The Growing Use of Nanotechnology in the Built Environment: A Review

M Ghosal¹,² and A Chakraborty³
¹ Jt. Secretary, Coal Ash Institute of India
²PhD Scholar, IIEST, Shibpur, India
³Associate Professor, IIEST, Shibpur, India
E-mail: mainakghosal2010@gmail.com

Abstract. Though the past industrial revolutions had unleashed many of the world's current problems including the Covid-19 virus but the 4th industrial revolution promises a sustainable future through the use of advanced materials like Nanotechnology. Not at all new, the use of this disruptive technology had its footprints in the pages of history - Ajanta Paintings, Damascus Sword & many others. Nano Titanium dioxide (58%) and Nano silica (21%) are the most used advanced materials in the nanotechnology-based building products while China in Asia and Germany in Europe are the two leading countries in the field of production of nanomaterials for building industry. India has been amongst the five top countries globally for technical publications in nano sciences & technology. This paper delves into the world of advanced nanomaterials and studies their impact on the construction industry vis-a-vis the built environment in India and abroad.

Keywords – Country, Industry, Nano, Nanotechnology, Revolution

1.0 Introduction

Rapid industrialization after 1800s has led to many of the world's current environmental problems like, over-crowding, climate change, unsafe levels of pollution and toxins in the air, water and soil and consequently into food chain, the depletion of fishing stocks, high mounds of waste on land and in large areas in the ocean, loss of biodiversity, and deforestation. However, the 4th Industrial revolution or Industry 4.0 promises a sustainable future for all by leapfrogging traditional developments and ushering in fast-est-ever technological disruptions like artificial intelligence (AI), robotics, advanced materials (including nanomaterials), 3D printing, blockchains and biotechnology, the Internet of things (IoT), autonomous vehicles and drones. Though 3D printing, robotics, blockchains and drones are already in use or close to deployment others like advanced materials, autonomous vehicles, biotechnologies, AI, etc. are in the various stages of development and testing. However, the question raised in the World Economic Forum in Davos was that whether we ready for this type of Technological revolution? This paper delves into the world of advanced nanomaterials and studies their impact on the construction industry vis-à-vis the built environment in India and abroad.
There are many applications of nanotechnology in building construction. It has given a new dimension for construction materials with its unique and amazing properties. However, this technology is not at all new and has its footprints in Ajanta Paintings, Tipu Sultan's Damascus Sword, and others. As per existing literatures, among the most important nanomaterials that are found in the building industry are nano-titania (TiO$_2$), silver, nano-zinc oxide (ZnO), nano-silica (SiO$_2$), calcium silicate, and aluminum phosphate and carbon nanotubes (CNT).

Titanium dioxide (TiO$_2$) is found in 58% of all nanotechnology products in the field of building. Increasing mechanical properties of the samples in the main structures, waterproofing application on internal and external surface of the buildings, prevention of dirt, UV-resistance, production of strengthened, self-repair and self-cleaning concrete, fireproof and self-cleaning glass and energy saving glass are the most important applications of these nanoparticles in building industry [5].

Nano silica (SiO$_2$) possesses a high share of nanotechnology-based building products by having a share of 21%. The use of nano silica decreases the viscosity of cement mortar which results in a decrease in water consumption. Based on studies, silicone chains are created in the nanometric structure of cement with various lengths. The length of the chains is very important in the stability of cement. Fireproof glass is another achievement of nanotechnology in the field of building industry. This product is produced by adding a transparent layer of silica nanoparticles between the two sheets of glass. When the glass becomes warm, the transparent layer turns into a hard, dark and fireproof coating [5].

The tasks of architects and engineers are now made much easier through nanotechnology by introducing construction materials such as seismic wallpaper, thermal insulation and additives which are easy to use and can aid in improving the durability, and structural integrity of our infrastructure. Amongst Asia and in Europe, China and Germany are the two leading countries in the production of nanotechnology-based products in the field of building industry; according to the statistics published by Statnano Database website. They are said to have possess a share of 30% and 25% of all nanotechnology-based building products in the global market, with Shanghai huzheng Co. alone producing 44 products. It is followed by USA (19%), Switzerland (6%), Greece
(5%), Poland (5%), Singapore (3%), Finland (2%) and Denmark (1%). Surprisingly, India the 5th largest economy and 3rd in terms of GDP, stands nowhere in either active nano technological research or product development.

![Cluster of Nanotechnology-Based Building Products’ Enterprises](image)

**Fig.2: Cluster of Nanotechnology-Based Building Products’ Enterprises [5]**

### 2.0 The Global Development Story of Nanotechnology

The manifestations of globalization are many for example - bank building's and company head quarters' sky scrapers, standardized hotel chains, franchise restaurants, shopping malls, branded stores and boutiques, specialty & multi-specialty hospitals, theme parks, fitness centers and multiplex cinemas. The predominance of load bearing structures of the 19th century gave away to reinforced concrete construction (RCC) structures which dominated the whole of 20th century with some steel structures. Globalization has brought along new architectural trends which incorporate sustainability and the role of technology in it. With its own buzzwords, nanotechnology is a sort of the miniature rebellion that was initiated with the discovery of sophisticated microscopes in the later part of the 20th century. Because of the opportunity it provides in creating new features in wide ranging applications, nanotechnology is attracting more funding than any other technological areas with an unbeatable patent processing record but the problem with it is that it requires lengthy team-work with people from multi-disciplinary fields like physics, chemistry, biology, engineering and medicine working together.

Technology plays an important role in globalization thus making our world a smaller and better place to live in. With the advent of 21st century, nanotechnology or manipulation of matter at the atomic level made a leap from science fiction (Star Trek, Spiderman, etc.) to reality, with both public and private players around the globe began focusing on its projected economic benefits. One expected impact is that nanotechnology may augment and magnify the already existing discrepancy between the rich and the poor. On the other hand, it may also reduce the disparity by making things more affordable over a period of time. It is contemplated that like the digital divide that has mushroomed with the introduction of ICT and computers, it is very likely that with differential rates of diffusion of these technologies, there will be 'nano divide' - nano have & have not countries. Some advocates of nanotechnology however, argue that scientific advances in this
nano-scale will bring a prosperity to material scarcity like wood or oil, due to the ability of the synthesizing power of nanotechnology. Discoveries in this domain would also lead to intense competition in acquiring patents and intellectual property rights amongst the nations reinforcing the concept of liberalization with MNCs continuing to play a promoting role in addressing global policies in the matter of trade, relations and policy.

Fig.3: Nanoarchitecture: Nanotechnology in Buildings [2]

There are numerous examples of nanotechnology products moving from simple to complex. From the simple dirt repellant nano-coatings we have moved towards mobile phones which dramatically have become smaller & smaller but cleverer, faster & cheaper. The applications of nanotechnology are numerous and can be found in medical science, textiles, mobile communications, transport, architecture and engineering. Nano functions can be effectively used in the interiors of commercial buildings as shown in Fig.4 for a Hotel Room or Office Room or also Hospital Room but strategically after studying their cost-benefit analysis.
Fig. 4: Schematic Plans of Hotel & Office Room for strategic use of Nanomaterials

Table 1. Nano-enabled products for different commercial usages

| (I) For Hotel Room                        | (II) For Office Room                       |
|-------------------------------------------|--------------------------------------------|
| 01- Curtains: Air-purifying              | 01-Glass Table: Anti-fingerprints          |
| 02- Windows: Self cleaning(photocatalytic)| 02-W.C.: Easy to clean                    |
| 03- Windows: Self cleaning(photochromatic or electrochromic) | 03-Walls: Nanoparticles ceramic covering |
| 04- TV: Anti reflective                   | 04-Windows: Self cleaning (photochromatic or electrochromic) |
| 05- Wall Paint: Air-purifying             | 05-Windows: Self cleaning (photocatalytic) |
| 06- W.C.: Easy to clean                  | 06- Walls: Nanoparticles ceramic covering  |
| 07- Mirror: Anti-fogging                 | 07-Switches & Handles: Anti-bacterial, non-stick |
| 08- Bath tub & Shower screen: Easy to clean, non-stick | 08-Chairs: Dirt-repellant |
| 09- Walls: Nanoparticles ceramic covering | 09-Upholstery: Air-purifying               |
| 10- Bedding: Anti-bacterial              | 10- Sanitaryware: Anti-fingerprints        |
| 11- Light Switches: Anti-bacterial, non-stick | 11-Screen: Anti-reflective                |
| 12- Wall Paint: Air-purifying             | 12-Carpet: Air-purifying                  |
| 13- Upholstery: Air-purifying             | 13-Counter: Anti-fingerprints              |
| 14- Glass Table: Anti-fingerprints        | 14-Screen: Anti-reflective                |
With the increasing availability of nanotechnological consumer products worldwide, it was a general expectation that the public at large would be rather familiar with the term ‘nanotechnology’ and understand what it means. Though companies using nanotechnology often deny using them to their end-customers and thus in the midst of this accelerating commercialization, public worldwide remain largely in dark about nanotechnology [8] perhaps due to fear of things they can’t visualize or perceive. Major studies in USA, Europe, Canada and even China have shown that majority of public has heard little or nothing about nanotechnology. What is even more surprising is that they have little or no faith in their government’s ability to manage the potential risks posed by nanotechnology. See what havoc nanoparticles like Coronavirus are playing in the world today with governments as mute spectators.

**Table 2.** Nano-enabled construction products identified in the UK [3]

| Type          | Number | Nanomaterials commonly used (bracketed entries less common)         |
|---------------|--------|--------------------------------------------------------------------|
| Coatings      | 70     | Silica, titanium, silver (CNTs)                                    |
| Glass         | 23     | Metal oxides                                                      |
| Concrete      | 22     | Silica, titanium (CNTs)                                           |
| Steel         | 11     | Nanostructured                                                    |
| Insulation    | 10     | Silica aerogels                                                   |
| Composites    | 1      | (CNTs, nanoclays)                                                 |
| Other(roofs, floors) | 19 | Titanium, aluminum                                               |

### 3.0 Nanotechnology: India’s Story

The micro-electronics revolution which occurred during 1970-80s failed to take off in India due to its then underdeveloped science and technological scenario. After the advent of liberalization-privatization-globalization in 1990s, the nation came to know of this nanotechnology but the government took no interest to develop it. However, in 2001, Nano Science & Technology Initiative (NSTI) was started under the Department of Science and Technology (DST) of the Ministry of Science as the nodal agency of the with a meager initial budget of only Rs.6 crores in the 11th - 5 Year Plan though the budget outlay for DST was Rs.20,000 crores. This was when private organizations like Reliance, Tata and a few other players had already made more investments in nanotechnological research.

In 2004, under the then President Dr. A.P.J.Abdul Kalam, a workforce was formed and in 2007 a Nano Mission was established in India with a budget of Rs.1,000 Cr. with 19 Centers of Excellence. That ‘nano-mission’ has been working to help scientists, institutions-industry interface in terms of promoting basic research, development of adequate manpower resources, international collaborations, augmentation of the infrastructure for research and generation of socially useful products. This nano-mission has resulted in about 5000 research papers and some useful products like nano hydrogel-based eye drops, pesticide removal technology for drinking water, water filters for arsenic and fluoride removal and nano silver based antimicrobial textile coating.

India has been able to rank amongst the top five countries in the world for Scientific Publications in Nanoscience & Technology due to the efforts led by the Nano Mission. The Nano Mission has established national dialogues to promote R&D in the development of standards for
nanotechnology and for laying down a National Regulatory Framework Road-Map for Nanotechnology (NRFR-Nanotech). Recently in the pandemic times, the Department of Science and Technology and the Science and Engineering Research Board (SERB) called for a Short-term Research Grant for Antiviral Nano Coating COVID-19 in April 2020 to combat the pandemic.

The budget for Nano Mission which has decreased considerably from Rs.1,000 crores in 2007 to Rs.650 crores in 2012 to NIL now [9]. But it developed physical infrastructure, with the DST, establishing Units on Nano Science, Centers for Nanotechnology, Centre for Computational Materials Science and Thematic Units of Excellence on Computational Material Science in various universities, IITs and government research centers/laboratories across the country. As far as human resource development is concerned, the Nano Mission has launched PG programmes (M.Sc. and M.Tech in Nano science and Nanotechnology) at various universities and colleges all across India. The NITI Aayog which replaced the Planning Commission is completely silent on nanotechnology, except in one area, as expressed in its strategy paper, New India @ 75 which says that - Foreign collaborators, consultants, visiting faculty, adjunct scientists, etc., need to be involved in pursuing R&D in the emerging areas of basic sciences such as nano-technology, etc. DST, in collaboration with Indian Missions abroad, may identify discipline wise foreign experts who can collaborate with Indian scientists to take basic research in these areas to the next level.

![Fig.5: Government-led nanotechnology projects sanctioned in India since 2002[4]](image)

**4.0 Conclusions**

Globalization cannot be simply stopped and countries have jumped from being developing to being developed in the past by powering a manufacturing/industrial revolution albeit remaining self-sufficient of the food front. Despite having a huge labor force and initiating economic reforms in 1991, India seems to have missed the last bus of manufacturing revolution. As against the conventional wisdom, India appears to have shifted from farming to services without having gone through an industrial stage which contradicts the experience of other fast-growing Asian economies like China. The Asian counterparts (China, Japan, Taiwan, South Korea and countries of South East Asia) essentially followed an export-oriented manufacturing strategy focused on low-end products which later progressed up the value chain to create economic growth. However, after the 1991 economic reforms, India started to export complex automobile parts and pharmaceuticals along with information technology and became a global hub of the business process outsourcing industry. Later, India cautiously experienced a huge expansion in banking, hotels, airlines, cable television, telecom etc. but none of this was low-end, like was the case of
Asian countries. Hence, it followed the high-end model of services, without going through an industrial/manufacturing stage which saw the country’s largest car-maker Tata failing to increase the sale of Nano and ultimately stop its production though it did very well in the foreign countries.

As far as nanotechnology is concerned there are hardly any codes or standards which holistically address the performance evaluation of nanomaterials in cement concrete apart from the recent report from American Concrete Institute (ACI 241R-17) in 2017[7]. Though the revised National Building Code of India, 2016 addresses nanotechnology/nanomaterials as sustainable and as alternate building materials. There exists a lack of coherence between the academic field and the industrial requirements and the need for a strategy in the new industry creation in the nanotechnology field, where not only public research institutes, but also existing industries (including SMEs) can participate [7].

As seen in countries like Japan, China and Europe, to nullify the size disadvantage of nanomaterials and overcome diseconomies of scale, SMEs often utilize the process of technology transfer from public funded R&D institutions [6,7].

Indian codes such as IS:456-2000 and the revised IS:1026-2019 mention Silica fume (with more than 70% having particle size diameter within 100nm range, but they are not marketed as nanomaterials by the manufacturers) for concrete but which has been in use for over 30 years and is widely available in the products of most major global concrete suppliers. Hence, commercialization of nano-products still remains a challenge. As happens with any emerging technology the parameters of Strategy + Demand + Policies + Initiatives are needed in sequence but in India does not have any regulatory framework for nanotechnology till now.

The pandemic has given India an opportunity to get on the bus for microelectronics and nanotechnology to boost ‘Make in India’ a success.

References
[1] https://aecom.com/wp-content/uploads/2015/10/Blue-Book-2014.pdf
[2] A Y Mohamed. 2015. ‘Nano-Innovation in Construction, A New Era of Sustainability’, Conference Proceedings.
[3] Jones, W. et al., 2016. ‘Nanomaterials in construction – what is being used, and where?’ Proceedings of the Institution of Civil Engineers: Construction Materials, 172 (2), pp.49-62.
[4] ‘The Emerging trends in agri-nanotechnology: fundamental & applied aspects’ (2018)/ editors: Prof. H. B. Singh, Dr. Sandhya Mishra, Prof. Leonardo Fernandes Fraceto, Dr. Renata de Lima, Published by CAB International, USA, ISBN-13:9781786391445.
[5] https://statnano.com/news/50098/Growing-Application-of-Commercial-Nanotechnology-based-Products-in-Construction-Industrial-Sector
[6] Purushotham, H., ‘Transfer of nanotechnologies from R&D institutions to SMEs in India’, Asia-Pacific Tech Monitor, vol. 29, no.4, pp. 23-33, October-December2012.
[7] Ghosal M., Chakraborty A.K. (2021) A Study on Performance of Carbon-Based Nano-enabled Cement Composites and Concrete. In: Ashish D.K., de Brito J., Sharma S.K. (eds) 3rd International Conference on Innovative Technologies for Clean and Sustainable Development. ITCSD 2020. RILEM Book series, vol 29. Springer, Cham. https://doi.org/10.1007/978-3-030-51485-3_29.
[8] Allhoff, Fritz and Patrick Lin (eds). 2008. Nanotechnology and Society: Current and Emerging Ethical Issues (Dordrecht: Springer).
[9] Kumar, Amit & Desai, Pranav. (2014). Mapping the Indian nanotechnology innovation system. World Journal of Science. 11. 10.1108/WJSTSD-09-2013-0039.