The significance of nanotechnology in architectural design

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ABSTRACT: Nanotechnology is one of the most active research areas that include a number of disciplines including civil engineering and construction materials. Nanotechnology is the understanding, control, and restructuring of matter on the order of nanometers (i.e., less than 100 nm) to create materials with fundamentally new properties and functions.

Traditionally nanotechnology has been concerned with developments in the fields of microelectronics, medicine and material sciences. However the potential for applications of many developments in the nanotechnology field in the area of architecture design is growing. The evolution of technology and instrumentation as well as its related scientific areas such as physics and chemistry is making the nanotechnology aggressive and evolutional. There are many potential areas where nanotechnology can benefit construction engineering like its applications in concrete, structural composites, coating materials and in nano-sensors, etc. Nanotechnology products can be used for design and construction processes in many areas.

The recent developments in the study and manipulation of materials and processes at the nanoscale offer the great prospect of producing new macro materials, properties and products. But till date, nanotechnology applications and advances in the construction and building materials fields have been uneven. Exploitation of nanotechnology in concrete on a commercial scale remains limited with few results successfully converted into marketable products. The main advances have been in the nanoscience of cementitious materials with an increase in the knowledge and understanding of basic phenomena in cement at the nanoscale. This paper serves as report of existing nanotechnology application, with a focus of utilization of nanotechnology in architecture materials development and building system design. Meanwhile this paper will identify the main obstacle for nanotechnology's development and application in design/construction field.

KEYWORDS: Nanotechnology, Building Materials

1.0 INTRODUCTION

1.1. Definition of nanotechnology

The definition of nanotechnology is both controversial and consequential. It is controversial because how it is defined has important implications for how it is managed and marketed. Several international organizations that deal with standards are working on nano definitions, and their work may result in greater agreement. Currently, all the nano definitions based on the physics and chemistry of the technology relate to size. Everyone agrees that nano is the technology of the very small—the manipulation of things at the level of individual atoms and molecules. The U.S. National Nanotechnology Initiative (NNI), the interagency effort to coordinate federal funding for nano research and development, defines nanotechnology as "the understanding and control of matter at dimensions of roughly 1 to 100 nanometers"(www.nano.gov, accessed 9/18/06). A nanometer is a billionth of a meter. A human hair is 60,000–120,000 nanometers wide. A red blood cell is 2,000–5,000 nanometers wide (ibid.).Things at the nanoscale can be seen only with techniques such as super-magnifying scanning tunnel microscopes, which were first used in the mid-1980s.

1.2. The origin of nanotechnology

Over 50 years have passed since the Nobel Prize physicist Richard P. Feynman, with the lecture at the California Institute of Technology entitled" There's plenty of room at the bottom" [1]has opened the way for innovations related to nanotechnology, prefiguring the possibilities associated with the transformation of matter at the molecular level. Studies conducted by Feynman and his intuitions have laid the basis for a radical transformation of nano-scientific horizon, starting from the possibility of miniaturization of computers to which much of technological innovations produced in the last fifty years is owed.

1.3. The significance of nanotechnology

Nanotechnology represents one of the fastest growing industrial sectors in recent years worldwide. The construction industry begins to look with increasing attention to nanotech innovations, identified as an important resource to give a new impulse to market growth. Nanotechnology applied to building materials represents an example of how innovation increasingly combines dematerialization, eco-efficiency and knowledge-based approach to develop new classes of products – often substitute of conventional technologies, with the aim of opening new market sectors based on the paradigm of the green high-tech.

Recent innovations in construction materials driven by nanotechnologies application are based on the design of material properties in order to obtain the required performances, developing sophisticated transformation processes that allow realizing custom-fit products for specific architectural applications. Recently, there are more than 600 manufacturer-identified consumer products are available on the market using nanotechnology. Which is projected will enable 15 percent of globally manufactured goods worth $2.6 trillion by 2014. [2] The U.S. federal government budget for nanotechnology for fiscal year (FY) 2009 totals $1.5 billion. China, Japan, Korea and several European nations are competing with the United States for the lead in developing nanotechnology, and Russia recently announced a $5 billion for research and development program of nanotechnology (Elder 2007).

"What is so unique about the nanoscale? At this dimension, materials start to behave in ways different to their bulk counterparts. It also marks a crucial crossroads: the scale where artificial systems can interact with molecules and biological systems. A water molecule is just a little smaller than a nanometer (10-9 m); basic functional biological units like proteins operate on the nanoscale, while basic living entities like cells are 10-100 µm (where 1 µm or micron = 1 x 10-6 m) and bacteria 0.5-20 µm in size. (European Commission 2014)

Nanotechnology will present new opportunities to make the stuff of life – electronics, medicines, everyday products and even our cars and homes – better, more cheaply and using fewer raw materials.
So what could a nano-enabled future look like? Feynman was right in his prediction that the room-sized computers of the 1950s would be miniaturised to a single, hand-held device, but could he have had an inkling of the transformation that smart devices from mobile phones to tablet computers have wrought on modern life? Ultimately, every industry that involves manufactured items will be impacted by nanotechnology. As Aidan Quinn, who heads the nanotechnology group at the Tyndall National Institute, University College Cork says: "Nanotechnology will play a key role in developing cheaper or better performing electronic devices, sensors and solar cells than those available now."

2.0. CURRENT APPLICATION OF NANOTECHNOLOGY IN BUILT ENVIRONMENT

2.1. Nanotech cement and concrete

In the case of many building materials, both those cement-based and certain types of polymers or composite materials, the observation of the physical-chemical properties at the nanoscale allows to rest the properties with such a degree of precision that is possible to "correct" and optimize the characteristics of material's nanostructures depending on the final performance expected, even without the addition of nanomaterials. (J. Clarence 2008). In high performance concrete, for example, the modification of the mix-design (depending on the type and size of the aggregates, the type of additives and the water/cement ratio) can increase of mechanical strength and durability. Concrete is probably unique in construction in that it is the only material exclusive to the business and therefore is the beneficiary of a fair proportion of the research and development money from industry. More details are available on concrete than the other materials because much of the research described is performed in universities and research institutes and therefor is in the public domain.

Silica (SiO_2) is present in conventional concrete as part of the normal mix. However, one of the advancements made by the study of concrete at the nanoscale is that particle packing in concrete can be improved by using nano-silica which leads to a densifying of the micro and nanostructure resulting in improved mechanical properties. Nano-silica addition to cement based materials can also control the degradation of the fundamental C-S-H (calcium-silicatehydrate) reaction of concrete caused by calcium leaching in water as well as block water penetration and therefore lead to improvements in durability. Related to improved particle packing, high energy milling of ordinary portland cement (OPC) clinker and standard sand, produces a greater particle size diminution with respect to conventional OPC and, as a result, the compressive strength of the refined material is also 3 to 6 times higher (at different ages) (J. Clarence 2008).

2.2. Nanotech steel

Research has shown that the addition of copper nanoparticles reduces the surface unevenness of steel which then limits the number of stress risers and hence fatigue cracking. Also research into the refinement of cementite phase of steel to a nano-size has produces stronger cables, high strength steel cables are used in bridge construction and in pre-cast concrete. (J. Clarence 2008) Tensioning and stronger cable material would reduce the costs and period of construction, especially in suspension bridges as the cables are run from end to end of the span. Nanoparticles are reducing the effects of hydrogen embrittlement and improving the steel micro-structure through reducing the effects of the inter-granular cementite phase. The additional of nanoparticles of magnesium and calcium makes the HAZ(Heat Affected Zone) grains finer in plate steel and this leads to an increase in weld toughness. “Two relatively new products that are available today are Sandvik Nanoflex(produced Steel Corp). Both are corrosion resistant, but have different mechanical properties and are the result of different applications of nanotechnology. Sandivik Nanoflex [5] has both the desirable qualities of high strength and resistance to corrosion. MMFX2 steel has a modified nano-structure that makes it corrosion resistant and it is an alternative to conventional stainless steel, but a lower cost.” (Crystal Research Associates 2012)

2.3. Nanotech wood

Wood is composed of nanotubes or “nanofibrils”; namely, lignocellulosic(woody tissue) elements which are twice as strong as steel. Harvesting these nanofibrils would lead to a new paradigm in sustainable construction as both the production and use would be part of a renewable cycle. Some developer have speculated that building functionality onto lignocellulosic surfaces at the nanoscale could open new opportunities for such things: self-sterilizing surfaces, internal self-repair and electronic lignocellulosic devices. “These non-obtrusive active or passive nanoscale sensors would provide feedback on product performance and environmental conditions during service by monitoring structural loads, heat losses or gains, temperatures, moisture content, decay fungi, and loss of conditioned air. Currently, however, research in these areas appears limited.” (J. Clarence 2008)

Due to its natural origins, wood is leading the way in cross-disciplinary research and modeling techniques which have already borne fruit in at least two areas. Firstly, “BASF have developed a highly water repellent coating based on the actions of the lotus leaf as a result of the incorporation of silica and alumina nanoparticles and hydrophobic polyers, And, secondly, mechanical studies of bones have been adapted to model wood, for instance in the drying process”. (European Commission 2009)

In the broader sense, nanotechnology represents a major opportunity for the wood industry develop new products, substantially reduce processing costs, and open new markets for bio-based materials.

3.0. CURRENT APPLICATION OF NANOTECHNOLOGY IN ARCHITECTURE DESIGN

3.1. Insulation

Nanomaterials stand to revolutionize insulating methods because they are structured at the molecular level to trap air between particles. They are far more efficient than traditional insulators like fiberglass and polystyrene which work at the macro level without the environmental harm associated with level, without the environmental harm associated with those materials. And because it traps air at the molecular level, an insulating nano-coating even a few thousandths of an inch thick can have a dramatic effect.

“Nanogel insulation, made by the Cabot Corp is a form of aerogel, the lightest-weight solid known as “ Frozen smoke’, nanogel is 5% solid and 95% air”. (Roya Naseri, Reze Davoodi, 2011), The high air content means that a translucent panel 3.5 inches thick can offer a high insulating value. Another company, Nanocoating are used to insulate both new and existing materials, and to protect wood, metal and masonry, without the hazardous off-gassing of many other coating. Nanoseal, makes insulating paint for buildings. Its insulating coating, applied in a layer only seven-thousandths of an inch thick, is being used on beer tanks in Mexico by Corona, resulting in a temperature differential of 36 degrees Fehrenheit. (European Commission 2009)

3.2. Self-cleaning coating

Nanotechnology may be good for our health too. The Hongkong subway system has coated its cars’ interiors with titanium and silver dioxide coatings that kill most of the airborne bacteria and viruses they come into contact with. And in cleansers and interior paints used around the world, Behr Premium Plus Kitchen & Bath Paint is one example. Nano-coating can break down dirt as well. PPG Industries and Pilkington Glass both offer self-cleaning window glass that harness nanotechnology. The Jubilee Church in Rome features self-cleaning concrete: Photocatalytic titanium dioxide nano-particles in the precast panels, manufactured by Italcementi, make them shed dirt. The panels trap airborne pollutants in a nano-particle matrix on their surface, then decompose them. Similar depolluting nano-coatings can be applied to almost any surface, making it a smog-eating machine. In the near future, road surfaces, bridges, and tunnels may be able to counter act pollution. This type of self-cleaning coating is base on Titanium Oxide(TiO_2) technology. “Titanium dioxide is a widely used white pigment because of its brightness. It can also oxidize oxygen or organic materials, therefore, it is added to paints, cements, windows, tiles, or other products for sterilizing, deodorizing and anti-fouling properties and when incorporated into outdoor building materials can substantially reduce concentrations of airborne pollutants. Additionally, as TiO_2 is exposed to UV light, it becomes increasingly hydrophilic (attractive to water), thus it can be used for anti-fogging coatings or self-cleaning windows". (Kumar and Devi 2011)

3.3. Fire-protective glass

This is achieved by using clear intumescent layer sandwiched between glass panels(an interlayer) formed of fumed silica(Si2) nano-particles which turns into a rigid opaque fire shield when heated.

4.0. CURRENT OBSTACLE

Cost and relatively small number of practical applications, for now, hold back much of the prospects for nanotechnology. However, construction also tends to be a fragmented, low research oriented and conservative endeavor and this plays against its adoption of new technologies, especially ones that appear so far removed from its core business. Materials though, as mentioned above, are construction's core business and the prospects for more changes are significant in the not too distant future. The main reasons that lead to the slow beneficiary of building sector from nano-technology could be concluded in the following:

- The majorities of architects especially in the developing country are not familiar with the applications of nanotechnology in building sector and they are ignorance with the huge potentiality of this technology to improve or introduce new building materials and related building systems.
- There is also a large research gap for understanding the potential for release of nanoparticulates due to weathering of these novel coatings despite recognition of considerable environmental uncertainties and concern at end-of-life.
- The lack of scaled up exploration research in institutions, most research projects are focusing on understand the capacities of materials.

4.1. Lack of business model

One of the largest challenges facing nanotechnology today is the lack of a business model to treat new materials as something other than commodities. Over the past century conventional materials prices have fallen relative to other goods, thus nanomaterials are often asked to compete with conventionally produced materials at costs that are lower by orders of magnitude. It can be a very different hurdle for a nanomaterials producer to demonstrate that a new quantum material may offer performance gains sufficient to compete with existing products.

4.2. Cost

Apart from the factors mentioned in the 4.0 of a fragmented and conservative business, cost or more accurately cost-to benefit is a major concern. Carbon nanotubes(Nano Steel) at the moment are priced at 20 to1000/gram depending on quality and this cost is simply incompatible with the 12bn tonner/yr concrete industry. This issue also touches on the topic of scalability, for even those processes, e.g. nano-vapour deposition, that might look promising in research may be difficult or cost prohibitive to do on an industrial scale. Furthermore, some of the nanotechnology research has no immediate practical application to construction and this is certainly a factor that holds back research spending. Something that is lacking and could certainly a factor that holds back research spending. Something that is lacking and could certainly help in this regards, is greater communication between researchers and industry.

4.3. Weak academic collaboration and information sharing

Nanotechnology is absolutely interdisciplinary, up to now research teams have been mainly composed of specialists on a single discipline or research field. Investment on new production processes is a serious drawback, especially for early adopters. Given nanotechnology's interdisciplinary nature, work across fields such as business, architecture, engineering, biology, chemistry and physics is also especially important and this is something that is lacking and needs to be addressed if nanotechnology, not just in construction but more generally, is to progress to the future that is hoped for it.

However, the potential effects of nanotechnology on construction are largely unknown to the construction profession in general, even though specific research is being carried out all over the world in universities and other institutes. Those provide pointers to what will soon be available to industry. Many of these advances are due to arrive within the next 5 years and in order to fully benefit from this new industrial revolution, a concerted effort is needed to overcome the key barriers of lack of knowledge and conservatism in construction regarding nanotechnology. Nanotechnology is a complex and deep subject and it is next to impossible to grasp for those who are not actively involved, therefore, awareness of research done can only be increased by educating both students and professionals through easily digestible information made available through universities, relevant institution's journals and other sources.

5.0. FUTURE RESEARCH IN NANOTECHNOLOGY

In conclusion, nanotechnology is disruptive and offers the possibility of great advances whereas conventional approaches, at best, offer only incremental improvements. Nanotechnology is not exactly a new technology, rather it is an extrapolation of current ones to a new scale and at that scale the conventional tools and rules no longer apply. Nanotechnology is therefore the opposite of the traditional top-down process of construction, or indeed any production technique, and it offers the ability to work from the "bottom" of materials design to the "top" of the built environment, However, many of the advances offered by nanotechnology, be they for economic or technical reason, are years away from practical application, especially in the conservative and fragmented construction business.

Figure 1: A selection of field where nanotechnology applications are being explored, Source: New Building Materials & Construction World (NBM&CW), August 2011.

Nanotechnology also presents an opportunity to rejuvenate traditional industries, like chemicals and catalysts, papermaking, and agriculture, bringing innovations in sustainability, processing, energy efficiency, recycling, emissions control and waste treatment.

In the future, the environment will interact with occupants in way hardly imaginable today, creating what a 2005 United Nations report calls "An internet of things". Tiny nano-sensors embedded in building materials will soon be able to track movement and detect temperature changes, humidity, toxins, weapons, even money. Sensors will pick up on user's preferences and attributes, which will then trigger responses in the intelligent objects around them, dimming the lights, altering the temperature, or as is already happening with "push" technology that marketers use to blitz cell phones, altering them to nearby sales and events. In the future, the design and construction of buildings will incorporate a rich network of interacting, intelligent objects, from light-sensitive, photochromic window to user-aware appliances.

The market for nano-enhanced building materials in the US is expected to grow to $400 million by 2016. $4 billion a year is known to being invested into Nanotech R&D worldwide, resulting in a pipeline of materials and products that will transform the way future buildings are constructed (European Commission 2014). A central aim of nanotechnology is to consistently use the minimum amount of raw material and energy: from an economic as well as an ecological point of view "nano" is a winning factor. From the point of view of the client or the user, the most realistic and sensible application of nanotechnology focuses on aspects of aesthetics, functionality, economy and sustainability.

The use of nanotechnology in the design and construction disciplines usually involves the optimization of existing products or common materials. Nanotechnology brings us a step closer towards customized materials with specific individual properties and represents a shift away from the catalogue of standard materials. Surfaces emancipate themselves from the underlying material, developing clearly defined functions that can differ fundamentally from the substrate material. This helps make products and materials more economical and also conserves resources. The application of nanotechnology makes a concrete contribution in the field the construction industry to the following areas:

- Optimization of existing products
- Damage protection
- Reduction in weight and/or volume
- Reduction in the number of production stages
- A more efficient use of materials

Author is currently conducting a research project "Smart Design Strategies for Novel Pollutant Reduction TiO_2 Coatings". Heterogeneous photocatalysis with TiO_2 is a rapidly developing field in environmental engineering with great potential for reducing a variety of air pollutants (Ohko, Tryk et al. 1998, Fujishima, Hashimoto et al. 1999, Irie, Watanabe et al. 2003, Hashimoto, Irie et al. 2005). As early as 1970, researchers discovered the hydrolysis of water in oxygen and hydrogen in the presence of light, by means of a TiO_2-anode in a photochemical cell (Kumar and Devi 2011). Now, there is a wide range of products marketed for both indoor and outdoor use. In the research arena, a number of efforts are underway in the academic and regulatory community to test and quantify the pollution reduction effectiveness of these novel coatings. Regarding the reduction of air pollution due to traffic in urban areas, early research indicates the application on building surfaces via cementitious materials can provide optimal results (Maggos, Plassais et al.2008). To ensure the efficiency of the photocatalyst, its presence at the surface of the material is crucial as it has to have sunlight in order to be activated.

Besides being at the surface, research has also indicated that maximizing the total surface area provides best results (Linsebigler, Lu et al. 1995, Tian, Fu et al. 2008); however, little work has been conducted to examine how much may be lost due to abrasion and weathering in real applications. Lab-scale work indicates that a potential application is TiO_2 as a thin layer on cementitious material; therefore concrete tile facades would be worth investigating further.

This research project is to study how smart design strategies can maximize the positive impacts of novel TiO_2 coatings by taking advantage of site-specific conditions. Specifically, this research will test physical, chemical, and environmental performance parameters in order to validate the pollution reduction potential for coated façade shading devices. This research will also quantify the degree of weathering the coating experiences in specific environments and whether or not this results in nano-particulate release. In regards to the smart design strategies, it is our hypothesis that the shape of the façade shading device will be very important. More random, omnidirectional shapes may provide more surface area to react with pollutants as well as scatter sufficient UV light to aid in the chemical reaction.

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