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The Impact of Nano-Concrete in Contemporary Architecture

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Abstract- The rapid development in technology of building materials and systems could be easily observed these days in the huge building advances such as achieving building sizes, shapes, forms and speed of building which could never be achieved by using ordinary building materials. One of the interested break overs in building materials technologies is Nano-Concrete. Nano-Concrete is the substance of adding nanomaterial to concrete. Nano-concrete has special specifications and properties when compared with the ordinary concrete mixes such as adding Nano SiO_2, Nano TiO_2 and Carbon Nano tubes to improve performance and structural resistance. This extended the limits of building technologies thus enabling architects to achiev more complex forms with higher performance, or giving the concrete special properties such as light pass-through concrete or self-compacting concrete.

The research deals with impact Nano-concrete on contemporary architecture by following a set of objectives:

- What is Nano-concrete in brief?
- How does Nano-concrete mixes differ from the ordinary mixes of concrete?
- The application of Nano-concrete in buildings and its effects on contemporary architecture.

The research extracted a set of main findings and recommendations from the analyzing of the effects of Nano-Concrete on Architecture.

Keywords-*Nanotechnology; nanomaterial ;nano Concrete ; self-compacting concrete*

تأثير الخرسانة النانوية في العمارة المعاصرة

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الخلاصة- وفر التطور المعاصر في تكنولوجيا المواد مدى واسع من الاستخدامات، الامر الذي انعكس على توفير الوسائل المناسبة في انشاء المباني من حيث الشكل والحجم والتنوع في الاشكال والسرعة في الانجاز ، والتي لم يكن انجازها ممكنا في السابق باستخدام المواد البنائية التقليدية. كما مثل الكونكريت النانوي أحد المفاصل المهمة التي قدمتها التطورات التكنولوجية في مجال هندسة المواد. ويعتمد هذا النوع من الكونكريت في جوهره على اضافة المواد النانوية الى الكونكريت، مما يمنح الاخير خصائص معينة متفوقا بها على الكونكريت الاعتيادي. وتتمثل هذه الاضافات بعدة انواع من المواد النانوية، لكن أبرزها واكثرها انتشارا هو اضافة مواد السليكا النانوية وثاني اوكسيد التيتانيوم النانوي وانابيب وألياف الكاربون النانوية، والتي تحسن ادائية الكونكريت ومقاومته الانشائية. وقد وفر ذلك حدودا اكثر اتساعا لإمكانيات التكنولوجيا في انشاء العمارة بالكونكريت، ومكن المعماريين من تحقيق اشكال معمارية أكثر تعقيدا وبأدائية اعلى. يتناول البحث اثر الكونكريت النانوي في العمارة المعاصرة متبعا الخطوات التالية: اولا، تناول ماهية الكونكريت النانوي. ثانيا، تناول الاختلاف بين الكونكريت النانوي والكونكريت الاعتيادي. ثالثا، تناول تطبيقات استخدام الكونكريت النانوي في المباني المنفذة. ويستنتج البحث عددا من المؤشرات الرئيسية الناتجة عن تأثير هذا النوع من الكونكريت على العمارة المعاصرة.

I. INTRODUCTION

Most of the contemporary architectural nowadays uses concrete as the main construction material. However, due to the development of building technology and design, concrete need to be developed as well as a building material to overcome its weaknesses and improve its performance. Reinforcing concrete increases its durability and quality, and achieving smooth surfaces are some of the major properties to be improved. In addition, the need for achieving sustainability in buildings has direct impact on concrete's development as concrete which is considered one as a major contemporary demand in the building materials industry. To achieve these improvements, researchers researched and experimented with many additions (nanomaterials) to concrete on the Nano-scale level.

Over the last decades, architects and engineers used to consider concrete as a building material with unique potential capability especially in terms of shape. Conventional concrete technology, nevertheless, has set up clear limits to architectural form for many years. In addition, many architects feel that traditional concrete is unattractive and needs to be improved. Architects and engineers explored self-compacting concrete as new aesthetic building materials to fulfill some of conventional concrete usage at overcome its limitations .

This research will discuss the new concrete mixtures that use nanomaterials for achieving special properties. The research will discuss the role of "Nano-Concrete" in achieving aesthetic forms and sustainability especially that it becomes more important for contemporary concrete structures. Generally, as seen by many researchers, the main focus of this paper will be on using concrete with nanomaterials additives including Nano-silica and Nano-titanium dioxide as well as carbon nanotubes or nanofibers (CNT-CNF) as they are the most commonly used additives.

Nano- additives like "Nano-silica and Nano-titanium dioxide are probably the most reported additives used in Nano modified concrete. Nanomaterials can improve the compressive strength and ductility of concrete. Carbon nanotubes or nanofibers (CNT-CNF) are used to modify strength, modulus and ductility of concretes" [1].

This research will try to fulfill its goal through a set of objectives; it will first start by defining Nano-concrete in brief and its common additives by comparing last literatures. Next, the research will discuss the main difference of Nano-concrete mixes compared to ordinary mixes of concrete. Following that, the research will discuss the application of Nano-concrete in buildings and its effect on contemporary architecture. Finally, the research will list the final key points in the conclusion.

II. Defining Nano-Concrete

Nanotechnology is not very new technology; however, researchers are still experimenting with this technology to find more about its usage. However, what does nanotechnology mean? Nanotechnology is defined as "the creation, investigation and application of structures, molecular materials, internal interfaces or surfaces with at least one critical dimension less than 100 nanometers, 1 nanometer equals to 10-9 meter" [2]. Nanotechnology has the potentiality to affect every domain of technology through controlling materials at nanoscale [3]

According to the study in [4] nanomaterial is a material with one, two or three external dimensions in the Nano scale. When nanomaterials are added to traditional building materials the result material will possess new properties which could be beneficial for building construction [5]. The main field of using nanomaterials in construction sector are coating of façade surfaces and optimizing building materials [6]. Nanomaterials, such as carbon nanotubes silica and polymers in cement, improve strength, and optimize other properties such as flow and setting in formwork, corrosion, acid-resistance [7].

Similarly, Nano concrete is concrete by adding nanomaterials to improve its performance and properties for construction [8]. The variety of nanomaterials additives to concrete results in a wide variety of Nano concrete applications in construction. Thus, producing intelligent structures and enhancing buildings performance in disasters through fire resistance coating or smog-eating concrete or other uses [9].

III. Nanoconcrete And Sustainability

Sustainability is defined "The development that meets the needs of present without compromising an ability of future generations to meet their own needs" [8]. Due to wide and large use of concrete in the construction industry, it plays very important role on environment. As building material, it needs large amount of energy for its production and usage, it produces large amount of CO2, and considering its heavy usage in buildings while playing huge role on nature [8].

The production of concrete releases large quantities of carbon dioxide into the atmosphere. In general, concrete consists of about 12% cement, 8% water and 80% aggregate by mass. This means 1.5 billion tons of cement are needed yearly. Estimates say that Portland cement contributes to about 7% of CO2 emission globally each year [9]. According to Naik and Moriconi [9] the production of one ton of Portland cement produces approximately one ton of CO2. The demand on concrete as a construction material is rised and is expected to grow from 11.5 billion tons a year to about 18 billion tons per annum by 2050 [10]. However, new innovations in concrete help the improvment its properties, thus, help tackling this problem.

Concrete usage can be lowered dramatically if concrete with higher strength and performance is used in specific parts of the building, hence, lowering CO2 emissions and making buildings more sustainable [8]. This sustainable concrete could be produced by improving the nanostructure of concrete using nanotechnology [11].

In addition to concrete the bad impact on environment, the process of using concrete consumes a lot of time, effort and usually produce large amount of waste, thus requiring workers to obey to many restrictions. Concrete is traditionally poured for the whole volume of the walls and roofs to avoid construction joints, the largest dimensions could reach 70 meters in length and 9 meters in height and for a thickness of around 10cm to 2 meters. In most cases, concrete is mixed on the construction site for as long as 18 hours in some cases. Moreover, the maximum height from which the concrete was poured is limited to 15 centimeters to avoid segregation and the required temperature is below 25 C ◦

As concrete is the most used material in the construction industry, many researchers are concerned with its development to increase its performance while decreasing its bad effects and restrictions [6]. Thus, the main challenge for concrete industry is reducing its impact on the environment and while improving its durability and cost efficiency. Nano concrete is the key for that challenge, through adding artificial pozzolana, ash and other very fine materials, concrete performance could be improved [6]. In the next part, the research will examine some of the Nano-concrete types according to the additives while discussing its use and properties.

IV. NANO-CONCRETE TYPES

As stated earlier, this research will discuss some Nano-concrete types, its mixes, additives, and properties. The reason behind selecting these types is because that they are the most commonly used, also the research is tries to focus on Nano-concrete in already constructed buildings rather than Nano-concrete in unconstructed buildings. This is because the research tries to understand the impact of Nano-concrete on contemporary existing architecture.

A. Self-Compacting Concrete (S.C.C.)

Self-compacting concrete S.C.C., was first developed in Japan in early 1990s. The main issue tries to tackle and to make it easier to deal with concrete in site. And according to Walraven [10] it was a revolutionary step forward in contemporary construction.

The idea of (S.C.C.) is to have concrete that flows when placed into formwork and the compact itself was under the influence of self-weight only without the need for vibration. While S.C.C. succeeded in achieving that, it also came with further advantages such as high concrete quality in terms of its surface finish and durability. Hence, ordinary Portland cement concrete could be replaced with smaller amount of S.C.C. [11].

S.C.C., while still liquid, can fill complex geometric shapes with dense reinforcement such as a asymmetric voided slab ceiling which should merge into cones without transition zones. The curing stage is the key for producing smooth finish of surfaces. Pumping S.C.C. to the formwork can provide uniform color and texture for the most complicated forms [12].

According to Birgisson [13] an effective way for producing S.C.C. is by adding Nano`-materials like nano-silica to the concrete mix. This additive will improve concrete's compression strength as well thus making it stronger than ordinary concrete mixes [13]. Moreover, S.C.C. improved performance in terms of heavily reinforced structures with complicated geometry therefore it can eliminate the need for skilled workers and vibrators which are usually used in such cases [14]. In addition, S.C.C is suitable for producing excellent white surfaces with marble-like finish, which is required in some architectural designs without the need of any extra finishing [15]. The advantages of S.C.C. could be summarized:

- Sustainability: S.C.C. increases sustainability through increasing concrete durability and aesthetic appearance thus lowering the amount of material needed in buildings [15] Filling ability: S.C.C. could flow in full homogeneity formworks .
- Passing ability: S.C.C. could flow through narrow sections, without being blocked by large aggregate particles .
- Resistance to segregation: S.C.C. can flow without segregation during transportation or casting
- Pumping ability: S.C.C. could be pumped to highest parts of the building during construction.
- Working environment: The use of S.C.C reduces noise during construction specifically noise caused by vibration. It also reduces the need for hazard precautions resulted from electrical cables and vibrators.
- Concrete strength: S.C.C. has improved strength when compared with ordinary concrete when hardened [16].
- Eliminating the need for vibration: S.C.C. has a honey-like consistency, thus it needs no vibration. It could be used in heavily reinforced structure elements without the need for vibration to produce complex forms.
- Reducing labor costs: S.C.C can save up to 50% in labor costs. This is because it could be poured up to 80% faster than ordinary concrete mixes [17].
- Finish surfaces quality: S.C.C. can be used to make marble like surfaces if needed in design which is almost impossible with ordinary concrete mixes [16] moreover, S.C.C. produce surfaces with no porous [18].

B. Nano-Silica

By adding Nano-silica to concrete mixture improves its micro/nanostructure and mechanical properties. Micro and Nano-scaled silica particles have a filler effect by filling voids between the cement grains [3], thus, the resulted concrete could block water penetration, which means the improved durability. In addition, it has higher compressive strength of about 3-6 times compared to ordinary concrete mixes [17]. Furthermore, Nano-silica concrete increased mechanical strength due to the lower water penetration and better durability [7].

The addition of nano-silica to concrete results with a more sustainable concrete as it reduces the amount of concrete needed for buildings, which in turn decreases cement, water and aggregate consumption, therefore lowering production and transportation effects on the environment. This type of nano-concrete is suitable for high speed building constructions as the concrete hits high strength after a very short time after casting [3].

C. Nano-Titanium Dioxide TiO2:

Nano TiO_2 is one of the concrete additives with high potentials. White cement containing TiO_2 nanoparticles have photo-catalytic properties. This allows the concrete to maintain its aesthetic characteristics over time [1]. When

TiO_2 is added to concrete or finishing materials it gives the surface self-cleaning effect, therefore, it is commercially applied on building facades and in concrete paving materials. This property is particularly important for new buildings and for the restoration of old facades [1]. Also in the presence of sunlight, it depollutes the environment by removing Harmful gases from the atmosphere [3] [5]. In addition, by adding Nano TiO_2 to the concrete increases its strength and wear resistance [7].

D. Carbon Nano Tubes CNTS:

Carbon Nanotubes (CNTs) are made from carbon. They are cylindrical in shape and have a diameter of nanometers thus called nanotubes. They can be several millimeters in length and can either be single walled or multi walled. CNTs possess many properties which could help to design an ideal construction material. Theoretically, They have about 100 times the strength of steel whilst being only 1/6th its density [19])

Carbon Nano-tubes are added to conventional structure materials for enhancing their strength and other properties. Ordinary concrete is a brittle material, strong against compression forces but relatively weak against tension forces. Mixing carbon nanotubes with the cementous materials to fabricate fiber composites that can increase the compressive strength of cement. The addition of small amounts (1% Volume) of carbon nanotubes, can improve the mechanical properties of mixture samples of Portland cement and water [20].

Moreover, Concrete can be transformed into a self-sensing concrete by properly embedding a network of CNTs, which makes the concrete capable of detecting damages at early stages of loading [1]. When Carbon nanotubes are added to Concrete by 0.025% of its weight- acts as bridges across cracks and voids, which ensures load-transfer in tension [5]. Hence, CNTs can be worked as a proxy for polymeric chemical admixtures and remarkably improved mechanical durability by gluing concrete mixtures, that is, *cementitious agents* and concrete aggregates, and prevented crack propagation [21].

E. Carbon nanofibers (CNFs)

Carbon Nano-fibers may be used as tension reinforcement in concrete to increase the flexural strength of a beam. This property is directly affected by the amount of fibers which are used, the orientation and the quality of bond [22]. By adding CNFs of about 0.048% of total concrete weight improve flexural strength of the matrix [5]. CNFs ensure load transfer in tension and they act as bridges across voids [1].

By adding Nano-fibers to concrete mixtures increase tensile strength by as much as five times. As a result tensile forces from shrinkage or thermal change can be resisted [12]. The advantages of adding nano-fibers to concrete are increasing the flexural strength, toughness, durability, air content, freeze thaw and resistance to earthquakes. They also increase compressive strength, drying shrinkage resistance and electrical resistivity. The only negative effect which is decreased compression, but this could be solved by adding silica fume. The minimum fiber content to give these properties is about 0.1% of the total volume [23].

V. Using Nano-Concrete in Architecture, Case Studies as Examples

As mentioned earlier in this research, concrete is one of widely used construction materials. This construction material has many advantages which explains why it is the most using in construction material, however, the production and use of this material have some restrictions, limitations and disadvantages which limit its use in contemporary architecture. Such limitations are the high CO2 emissions, need for vibrators for complex forms, rough surfaces which usually require finishing and many more. In the beginning of the 21st century, huge advancements occurred which lead to the invention and use of Nano-concrete, a form of concrete with Nano additives to improve its performance on the nanoscale structure. Nano-concrete has many advantages over the traditional concrete mixes such as self-compacting, self-cleaning, eco-friendly, depollution property, improved strength and durability, high liquidity and other properties. Those properties had huge influence on architects around the world as it gave them more flexibility and made concrete go back in line with the new architectural and construction requirements and ambitions.

In this section, the research will discuss some of architectural projects in which Nano concrete was used. It is important to mention that most of Nano concrete they used in building construction is Self-Compacting Concrete, thus most projects which are discussed here is using S.C.C.. Other Nano concrete types are less frequent in building construction and some of them still in the experimental phases.

- National Museum of 21st Century Arts (MAXXI) in Rome, Italy, Zaha Hadid (Figure 1)

  In this project, a 400mm thick reinforced S.C.C. was used to produce the required fair-faced walls with extreme quality ,continuity, homogeneity and fine surface texture. To achieve continuous flow of the design from one gallery to the other [27].

- The S. Peter Apostle church , Pescara ,Italy (Figure 2).

The achievement of this ship-like design required high fluidity of concrete (600mm after 1hr at 30C^{o}), high cube compressive strength (35 Mpa) and high durability of concrete due to it is exposure to sea water [28]. That means the use of S.C.C to produce the highly reinforced structure without vibrators. [17].

- Phaeno Science Centre, Wolksburg, Germany, by Zaha Hadid , 2005 (Figure 3)

S.C.C is used for making nice jagged angles, looming curves, fracted plans and daring protrusions [29]. Pheano is a Schizophrenia of multiple systems , Disproportionally heavy cones , Prefabricated and cast in situ S.C.C. walls , Metal columns on specific spots The result is elegance of complexity [30].

- The extension of the art museum Ordrupgaard Copenhagen in, by Zaha Hadid ,2001-2005 (Figure 4)

The choice of S.C.C. as the main construction material was due to the complex form with heavy reinforcement [16].

- Arlanda Airport Control Tower, Stockholm, Sweden by Wingårdh Arkitektkontor AB, 1995 (Figure 5)

The reason of using S.C.C. is to achieve fast curing and weight-lifting speed – A built height of 3.27m for every four days. In addition, achieving high-quality concrete with no vibration while reducing noise to allow continuous concrete casting overnight [13].

- The Cathedral of Christ, the Light, Oakland, California (Figure 6).

S.C.C. was used for achieving the curved walls for its out coming sharp details and uniform appearance [32].

- British Airways headquarters , 1998 (Figure 7).

The design needed concrete boxes shimmed to exact height and angle (up to two degrees from the vertical axis). Precast S.C.C. elements were delivered to the site for achieving the design while guaranteeing the exact shape [29].

- Contemporary Arts Center, Cincinnati, Ohio, Zaha Hadid , 2003 (Figure 8)

S.C.C. was used for constructing the roll and vertical portion of the urban carpet [30].

- BMW Central building Zaha Hadid, Leipzig, Germany 2003 (Figure 9).

The cascading floor system structure was made with S.C.C. while the roof was assembled with series of steel H-Beams [31].

- The façade of Jublee church in Rome by Richard Meirs & Partners (Figure 10).

TiO2 Nano concrete was used to construct walls that maintain its aesthetic characteristics over time while achieving self-cleaning effect.

- The façade Air France headquarters at Charles de Gaulle airport (Figure 11), Cite de la Musiqueet des Beaux Arts in chambray and Hotel de Police.

In these projects, TiO2 Nano concrete was used to achieve white walls with self-cleaning effect while depolluting the environment that is one of Air France's key goals.

- The New Enexis building in Zwolle (Netherlands) (Figure 12).

Carbon Nanotubes (CNTs) have been used with concrete to manufacture façade elements with large sizes that can be mounted in a very short period, for constructing the new Enexis building in Zwolle (Netherlands). The low panel weight resulted in a fast and easy installation. In addition, the specific shape of the panels will contribute significantly to the low energy consumption of this energy neutral building.

- Marine and Offshore (Figure 13) .

CNF was used to enhance ultrahigh performance concrete coating for marine and offshore rooftops; retainer walls; repair material. CNF was used for its superior bonding strength to other cementitious materials and to steel.

Fig. 1:National Museum of 21st Century Arts MAXXI [1]

Fig. 2: The S. Peter Apostle church [1]

Fig. 3: Phaeno Science Centre [1]

Fig.4: The extension of the art museum Ordrupgaard in Copenhagen

Fig. 5: Arlanda Airport Control Tower, Stockholm, Sweden [1]

Fig.6: The Cathedral of Christ, the Light, Oakland, California [2]

Fig.7: British Airways headquarters

Fig.8: Contemporary Arts Center, Cincinnati, Ohio [3]

Fig. 9: BMW Central building, Leipzig, Germany[4]

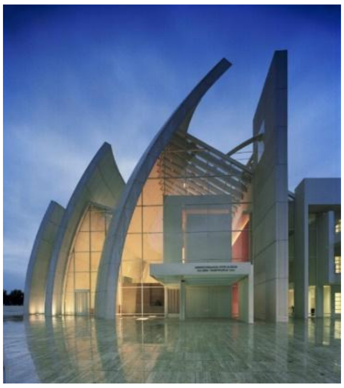

Fig.10: Jublee church in Rome by Richard Meirs & Partners [5]

Fig. 11: Air France headquarters at Charles de Gaulle airport [6]

[1] Picture from http://arcadenw.org/images/uploads/content-media/arlanda-twr-wingardh.jpg
[2] Picture from http://ucanr.org/blogs/WoodyBiomass/blogfiles/7048.jpg
[3] Picture from http://www.urbanophile.com/2008/05/
[4] Picture from http://en.urbarama.com/project/bmw-plant-leipzig-central-building
[5] Picture from https://s-media-cache-ak0.pinimg.com/736x/c2/ec/b4/c2ecb4baf93a5a0459d3bea5aa3866f4.jpg
[6] Picture from http://blobsvc.wort.lu/picture/c72fd6075c82afb9496106a8e6f6b476/577/356/wortv3/eaf47c56590d43ec95dcb20dd08d6be088bb7a3a

Fig. 12: The New Enexis building in Zwolle [7]

Figure 13: Marine and Offshore[8]

VI. Conclusion

Nano-concrete is important not only as an enhanced construction material but also in the context of energy and effort conservation effort. Contemporary architects use Nano-Concrete as construction material for its extraordinary properties. Thus enabling the construction of more creative forms which was impossible to construct the use of ordinary concrete mixes. Self-Compacting Concrete (S.C.C.) which is produced through the addition of small amount of nano-SiO_2 results in concrete with high strength and durability. Hence, it could be used to construct complex shapes and improved concrete's mechanical strength.

- Self-cleaning concrete could be made by adding nano-TiO_2. This results in a self-cleaning concrete with special photo-catalytic property to convert air pollutants into harmless substances with sunlight help. It also causes cement for rapidly hydrate.
- Carbon nanotubes (CNTs) and nanofibers (CNFs) can improve concrete's mechanical durability and prevent after-curing cracks, CNTs to improve resistance to corrosion, fatigue, wear and tear, and abrasion. In addition, it indirectly contributes to energy saving which are usually needed for repairing or replacing deteriorated infrastructure.
- All these new characteristics added to concrete's characteristics and properties, made Nano-concrete as new favorite construction material by architects as it allow long-spans, unusual and complex forms, consistent appearance and many more properties.

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