's aerogel particles can be added to plasters and other coating systems to provide thermal insulation [28].
		[I]	• Cabot's aerogel particles are useful as loose-fill insulation in walls or other confined spaces, particularly in retrofit projects where installing other types of insulation may be complicated. In contrast to larger, bulky insulation, Cabot's particles can be poured like water and packed densely with no residual air gaps to maximize flexibility and efficiency. • Cabot reduces outside noise and is water repellant and durable over time and resists settling [28].
		[L]	• Cabot aerogel can be employed in architectural daylighting, which allows architects to create unique glass and window designs while still meeting energy and building code requirements. Branded Lumira™, Cabot's translucent aerogel has been employed in daylighting systems across the U.S. and Europe, including on the glass covered atriums and walkways at the JF Ahern Building in Fond du Lac, Wisconsin, and on the transparent walls of Yale University's Sculpture Building. • Lumira™ has a thermal efficiency (an R-value) of 8.0 per inch [28].
		[S]	• Dye solar cells are cheap manufacturing processes through screen printing [29].
N_07	CNTs (Carbon Nano-Tubes)	[C]	• CNTs could be incorporated during the manufacturing process or applied to existing surfaces to keep them microbe-free. However, since CNTs can kill bacteria, they could have a major impact on ecosystems [30].
N_08	Cork and Carbon nanotubes	[I]	• Cork and carbon nanotubes use in acoustic and thermal insulation and strength could be incorporated in one sole material: composite materials made from cork dust reinforced with carbon nanotubes could be capable of achieving high tensile strengths and significant ductility, while acting as acoustic and thermal insulators: cork and carbon nanotubes, melded into one single material, will help reducing man hours by eliminating construction layers due to functional integration within one single material [31].
N_09	Hüper Optik's nanoceramic film	[W]	• Using multiple layers of ceramic Hüper Optik's products is intended to outperform single-ply ceramics by increasing infrared heat rejection and durability while lowering visible light reflection. • Aesthetics, as Hüper Optik's ceramic films do not change the aesthetic of glass; Durability that is believed to be as much as 25 times greater than conventional film, with chemical stability in saltwater, coastal, and elevated environments (improving the potential for energy conservation on vacation properties). • Performance, as Hüper Optik's window film provides up to 98%

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Table 3: Identification of potentials and impacts of selected nanotechnologies used in non-structural elements of buildings in achieving sustainable and green architecture (Source: Authors).

#	Name of Nanotechnology	Uses	Potentials and impacts in achieving sustainable and green architecture
N_01	ActiFloor	[A]	• The ActiFloor treatment is incorporated into the matrix of the floor board giving it additional features like easy-to-clean with quick dry effect and no streaks or spots. • The ActiFloor can eliminate formaldehyde release from the floor itself and from other sources such as particle boards, furniture, smoking in the indoor air, while reducing formaldehyde emissions with 98 pct [26].
N_02	Aerogel	[I]	• This material, nicknamed "frozen smoke" is a gel in which liquid component has been replaced with gas. Its unique physical properties result in low thermal conductivity and low sound velocity, as well as high transparency. • Despite its lightness, it can support over 2000 times its own weight. • Since nonporous aerogels can be sensitive to moisture, they are often marketed and sandwiched between wall panels that repel moisture. • Architectural applications of aerogel include windows, skylights, and translucent wall panels [27].
N_03	AR-surface	[W]	• Glass surface which releases six to eight per-cent more sunlight in depending on the glass slope. • The nanostructure becomes part of the glass itself rather than by adding a coating. In this way, the glass can become Nano-porous at both sides of the glass contributing to high anti-reflectivity [26].
N_04	Aspen Aerogels	[I]	• Aspen Aerogels offers up to five times better performance than normal materials used for insulation, including fiberglass, polyester microfiber, foam, and micro-porous silica. Aerogel insulation is used to conserve energy, reduce CO2 emissions, and protect workers and assets [28].
N_05	Three ultra-thin Aspen aerogel insulation product lines Cryogel®, Pyrogel®, and Spaceloft®	[I]	• The patented Spaceloft® nanotechnology offers low thermal conductivity, improved flexibility, compression resistance, hydrophobicity, and ease of installation in an environmentally safe product. • Spaceloft® repels water and can withstand a maximum heat temperature of 390°F. It simplifies logistics due to the reduced volume and weight of material needing to be purchased, inventoried, transported, and installed in the field [28].

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Table 2: Most covered issues within current systems of sustainability assessment in buildings (adopted from [25]).

Environmental Issues	Economic Issues	Social Issues
Energy	Management and Maintenance	Comfort and health
Materials	Lifecycle costs	Accessibility of the building and access to transport
Climate change	Building adaptability	Safety and security
Land use and ecology	Process quality	
Water management	Innovation	
Waste		

POTENTIALS AND IMPACTS OF NANOTECHNOLOGIES IN ACHIEVING SUSTAINABLE AND GREEN ARCHITECTURE

In order to identify the potentials and impacts of the selected 27 nanotechnologies that are most commonly applied in non-structural elements of buildings that include coatings, adhesives, insulation, window chain, lighting, and solar energy, an in-depth analysis has been conducted as an analytical approach on the details of these nanotechnologies in the published literature. The most influential roles and potentials of each of the selected 27 nanotechnologies in terms of contribution to the achievement of green and sustainable architecture have been extracted and organized as shown in Table 3.

MAJOR CONCERNS OF SUSTAINABLE AND GREEN ARCHITECTURE

Sustainability is the capacity to endure and to sustain. For humans, sustainability is the potential for long-term maintenance of well-being, which has environmental, economic, and social dimensions. As for buildings, the core issues are long-term maintenance and well-being of the users, seen under the aspects of environmental, economic, and social dimensions. On the other hand, a green building covers measures like limiting consumption of non-renewable fuels, water, land, materials, emissions of greenhouse gas and other emissions; minimizing impacts on site ecology, solid waste or liquid effluents, improving indoor air quality, natural lighting and acoustics and securing maintenance of performance. A sustainable building features all of the same measures, addresses longevity, adaptability and flexibility of the object, accounts for the efficiency of resources spent, addresses safety and security, includes social and economic considerations and regards urban and planning issues. Buildings consume more than 40% of the energy spent in industrialized countries, the building sector is an obvious place to look for leverage on the three-part challenge to minimize energy consumption and carbon emissions, secure political independency of energy availability and create economic growth through incentives and innovations in the building sector [23, 24]. In searching for common major concerns of sustainable and green architecture, the organization of Sustainability Performance Assessment and Benchmarking of Buildings [25] identified the most covered issues within the current building sustainability assessment systems as shown in Table 2.

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#	**Name of Nanotechnologies**	**Uses of Nanotechnologies in Non-Structural Elements of Buildings**					
		Coatings **[C]**	Adhesives **[A]**	Insulation **[I]**	Window chain **[W]**	Lighting **[L]**	Solar Energy **[S]**
N_12	VELUX	X			X		
N_13	Neat Glass				X		
N_14	Organic Light-Emitting Diodes (OLED)					X	
N_15	Photocatalytic paints	X	X			X	
N_16	PRO TEC 7				X		X
N_17	Quantum dots, such as CdSe					X	
N_18	SGG Aquaclean				X		
N_19	Silicon nanocrystalline ink						X
N_20	SunClean				X		
N_21	Super-critical CO2		X				
N_22	The Hypucem			X			
N_23	The Pilkington Activ				X		
N_24	Thin-film				X		
N_25	Thin- layer solar						X
N_26	TiO2-DDA hybrid film	X					
N_27	Titanium dioxide nanoparticles in dye solar cells						X

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Table 1: Classification of multiple uses of nanotechnologies in non-structural elements of buildings (Source: Authors).

#	Name of Nanotechnologies	Uses of Nanotechnologies in Non-Structural Elements of Buildings					
		Coatings [C]	Adhesives [A]	Insulation [I]	Window chain [W]	Lighting [L]	Solar Energy [S]
N_01	ActiFloor		X				
N_02	Aerogel			X			
N_03	AR-surface				X		
N_04	Aspen Aerogels			X			
N_05	Aspen manufactures three ultra-thin aerogel insulation product lines Cryogel®, Pyrogel®, and Spaceloft®			X			
N_06	Cabot (CBT-NYSE)	X		X		X	X
N_07	CNTs	X					
N_08	Cork and Carbon nanotubes			X			
N_09	Hüper Optik's nanoceramic film				X		
N_10	Nano Films	X					X
N_11	Nanostructured Antireflection Layers						X

MULTIPLE USES OF NANOTECHNOLOGIES IN NON-STRUCTURAL ELEMENTS OF BUILDINGS

The identified most common 27 nanotechnologies used in non-structural elements of buildings resulted from the extensive search and presented in Appendix I, have been classified based on the multiple uses of these technologies as found in their descriptive information. The results of this classification are illustrated in Table 1 with a range from single to quadruple uses of these nanotechnologies in non-structural elements of buildings that include coatings, adhesives, insulation, window chain, lighting, and solar energy. This classification table offers and facilitates an overall recognition for targeted beneficiaries such as architects, building engineers and construction contractors to realize the various uses and applications of the most common nanotechnologies in non-structural elements of buildings from the very outset without getting lost in details at an earlier stage of design and construction of buildings. At the same time, Appendix I provides and increases their level of awareness on these technologies through the provision of brief description and visualization.

OBJECTIVE AND METHODOLOGIES

This paper aims at developing a guide that can be used by architects, building engineers, and construction contractors to help them in selecting the most appropriate nanotechnologies in non-structural elements of buildings in order to progress for the achievement of green and sustainable architecture. In order to achieve this aim, a comprehensive search has been conducted using a descriptive approach to survey the most common and effective application of Nano-technology in the non-structural elements of buildings including coatings, adhesives, insulation, window chain, lighting, and solar energy. The resulted survey is presented in Appendix I wherein 27 different nanotechnologies used in the non-structural elements of building (coatings, adhesives, insulation, window chain, lighting, and solar energy) are identified and briefly described with visualization along with the possible different applications for each of these nanotechnologies. The previous step was then followed with extracting the set of most influential roles and potentials of each of these 27 nanotechnologies using an in-depth analysis of published literature as the analytical approach in order to identify the expected impacts of each of these 27 nanotechnologies in contributing to the achievement of green and sustainable architecture. Then, in order to develop a guide in the form of a matrix of the roles and potentials of nanotechnologies in achieving green and sustainable architecture a deductive approach is used.

sustainable buildings is that such buildings should have the least inconsistency and conflict with its natural surrounding environment. This should be reflected on rational use of natural resources while minimizing the fossil fuel consumption and using alternative resources [5], minimizing the use of non-recyclable materials [6], optimizing the use of environmental capabilities (e.g. sunshine, wind energy, energy of fluids such as water) and available local resources [7], reducing consumption of non-renewable resources, eliminating or reducing the consumption of toxic or harmful materials, and blending with natural environment, e.g. green roof [8].

The utilization and impacts of Nanotechnology in architecture has been introduced and presented in the literature from various dimensions such as applications of Nano-materials in interior architecture and design [9, 10, 11, 12]; Nanotechnology as an approach to sustainability [13, 14, 15, 16, 17, 18, 19, 20]. Also, some studies were conducted to focus on specific elements such as the impact of Nano-insulation coating on envelope of the buildings to reduce energy consumption [21]; and application of nanotechnology on the glass and its impact on the efficiency of energy use in building [22]. Even though most of these previous studies offered valuable information about the applications of nanotechnology in architecture and sustainability, however such studies provided general knowledge and cases of applications. Accordingly, there is a gap in the study of the inter-relationships and impacts of advanced and most current nanotechnologies with specific indicators of sustainable and green architecture that can enable the appropriate selection from these nanotechnologies; hence, this paper aims to address this gap.

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INTRODUCTION

Nano-materials have at least one of its dimensions (length, width and thickness) is below 100 nanometer. A nanometer is 1,000 of a µm or about 100,000 times smaller than the thickness of a human hair. The fundamental changes in Nano-materials are not only at the level of Nanoscale in terms of small size but also in terms of new properties [1]. The technology of Nano-materials is currently used in manufacturing a wide spectrum of products such as garment, cosmetics, tools, coatings, insulation, medicine, etc. However, in building and construction industry the technology of Nano-materials has great potentials for environmental compliance [2]. Wiek et al. [3] argued that visions about the use of nanotechnologies in the city, including in the design and construction of built environments suggest that these technologies could be critically important for solving urban sustainability problems. The application of Nano-technology in building construction is in both structural elements and non-structural elements. This paper focuses on the application of Nano-technology in the non-structural elements of buildings including coatings, adhesives, insulation, window chain, lighting, and solar energy. These non-structural elements play an important role in achieving energy efficiency, economic and comfortable places for people in their buildings. These issues are extremely critical towards green and sustainable buildings. For instance, the application of Nano-technology in coatings for interior and exterior facades of buildings contributes to desorbing water, minimizes absorption of pollutants and makes façades resistant to UV radiation [4]. Green and sustainable architecture aims primly at preserving the environment and creating human welfare. Therefore, one of the basic requirements of green and

تحليل دوروإمكانات تقنيات النانو في تحقيق العمارة الخضراء والمستدامة

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ملخص:

يهدف هذا البحث إلى تحليل كل من دور تقنيات النانو وإمكانياتها في تحقيق العمارة الخضراء والمستدامة. وستتم مناقشة انعكاس صناعة البناء والتشييد في كل من البلدان المتقدمة والنامية من هذا المنظور، ويتركز نطاق هذا البحث على قضيتين رئيسيتين فقط تتعلقان بالعمارة: (أ) المواد النانوية غير الهيكلية، و(ب) التطبيقات النانوية في النوافذ، والإضاءة، والطاقة الشمسية. المنهجية المعتمدة في هذا البحث هي: (1) استخراج مجموعة من الأدوار والإمكانيات الأكثر تأثيراً لتقنيات النانو في تحقيق العمارة الخضراء والمستدامة ؛ (2) تحليل أدبيات الأعمال المنشورة وتصنيف تطبيقات مواد تكنولوجيا النانو (العزل، الطلاء، المواد غير الهيكلية، المواد اللاصقة، النوافذ، الإضاءة والطاقة الشمسية) وتأثيراتها. و(3) استنتاج مصفوفة لأدوار وإمكانات التقنيات النانوية في تحقيق العمارة الخضراء والمستدامة. وسيتم تحديد استخدام هذه المصفوفة لاستخدام تقنيات النانو في تحقيق العمارة الخضراء والمستدامة من قبل المهندسين المعماريين ومصممي المباني.

الكلمات المفتاحية: العمارة الخضراء، الاستدامة، تقنيات النانو، المباني الخضراء، كفاءة الطاقة.

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environments. This paper surveys the most common and effective application of Nano-technology in the non-structural elements of buildings including coatings, adhesives, insulation, window chain, lighting, and solar energy; and analyzes the roles and potentials of these nanotechnologies towards achieving green and sustainable architecture. A descriptive approach is applied to identify and differentiate these nanotechnologies; and an analytical approach is applied in order to extract the set of most influential roles and potentials of nanotechnologies in achieving green and sustainable architecture through analyzing published literature and classifying the applications of nanotechnology materials in non-structural elements of buildings. A deductive approach is used to develop a matrix of the roles and potentials of nanotechnologies in achieving green and sustainable architecture. The matrix of nano-technologies can be utilized by architects, building engineers, and construction contractors as a guide to offer alternative nanotechnologies for contributing to the achievement of green and sustainable architecture.

Key Words

Sustainable and Green Architecture, Sustainability, Nano-Technologies, Nano-Materials, Energy Efficiency

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Analyzing the Roles and Potentials of Nano-Technologies in Achieving Green and Sustainable Architecture

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ABSTRACT

The transformation from a fossil fuel-based to a clean and renewable future relies on the widespread implementation of sustainability in our industries and lifestyles. Significant uses of nanotechnology have surfaced in the last few years with applications for architectural design and the construction of built environments. Some nanotechnologies can take building enclosure materials (coatings and insulation) to dramatic new levels of performance in terms of energy, light, security and intelligence. Taking advantage of some of the many uses of nanotechnologies, from solar energy to insulation, has the potential for developing green and sustainable buildings that are more cost-effective, energy-efficient and more in tune with their

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