Al Azhar University
Faculty of Engineering
Department of Architectural
Engineering

# The Usage of Nanotechnology in Architecture

## Nanotechnology Effect on the Architectural Form and Function

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B.Sc. of Architecture, Al Azhar University

A Thesis Submitted to the
Faculty of Engineering at AL Azhar University
For the Degree of Master of Science in Architecture

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# Dedication

**I dedicate this work to the soul of my father**

Acknowledgements

Firstly, I thank **God** who gave me the ability to complete this research. Wishing God to honour me by making this research "*a knowledge which is beneficial*" as our prophet PBUH said.

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# Abstract

New technologies and novel materials, as building systems, have a radical impact on architecture, since buildings were one of the oldest occupations of the human race. Material plays a significant role in architecture; it affects building form and functional performance. The role material plays became more involved in the design process and, consequently, influences the way architects think. Indeed, material has traditionally been a follower to the form but, it appears that the hierarchical sequence in the design process which is to start with form, then use structural system and material to reach this form, with no participation for material in the early design stages, will not domain the design process. Instead, material will no longer appear as a texture or surface, but is experienced in the whole depth of architecture, coinciding with the emergence of new design methodologies that depend on calculations and analyses to generate form through entering some inputs, including material choices and its properties as one of these inputs (Digital materiality) . Now we may depend on material as an initiative giver involved in the early design stages to outline architectural form. That is why architects should pay interest to the material science world.

The research explores Nanotechnology as a proposed technology for material design; it is a science that examines the nature of our world at every tiny scale. This technology became popular not only in scientific fields but also in all aspects connected with our daily life, it makes it possible to develop a new generation of materials and devices which are stronger, lighter, more durable and more efficient than conventional materials. Moreover the research investigates the integration between architecture and nanotechnology which promising great expectations with novel materials as well as modified materials, which allows designers to think freely and discover novelty in their designs.

The research will discuss the issue through three main parts:

i. Investigating the role that material plays in the design process, and how evolving understanding of the material properties enables it to participate in the design process in its early stages. This part will introduce almost all material classifications, in order to understand material general background, and to recognize construction materials and how far materials affect the architectural form since trabeated architecture until now.
ii. Illustrating nanotechnology and its general application. The research will focus on the integration between nanotechnology and architecture. Mainly, this integration will appear in two major methods; the first one is nanomaterials in architecture including structural, non-structural materials, coatings, lighting and insulations. The second one will be the nano devices and nano systems in architecture.

iii. Reviewing nanotechnology applications in architecture through an analytical and comparative study for nano architectural buildings; this study will discuss the effects of nanotechnology on both architectural form elements and functional performance.

Thus, the research shows the possibilities of nanoarchitecture as a new design trend which will affect architectural form and functions. It also offers more involving participation for material in early design stages as a result of bringing a new palette of materials which will influence the whole design process. Finally it investigates more capabilities of buildings performances and spatial configurations.


## Key words

-Nanomaterials in architecture, Nanoarchitecture, Material as a design approach.

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# List of Abbreviations and Acronyms

| | |
|---|---|
| **CNT** | Carbon Nanotube |
| **CSI** | Construction Specifications Institute |
| **DMM** | Digital Molecular Matter |
| **DNA** | Deoxyribonucleic Acid |
| **DWCNT** | Double-Walled Carbon Nano tubes |
| **ETC** | Easy To Clean |
| **LED** | Light Emitting Diode |
| **LEED** | Leadership in Energy and Environmental Design |
| **MNT** | Molecular Nanotechnology |
| **NA** | Nanoarchitecture |
| **NVS** | Nano Vent Skin |
| **PCMs** | Property Change Materials |
| **OLED** | Organic Light Emitting Diode |
| **SWCNT** | Single-Walled Carbon Nano tubes |
| **$TIO_2$** | Titanium Dioxide |
| **UHPC** | Ultra High Performance Concrete |
| **VPD** | Variable Property Design |

# 1 Chapter 1 Introduction and Research Objectives

## 1.1 **Introduction**

This research focuses on nanotechnology; the science of manufacturing material at a tiny scale, that could bring new possibilities and make dramatic improvements to all aspects of life, including architecture. The thesis will discuss the integration between nanotechnology and architecture (nanoarchitecture), which promises transforming architecture in ways we can hardly imagine today. It will bring a paradigm shift in building performances. As we consider the industrial revolution as a turning point in modern architecture, many researchers and architects pointed that nanoarchitecture will create a new revolution in our built environment. Moreover; the research will explain its potential to make a huge impact on serving new architectural design methodologies.

## 1.2 **Motivation**

Current architectural age is mainly affected by new technologies. However architect's aspirations are still outweighing available techniques in construction field, especially with the advent of new design trends that generate complex forms. As a result the available pallet of materials keeps us looking for new technologies that could offer designers new materials with more capabilities in executing these generated forms. That could be accelerated by spreading the use of nanotechnology in architecture, due to its importance; it draws our attention to be tested combined with architecture.

## 1.3 **Previous studies**

Many studies have reported in this area to investigate the applications of nanotechnology in architecture, many of these researches are only oriented to inventory nanomaterials which could be used in architecture in general, such as, Nano materials in Architecture, Interior Architecture and Design by Sylvia Leydecker, 2008. Other researches have pointed at nanomaterials that could support sustainable architecture like Green nanoarchitecture by Fahd Abd Elaziz, 2010. However, topics related to nanotechnology impact on the architectural form and its contribution to rise building's performance and its level of actuation, and the participation of this technology in the early stages of the design process are not yet established.

## 1.4 **Research question**

As design trends have changed after the industrial revolution since new materials and techniques have appeared in construction field, can we predict another big leap in the near future with nanotechnology?

The previous introduction could lead us to important issues;

1. **What** is the reason that makes material an important factor in an initiative architectural design stage; thus causes us to search for new materials?
2. **What** is the impact of construction materials on architectural form since trabeated architecture?
3. **What** are the modern technologies that impose themselves on the scene, especially in materials science?
4. **What** is nanotechnology? And what is the ways of integrating this technology in architecture?
5. **What** is the impact of using nanotechnology on architecture in terms of both form and functional performance?

## 1.5 Research Objectives

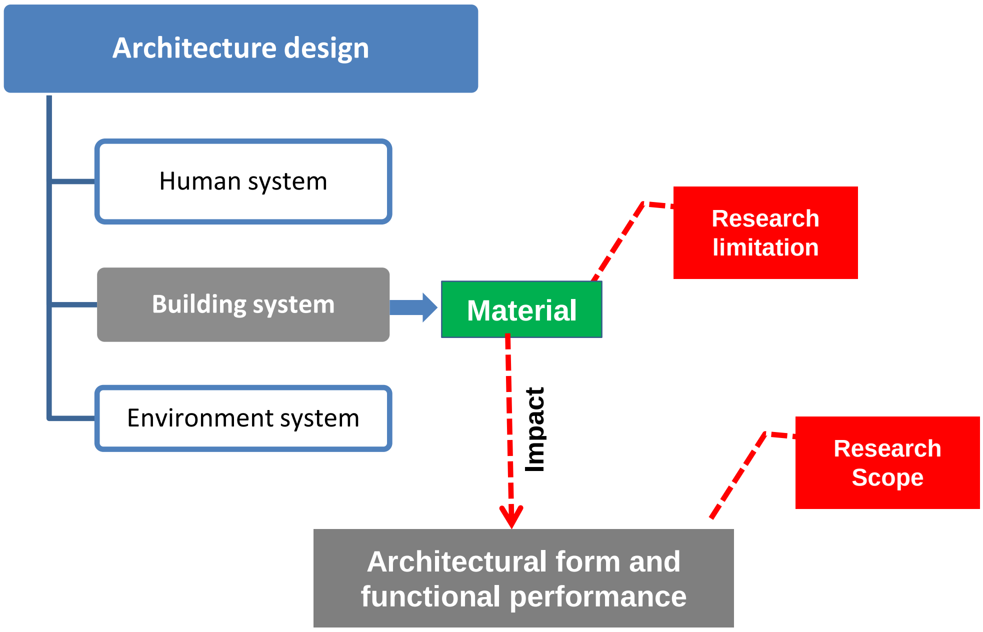
The main objective of this research is **to investigate the impact of using nanotechnology in architecture in terms of both form and functional performance.**

In order to achieve the main objective of the research, there is a group of sub-objectives:

1. Exploring **the effect of construction materials on architectural design**. Including new design methodologies that depend on material properties in its design stages.
2. Emphasizing **the role that material plays** and its contribution in finding architectural form.
3. Investigating **the integration between nanotechnology and architecture** in order to get a new architectural trend (nanoarchitecture).
4. Exploring the capabilities of nanotechnology to **raise building's functional performance**, and its contribution in **conserving energy**.
5. Identifying nanotechnology to make it a well-known **tool for architects and designers** in order to benefit from this technology and its implementation in the building process.
6. Spreading the knowledge of material design and how we can use nanotechnology to **design our own materials** and improve our current construction materials' properties as well.

## 1.6 Research scope and limitations

This research will focus on the integration between architecture and nanotechnology, and the impact of this technology on architectural design process according to the changes caused by material as a sub-system of building system. It will examine how this impact can reflect the architectural form and functional performance.




The impact of nanotechnology on the architectural form will be specifically on the form elements which are: shape, colour, size and texture. On the other hand any form of energy saving capability and environmental control ability will be considered as functional performance.

Moreover, the research will not be restricted with specific country or city due to the limitation of this new trend as the topic is recently covered in the architectural community.

## 1.7 Methodology

The methodology of the study follows:

A. **An inductive approach** to understand the theoretical framework of the architectural design process and the role material plays in this process.
B. **A historical review** for the influence of construction materials on architectural form evolution.
C. **An analytical study** for nanoarchitecture buildings.
D. **A comparative analytical study** for the elective case studies and the influence of nano products on each of them in terms of form and function.
E. **A deductive analytical study** for nanotechnology effect on architectural form elements and functions.

## 1.8 Predicted Results

As the industrial revolution has been considered as a paradigm shift in the architectural history; our aspiration goes to the most promising technology in our era "nanotechnology" and its applications in architecture. The research expects that nanotechnology has the capability of changing our architectural future plans, including both architectural form and functional performance.

## Research Structure

The overall structure of the study takes the form of four chapters, including this introductory chapter;

- Chapter Two begins by laying out the theoretical background of using material in architecture, and the role material plays in the design process. Focusing on the new design methodologies which employee material in the initiative stages at the design process, therefore, to let material characters outline how the form will be. Also this part discusses how far materials affect the architectural form since trabeated architecture until now, passing through the paradigm shifts that have occurred in architectural history as a result of the advent of new technologies.
- The third chapter is concerned with nanotechnology; the most promising technology in our era. This part will focus on the integration between nanotechnology and architecture (nanoarchitecture). This merging is expected to express new generation of architecture, which will be a great change in our built environment. Methods of this integration are varied from:
  -Using nanomaterials in architecture (structural materials- non-structural materials- coatings- lightings- insulations).
  -Using nano systems and devices in architecture.
- In chapter four; the research is going to analyse a group of nanoarchitectural buildings, this will include the different nano-functions in building materials; exploring nanotechnology effect on form elements and building's functional performance.
- Finally, the conclusion gives a brief summary and critique of the findings. At the end of the research, recommendations and suggested further researches are identified.

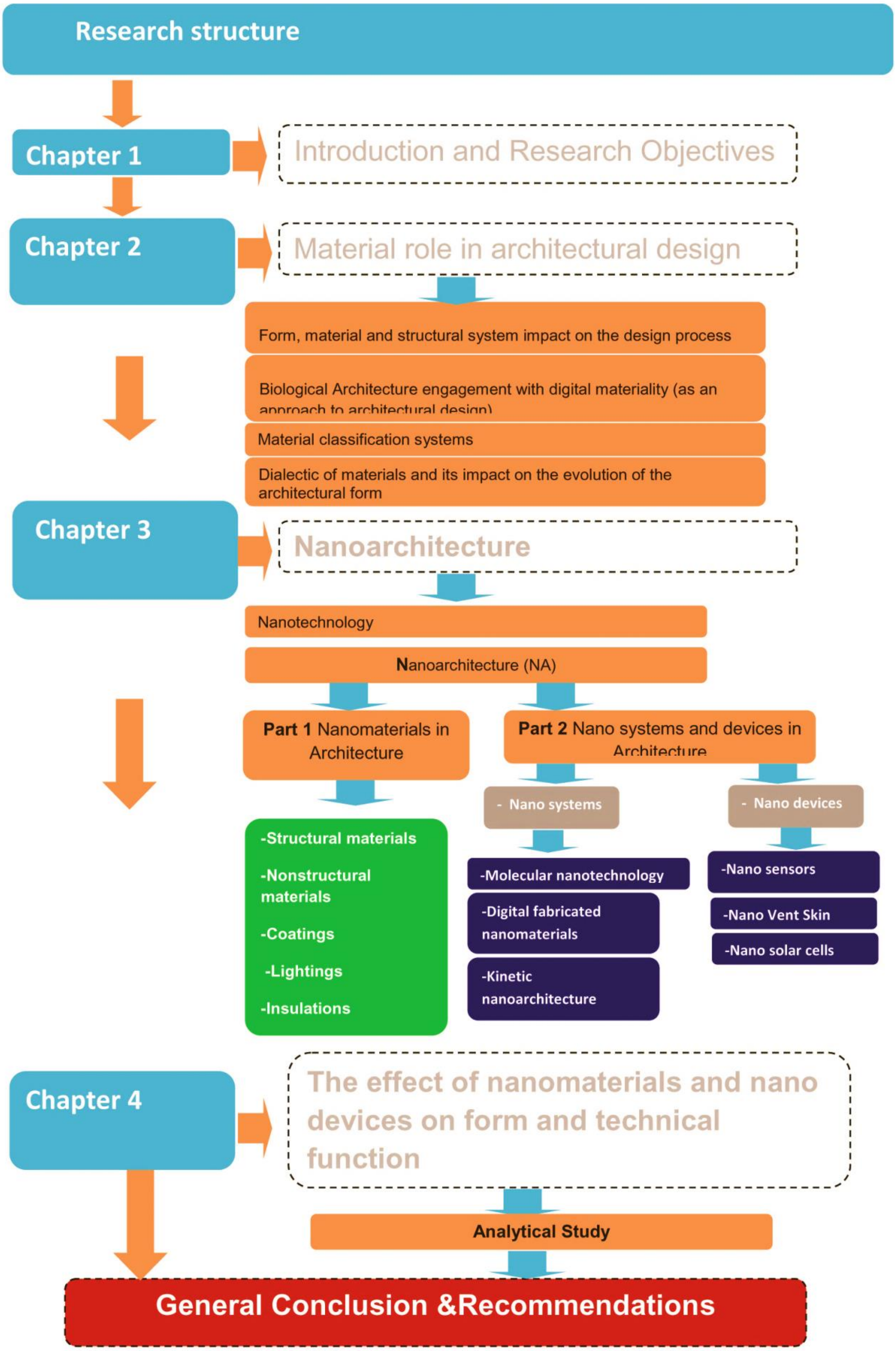



**Table 1 Research structure**

# 2 Chapter 2 Material role in architectural design

# Chapter 2

**Form, material and structural system impact on the design process**

Biological Architecture (material approach)

Material classification systems

Dialectic of materials and its impact on the evolution of the architectural form

# 2. Material role in architectural design

## 2.1 Form, material and structural system impact on the design process

### 2.1.1 Introduction

This part of the research will discuss many approaches to the design process, including form, structural system and material. Lately; material plays a significant role in architectural design as a result of prosperity that happened in technology related to material science, besides, deeper understanding of material performances and the way we address it as a construction materials. The research will investigate new design methodologies based on material characters (performances) in order to emphasis the role that material plays in the design process.

### 2.1.2 Form, Structural systems, Material and the Design process

In order to design a building, three kinds of information are needed to be covered; human system, building system and environmental system. The three main factors (systems) control the architectural design since buildings were one of the oldest occupation of the human race. These systems influence the architectural form; building proportions, heights, openings and elements. Each of the three systems contains many variables that change due to place and time, which cause delaying or progressing in the evolution of the architectural product.

Building system contains an important sub-system, that is (material); it directly influences the architectural form.  In order to examine the role marterial plays in the design process, it is important to define what design process is.

#### 2.1.2.1 Architectural design process

Designing is a continual process of selecting and organising elements, trying to establish which are the most important and how they might all play their role in the creation of the new product.[1] This, generally, explains what the design is.

To go through the design process itself, it is quite helpful to understand each element or tool that designers use in this process.

G.H. Broadbent put the next articulation which lists the three systems (human system, building system and environment system) in one possible form, which regulates the relationship between its components. [2]

The research will address the notion of design process from the perspective of **building system**, focusing on building technology and the role it plays in architectural design, due to its locality as an acceptable filter between user requirements and physical context.

**Material and structural systems** are sub-systems in this configuration, which link all systems together. Both variables influence the

[1] Tunstall, G., **Managing the Building Design Process**, Butterworth-Heinemann, Second edition, 2006, P 25

[2] Broadbent, G. , **Design in Architecture**, wiley,1973,P 385

extension of the design process as a whole, and consequently, the architectural product. Therefore, the character of the architectural space depends on how things are done and formed, and hence it is determined by its structural composition of the substances and the used building materials.

| Interrelation in building design | | | | | | |
|---|---|---|---|---|---|---|
| Environmental system | | Building system | | | Human system | |
| Cultural context | Physical context | Building technology | | Internal ambience | User requirements | Client objectives |
| social | Climatic | Available resources | | Structural mass | Organic | Security |
| | | Material | equipment | Sensory environment (lighting/ sound control/ heating/ vent) | | |
| Economic | topographical | Structural systems | | | Locational (static/ dynamic) | Profit |
| Technological | Constrains (land use- existing built..) | Services system | | | Spatial | The ability to change |
| historical | | Fitting system | | | | |
| political | | | | | | |
| aesthetic | | | | | | |
| religious | | | | | | |

**Table 2 Interrelation in building design.**

**Source; by the researcher according to G.H. Broadbent, 1973**

As architects; there are many components in this system to be reliance on in initiative design stages; form, structure system and material, in terms of addressing these three elements; as Rivka Oxman[3] claimed in her theory that architects have three strong elements which are form, structure and material, the three givers that inspire them during the design process and affect their way of thinking.

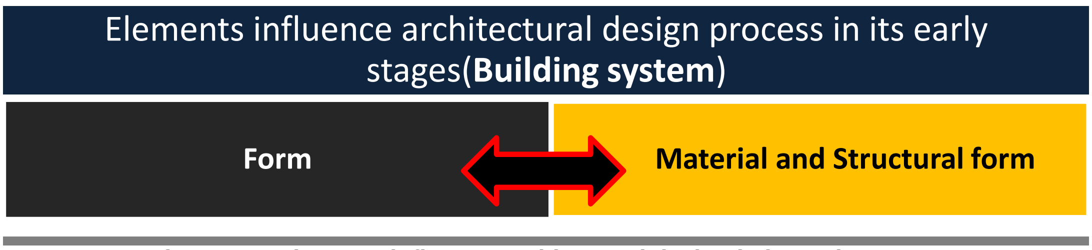



**Figure 2.1 Elements influence architectural design in its early stages.**

**Source; the researcher according to Rivka Oxman view**

[3] **Rivka Oxman;** is an architect, researcher, professor, and author. She is an Associate Editor of Design Studies (Elsevier) - the international journal for design research in engineering; she is also a member of numerous editorial boards of leading international scientific journals and conferences on design research and theory and on digital design.

## 2.1.3 **Form as an approach to architectural design**

### 2.1.3.1 Architectural form

What is form? This term means to denote the formal structure of a work the manner of arranging and coordinating the elements and part of a composition so as to produce a coherent image[4]

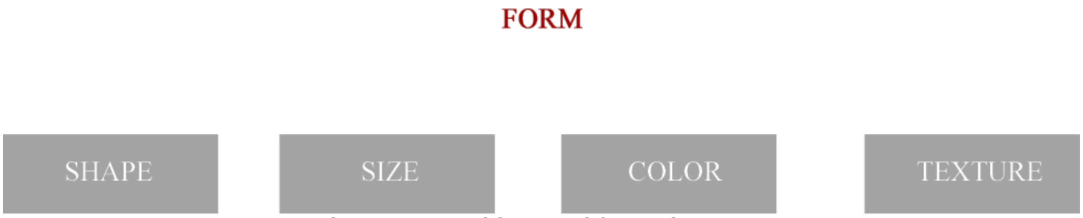



**Figure 2.2 Architectural form elements.**

**Source; the researcher according to Ching, F. D. Architecture: Form-Space and Order, 1996**

The image of architecture as form-giver has dominated the profession for many years. A formal concept is first conceived by the architect and subsequently structured and materialised in collaboration with the engineer.

Material selection depends on structural solutions. Such views emphasise the hierarchical nature of the design process with form being the first article of production, driving both structural and material strategies. [5] In this design approach material and structure are recruitment to achieve specific form, in order to put it in the final image. Decisions about the material choice come in late stages.

**Figure 2.3 Frank Gehry and Zaha Hadid sketches which were translated into buildings (form as an approach to architectural design).**

[4] Francis, C.**, Architecture: Form-Space and Order**, 2nd edition. Van Nostrand Reinhold, 1996, P 34

[5] Castle, H., **The new structuralism**, Wiley, 2010, P 90

## 2.1.4 **Structural form and material as approaches to architectural design**

### 2.1.4.1 **Structural form**

**Structure** is a columnar, planar, or a combination of these which a designer can intentionally use to reinforce or realize ideas.[6] Structural elements have varied from linear structural elements (linear frames, cables and surface structural elements (shell structures, tensile membranes).[7]

This approach emphasises that the structural engineer is no longer the fixer brought in during the late design stage to make a design work, but integral to the earliest generative stages.

Architectural form is essentially understood as, and limited to enveloping form, or shape. This deliberate simplification and clarification conceptually excludes from architectural form any consideration of interior and exterior structural organization. Due to the limitation of the architectural form definition in Ching book; the term **(structural form)** is used instead, it describes the role structure plays in various areas and aspects of building's architecture.

Many structural systems are typically exemplifying a synthesis between architectural and structural form. In these systems structure defines architectural form and function, at least partially, as the building envelope. Which make structural systems are discussed, begins with shell structures that of all structural systems most closely integrate the form.[8]

As a result we can consider the second element which influence the design process in its early stages is **the structural form**.

Moreover; structural design can form building envelop, reflect spatial configurations and contributes to create a visual experience to building's users and control the relationship between the inside and outside. It is the strongest and most powerful element of form, so that if it is not the last consideration in the long series of decisions determining form, it distorts or modifies all other determinants of a building. [9]

### 2.1.4.2 **Structural form as an approach to architectural design**

Many buildings are designed by starting to select a specific known structural system as an approach to the design process, rather than investigating a stability structure that depends on material choice. This approach appears particularly in projects of engineering complexity such as bridges and skyscrapers. Millennium Dome in London and Palazzetto Dello Sport in Italy are examples of this approach.

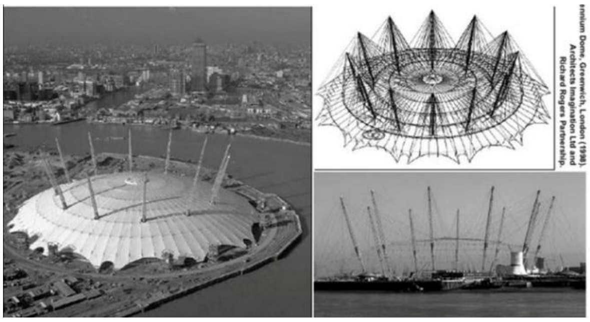



**Figure 2.4 The Millennium Dome, London**

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[6] Andrew w. Charleson**, Structure As Architecture** ,Elsevier, Architectural press, 2005, P 1

[7] Raffat, A., **Traid of Architecture creativity**, Inter consult research center, 1997, P61

[8] Andrew w. Charleson**, Structure As Architecture** ,Elsevier, Architectural press, 2005,P 23

[9] Suckle, A., **By Their own Design**, Whitney Library of Design, 1980, P 14

### 2.1.4.3 Material as an approach to architectural design

The relationship between architecture and material had been fairly straightforward until the industrial revolution. Materials were chosen pragmatically for their utility and availability or they were chosen formally for their appearance and ornamental qualities.

**Figure 2.5 Palazzetto Dello Sport, Rome, Italy.**

**Source; Andrew w. Charleson, 2005**

Material has been traditionally a follower to the form, mainly it changes the final image of the architectural product but it's not participating in early stage in the design process itself, In fact, it appears that the hierarchical sequence 'form–structure–material' is dominated the design process from a perspective of building systems. But is it possible that material occupies a preliminary stage in the design process?

The study of material structure and its role in digital design has become an important subject on both the professional and the academic levels. Researching and understanding the function of material in design has become an important element of the architectural knowledge base and one of its research areas. These research areas also include the techniques of manipulating representations of material structures through digital tectonics.[10] The recent developments of material performance became a key driver of architectural design, new materials which start to appear in the architecture field **which we can control and adaptt its thickness, pattern density, stiffness, colour, flexibility** and **translucency,** emphasises this design approach**,** and it gives us new possibilities and potentials which affect the way we think.

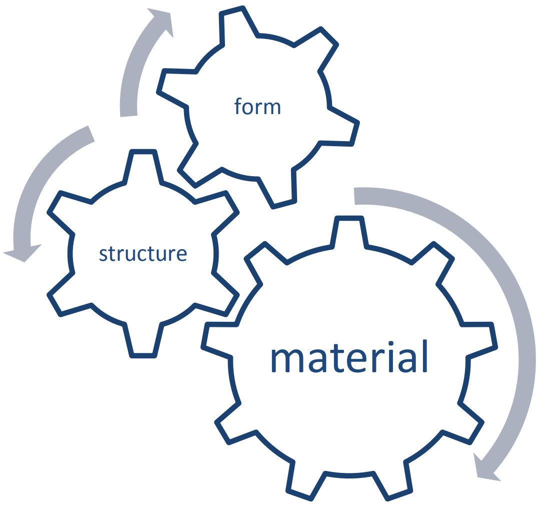


**Figure 2.6 Materials as a main engine in the design process.**

**Source; by the researcher**

[10] Castle, H., **The new structuralism**, Wiley 2010, P 20

#### 2.1.4.4 Form finding operation by using computational method and material behaviour

Computers in design are used at every step in the architectural process. Such uses include conceptual design, 3 dimensional modelling, visualization, analysis, generative form finding and construction. New forms could be generated from computational design tools that depend on mathematical approaches, such as algorithms. These complex forms are expected to change the architectural image in the future.

In recent years, the Smart Geometry Group (an organization focusing on the use of the computer as an intelligent design aid in architecture, engineering and construction) has done much to promote those innovative design techniques through its international conferences and teaching workshops. It is easy now to control any sophisticated and curved shapes with specific points and coordinates which can make implementation possible. These design methodologies effectively reversed the traditional sequence in design process to become 'material, structure, form'.

#### 2.1.4.5 Material characteristics lead to new structure systems

The structuring, encoding and fabricating of material systems has become an area of design study shared by both the architect and the structural engineer. The emersion of new research practice has established the new design science of **digital materiality or materialization** which represents the threshold of the revolution of architectural technologies and material practice. Designing and fabricating new stable structural systems that depend on material choice and its characteristics has become applicable.

An emerging material practice that contributes to both the architect and the engineer has continued in a sequence of work including those of Frei Otto, Jörg Schlaich and others.

<u>Digital materiality</u>

Digital materiality describes an emergent transformation in the expression of architecture. Materiality is increasingly being enriched with digital characteristics, which substantially affect architecture's physics. Digital materiality evolves through the interplay between digital and material processes in design and construction.[11] This approach focuses on the potential of these design processes to **return architecture to its material sources.**

Digital materiality leads us from the design of static forms to the design of material process. In doing so, geometry is given up, whether drawn or modelled. Instead, we design the relationships and sequences that inhabit architecture and that emerge as its physical manifestation.[12]

Such approach usually acts like natural living systems, thus architecture culture appears to move with this transformation, "*Designers now seek to advance nature's strategies in structuring matter by designing synthetic multifunctional materials competing with evolution's unrestricted time frame of the design process*. " Helen Castle.

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[11] Gramazio, F. and Kohler, M.**, Digital Materiality in Architecture**, Lars Müller,2008, P 7
[12] Op.cit., P 11

Theoretical and technical basics of this approach have been termed (material-based design computation). A lot of researches and institutes began regarding this issue. Neri Oxman- the founder of Materialecology and one of the important researchers in the materiality approach field in design at MIT ( Massachusetts Institute of Technology)- takes the paradigm a step further and advocates the inversion of form, structure and material, placing material squarely first in the design sequence and making it the driver of structure and then design. [13]

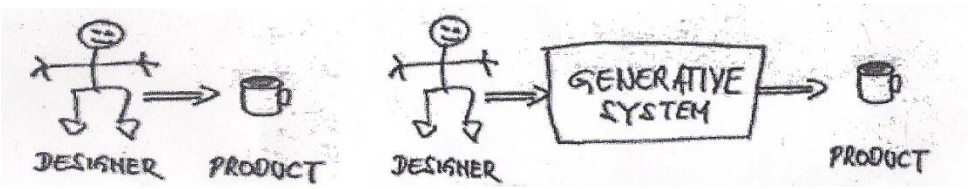


**Figure 2.7 Left; tradition design approach. Right; generative design approach.**

**Source; Ahmed Medhat El Iraqi, 2008, P 194**

As a result material characteristics should be considered in this approach. Traditional design process used material as a rigid element in the design process, it considers material performance fixed in time and space, however in implementation you have to control the dynamic qualities of these materials so that materiality approach focuses on expert material possibilities through the design process, focusing on what is called **material behaviour**.

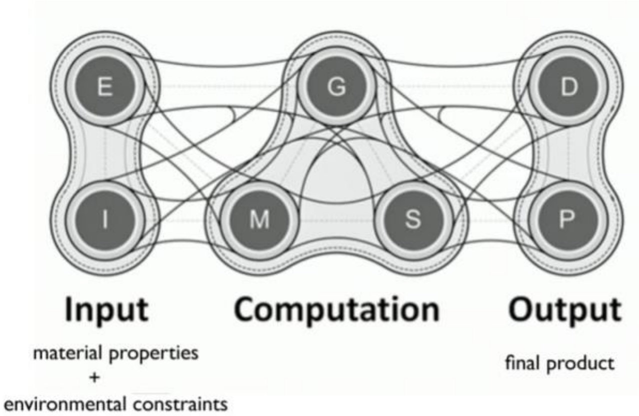


**Figure 2.8 Form generation operation.**

**Source; Neri Oxman, 2010**

Now 3D modelling with the ability to program models parametrically, and with using direct simulation of material behaviour becomes possible, For example programs such as Grasshopper, Kangaroo Physics and DMM (digital molecular matter) plug in 3D Maya are able to simulate a prototype with its own material and expert how this model will act under dynamic effects. Furthermore, beside this ability of merging material characteristics into digital model; it is possible to take its behaviour and performances to the maximum level through **optimize material choice** among different candidate materials.

[13] Castle, H., **The new structuralism**, Wiley, 2010, P 5

### 2.1.4.6 **Examples**

A- (Thaw) woven wall at ROM gallery, Oslo[14]

This project is a woven ash wall consists of ten slats of varying lengths locked in one end, braced by steel joints; its form is generated by creating a digital parametric model-whose material is already defined- and measuring the deformation under their own weight due to gravity and through the elastic bending and twisting of its wooden members, as well as the friction based interlocking of the weave by using corresponding n-meshes (a polygon mesh with embedded material properties in the digital model) and simulated the approximate behaviour. Subsequently the produced data set was abstracted into formulas which could simulate the "bend" of members using a curve law in the parametric model. This process created the final determined curvature of the wooden slats.

Next Figure 2.9 shows screenshots from the dynamic model for Thaw woven wall at ROM gallery in Oslo, and the process of woven slats and the connection with joints.

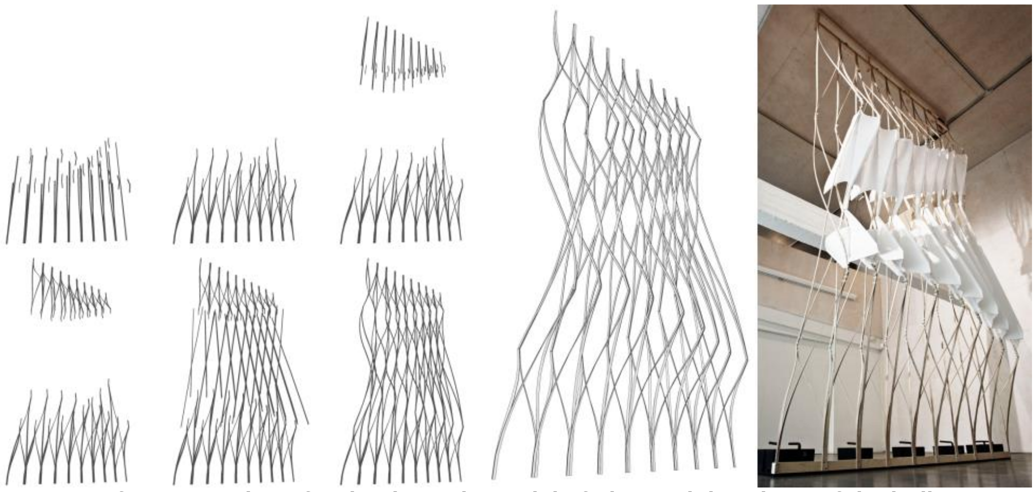

**Figure 2.9 Left, Screen shots for the dynamic model of Thaw. Right, Photo of the built structure with fabric skin.**

**Source; Anders Holden Deleuran, Martin Tamke and Mette Ramsgard Thomsen, 2011**

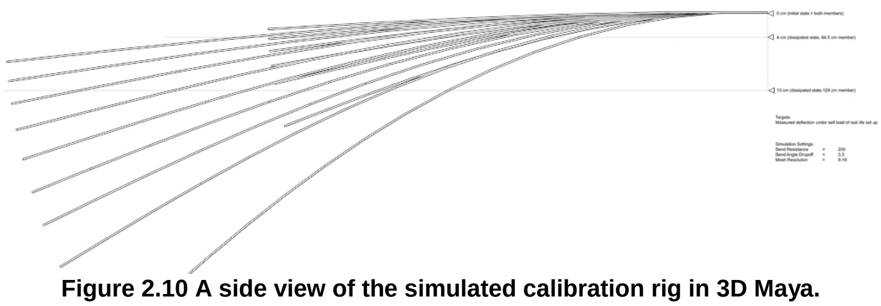

**Figure 2.10 A side view of the simulated calibration rig in 3D Maya.**

**Source; Anders Holden Deleuran, Martin Tamke and Mette Ramsgard Thomse, 2011**

[14] Deleuran, A., Tamke, M. and Ramsgard, M., **Designing with Deformation - Sketching material and aggregate behaviour of actively deforming structures**, paper, Symposium on Simulation for Architecture and Urban Design, 2011, P 7

B- Example 2 Daniel Coll Capdevila, Strip Morphologies, AA Diploma, London, 2004[15]

This project focuses on the development of a multi-performance material system, with the capability to provide for different spatial arrangements and to modulate the environment in order to gain ranges of privacy and exposure to light, sounds, temperature and airflow. By making a parametric model with digital element that integrates material characteristics, that was defined before (steel strips) and under a range of transformations. **Form-finding process** started through bending and twisting the model enabling a systematic study of geometric behaviour. Manufacturing constraints also have taken into account emphasising that any derived arrangement of strips can be directly fabricated and assembled (Figure 2.12).

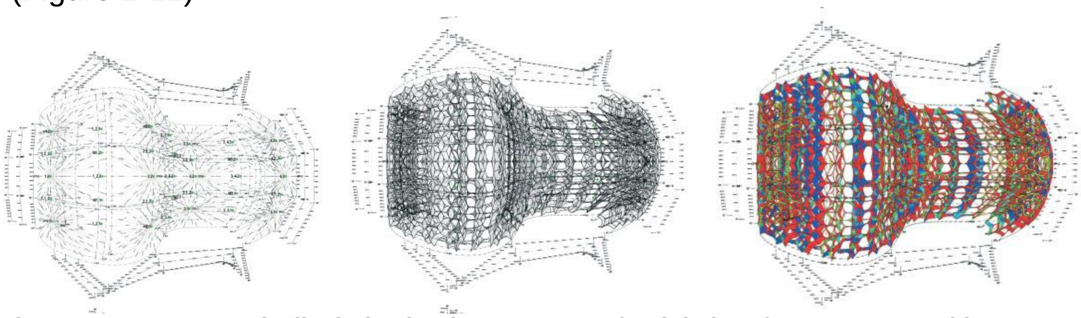

**Figure 2.11 A parametrically derived strips system. Left; global surface geometry with tangency control framework. Middle; corresponding population of digital strip components. Right; Curvature analysis of resultant strip morphology.**

**Source; Helen Castle, 2006**

**Figure 2.12 Left; and middle view of prototype model. Right; the fabricated prototype.**

**Source; Helen Castle, 2006**

## 2.1.5 **Summary**

Material as a variable factor in building systems that influences the design process are offering more participation through involving its characteristics into architectural physics, when material outlines how the form will be generated. Engaging with new design methodologies and generation tools which are very oriented on material behaviour, that changed the direct traditional design operation from (architect –product) to be (architect- generative tools and systems – product), or it can be expressed as form finding operation. This emphasis the role material plays in the

[15] Castle, H., **Techniques and Technologies in Morphogenetic Design**, Wiley, 2006, P60

design process in order not to be a follower but a primary giver in this operation.

From this perspective, data and material, programming and execution are interwoven. This synthesis is enabled by the techniques of digital fabrication, which allows the architect to control the manufacturing process through design data, affording a hypothetically seamless connection between the designed models and making.

Therefore, material doesn't appear primarily as a texture or surface, but is exposed and experienced in the whole depth of architecture. As a result, architects should consider material as a functional element that has behaviour which could be morphic, adaptive and affective in each stage of design operation.

Exploring the relationship between digital materiality as a design approach and natural laws could lead for more integration due to the capability of transferring principles of nature into material functions and behaviour; this will lead to get a wide matrix of materials that could be more involved in early architectural design stages, as it will be explored in next part.

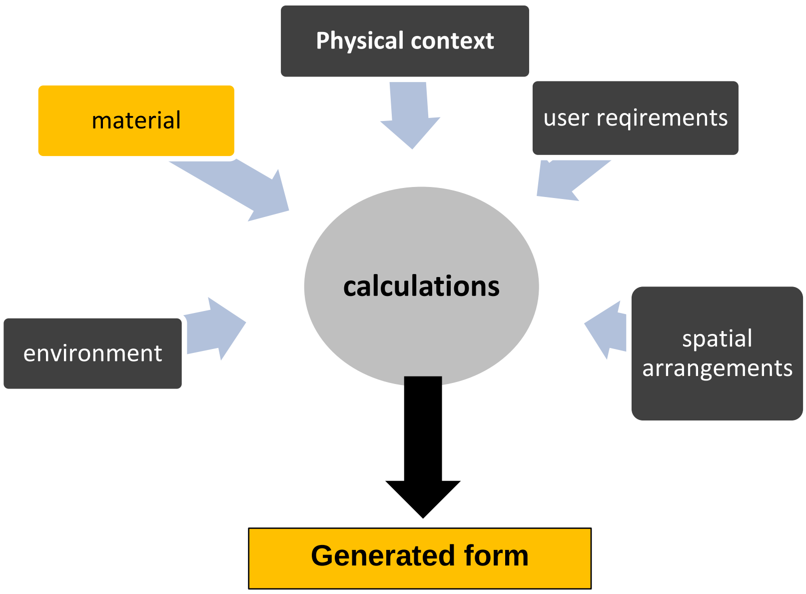


**Figure 2.13 Material role in design operation.**

**Source; by the researcher**

# Chapter 2

- Form, material and structural system impact on the design process
- **Biological Architecture (material approach)**
- Material classification systems
- Dialectic of materials and its impact on the evolution of the architectural form

# 2.2 Integrating digital materiality (as an approach to architectural design) with Biological Architecture

## 2.2.1 Introduction

"*Architecture should strive to imitate the principles of nature without imitating its forms*." Frank Lloyd Wright.

The desire to respond to multiple states rather than being optimized for a single state has rendered (**Biological Architecture**).

Biological or Self-organizational architecture can be described as a dynamic and adaptive process through which systems achieve and maintain structure without external control. Michael Hensel [16] introduces the issue: it is integration between processes of self-organisation and emergence, and theoretical methodological of architecture. Indeed, it studies the natural principles of animal and human constructions from several different perspectives, and presents a great part of the knowledge that gives origin and shape to be transferred to architecture.[17]

New visions which are looking forward natural laws as an inspiration source for design methodologies, a theme of new design trends, methodologies and tools like **Kinetic, Automated systems, Smart materials, Responsive and Biomimetic Architecture** are all inspired by nature; learning from nature gives us potentials and new methodologies to be used. Therefore starting to create something which copes with nature environmentally and technically in behaviour is now the aim, environmental fitness is the idea.

**Figure 2.14 Environmentally sensitive growth can deliver a paradigm for architectural design.**

**Source; Helen Castle, 2006**

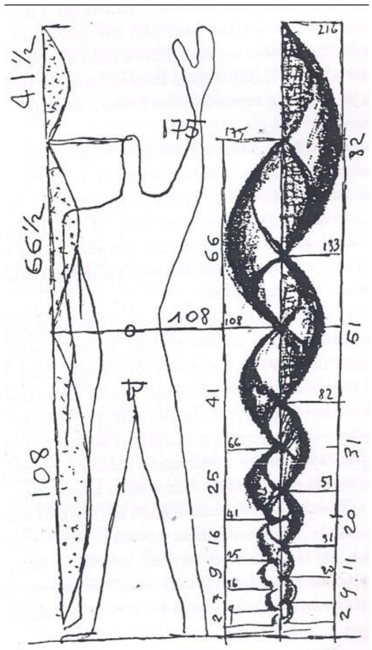

**Figure 2.15 The relation of the golden section and the proportions of the human body.**

**Source; Le corbusier, 1961, P 51**

[16] Michael Hensel is an innovative German architect, researcher, educator and writer. Concerned with "performance-oriented Design" and "Performance-oriented Architecture".

[17] Pourjafar, M., inejad, M. , Ahadian, O. , **Design with Nature in Bio-Architecture Whit emphasis on the Hidden Rules of Natural Organism**, paper, International Journal of Applied Science and Technology, USA, 2011, p 6

### 2.2.2 Using natural laws as a source of design methodology

In order to enhance digital materiality design approach to be adaptable with nature and its behaviour, it requires well knowledge of living systems, natural harmonics and fractal geometric relationships, expressing this as form, pattern, rhythm, ratio, proportion, structure, response, motion and behaviour.

There is a long tradition of using aspects from nature in architecture. This engaging started since the beginning of the early investigation of nature's geometry that has been the object of discovery, which satisfies the needs of safety and security like shell structures. Geometrical proportion and symmetry were also investigated and inspired also from nature.

It has been believed that it is possible to achieve particularly well-proportioned and aesthetic spaces and arrangements by taking the measurements of nature. The measurements used in traditional architecture were almost always derived from the human body. For aesthetic or practical reasons the use of fingers, hands and limbs as measurement units was common in all societies before developments in science that led to the introduction of a common metric system in the 19th century. In addition, Le Corbusier developed the so-called "Modular", it is a system of measurements based on the relation of the golden section and the proportions of the human body of the average size of 1.83m and 1.75m (Figure 2.15)[18] .He applied the system in his works.

Investigating the methodology of translating knowledge gained from nature into technical solutions in architecture is more important than superficially transition; it goes beyond that, and to involve living organisms system. The Arab institute in Paris which designed by Jean Nouvel was a trial to simulate the human lens motion and translate it into a kinetic building skin (Figure 2.16).

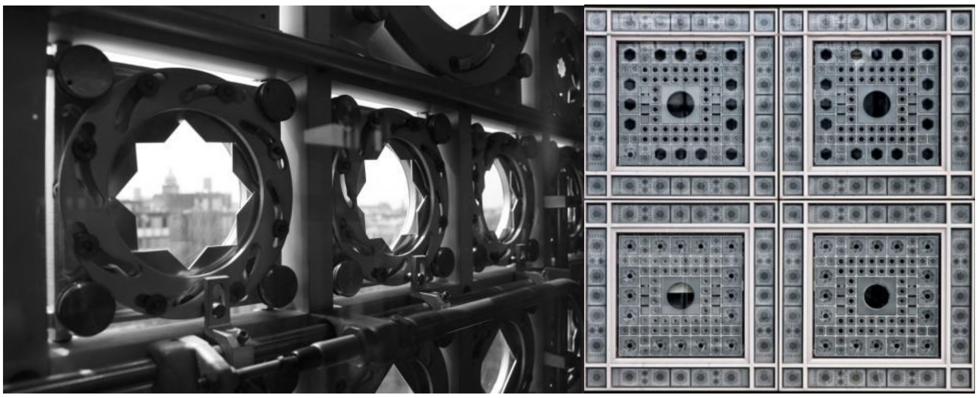

**Figure 2.16 Eye lens concept, Arab institute Kinetic facade, Paris.**

### 2.2.3 Material behaviour

Conditioning refers to a learning process in which an organism's behaviour becomes dependent on the occurrence of a stimulus in its environment. In return, this implies a careful calibration between behavioural and, by extension, **performative scope** in relation to specific ranges of external environmental conditions. The capacity for this can be embedded in

[18] Le corbusier, **The modulor**, Faber and faber, 1961 , P 51

the makeup of materials and in the logic of **material assemblies**. Self-organizational and behavioural capacity of the built environment can thus be facilitated by a related material, fabricating and assembly approach.[19]

Consequently, the deep study of living organism's behaviour and construction has transferred into material science in order to be mimicked, which strengthens material approach in architectural design. This approach must be based on a related understanding and utilizing of material characteristics, behaviours, capacities and ranges from using existing materials in different ways, to be used in computer-aided manufacturing (CAM) technologies strategies and finally to design materials with greater performance capacities.

Organisms often reach to the best structural form with the least amount of materials, for instance; human bones; a perfect example of a dynamic adaptable structure that has the capacity to modulate itself, re-modelling itself according to structure loads (Figure 2.17); it represents a natural lightweight construction which has some very dynamic characteristics helping to efficiently fulfil the task of the organism's primary construction. [20]

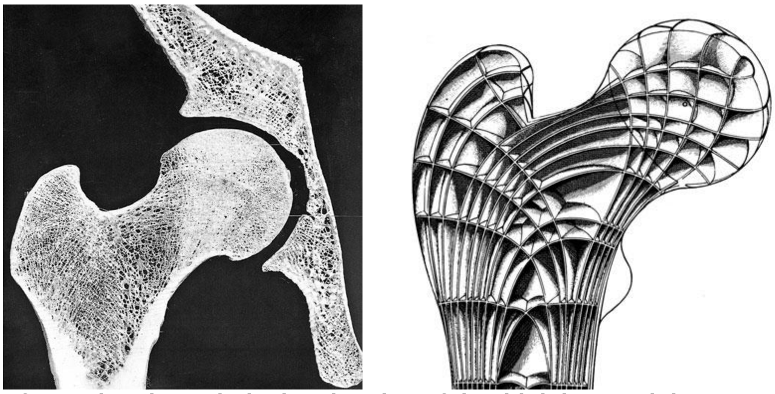

**Figure 2.17 Left; section through the head region of the thigh bone. Right; reconstruction model of the spatial trajectory surfaces, showing direction of pure tension and pressure.**

**Source; Petra Gruber 2011**

Recent advances in material science and related innovative methods of producing synthetic materials have had a radical impact on advanced industries. New cellular materials, such as foamed metals, polymers and glass, are indications of a significant change in the design of materials, where the **boundaries between the 'natural' and the 'manufactured' begin to be eradicated**. [21]

### 2.2.4 **Summary**

Getting inspired from nature and organism systems gives the designers renewable sources of innovation, not only in terms of simulating its appearance and form, but also beyond that regarding to its behaviour, motion and adaptation. Furthermore this promotes the digital materiality as a

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[19] Castle, H., **Techniques and Technologies in Morphogenetic Design** ,Wiley, 2006, P11
[20] Gruber, P., **Biomimetics in Architecture (Architecture of Life and Buildings)**, Springer-Verlag/Wien, 2011, P 34
[21] Castle, H., **Techniques and Technologies in Morphogenetic Design**, Wiley, 2006, P9

design methodology. As a result; material as an interesting area of investigation promote us to study material general background and its classifications in order to be employed in recent design methodologies.

# Chapter 2

Form, material and structural system impact on the design process

Biological Architecture (material approach)

**Material classification systems**

Dialectic of materials and its impact on the evolution of the architectural form

# 2.3 Material classification systems

## 2.3.1 Introduction

Studying and examining the structure of different material classification helping engineers to put materials in exact suitable order as well as understand their behaviour. As designers, we understand conceptual characteristics, while engineers understand physical characteristics as tools in implementation.

Material classification systems are useful, not only for simple categorization and description purposes, but also they can suggest more far-reaching fundamental constructs of a field.

## 2.3.2 Traditional material classification systems

Firstly there are a number of classifications for materials (Figure 2.18), each of these cover a specific category according to many variables; in general, sorting materials according to its physical and chemical properties is fundamental and can reflect most of aspects, however other classifications could be done for specific applications.

In the process of architectural design, a host of different loose categorizations are used, many of which are particular to individual fields. For instance, interior designers use classification types that are distinctly different from those used in landscape architecture.[22]

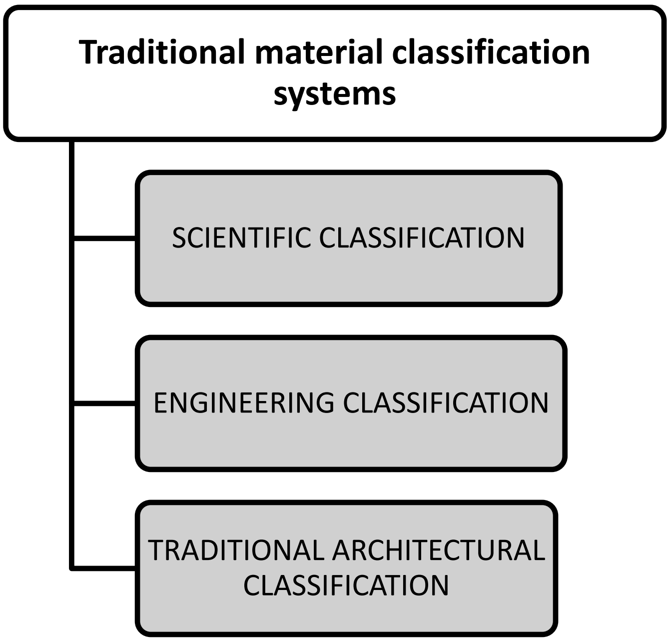


**Figure 2.18 Traditional material classification systems.**

**Source; Michelle Addington and Daniel Schodek, 2005**

[22] Addington, M. and Schodek, D., **Smart Materials and new technologies**, Architectural Press, 2005, P 22

#### 2.3.2.1 Scientific Classification[23]

The Scientific approach of classification goes directly to the core understanding of the basic internal structure of material. This way of classifying materials is extremely useful for many reasons. The understandings reflected in the classifications provide a way of describing the specific qualities or properties that characterize different materials; consequently, it provides a basis for developing a method for **designing materials** that possess different qualities or properties.

#### 2.3.2.2 Engineering Classification

This type is primarily used in the mechanical engineering profession to distinguish between the fundamental problem-solving characteristics of the nearly 300 000 materials readily available to the engineers.

The engineering classification is one of mapping that enables the engineer to mix and match properties and attributes to best solve the problem or need at hand.

**If the material science classification describes how a material is composed, then the engineering classification explains what it does.**

Other considerations may be contained in other engineering classifications include cost, availability, or recyclability, even though the final objective in all engineering applications is the optimization of a material property for a particular situation.

Many industries have developed their own classification systems to help narrow down the choice of materials to those that are appropriate for their own uses. The American Welding Association is even more specific, classifying electrode materials by tensile strength and welding technique. Regardless of the source of the classification system, each one clearly highlights properties that underpin the useful **behaviour** of the material.[24]

#### 2.3.2.3 Traditional Architectural Classification

Architectural classification tends to be more prescriptive, it is simply listing materials and uses in accordance with standard building requirements.

Within architectural practice, these various requirements are codified in different ways. The Construction Specifications Institute in the United States has maintained a standardized classification system for over 50 years. This system is known as the **CSI index**.

<u>CSI index</u>

CSI classifies materials in two ways. The first places the material typically used in a building into broad classes. In this section, generic material groupings will be found such as paint, laminate and concrete. The second is organized by components or systems. These categories are equally generic and are not even material-specific. For instance, windows

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[23] Addington, M. and Schodek, D., **Smart Materials and new technologies**, Architectural Press, 2005, P 22
[24] op. cit., P 25

fall into this category, even though they may be manufactured using wood, vinyl, aluminium or steel. [25]

| | |
|---|---|
| DIVISION 01 00 00 | GENERAL REQUIREMENTS |
| DIVISION 03 00 00 | CONCRETE |
| DIVISION 04 00 00 | MASONRY |
| DIVISION 05 00 00 | METALS |
| DIVISION 06 00 00 | WOOD, PLASTICS AND COMPOSITES |
| DIVISION 07 00 00 | THERMAL AND MOISTURE PROTECTION |
| DIVISION 08 00 00 | OPENINGS |
| DIVISION 09 00 00 | FINISHES |
| DIVISION 10 00 00 | SPECIALTIES |
| DIVISION 11 00 00 | EQUIPMENT |
| DIVISION 13 00 00 | SPECIAL CONSTRUCTION |
| DIVISION 14 00 00 | CONVEYING EQUIPMENT |
| DIVISION 21 00 00 | FIRE SUPPRESSION |
| DIVISION 22 00 00 | PLUMBING |
| DIVISION 23 00 00 | HEATING, VENTILATING, AND AIR-CONDITIONING (HVAC) |
| DIVISION 26 00 00 | ELECTRICAL |
| DIVISION 31 00 00 | EARTHWORK |
| DIVISION 32 00 00 | EXTERIOR IMPROVEMENTS |
| DIVISION 33 00 00 | UTILITIES |
| DIVISION 40 00 00 | PROCESS INTEGRATION |

**Figure 2.19 CSI Classification system.**

**Source; CIS list http://www.icc-es.org/reports/index.cfm Retrieved December, 2013**

Essentially, if the **materials science classification** explains 'why one material is differentiated from another', and the **engineering classification** determines 'how a material performs', then the **architectural classifications** operates at the other end of the sequence by listing 'what a material is and where it is used'.

[25] **CIS list** http://www.icc-es.org/reports/index.cfm Retrieved December, 2013

**DIVISION 09 00 00 FINISHES**

09 00 00 - Finishes
09 21 16 - Gypsum Board Assemblies
09 21 16.23 - Gypsum Board Shaft Wall Assemblies
09 21 16.33 - Gypsum Board Area Separation Wall Assemblies
09 22 16.13 - Non-Structural Metal Stud Framing
09 22 16.23 - Fasteners
09 22 26 - Suspension Systems
09 22 36 - Lath
09 24 00 - Portland Cement Plastering
09 28 13 - Cementitious Backing Boards
09 29 00 - Gypsum Board
09 29 10 - Gypsum Board Accessories
09 30 00 - Tiling
09 51 13 - Acoustical Panel Ceilings
09 51 23 - Acoustical Tile Ceilings
09 53 00 - Acoustical Ceiling Suspension Assemblies
09 54 00 - Specialty Ceilings
09 69 00 - Access Flooring
09 77 00 - Special Wall Surfacing
09 80 00 - Acoustic Treatment
09 84 00 - Acoustic Room Components
09 96 43 - Fire-Retardant Coatings

**Figure 2.20 Subdivision of CIS index.**

**Source; CIS list http://www.icc-es.org/reports/index.cfm Retrieved December, 2013**

## 2.3.3 Construction material classification

Lorraine Farrelly [26] puts in her book "construction materials" a global layout, to explain the way materials have been used historically in architecture, and also give an awareness regarding innovations in material applications.

| Construction Materials | | | |
|---|---|---|---|
| **Traditional materials** (Brick, Stone, concrete ,Timber, Glass and Steel) | **Composite materials (plastic,Carbon Fibers)** | **Sustainable materials** | **Future materials** (Smart materials,Light-emitting materials, Shape-memory materials, **Nano materials**) |

**Table 3 Construction materials layout.**

**Source; the researcher according to Lorraine Farrelly, construction+ materiality, AVA Publishing,2009**

[26] Lorraine Farrelly, **Professor of architecture and design at University of Portsmouth and the author of** "construction materials"**, "**Architectural representation techniques" and "Fundamentals in Architecture"

### 2.3.4 **Summary**

Materials can be classified in different ways such as, science classification that is concerned with the basic internal structure of materials and its properties at the atomic and molecular level. The engineering classification that is based on what the material can do, how they behave and what they can withstand, this kind of classification is not fixed; it might include cost, availability, recyclability or other variations. Finally; the Architectural classification that is simply oriented to list materials and its utilization in accordance with standard building requirements.

# Chapter 2

Form, material and structural system impact on the design process

Biological Architecture (material approach)

Material classification systems

**Dialectic of materials and its impact on the evolution of the architectural form**

## 2.4 Dialectic of material and its impact on the evolution of the architectural form

### 2.4.1 Introduction

The role of materials changed dramatically with the advent of the industrial revolution. Rather than depending on an intuitive and empirical understanding of material properties and performance, architects started to be confronted with engineered materials. The history of modern architecture can almost be viewed through the lens of the history of construction materials. This emphasizes the role of material in the architectural product form, starting from prehistoric architectural age till now. Following architectural history shows how materials always have an impact on the architectural form.

There are many factors that contributed to the formation of architectural character, whether they are related to human or environment, however the study here will be limited to material -as one of building systems- and its impact on form evolution to be followed. In the next study the research will address four different architectural periods of time to be analysed, the aim of this study is to track and monitor the differentiation between the effect of materials on the architectural form among those 4 architectural ages, this study is considered as an indicator of balance and imbalance between construction materials and the evolution of the architectural form.

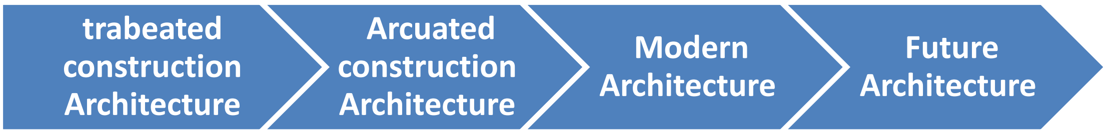


**Figure 2.21 An induction of architecture history through four periods of time.**

**Source; the researcher**

### 2.4.2 Trabeated architecture (Ancient Egyptian and Greek architecture)

The main features of a building were determined by the shape of walls or the mode of arrangement of the pillars that take the place of walls, the way roof is constructed, and how the openings (doors and windows) are spanned. The earliest roof construction were in flat form, and the most ancient mode of linking together the supports of doors and windows was to place a plank of wood or slab of stone known as a lintel across them at the top. This style of roofing and spanning, were reached its most perfect development in the temples of Greece. Therefore the name of the **trabeated** was given, derived in the first instance from the so-called (trabea), which is a toga adorned with horizontal stripes.[27]

[27] Bell, A., **Architecture**, The Original Classic Edition, DODGE publishing co, 1914, P 8

### 2.4.2.1 Ancient Egyptian Architecture

The Egyptian architecture represents a synthesis of four fundamentals intentions: the enclosed oasis, the durable megalithic mass, the orthogonal order and the path or axis.

One of indications of the existential meaning implicit in Egyptian architecture is how the geography of the country favoured the conceptualization of basic natural elements. The character of Egyptian architecture stemmed directly from the geological and climatic circumstances of the Nile valley, materials were chosen either pragmatically for their appearance and availability. The available materials were sandstone, limestone and granite, which were found in the South valley, and they used limestone extensively.

Material choice was important in determining the style and the scale of buildings. Stone shows high performance against pressure loads in contrast with tensile loads. The effect of this material was recognized clearly in architectural form of temples and internal spaces, these spaces were bounded with huge structural elements and also spaces that are full occupied with columns. A textural effect also is obtained by using stone which enhances the comprehensive orthogonal structure. It leads up to a play of light and shadow, the effect was strengthened by the use of colours. [28]

The Egyptian used stone in two different ways:

1- Post and lintel construction.
2- External walls and pylons details to describe single homogeneous surfaces upon which were inscribed figures and symbols.

Stone columns played a role as structural members and were primarily emblems symbols of the land and of sacred plants which rose out of the fertilized soil to bring protection, permanence and sustenance to the land and its people. This symbolic meaning was combined with the conception of stone masses, solidity and size as an expression of durability. The details of the column reaching upwards to make a comfortable connection between the column and undecorated lintel were inspired by the louts. Columns were relatively squat in proportion.[29]

### 2.4.2.2 Greek Architecture

The architecture of ancient Greek was generally associated with temples which in many places still impress with the power of their articulation. Greek society was inclusive; as a result many types of buildings have appeared like stadiums and theatres. Besides abstraction and organization characters of Greek architecture which were also founded in Egyptian architecture, they also wanted to symbolize these individual characters. Greek temples may look alike to a superficial eye, but actually they have differences in form and expression.[30]

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[28] Norberg-schulz,C., **Meaning in Western Architecture**, Studio Vista, 1974, P9
[29] Foster,M., **The principles of architecture, style, structure and design**, Phaidon, 1983, P 30
[30] Norberg-schulz,C., **Meaning in Western Architecture**, Studio Vista, 1974, P24, 25

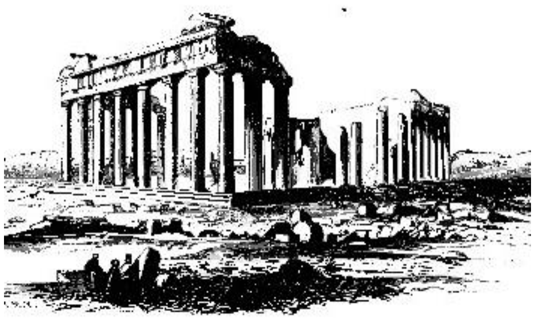

**Figure 2.22 The Parthenon.**

**Source; the international magazine of Literature, Art and Science. http://www.gutenberg.org/files/20955/20955-h/20955-h.htm, Retrieved February, 2014**

Greek architecture had different spatial orders; symmetry of geometry and general orthogonal orders, which was generally used in connection with the planning of Greek cities; The symmetry was one of their most distinctive characteristics; they achieved their highest results by means of correctness of proportion and dignity of outline, they gave more attention to the exterior than to the interior of their buildings, in this respect, differing greatly from the Egyptians.[31]

The general organization is orthogonal and axial organization, but it wasn't emphasised as in Egyptian architecture, there is another change in spatial configuration of temples; Egyptian temples had internal stone columns and exterior walls, while Greek temples had internal walls surrounded by stone columns. See the Parthenon (Figure 2.22).

The grand temples of Greek were built either of stone, the **Greeks developed a greater understanding of stone as a construction material**, confidence grew, and the proportion of both column and beam became slimmer and finer, the distance between columns became greater and the arcade more generous. The ability of mason's skills appeared in stone structural masses which were articulated. Variations in dimensions, organisation and detailing are interpreted in terms of stylistic development. Human body proportions were employed in columns, such as Doric column. The majority of early Greek great temples were constructed from marble; this had smooth, hard and creamy consistency. Later the pieces of stone were mechanically coupled one to another by a metal tie of bronze or more usually iron. [32]

**To sum up this;** The next figure is an attempt to monitor the relevance between construction materials and the evolution of the formation in trabeated architecture; we can recognize that architectural form was very advanced comparing with available materials. Thinking of proportions and shapes within the limits of possibilities was impressive. Even vaults which are considered to be related to the Arcuated Architecture era were found in fact in Ancient Egyptian architecture especially in service buildings and stores such as Ramsum storage in Teba 1300 BC.[33]

[31] Bell,B., **Architecture**, The Original Classic Edition, DODGE publishing co, 1914,P 15
[32] Foster, M., **The principles of architecture, style, structure and design**, Phaidon, 1983, P 34
[33] Raffat, A., **Traid of Architecture creativity**, Inter consult research center, 1997, P 9

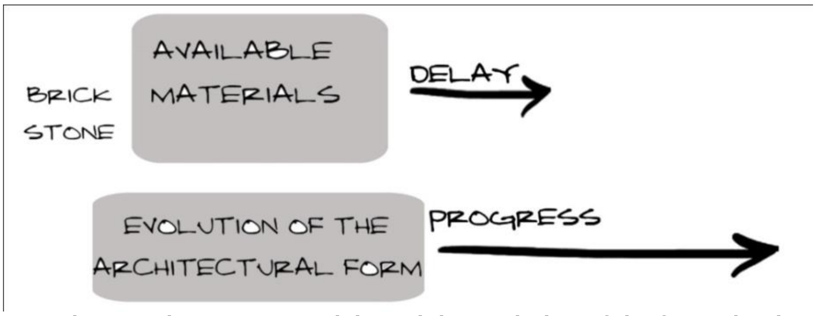


**Figure 2.23 Relevance between materials and the evolution of the formation in trabeated architecture.**

**Source; by the researcher**

The Figure 2.23 shows that there is a delay in construction materials (Brick and stone) however, there is a great progress in the architectural form, shapes and masses which were established with more advance, comparing with available materials as well as techniques.

## 2.4.3 Arcuated Architecture

Arcuated is a description of a building incorporating arches, the inventor of which is unknown, gradually revolutionised the science of architecture. Traditionally an arch was used as a self-supporting method of framing an opening, support elements under compression.

Among West Asiatic, Roman, Byzantine, Romanesque, Gothic and Islamic architectural ages this kind of construction and techniques were used widely in a sophisticated way especially in Romanesque and Gothic architecture when the ability of forming buildings, details illustration and implementing complicated shapes were different than any other architectural age.

### 2.4.3.1 Roman Architecture

Roman architecture can't be associated with one particular leading building type such as temples; instead there are multitudes of building types. For example the grandiose structures of the basilicas, amphitheatres, and circuses. This represents more complex social functions and structures, and existential meanings. In early Roman temples and palaces of the Greek style were long carefully copied, the classical orders of Greek had been transferred, but in utilitarian works such as bridges.

Roman architecture has orthogonal spaces orders combined with form complex, and axially organised orders. Thing that distinguishes the roman architecture is the grand interior spaces and complex group spaces, which shows a large variety of forms.

Roman Architecture shows great constructive and engineering ability combined **with a power to use the materials at hand with the best possible results**. The Romans adopted the columnar and trabeated style of the Greeks, and added to it the arch, the vault and the dome; this union of beam and arch is the keynote of the style in its earliest developments.

They used brick and stone. later, and to be more economically in using materials and instead of composing the walls of their monuments of squared-blocks of stone, they inaugurated the use of concrete, using concrete cause continuous system of vaults, arches, walls and pillars which incorporate hardly any horizontal elements. This represents an important step towards employing the real technical structure as a means of spatial organisation. They made it simple and practical by the employment of concrete, by which they covered the largest areas even now in existence. The effect was far reaching and gave freedom in the planning of complex structures, which were easily roofed (Figure 2.24).

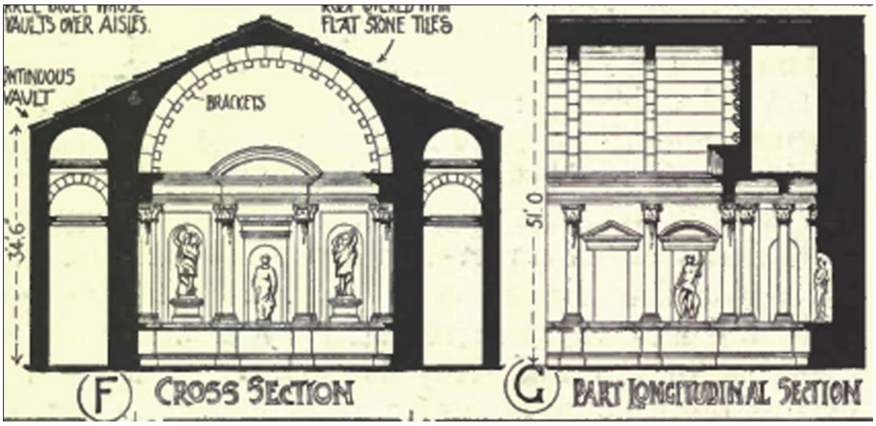


**Figure 2.24 Vaulting system, temple of Diana At Nimes.**

**Source; B. Fletcher, 1905**

Thus it will be understood that **vaults of concrete** had a very important effect on the forms of Roman buildings, and they were employed universally, so much so, that every Roman ruin is filled with their remains.

### 2.4.3.2 Gothic Architecture

Gothic construction had forms of great complexity and variety compared with the whole like forms of the any arcuated buildings. Auguste Choisy, the author of (histoire de l'architecture) spoke of gothic architecture as a triumph of logic in art, whose form was governed not by traditional models but by its function and by its function alone, this view was reinforced by stunningly simple drawings in which buildings portrayed as structural diagrams, as if structure and only structure had been the architects concern.[34] See Figure 2.25.

The character of Gothic architecture is fundamentally new, it based on the fundamental themes of longitudinally and centralization. Buildings were formed with skeleton whose mass is ideally reduced to a network of abstracted lines, a network of vaults, with diagonal ribs. Pointed vaulting was the key discovery of gothic architecture; ribs also were the essential component of the gothic arcade. As a result; any feeling of mass has disappeared, the patterns of rips and panels became finer and more intense.

Stone, brick and glass were used, stone with not simply used on a grander scale to its fullest capacity to create space, it was shaped, formed and profiled to produce a fabric enclosure, which has the ability to transfer light into inner spaces. The understanding of stone ability reached great

[34] Curtis, W. J. , **Modern Architecture Since 1900**, Phaidon Press, 3rd edition, 1996

apogee in Gothic buildings. This were resulting a form of complex, three-dimensional geometries**. It is possible to trace an increasing sophistication and awareness of stone** which was lightened in a conscious attempt to dematerialize stone work.

Coloured glass was used to transfer natural light into internal spaces. The meaning of the Gothic buildings was no longer enclosed but had become part of the daily environment. Walls were designed as a thin shell of stone and glass, the large windows fitted with stained glass produced a heavenly light. Walls seem to be a composite of several overlaying layers of sophisticated stone works and glass.[35][36]

**Figure 2.25 Vitus Cathedral, Prague Castle, Prague, Czech.**

**Source; http://www.richard-seaman.com/Travel/CzechRepublic/Highlights/, Retrieved December, 2013**

What distinguishes the Gothic style in architecture is the deep understanding of used materials, and how far can they do, resulting the big leap in spatial configurations, converting vertical structural solid elements to multi-layer fabric composition of finer structural elements (ribs), plates and glass, letting light flow in the internal spaces, which gave primary importance for spiritually experience.

#### 2.4.3.3 **Renaissance Architecture**[37]

The Renaissance architecture was characterized by artists, town planer and musicians, all involved in a quest for the ideal. Symmetrical orders and the study of the relationships between light and dark, solid and void, and the general belief in the visual and spiritual advantage of harmony, became the bases of Renaissance architecture.

Mathematical systems employed for studies in the proportions of objects; this led to a greater comprehensive of the phenomenon of perspective and techniques for portraying it. Also the proportion of the human body took on a renewed. Renaissance articulation has a basic of geometrization, it satisfied by an exclusive use of elementary geometrical form and simple mathematical ratios.

Although stone played a part in furnishing the architecture of the Renaissance, it was habitually used as dressing material and not for a functional sense.

[35] Foster, M., **The principles of architecture, style, structure and design**, Phaidon, 1983, P 40
[36] Norberg-schulz,C., **Meaning in Western Architecture**, Studio Vista, 1974, P92
[37] Foster, M., **The principles of architecture, style, structure and design**, Phaidon, 1983, P 44

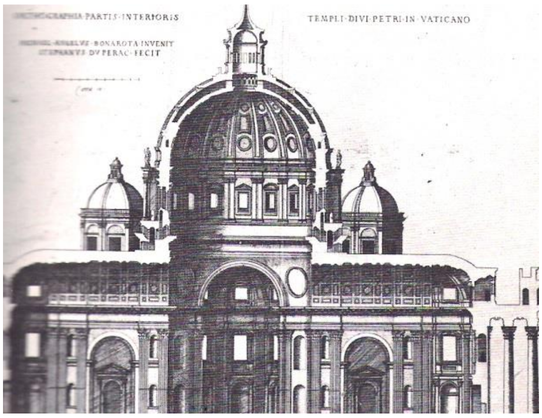


**Figure 2.26 St Peter church, Rome.**

**Source; Christian Norberg-schulz, 1974**

Glass windows were elements of surface modelling; its form was more determined by aesthetic rules of proportion and masses, than by functional necessities. Clearer types of glass became available for general use, and it was just possible to see through it. The pointed arches windows of gothic architecture were gradually replaces by the more practical flat arched. The height of domestic buildings was restricted and the greater glazed area at the top of a squared window gave variable additional light to the interior.

#### 2.4.3.4 **Islamic architecture**

Islamic architecture has its own special vocabularies. The range of scale of architectural form, and the style are resulting out of these vocabularies, puts this architecture in a category by itself. The orders of centrality, axially, and quadrature were determining the spaces. Moreover, sensibility and modes of spatial ordering were rooted in a complex web of scientific and mathematical thinking. [38]

Islamic architecture took function and privacy in consideration. The used materials reflect the availability of natural resources and the diversity of cultural influences. Brick, wood and stone were the used materials. Climate factor has a large impact on the form evolution in Islamic architecture, thus there have been some architectural elements that help to reduce the temperature. Interior courtyards, wooden mashrabiya, Minaret and other elements are characteristic of this era (Figure 2.27).[39]

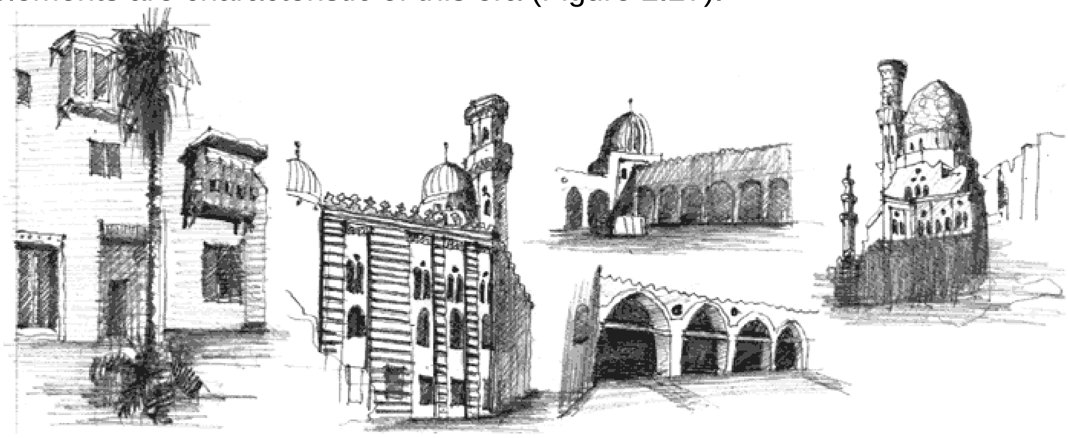

**Figure 2.27 Islamic architectural elements.**

**Source; Aesthetics of Architecture and Urban Form in Islamic Cairo, Gamal Taha, http://www.egyptarch.net/gamalweb/main.htm , Retrieved January, 2014**

[38] Akkach, S., **Cosmology and architecture in pre-modern Islam**, State University of New York Press, 2005

[39] Hillenbrand, R., **Islamic architecture, Form, Function and meaning**, Edinburgh University, 1994, P22

**To sum up this**; prosperity of all arts fields enhance architects to create such shapes with same raw materials, when stone was used in construction in its raw state, but as stonemasonry skills developed with a deep awareness of material character; the surface became an opportunity for architectural expression. In trabeated architecture the used materials were almost the same however there is a leap in the architectural form in arcuated architecture, using vaults and domes with its different shapes and proportions adds more value to the form. The deep understanding and awareness of material properties grew, which cause designing buildings with different styles, expressing their own individuality.

The (Figure 2.28) shows that there is high progress in the architectural form comparing with used materials; the ability to generate magnificent forms rises strongly at this time; however the raw materials are still bounded. This may illustrate that the innovation and creation ability were not parallel to the available possibilities at this period of time and stonemasonry skills and art were impacted strongly on building's form.

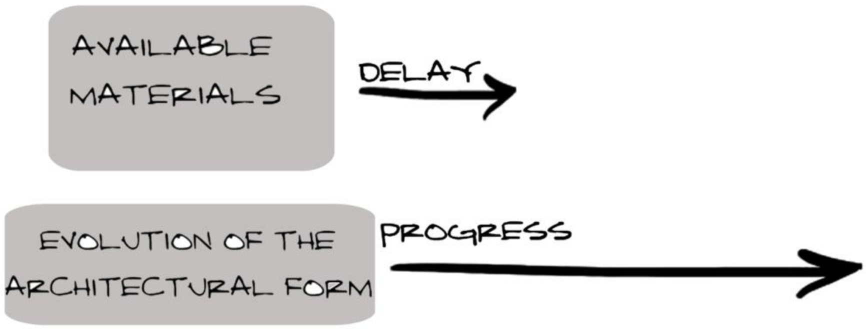


**Figure 2.28 Relevance between materials and the evolution of the formation in arcuated architecture.**

**Source; by the researcher**

### Theory of limits in Architecture:

The theory of limits came with a belief that all things work between limits, geometrical structures has its limits in growth as the reliance is on form only. Embedding materials and its performance bring new structural forms. For instance; Soufflot church in France, which took the typical classical orders and architectural elements of Greek Panthéon (Figure 2.22) with arches and domes of gothic and renaissance style, its structure was extensively relied on iron reinforcement, which had taken masonry construction beyond its natural limits. Nothing comparable would be built with the used conventional materials before using iron in construction. On the other hand, the Panthéon currently exhibits some problematic deformations. The most significant of these are in the four great stone arches, each about 100 feet in span, that carry the drum from which the columns of the peristyle rise, which Indicates the limitation of material performance (stone) regarding to the form.[40]

[40] Alexan J. Hahn, **Mathematical Excursions to the World's Great Buildings**, Princeton University Press, 2012, P 213

## 2.4.4 Modern Architecture

### Early modern architecture

Early modern architecture occupies **the transitional phase between traditional and modern architecture (**Figure 2.29). Iron-frame buildings were erected. Joseph Paxton's Crystal palace was a bold building of this time, embodying the technological spirit of the industrial age and heralding a future of steel and glass buildings. Also, Gustave Eiffel's Tower in Paris manifested the soaring heights that new buildings could reach. The two examples present **the shift** happened in iron-frame buildings and as a result; **paradigm shift of industrial age** occurred in architecture.[41]

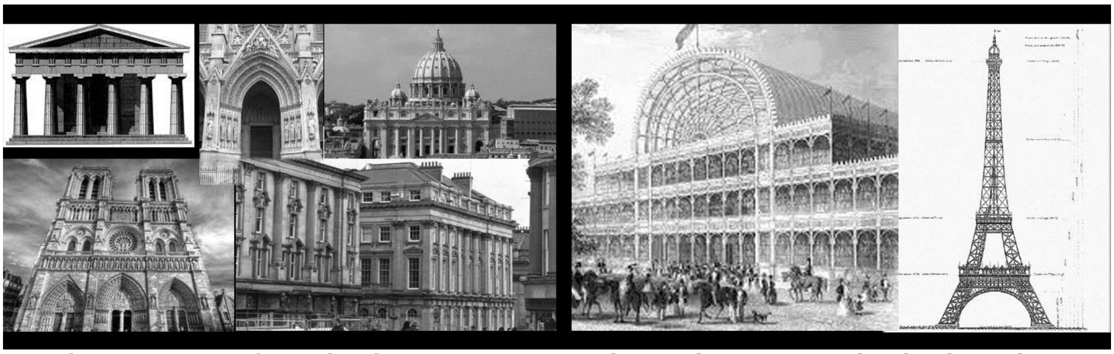

**Figure 2.29 Transformation from stone constructions to iron construction (Early modern architecture)**

Modern architecture came with new language of forms which originated from: functional concerns and construction materials**. A faith in materials and new technologies** was a cornerstone of a new modern movement. Modernism suggested that only available materials and building techniques should be only factors which determined the character of architecture, besides the need for new forms that would reflect the spirit of the time. Composition of delicate screens and large plates of glass provided a forward looking image to a relatively new building style.

Walter Gropius said *(the role of the walls becomes restricted to that of mere screens stretched between the upright columns of the frame to keep out rain, cold and noise).* Therefore, perhaps the strongest and certainly the commanding criterion of modernism was the notion of honesty of expression, which makes modern movement dedicated to truth to materials.

There was a return to the elementary shapes and geometric relationships introduced by the revolutionary architects of the late eighteenth century, the modern buildings are distinguished by a few characteristic properties, they are usually derived from simple shapes, and they appear as unity volumes wrapped up in a thin weightless skin of glass and plaster.42 See Villa Savoye Figure 2.30.

[41] Kolarevic, B., **Architecture in the digital age, design and manufacturing**, Taylor & Francis, 2005, P3

[42] Norberg-schulz, C., **Meaning in Western Architecture**, Studio Vista, 1974, P191

Figure 2.30 Villa Savoye.

Source; Christian Norberg-schulz, 1974

Modern architecture used construction materials with lack of texture and articulation details. Concrete, steel, glass, brick and stone were used in a wide range. Concrete had been employed by Roman and early Christian architects but then had been dropped out of use through most of the Middle Ages and Renaissance. It was not until the second half of the nineteenth century that the material was fully explored again, but usually for mundane purposes, where its cheapness, its wide spans and its fire proof characters recommended it. The invention of reinforcing, whereby steel rods where inserted to increase its strength. [43] When steel was employed it was used as a linear members, first as a tie bars, then as columns and finally as a complete frames. Large areas of glass were used also for a play of reflection more than the effect of light and shadow as in ordinary buildings. Later, polymers and composite materials (Composite materials are a high performance materials that are made by combining two or more primary materials they comprise a huge class of materials, there are literally thousands of them.[44]) appeared and used as a result of the desire to design by using a high performance materials that bring more possibilities to architectural design.

**To sum up this;** for many centuries architects had to accept and work with the properties of standard material such as wood or stone, designing to accommodate the material's limitation, whereas in the last few decades of the nineteenth century the relationship between architecture and materials had been fairly straight-forward. The role of materials changed dramatically, rather than depending on an empirical understanding of material proprieties; architects began to deal with engineered materials. This means that the delay in material varieties wasn't existed, and the gap between form evolution and available materials was declined. It became obvious that architects in the last few years of the nineteenth century attempted to discover a **style based on the materials.**

[43] Curtis, W. J. , **Modern Architecture Since 1900**, Phaidon Press, 3rd edition, 1996
[44] Addington, m., Schodek ,**Smart materials and new technologies for the architecture and design professions,** Architectural press, Oxford, 2005, P 43

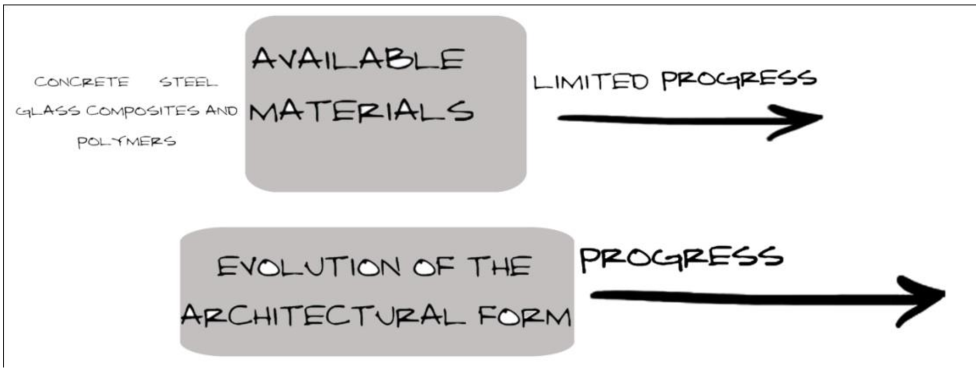


**Figure 2.31 Relevance between materials and the revolution of the formation in modern architecture.**

**Source; the researcher**

### 2.4.5 **Future Architecture**

Creating architecture means shaping the future; when architects make a proposition they always assume that it take place in some imagined future. Since the early 20th century, architects and designers have been smitten by the novel and the new.

Regarding future architecture; it seems that design methods and tools changed dramatically in terms of design methodology and formalist agendas facilitated by the 'shape making' and 'form finding' operations. Potential of new computer based design tools, including the usage of software programs, visual perception methods and analysis tools, which are considered as one of the most important transformations that have occurred in architecture over the last 30 years.

**The old order of standardized design and its established processes no longer hold sway; contemporary architectural design can now be characterized by irregularity, and the desire for producing customized non-standard, complex, curvilinear forms.** [45]

As a result, new design trends and methodologies are originated like parametric design, smart architecture, green architecture, bio architecture, digital architecture, kinetic architecture, sustainable architecture, responsive architecture and **nanoarchitecture**. **Nanoarchitecture** is a new design trend that integrates **nanotechnology** with architecture in order to take advantage of its extraordinary advancements.

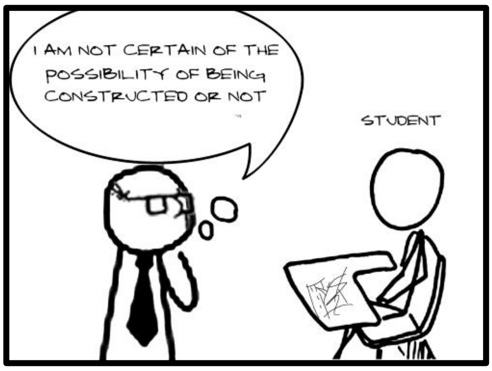


**Figure 2.32 Architecture student's aspirations are outweighing the available possibilities.**

**Source; by the researcher**

We; as designers often let ourselves dream into the future, forgetting the work toward implementation which true creativity entails, and this impact even our architectural students in the academic design studios; with the famous question they should have asked about their designs and the possibility of being constructed or not (Figure 2.32). Another

[45] Castle, H., **The new structuralism**, Wiley, 2010, P 5

example; EVolo skyscrapers- the famous annual magazine- which records the most avant-garde ideas generated in schools and professional studios around the world.[46] It is an attempt to explore and visualize the reality and future of design, it organizes an annual competition shows clearly every year the great aspirations concerning of building technologies and new materials in order to produce a high tech building (Figure 2.33).

**As a result**; this shows a paradigm shift occurred in the design process and, consequently, the architectural product, especially regarding to form wise. On the other hand there is also a wide array of novel materials. However; architects aspirations regarding to new materials which enable them to reach the novelty in their designs are outweighing the available one. This motivates us to investigate new technologies such as **nanotechnology** which brings new possibilities to architecture with a new whole pallet of materials (whether new or modified materials). A new transformation movement in architecture is expected as a result of combining this technology to architecture.

[46] **EVolo Magazine**, http://www.evolo.us/, Retrieved September, 2013


**Figure 2.33 Samples of Evolo competition ideas.**

**Source; http://www.evolo.us/, Retrieved September, 2013**

## 2.4.6 **Summary**

This part is a trial to evaluate architectural form evolution coincidence with used materials through an induction of different selected architectural ages.

Trabeated architecture shows that comparing with available materials, there was advancement in buildings form, while in arcuated architecture material sources were almost the same, however this architectural age shows magnificent ability in forming architecture, in parallel with the advent of new structural systems (vaults, domes), combining with an understanding of material characteristics.

Early modern architecture shows a **revolution** in the architectural form, iron-buildings started to be established (Evil tower, crystal palace), the contribution of iron as a construction material leads to a transform in the formation of architecture which **based on material performance**. Therefore, new materials and technologies create completely novel architectural forms.[47]

In modern architecture and as a result of the emergence of new materials in construction field (concrete, steel); architectural vocabularies were changed dramatically, and buildings form was affected. The gap between available materials and form revolution was eradicated.

General assessment of the architectural attempts now with respect to the future architecture makes us notice that there is a gap between available materials and implementation techniques compared with the big leap occurred in the form generation in recent architectural methodologies. Incorporating new technologies like **nanotechnology** in architecture contributes to fill this gap.

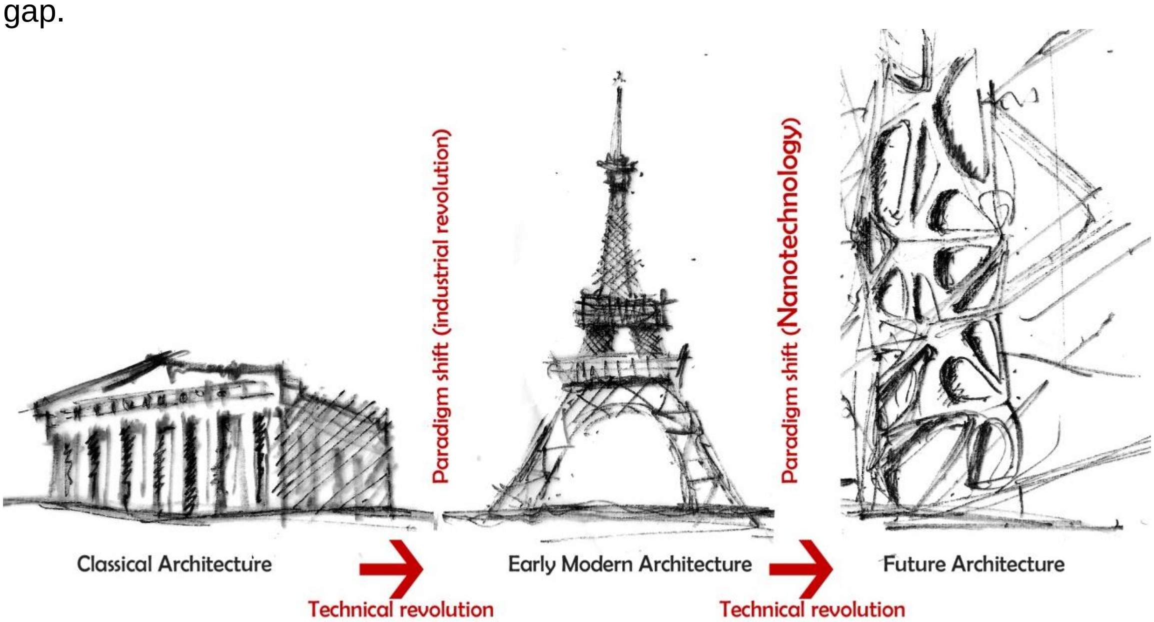


**Figure 2.34 The paradigm shift happened between the classical model of architecture and modern model, and between the modern model and the futuristic model.**

**Source; by the researcher**

[47] Alexan J. Hahn, **Mathematical Excursions to the World's Great Buildings**, Princeton University Press, 2012, P 206

Figure 2.34 shows the shift that happened after the industrial revolution which transformed the classical architectural image to a high-tech architectural image. And the predicted shift that will happen with the participation of new technology (**nanotechnology**). Methods of integrating nanotechnology to architecture are through:

1. nanomaterials
2. nano systems and devices

## 2.5 Conclusion

By taking into consideration the variations of building systems, this shows that form, structure and material, as sub-systems, have different orders during the design process. To begin with a steady form to be the starter of this process whilst the structure and materials are recruitment to achieve this image; this brings form to be the starter among those elements. In many cases, building types depend on structural idea such as skyscrapers and bridges, in such cases, structure could be the starting point in the design process. Finally to make material the main engine in this process that impacting both structure and form, this is called Materialization or Digital materiality. Digital materiality is a new promising method in architectural design that engages with the new computational design methods and tools (software programmes) which are employed to run the form finding operation using a 3D model that applied the construction materials. This new method brings material to be an effective and initiative step instead of being a follower to the other elements. Thus material properties and behaviour became considered.

Natural laws are considered as a source of design methodologies among architectural history. In order to transfer performative behaviour of living systems into material characteristics, and accordingly, make up materials that have specific desired behaviour; it is required to select properties and assemble it at the molecular scale, assembling material is required an advanced technology to be able to contend with materials in a very tiny scale. All of this brings technologies like **nanotechnology** and tools like digital fabrication, to be tested (Figure 2.35).

As a result; the study of construction material properties has become very important, there are variable material classifications; some address materials according to a scientifically view; others are more speciality to classified it according to its mechanical properties (Engineering classification), and finally the architectural classification which covers the architectural needs.

Putting material properties into consideration enhances digital materiality as a design approach. On another hand, tracking and monitoring the architectural history and the effect of construction materials on the revolution of form during different architectural ages (Trabeated, Arcuated, Modern and Future Architecture) gives us an indication of how far could materials affect the architectural character during those different ages. The balance between available materials and form evolution was missed sometimes and other times not, but surly materials reflect the form directly, this arise especially when the awareness and deep understanding of material characters were found (Gothic Architecture).

Despite the presence of a wide array of new and smart materials (which are mainly very oriented to technical functions), however there is a gap between architects' aspirations (combined the usage of computational design methodologies) and available materials nowadays, which cause the endless fantasy proposals of how our built environment would be after many decades from now through architectural competitions and academic design studios, and subsequently, the uncertainty of the possibility for the concepts in order to be constructed or not. The need for adequate knowledge of novelty materials and the new in material science field with new potentials and advanced characters is required in order to eradicate this gap, to make our aspirations more realistic, to find effective solutions for implementation problems and to follow the new design trends using materiality design approach.

All of the above make us look for the most important technology in designing new materials in our modern history; "**nanotechnology"**, the most promising technology that is expected to change our architecture future plan.

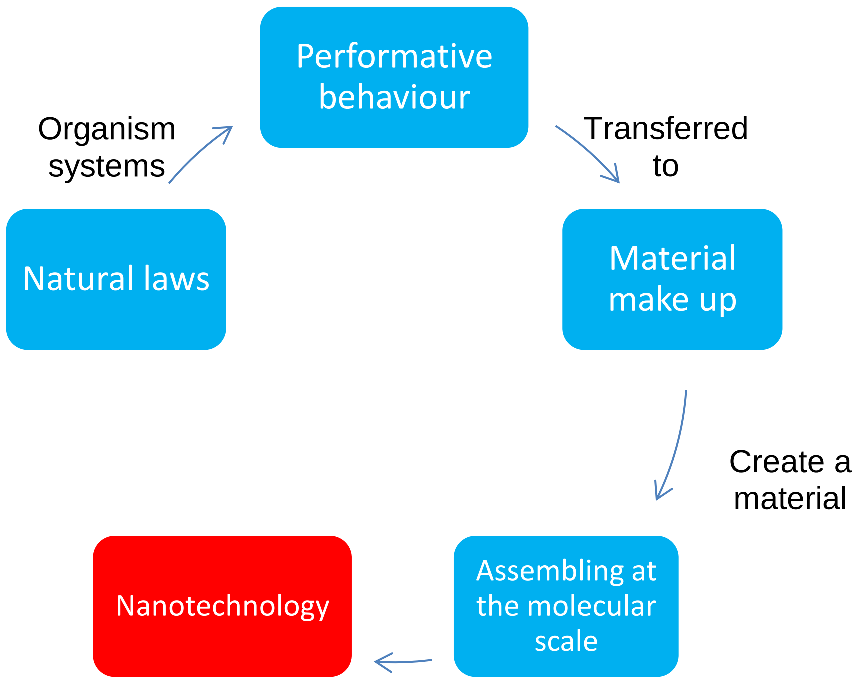


**Figure 2.35 Using natural laws led to transfer the performative behavior to material make up and assembly (Nanotechnology).**

**Source; by the researcher**

# 3 Chapter 3 Nanoarchitecture

# Chapter 3

**Nanotechnology**

Nanoarchitecture (NA)

Nanomaterials in architecture

Nano systems and devices in architecture

# 3. Nanoarchitecture

## 3.1 Nanotechnology

### 3.1.1 Introduction

From previous study we can consider materials as a very effective variable factor and strong engine in the design process. In the near future researches believe that priority will be for materials, in contrast with past when form dominated the architectural design in its initiative stages.

If contemporary field experts in materials science are correct, the near future of science and technology will offer products and procedures which follow the principles of plant and animal growth and regeneration in extraordinary ways[48].

New technologies always provide new materials with qualifications and advanced behaviour such as smart materials which are considered to be a leap in architecture world with several applications and possibilities.

Moreover; one of these promising technologies is **Nanotechnology**, the most promising technology in our architectural age. Recent researches claim that the interplay between nanotechnology and architecture can be more than buzzword in the latest design reviews.

In addition, nano products can affect both architectural design and construction. This chapter will discuss that nano products will not only allow for new and better response to the performance needs of today's most efficient buildings, but will also allow for the shift in architectural thought regarding to using materials in architectural design **(material approach to architectural design)**.

### 3.1.2 Nano scale

Nano is a scale unit, the word nano is derived from Greek word nano (in Latin nanus), and it means (dwarf). Nanometer (nm) is equal to a million of a millimetre (1/1,000,000 mm).[49]

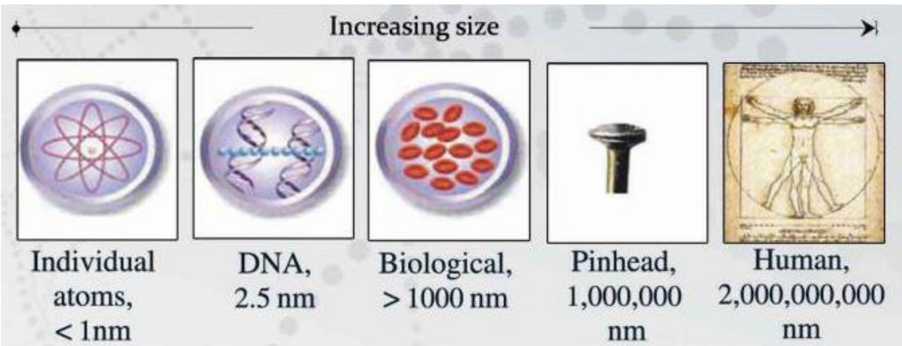


**Figure 3.1 Sequence of images showing the various levels of scale.**

**Source; Daniel L. Schodek, 2009**

[48] Daveiga, J., Ferreira, P., **Smart and Nano materials in Architecture**, paper, ACADIA conference(05), 2005, P 2

[49] Leydecker, S. , **Nano materials in Architecture, Interior Architecture and Design**, Birkhauser, Basel, Switzerland, 2008, P 12

### 3.1.3 Definition of Nano science[50]

Nano science: the area of science where the dimensions play a critical role (in the range of 1 to 100 nanometers).

When objects are below 100 nanometers in size they can exhibit unexpected chemical and physical properties. For example, you could cut a block of gold into smaller and smaller pieces and it would still have the same colour, melting temperature, etc, but at certain ranges of the nano scale, gold particles behave differently.

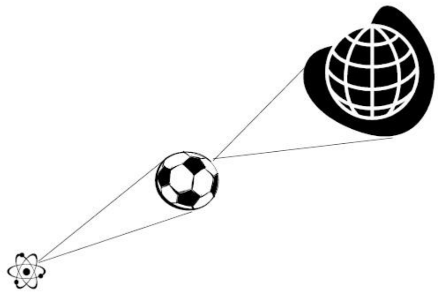

**Figure 3.2 The diameter of a nanoparticle is to the diameter of soccer ball as the soccer ball's diameter is to the Earth's.**

**Source; George Elvin, 2009**

### 3.1.4 What is Nanotechnology?

The term **nanotechnology** attracted considerable scientific and public attention over the past few years**.**

- German federal Ministry of Education and Research (BMBF) definition: "Nanotechnology refers to the creation, investigation and application of structures, molecular materials, and internal interfaces for surfaces with at least one critical dimension or with manufacturing tolerances of –typically- less than 100 nano meters. The decisive factor is that the very nanoscale of the system components results in new functionalities and **properties for improving products or developing new products and applications**"

- The essence of nanotechnology is to manipulate atoms and molecules at nanoscale level and create nanostructures with fundamentally new organizations and properties.[51]

### 3.1.5 Development of Nanotechnology

Nanotechnology isn't something that was created in the past few years, or even the past few centuries, nanostructure materials were existed on this earth long before artificial intelligent age even appeared. The basics of the history of nanotechnology have been implemented for thousands of years or longer, but the scientific society did not put a name to it until somewhere in the mid-60s.[52]

Among the earlier examples in which "nano structures" were found the red colour of Roman glass trophies and the red colouring of stained glass in medieval church windows (Figure 3.3). The deep red colouring of the gold that was used for this purpose is partly responsible for the illustrious

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[50] Hemeida, F., **Green nano architecture,** Master of Science in Architecture, Alexandria University, 2010, P 3
[51] **Technology Areas,** http://www.itc.gov.hk/en/area/nano.htm Retrieved January, 2014
[52] **The history of nanotechnology**, http://nanogloss.com/nanotechnology/the-history-of-nanotechnology/#axzz2AdBJkBIO Retrieved December, 2013

colour of the stained glass windows. The colour of gold particles changes depending on their size and form and can appear red, blue or violet. Also the Lycurgus Cup, from Roman times, is another famous historic artefact that uses this effect, it was exhibited in the British Museum in London, cup colour changes from red to green depending upon the angle of incident light (Figure 3.4).[53]

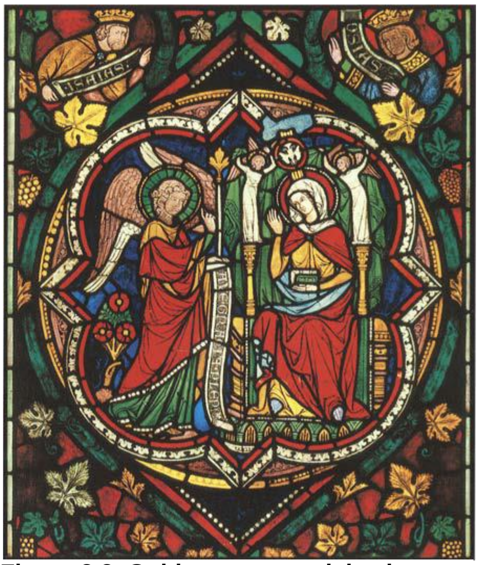

**Figure 3.3 Golden nano particles in Church's windows.**

**Source; Sylvia Leydecker, 2008**

In order to accurately document the history of nanotechnology, it could believe that it began when the ability to determine particle size were developed, which is indicated to be around the turn of the 20th century. It was during this time that particle size became a constant factor in scientific exploration. These explored measurements were recorded at smaller than 10 nm, which translated roughly into less than microscopic.

The first use of the concept of 'nano-technology' (but pre-dating use of that name) was in "There's Plenty of Room at the Bottom," a talk given by physicist Richard Feynman at an American Physical Society meeting at Caltech on December 29, 1959.

After that the term "**Nanotechnology**" was defined by Tokyo Science University Professor Norio Taniguchi in a 1974 in paper named as follows: "'Nano-technology', it mainly consists of the processing, the separation, the consolidation, and the deformation of materials by one atom or by one molecule.

**Figure 3.4 Lycurgus Cup.**

**Source; http://someinterestingfacts.net/what-is-plasmons/, Retrieved October, 2013**

In the 1980s the basic idea of this definition was explored in much more depth by Dr. K. Eric Drexler, who promoted the technological significance of nanoscale phenomena and devices through speeches and the books (Engines of Creation: The Coming Era of Nanotechnology) (1986) and (Nano systems: Molecular Machinery, Manufacturing, and Computation), and so the term obtained its current sense. (Engines of Creation) is considered the first book on the topic of nanotechnology.

[53] Leydecker, S. , **Nano materials in Architecture, Interior Architecture and Design**, Birkhauser, Basel, Switzerland, 2008, P 20

Nanotechnology got started in the early 1980s with two major developments: the birth of cluster science and the invention of the **scanning tunnelling microscope.**

The 1980s and early 1990s saw a significant increase in the knowledge of nanotechnology. It is the science that can find out how to power our lives with nothing more than molecules and atoms, a science where advancements are always happening and being tested.[54]

After this, many institutions, universities and organization started conducting researches in this area, mainly in Europe, Asia and North America (Table 4). In addition, there are speciality nanotechnology research centres that were founded lately such as Krishnap Singh center in Philadelphia (Figure 3.5). These centers house several multi-user experimental laboratories that are critical to advanced research and development in nanotechnology.

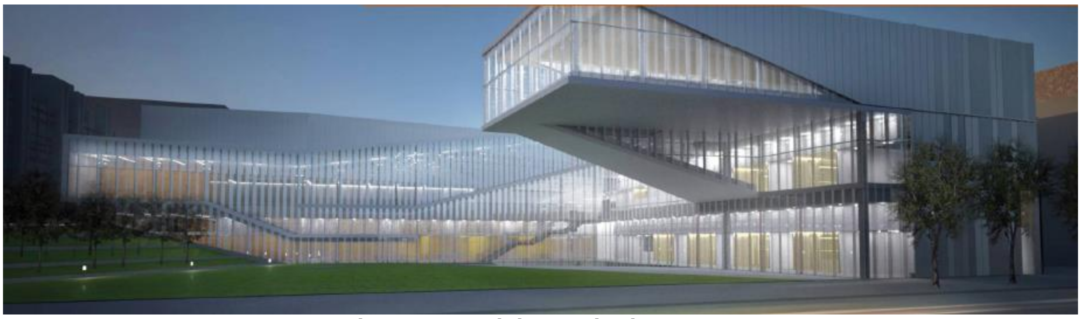

**Figure 3.5 Krishnap singh center.**

**Source; http://www.nano.upenn.edu/core-facilities/, Retrieved November, 2013**

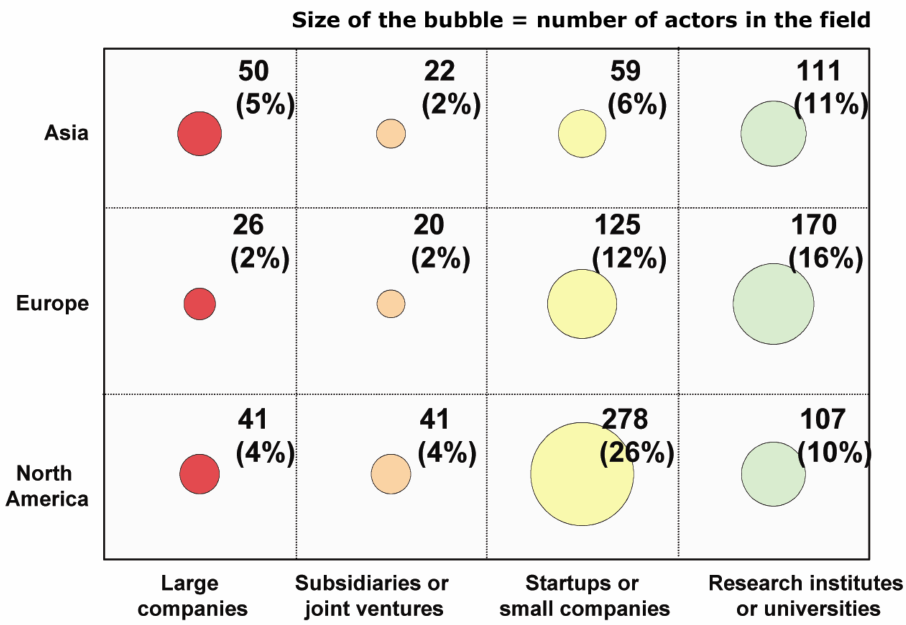


**Table 4 World-wide Nanotechnology Organizations 2002.**

**Source; Científica and Jaakko Pöyry Consulting**

[54] **Nanotechnology**, http://en.wikipedia.org/wiki/Nanotechnology , Retrieved November, 2013

### 3.1.6 **Nanotechnology areas of focus**

Nanotechnology appears as an important solution for world's problems in all fields, for instance global warming, cancer, saving energy and other important problems. This technology will reflect on industry, materials production, electronics and manufacturing, that is why great expectation is waiting for our future.

Moreover, this technology can be applied in aerospace and military application. Mosquito spyware is an example of this (Figure 3.6); it's an insect spy drone already in production, for urban areas, funded by the US government. Nano mosquito can be remotely controlled and is equipped with a camera and a microphone. It can land on human, and it may have the potential to take a DNA sample.[55]

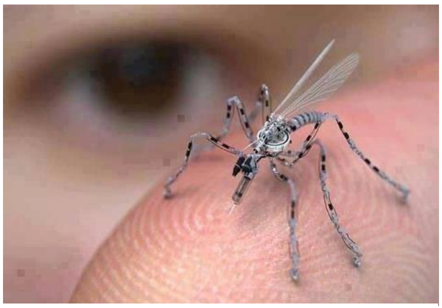

**Figure 3.6 Mosquito spyware**.

**Source; http://www.snopes.com/photos/technology/insectdrone.asp**

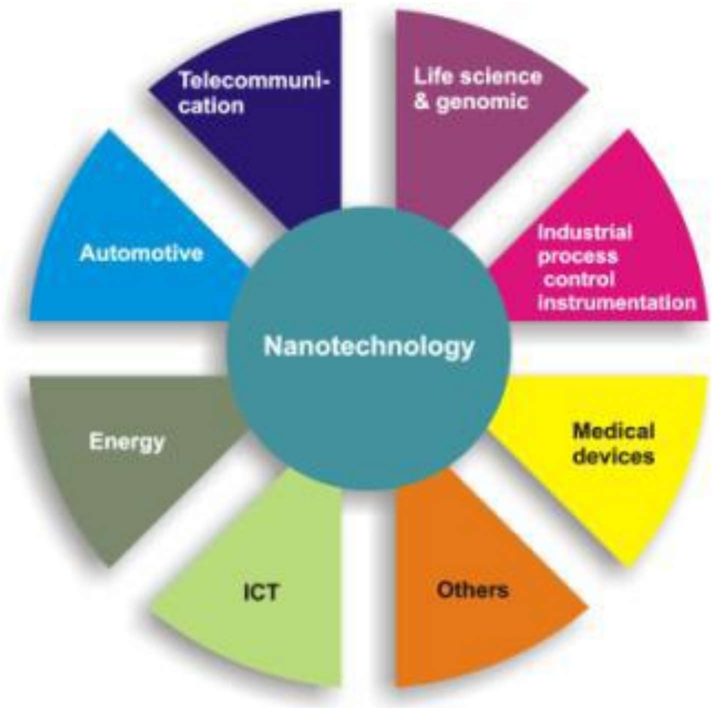


**Figure 3.7 Nanotechnology focusing areas.**

**Source; http://www.eminent.ivam.de/main.html**

[55] **Mosquito spyware,** http://www.snopes.com/photos/technology/insectdrone.asp, Retrieved September, 2013

### 3.1.7 <u>Nanotechnology and Economy</u>

Due to its potential for business, nanotechnology became global interest. It attracts more public funding than any other area of technology; it is also the one area of research that is truly multidisciplinary.[56]

Next chart shows the US Federal Nanotechnology Funding from 2000 to 2013, affiliated to the area, which was supported (science, health, energy, …).

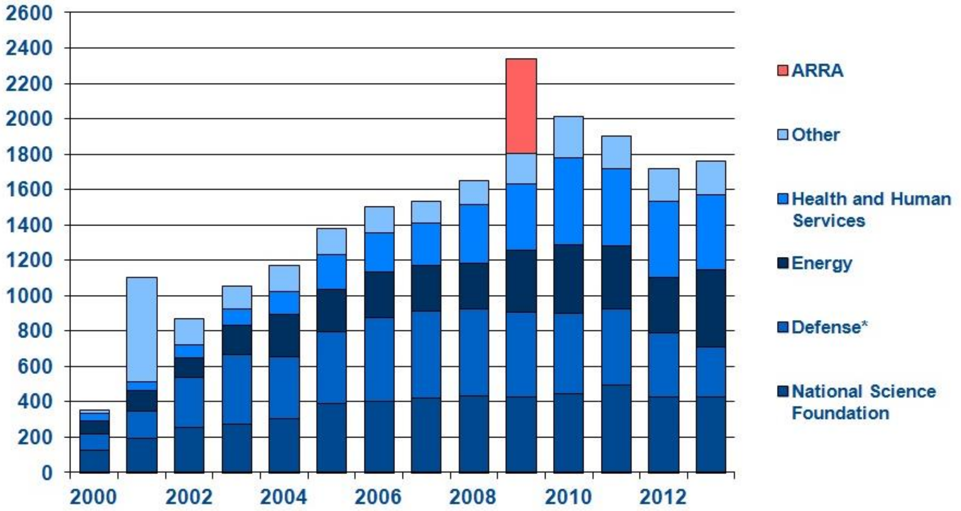


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**Figure 3.8 US Federal Nanotechnology Funding from 2000 to 2013.**

**Source; AAAS,the American Association for the Advancement of Science http://www.aaas.org/page/guide-rd-funding-data-%E2%80%93-historical-data, Retrieved December, 2013**

The next figure shows a study that was prepared by PEN (the project on emerging nanotechnologies, Washington, USA) of nanotechnology consumer products inventory contains 1628 products or product lines.

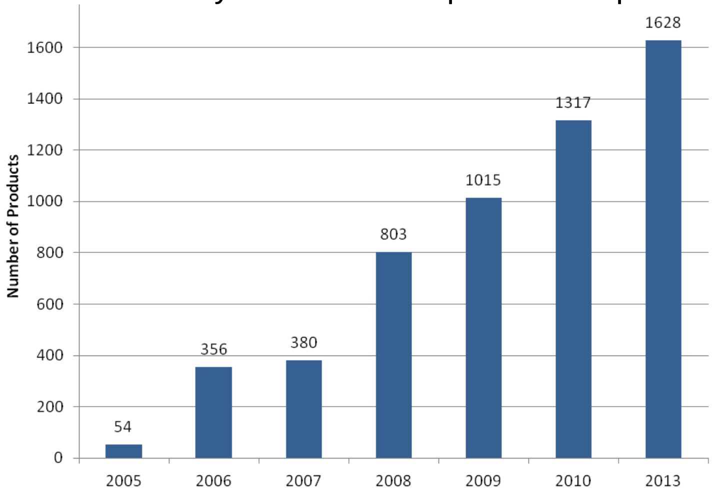


**Figure 3.9 Number of nano products till 2013.**

**Source; <u>http://www.nanotechproject.org/cpi/about/analysis/</u>, Retrieved January, 2014**

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[56] **Nano magazine,The Magazine for Small Science**, http://www.nanomagazine.co.uk/ Retrieved September, 2013

[57] ARRA refers to American Recovery and Reinvestment Act.

These products were grouped according to relevant main categories as shown in (Figure 3.10). Under each category are a number of appropriate sub-categories that allow for further organization of the products. For example, paint is a subcategory under Home and Garden, while coating is a subcategory under Cross-Cutting.

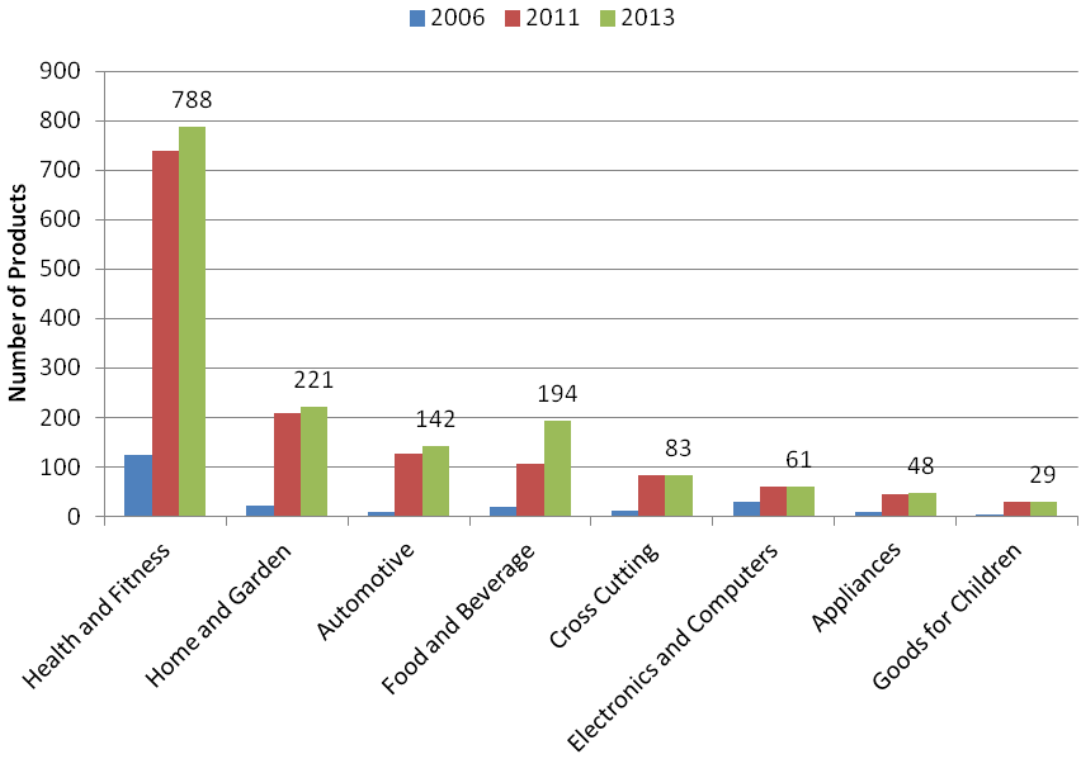


**Figure 3.10 Number of products according to category.**

**Source; http://www.nanotechproject.org/cpi/about/analysis/, Retrieved January, 2014**

### 3.1.7.1 Cost

In comparison to traditional materials; the cost of most nanotechnology materials is relatively high. For instance, comparing self-cleaning nano glass price with conventional window glass; the increase in the price of nano glass ranges from 10% up to 20%.

## 3.1.8 **Nanomaterials**

### 3.1.8.1 **Definition**

Nanoscale materials are defined as a set of substances where at least one dimension is less than, approximately100 nanometer.[58]

The nanomaterials field includes subfields which develop or study materials having unique properties arising from their nanoscale dimensions.[59]

### 3.1.8.2 **Nanomaterials field**

Nanomaterials, the field which takes **a materials science** based approach to nanotechnology; it studied materials with morphological features on the nano scale and especially those which have special properties from their nanoscale dimensions. [60]

Nano materials production depends on (selection) which means that we could select any properties we need at the molecular scale and rebuild it to create new materials with specific properties. [61]

**Size-dependent properties are the major reason that nanoscale objects have such amazing potential.** These remarkable effects are achievable because of the ability of varying their fundamental properties (magnetization, optical properties (colour), melting point, hardness, etc). [62]

Controlling **designing materials** at this tiny scale considered as a very important stage which divides our own world into visual reality and non-seen tiny world. This technology will produce a new generation of materials with better properties. It is expected that nanomaterials will make significant changes in all aspects.

Construction industry is not an exception and is completely affected by the transition which nanotechnology caused in improving and developing material characteristics. New generation of materials with more efficiency, better performance and different physical and chemical properties from conventional ones are the results of nano-scale researches on materials[63]

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[58] Alagarasi, A., **Introduction of nanomaterials**, National Center for Environmental Research, 2011, P 1

[59] Clarkson, AJ; Buckingham, DA; Rogers, AJ; Blackman, AG; Clark, "**Nanostructured Ceramics in Medical Devices: Applications and Prospects**", article, Springer, 2004

[60] Berger, M., **Nanotechnology and the future of advanced materials,** article**,** Nanowerk, 2010**,** http://www.nanowerk.com/spotlight/spotid=16047.php, Retrieved December, 2013

[61] Mohamed, M., **New Designs for Future Applications**, presentation, Alexandria Library, 2009

[62] Bradley D.Fahlman, **Material Chemistry** , Springer, 2007

[63] Javad, M. , Ghasempourabadi, M. , Nikhoosh, N. and Ghaedi, H., **The Usage of Nanomaterial in Building Constructions in Hot and Dry Climate** (Case Study: IRAN, South East) paper, International Conference on Nanotechnology and Biosensors,2011, P 1

### 3.1.8.3 **Approaches to make nanomaterials**

There are two important approaches to make nanomaterials:

A- The top down approach

It is an operator that designs and controls macroscale machines shop to produce an exact replica, but smaller in size. This process of reducing the scale of the machine shop continues, until a nano size machine shop is produced and is capable of manipulating nanostructures. One of the emerging fields that based on this top-down approach is the field of (nano, micro) electromechanical systems.[64]

In this approach the actual implementation is very complex and expensive. This is due to:
1-Nanostructures which are smaller than 100 nm are difficult to produce due to different effects.
2-Photolithographic tools are very costly, ranging in price from tens to hundreds of millions of dollars.[65]

B- The bottom up approach

Here we start from atoms and molecules to form larger structures, in this approach; it could be able to rearrange molecules to get a new atomic structure in order to create several novel materials. This approach is used in a wide range in medicine, on another hand this approach seems to be more economical than the first approach in production.

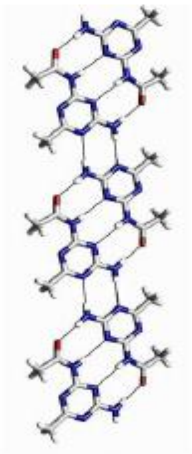


**Figure 3.11 Assembling molecules in nanoscale, bottom up approach.**

**Source; Sylvia Leydecker , , 2008**

As a result; contend with materials at nano scale gives new different properties both physical (material phase: liquid, solid or gas) and chemical properties as well. This is a promising architecture with novel materials that could change the whole architecture image.

### 3.1.8.4 **Nanomaterials classifications**

There are different ways to classify nanomaterials, firstly; it is classified scientifically according to their dimensions, and this classification is based on the number of dimension which is not confined to the nanoscale range which is less than 100 nm. Secondly; it is classified according to its based material.

A- First Classification (according to its dimensions)

This sort of classification depends on nanomaterial's dimensions; types of these materials are less than 100 nm in its all three dimensions, nano particles lay in this classification, the importance of nano particles comes from the ability to change properties of many conventional materials

[64] Fouad, F., **NanoArchitecture and Sustainability**,master research, Alexandria University,2012, P 55
[65] Williams, D. E. **, Sustainable Design : Ecology, Architecture, and Planning**, FAIA , 2008

when formed from nanoparticles. This is typically because nanoparticles have a greater surface area per weight than larger particles; therefore they are more reactive to certain other molecules. [66]

Carbon nanotube, the most promising material in construction field, lies in the two dimensions category; it has only two dimensions less than 100 nm. The last category is the one dimension material, which has one dimension less than 100 nm, such as coatings and thin films.

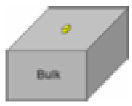
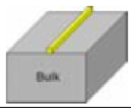
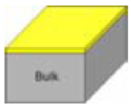
| Nanomaterial Dimension | Nanomaterial Type | Example |
|---|---|---|
| All three dimensions < 100 nm | Nanoparticles, Quantum dots, nanoshells, nanorings, microcapsules |   |
| Two dimensions < 100 nm | Nanotubes, fibres, nanowires |   |
| One dimension < 100 nm | Thin films, layers and coatings |   |

**Figure 3.12 Classification according to material dimensions.**

**Source; Luisa filipponi & Duncan, 2009**

<u>B- Second Classification (according to based materials)[67]</u>

It classifies nanomaterials due to its based material; carbon, metal, dendrimers or composites.

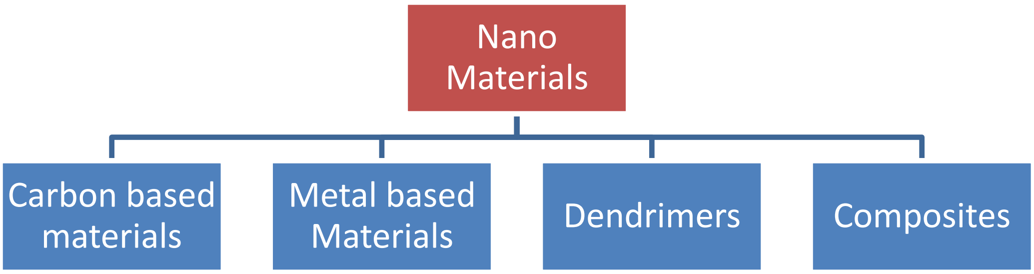



**Figure 3.13 A classification of Nanomaterials according to its base material.**

**Source; Mohamed Abdallah Ibrahim and students group, 2011**

**<u>Carbon based materials</u>**

[66] Filipponi, L.& Duncan, **Nanotechnology, a brief Introduction**, paper, Nano science center (INANO) University of Aarhus, Denmark, 2009, P 4

[67] Mohamed Abdallah Ibrahim and students group, Nanotechnology**, nano science and information society**. Background and scientific understanding, brochure, NAL Nano Architecture Lab, Alexandria University, 2011

Carbon is the most important element for all living organisms in earth, most of the organic elements have carbon in its structure, so carbon based materials refers to material with carbon as a main content, in addition; it shows high performance in deformation and stiffness such as carbon nanotubes, nano-fibers and nano-sheets.

**Metal based materials**

It refers to amended metal in the nano scale to improve its mechanical and electrical properties.

**Dendrimers**

Dendritic polymers are highly branched polymer structures, it exhibits very different properties compared to their linear analogues.[68]

**Composites**

It refers to combining nanomaterials with traditional materials, like plastic, concrete and glass to show high quality, performance, strength to-weight ratio, durability and stiffness, like the modifications which can be added to cement and concrete to improve its strength and durable efficiently.

### 3.1.9 Summary

The word nano is derived from Greek word nano (in Latin nanus), and also is a scale unit that is equal to a million of a millimetre.

Nanotechnology is a technology that is exploring our physical world at a very tiny scale. It is an old technology which was found before artificial intelligent age, it was widely explored and defined in the mid-60s.The importance of this technology lies in its ability to control molecular structure of any material, in order to make modifications to its properties. It is a global interest that could solve our todays problems (global warming, cancer..), therefore it attracts public funding.

What is interesting about nanomaterials is the “select-ability” for the desired properties, and rebuild it to create new materials with completely new properties, these modifications could include optical, structural and aesthetical properties which enable more freedom in designing new generation of construction materials.

[68] Carlmark, A., Hawker, C., Hulta, A. and Malkoch, M**., New methodologies in the construction of dendritic materials**, article,Chemical Society Reviews, 2009, http://pubs.rsc.org/en/Content/ArticleLanding/2009/CS/b711745k#!divAbstract, Retrieved December, 2013

# Chapter 3

Nanotechnology

**Nanoarchitecture (NA)**

Nanomaterials in architecture

Nano systems and devices in architecture

# 3.2 Nanoarchitecture (NA)

## 3.2.1 Introduction

The growing attention regarding to the potential of nanotechnology in architecture is a result of looking for new technologies that affect both functional and aesthetic aspects of buildings.

## 3.2.2 Nanoarchitecture

### 3.2.2.1 What is Nanoarchitecture term referring to?

**Nanoarchitecture (NA)** is a term that describes the integration between nanotechnology and architecture (Figure 3.14). This merging is expected to express new generation of architecture, which will be a great change in our built environment. The use of nanotechnology in architecture goes beyond the use of material to have its impact also on design methods and theories.[69]


**Figure 3.14 The integration between nanotechnology and architecture is leading to nanoarchitecture.**

**Source; by the researcher**

Nanotechnology, the manipulation of matter at the molecular scale, promises transforming architecture in ways we can hardly imagine today. It will bring dramatic improvements in building performance including energy efficiency and sustainability. As we consider the industrial revolution as a turning point in modern architecture, many researchers and architects pointed that nanoarchitecture will create a new revolution in our built environment.

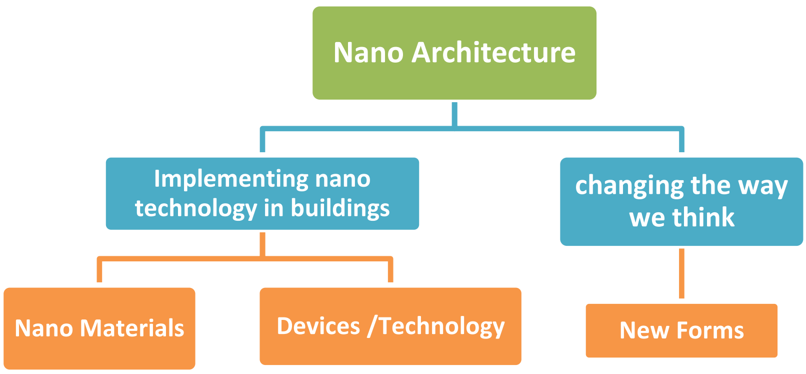



**Table 5 Nanoarchitecture analysis diagram.**

**Source; Mohamed Abdallah Ibrahim and students group, 2011**

[69] Mohamed Abdallah Ibrahim and students group, **Nanotechnology, nano science and information society**. Background and scientific understanding, brochure, NAL Nano Architecture Lab, Alexandria University, 2011

### 3.2.3 Methods of integrating nanotechnology with architecture

We can consider architecture as one of the most fields which can get benefits from nanotechnology; focusing on what will nanotechnology serve for architecture is the point. This could be through two major ways (Figure 3.15):

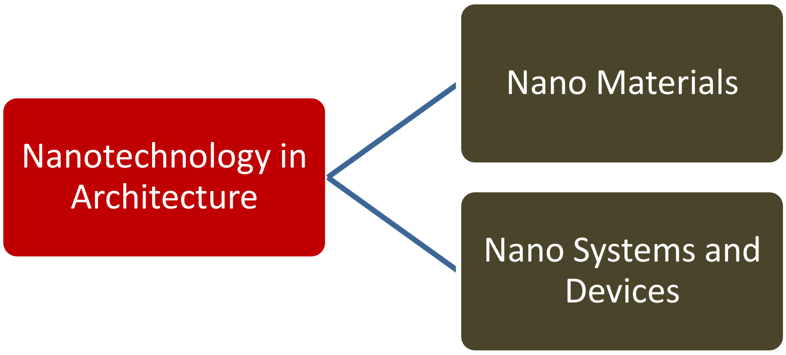



**Figure 3.15 Nanoarchitecture general layout.**

**Source; by the researcher**

#### 3.2.3.1 Nanomaterials in architecture

Materials with new potentials and properties can be an effective input in design process, as it was pointed in chapter two. For instance new nanomaterials can be more strong, lighter and effective than the traditional one which is used in recent building constructions as it will be illustrated later, these improved properties bring material's selection decisions to be in initiative stages in design operation, and consequently, follows materialization design approach.

Designing our own materials

By merging both nanotechnology and architecture, nanotechnology will give architects renewed freedoms that we haven't experienced today. The wide array of new available and improved nanomaterials with new characteristic offer for architects a new pallet, which provides a massive matrix of construction materials to deal with.

Moreover, and as a result of select-ability of materials properties; enabling material scientists to select or add any character they need while designing material at the nano scale have become applicable. For architects; controlling materials properties such as colour, flexibility, hardness and any other properties, in addition to the ability of integrating building's structure with its shell, wall and enclosure becomes possible. All of this would affect architects decisions and choices.

#### 3.2.3.2 Nano Systems and devices

Besides nanomaterials; nanotechnology provides new nano devices which could be embedded into building elements. These devices will convert building's envelop to be an interface that has the possibility of both sensing and actuating functions. Besides their sensing and actuating properties, such skins will be able to learn and adapt with time in addition to simulate living systems. This could be achieved by the usage of devices like improved nano sensors, nano solar cells, etc.

Engaging with **biological architecture**; nanoarchitecture could offer systems and devices that could simulate living system's growth and behaviour. It will allow having designs that interact better with the human senses. Exploring this type of architecture could **feel more "natural" and less forced** than many of the designs we experience today. [70]

### 3.2.4 **Summary**

Nanoarchitecture; the term describes the integration between nanotechnology and architecture; this integration includes two major methods:

a) Applying nanomaterials in architecture.
b) Applying nano system and devices in architecture.

[70] Lehman, M., **The Future of Architecture with Nanotechnology**, article, sensing architecture magazine, 2009 http://sensingarchitecture.com/1347/the-future-of-architecture-with-nanotechnology-video/ Retrieved December, 2013

# Chapter 3

Nanotechnology

Nanoarchitecture (NA)

**Nanomaterials in architecture**

Nano systems and devices in architecture

# Part1 Nanomaterials

## 3.3 Nanomaterials in architecture

### 3.3.1 Introduction

#### 3.3.1.1 How can nanomaterials affect architecture?[71]

- Nanomaterials promises architecture new opportunities to solve problems, and raise building performance to an optimum level, by improving significantly the nature of building structure, efficiency and the way buildings interact with the environment.
- Nanomaterials can expand design possibilities for both interior and exterior spaces. It can open up new possibilities for sustainable design strategies and provide a new array of functions that would help interaction between the occupants and the building.
- The development of carbon nanotubes and other breakthrough nanomaterials will affect building design and performance. These materials can add functional characteristics and novel sensing properties such as structural health monitoring, increasing its strength, self-cleaning capacity, thermal insulation, fire resistance, and many other capacities like heat absorbing windows and energy coatings, taking building materials (coatings, panels and insulation) to a maximum capacity of performance in terms of energy saving, security and intelligence.

**Nanomaterials in architecture**

According to current researches and applications that covered nanomaterials, we can classify materials which are used in architecture into: structural and non-structural materials, coatings, lightings and insulations.

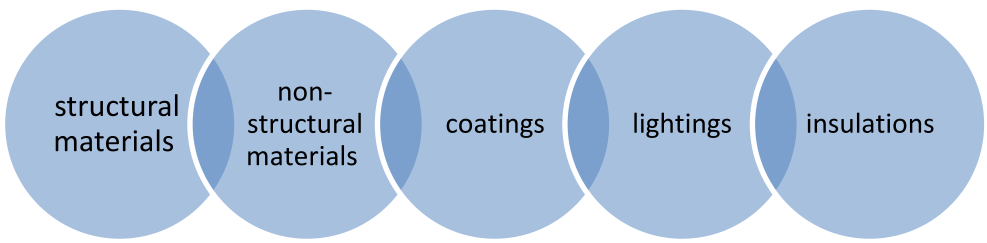



**Figure 3.16 Nanomaterials in architecture.**

**Source; by the researcher**

[71] **Cambridge Nanomaterials Technology LTD,** http://www.cnt-ltd.co.uk/nano/nanomaterials-in-architecture/ , Retrieved December, 2013

## 3.3.2 **Structural Materials**

A “nanostructured material” can be defined as a traditional material such as steel, cement,.. with nanomaterials (nano-composite), or modified in its chemical and physical structure through observation, testing and characterization of the properties at the nanoscale (nano engineering). In both cases the original characteristics of the materials are modified and improved in order to obtain specific requirements, usually not comparable to those shown by the original materials.[72]

The integration between nanotechnology and architecture will lead to significant changes and improvements to structural materials. The image of architecture in the future will show this change when we use materials like carbon nanotubes which is expected to be 100 times stronger and 6 times lighter than steel, or using nanomaterials in order to improve current construction materials. Consequently, structural nanomaterials are divided in to two types:

-Firstly; the **new nanomaterials**, like carbon nanotube and other materials which were not existed before.

-Secondly; **nano composite materials**, which is existing materials like concrete and steel produced by adding nanoparticles to improve it. Developments are including improved strength, ductility, toughness, abrasion and transport properties.[73]

Compared to other industries, applications of nano structural materials are very limited in construction engineering and the built environment. However structural nanomaterials are implemented in cases where structural strength is just one aspect of performance, as in case for intelligent windscreen glass.

### 3.3.2.1 **Carbon Nanotubes (C.N.T)**

Carbon nanotubes (CNTs) are among the most promising types of nanomaterials for their excellent electrical and mechanical properties and the many potential applications in the building sector.[74] It makes its way into many architectural components. It was discovered in 1991 by Professor Sumio Iijima at the electronics concern NEC in Tsukuba, Japan.

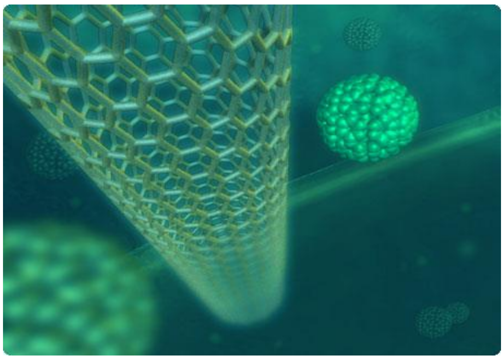


**Figure 3.17 Carbon nanotubes.**

Carbon nanotubes are a recently discovered unique material, possessing

[72] Leone, M.**, Nanotechnology for Architecture. Innovation and Eco-Efficiency of Nanostructured Cement-Based Materials,** paper, Architectural Engineering Technology conference,2012, P 2

[73] Mulenga, D.M. & Robery, “**Can Nanotechnology Address Today´s Civil Engineering Challenges?"**, paper, Fifth International IABMAS Conference, Philadelphia, USA, 2010, P 7

[74] Leone, M.**, Nanotechnology for Architecture. Innovation and Eco-Efficiency of Nanostructured Cement-Based Materials**, paper, Architectural Engineering Technology conference,2012, P 7

amazing structural properties, beside electrical, thermal characteristics, and. They are highly conductive both to electricity and heat, with an electrical conductivity as high as copper, and a thermal conductivity as great as diamond.


**Figure 3.18 The diameter of carbon nanotubes is to the diameter of a hair as the hair's diameter is to house wide.**

**Source; http://nano.gov/nanotech-101/what/nano-size, Retrieved December, 2013**

-Carbon nanotubes also have extraordinary mechanical properties. They are **100 times stronger than steel**, while only one **sixth of its weight.** These mechanical properties offer huge possibilities, for example; it is used in the production of new stronger and lighter materials for military, aerospace and medical applications.[75]

-It has been calculated that nanotube-based material has the potential to become **50–100 times** stronger than steel at one sixth of its weight.[76]
- They have 5 times the Young's modulus and theoretically **100 times** the strength of steel whilst it being 1/6th of steel density.[77]

CNTs have a tensile strength far in excess of steel, yet are flexible and lighter. Their thermal conductivity is also higher than any other known material, exceeding that of diamond. Their key properties of great strength coupled with low weight are predestined for use in future composite materials.[78]

For its use in architecture; nanotubes are already the building blocks for hundreds of applications. Due to advanced properties of carbon nanotubes it is expected to be used in a wide range in the architecture structural elements, especially in skyscrapers and bridges in addition to high

[75] Nano magazine, The Magazine for Small Science, article, http://www.nanomagazine.co.uk/ Retrieved December, 2013
[76] Arnall, A., **Future Technologies Today's Choices**, Greenpeace Environmental Trust, 2003, P 14
[77] Mann, Surinder, "**Nanotechnology and Construction**", Institute of Nanotechnology, 2006, P10
[78] Leydecker, S., **Nano materials in Architecture, Interior Architecture and Design**, Birkhauser, Basel, Switzerland, 2008, P 28

expectations in aircrafts world as it is known that NASA started to use this material in its researches.

There are two types of CNT, it could be single walled nanotubes (SWNT) or double walled nanotubes (DWNT) (Figure 3.19).

CNT could be conductive, semi-conductive or insulating material depending on its molecular structure. Each SWNT and DWNT could bring several arrays of CNTs with different prosperities (Figure 3.20).

Carbon nanotubes can be mixed with other materials, or applied to surfaces in order to enhance and improve its qualifications, so it is not related to structural materials only but it goes far to other non-structural and coating materials. Therefore expectation put this material as one of the most important factors that will impact architecture. This material and its derivatives will affect external and internal construction materials.

Nanotubes are an ideal reinforcing component of modern fibers. A possible application is in supporting long span or high rise structure cables.

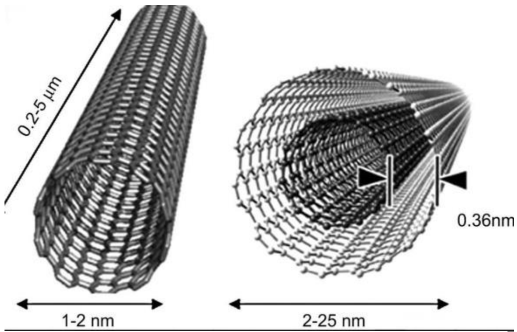



**Figure 3.19 SWNT and DWNT carbon nanotubes.**

**Source; Raymond M. Reilly, Carbon Nanotubes: Potential Benefits and Risks of Nanotechnology in Nuclear Medicine, THE JOURNAL OF NUCLEAR MEDICINE, 2007**

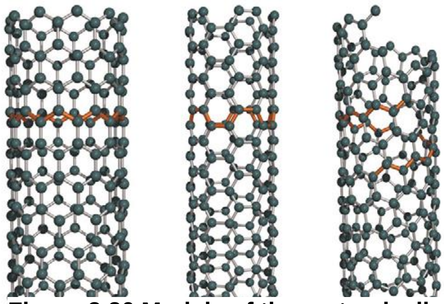


**Figure 3.20 Models of three atomically perfect SWNT structures.**

**Source; Nicole Grobert, Oxford University, Carbon nanotubes becoming clean, material today press, 2007**

### 3.3.2.2 **Nano Glass (From non-structural to structural material):**

Nanotechnology has also led to the strengthening of glass. A research has been done to instil carbon nanotubes in structure of glass, in order to create strengthened carbon nanotubes glass that represent the strongest and stiffest material discovered by man. Also it has been shown to be harder than or just as hard as diamonds.

These developments drastically changes the way glass is used in both architectural and non-architectural applications, such as windshields, eyeglasses, light bulbs, and mirrors. This is because glass has become stronger and more efficient than concrete or brick. Glass was previously only used for windows in small portions of buildings because it was not as reliable as brick or concrete; now glass is being developed to become stronger, buildings will have larger portions to be built out of glass. It is also keep buildings behave environmentally, because it helps in energy consumption, it saves energy and naturally provides sunlight, rather than having to supply electricity to every corner inside our buildings.[79]

**Figure 3.21 Strengthened glass applications.**

**Source; http://www.santambrogiomilano.it/, Retrieved March, 2014**

All of these carbon structures of architectural scale will be predicted to be transparent, these qualifications have been made possible by nanotechnology that create an intriguing paradox; lightweight, invisible structures that has significant strength.

#### 3.3.2.3 **Nano fiberglass**

Nano fiberglass shell is a thin shell structural material which can be formed in any desired curvature forms; it has been created in lengths ranging up to 175 feet. The significant advantage of this material is the great strength that can be achieved by bending, curving the shells.

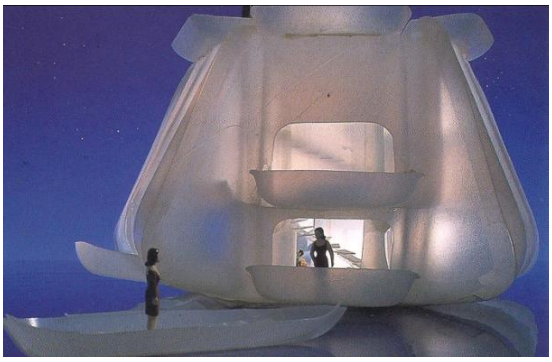


**Figure 3.22 The floating House.**

**Source; Johansen John M, 2002**

Application: The floating House (Figure 3.22 and Figure 3.23).

The floating house applies nano fiberglass to its shell (Figure 3.22). The form of building envelop, appears like unfolding translucent petals. This makes a great experience for users, and an interaction between inside and outside. The three stories home has a central, spiral stair and a roof deck above where residents might enjoy the canopy at night. Furniture is sculpted from the same material used in structure.[80]

[79] **Novel Materials,** http://blogs.dickinson.edu/mindmeetsmatter/category/glass/ ,Retrieved December, 2013

[80] Johansen, J., **Nanoarchitecture: A New Species of Architecture**, Princeton Architectural Press, New York, 2002, P 117

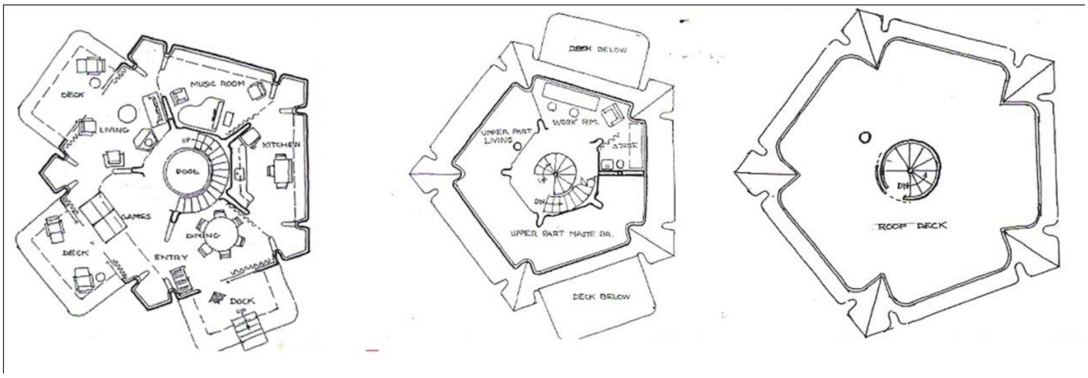



**Figure 3.23 The floating house plans.**

**Source; Johansen John M., 2002**

**Figure 3.24 A model for interior spaces.**

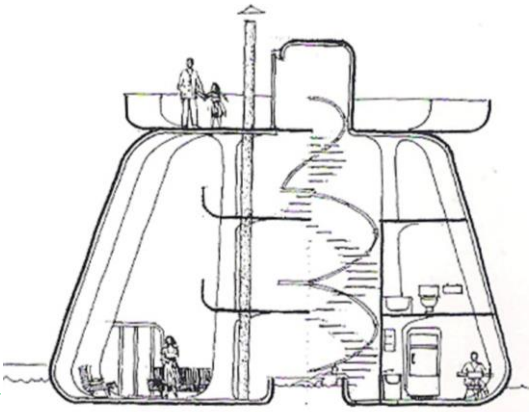


**Figure 3.25 Longitudinal section.**

### 3.3.2.4 Nano Steel

As other traditional materials; nanotechnology impacts steel manufacturing in order to improve steel performance in building construction.

Nano structured steel has existed long time before, researchers recently discovered that Damascus swords (Figure 3.26 ), made in the eighth century and known for their unusual hardness and sharpness, incorporated naturally occurring nanoparticles including iron, carbide nanowires and carbon nanotubes into their structure. [81]

Many types of improved steel are now in markets such as MMFX, other types are in progress.

**Figure 3.26 From macro to nano. The four images of parts of a Damascene sabre show that the blade is made of -carbon nanotubes which responsible for the extraordinary strength and flexibility of the steel.**

**Source; Sylvia Leydecker, 2008**

[81] Elvin, G. ,**Nanotechnology for Green Building**, Green Technology Forum, 2009, P71

MMFX Steel

According to its manufacturer; it is five times more corrosion-resistant and up to three times stronger than conventional steel.

It has been developed through restructuring of the metal, mimicking the material build-up of a sea shell and providing extreme toughness.[82]

### 3.3.2.5 Nano Concrete

Concrete is an important material for architects and structural engineers. When they call concrete for structure system they have a lot of variables to be defined, such as strength, durability, forming techniques, hardening characteristics, nature and extent of reinforcement and more. World's tallest building Kalifa tower is one of the buildings which high quality concrete was used in with micro silica additives in order to get strong concrete for the building.

Nanomaterials that added to concrete are extremely effective, and have changed the way concrete is used in structural systems. Experimentations conducted with nanomaterials additives have shown great results in concrete properties and its quality, it gives the way to the emersion of new types of cement, concrete and admixtures, such as carbon nanotubes that can be effectively added to concrete in order to reinforce it. Through these facilities, it is possible to design concretes with improved mechanical properties. As a result, material quantities could be reduced and we can have thinner cross sections carrying equal loads. Consequently, this will reduce energy consumption and pollutant emissions.

Several studies on concrete samples reinforced with carbon nanotubes (1% of the total weight) have been conducted; it illustrates how the oxidation of water in the cement mixture and the reaction during the hydration process allows the creation of stable links with the cement matrix, leading to a significant increase in its strength. The use of a CNT reinforced concrete would allow reducing the dimensions of structural sections, using an amount of material up to 10 times lower.[83]

Next figure shows the compressive strength of concrete with (top) and without (bottom) nano binders after curing 28 days.[84]

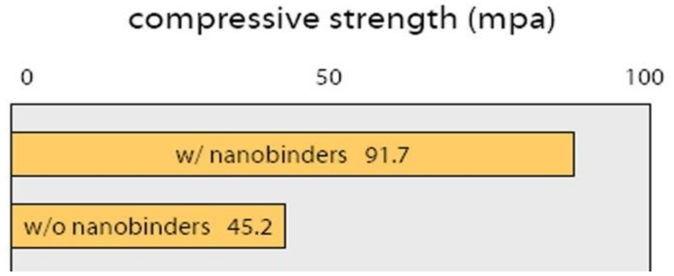



**Figure 3.27 Nanobinders double concrete's compressive strength.**

**Source; Sobolev K. and Ferrada-Gutiérrez M, 2005**

[82] Mulenga, D.M. & Robery, "**Can Nanotechnology Address Today´s Civil Engineering Challenges?"**, paper, Fifth International IABMAS Conference, Philadelphia, USA, 2010, P 7

[83] Leone, M.**, Nanotechnology for Architecture. Innovation and Eco-Efficiency of Nanostructured Cement-Based Materials**, paper, Architectural Engineering Technology conference, 2012, P 7

[84] Sobolev K. and Ferrada-Gutiérrez M., **How Nanotechnology Can Change the Concrete World**, 2005

When using nano particle reinforced wall panel in a nineteen story governmental office building, and after exposure this wall to a virtual explosion, simulation techniques were used to estimate the expected damage after and before adding nano particle to concrete. After simplified blast simulation to estimate the extent of damage for evacuation scenarios, the result shows that the heavily damaged areas shown in red were transferred into the models as "kill-zones", where all agents are assumed to be killed by the effects of the blast. The next figure shows the difference between nano protected and non-protected wall damaged areas.[85]

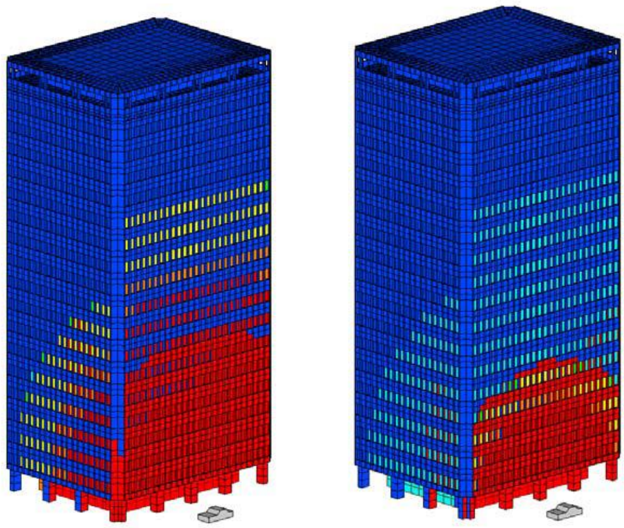


**Figure 3.28 Left unprotected walls. Right Nano-particle protected walls.**

**Source; Ahmed Al-Ostaz, Chris Mullen, and Alexander Cheng, 2009**

<u>Applications</u>

**Ultra High Performance Concrete (UHPC) with nano additives:**

What is Ultra High Performance Concrete UHPC?

The UHPC (Ultra High Performance Concrete) is a "conventional" composite material, consisting of a cement matrix and short polymer or metal fiber reinforcement that determines the improvement of mechanical and durability properties.

The comparison between ultra-high-performance concrete (UHPC) and conventional reinforced concrete shows a significant reduction in the consumption of material (about 6 times lower), and energy resources (around 40%), as well as lower emissions of greenhouse gases (about 50%). These characteristics have allowed the UHPC to obtain LEED certification (Leadership in Energy and Environmental Design) in United States and Canada.[86]

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[85] Al-Ostaz, A., Mullen, C., and Cheng, A.**, Structures Subjected to Blast Loading: Protection, Stabilization and Repair**, paper, Aging Infrastructure Workshop, University of Columbia, 2009, P 11

[86] Leone, M., **Nanotechnology for Architecture. Innovation and Eco-Efficiency of Nanostructured Cement-Based Materials**, paper, Architectural Engineering Technology conference,2012, P 5

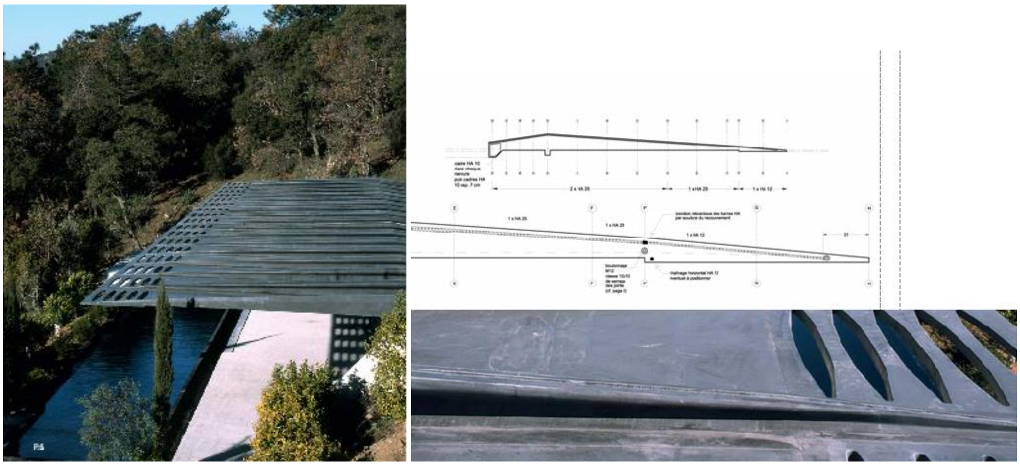

**Figure 3.29 Villa Navarra, Le Muy, South of France, designed by Rudy Ricciotti.**

**Source; Villa Navarra, Rudy Ricciotti, architect, Provence, http://www.lafarge.com/05142008-research_innovation-liflet_Villa_Navarra-uk.pdf, Retrieved December, 2013**

The possibilities of UHPC have reached the extent that it could be used to implement a 7.8 meter depth cantilever; see villa Navarra, (Le Muy, South of France), Figure 3.29 . UHPC can be used in many applications, such as; security sensitive projects where there is a need for protection against intrusion, (such as banks, prisons and bomb shelters), beside structures that need to withstand impact and shock from natural disasters or explosive projectile weapons.

Even though this material is already highly developed, it is still possible to increase its potential even further by using recent advancements in nanotechnology. UHPC smart materials will be adopted as the next level of high performance concrete, with embedded nano-additives such as carbon nanotubes and metallic based nanoparticles to create a new generation of UHPC. The usage of nano-UHPC has the potential to be a repair material for damaged conventional concrete structures, it also can be applied to all cement based materials (concrete, plaster, mortar …etc.).

## Self-healing concrete:

With the help of nanotechnology; a concrete material developed at the University of Michigan can heal itself when a crack happens. No human intervention is necessary, just water and carbon dioxide. This behaviour is possible because the material is designed to bend and crack in narrow hairlines instead breaks and split in wide gaps, as traditional concrete behaves.

Self-healing concrete works because it can bend. When it's

**Figure 3.30 Concrete under force, small and narrow cracks happen instead of one big crack.**

**Source: http://www.sciencedaily.com/releases/2009/04/090422175336.htm, Retrieved December, 2013**

strained, many micro cracks form instead of one large crack that causes it to fail.[87] The means of increasing the service life of concrete structures would make the material not only more durable, but also more sustainable.

## Translucent Concrete:

Translucent concrete is produced out of fine-grain concrete and translucent fabric, which is layer cast in prefabricated moulds based on **Nano-Optics**.

There are many types of optical fiber to be used, but nano- based optical fibres passes as much light when tiny slits are placed directly on top of each other, as when they are staggered. Transparency can be achieved because nano optical fibers in the concrete act like the slits and carry the light across throughout the concrete.[88] Distributions of fibers could change concrete appearance (Figure 3.32).

Almost loss-free light penetration through optic fibers makes it possible to see light; the glass fibres lead light by points between the two sides of the blocks because of their parallel position. Shadows and even colours appear through concrete even by very thick walls. [89] The result is not only two materials – glass in concrete – mixed, but a third, new material, which is homogeneous in its inner structure and on its main surfaces as well, also it can be manufactured in any colour upon request.

**Figure 3.31 Transparent concrete Europe Gate, Komárom, Hungary.**

**Source: http://www.litracon.hu/, Retrieved January, 2013**

**Figure 3.32 Left; transparent concrete when optical fibres are In Layered Distribution. Right; transparent concrete when optical fibres are in organic distribution.**

**Source; Bhavin K. Kashiyani, Varsha Raina, Jayeshkumar Pitroda, Dr. Bhavnaben K. Shah, 2013**

[87] **Self-healing concrete,** http://www.sciencedaily.com/releases/2009/04/090422175336.htm, Retrieved January, 2013

[88] Kashiyani, B. K., Raina, V., Pitroda, J., & Shah, B. K. A.**, A Study on Transparent Concrete: A Novel Architectural Material to Explore Construction Sector**, paper, International Journal of Engineering and Innovative Technology (IJEIT) Volume 2, February 2013, P 2

[89] Carts-Powell, Y., "**Using Nano-Optics to Control the Phase of Light**", article, Optics and Photonics News issue, September, 2008

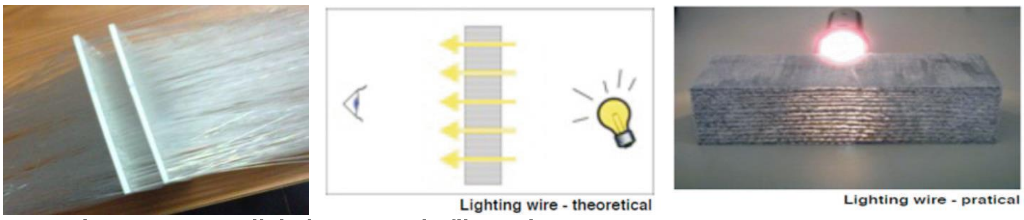


**Figure 3.33 paralleled nano optic fibers that cause transparent concrete appearance.**

**Source; M.N.V.Padma Bhushan,**

**Optical Fibres in the Modeling of Translucent Concrete Blocks, paper, IJERA, 2013**

**Figure 3.34 Transparent concrete.**

**Source; http://freshome.com/2011/06/07/an-intriguing-design-innovation-litracon%C2%AE-transparent-concrete/, Retrieved December, 2013**

Till now it's not popular in the market and also so expensive due to its limited producers.

## 3.3.3 <u>Non-structural materials</u>

### 3.3.3.1 **Thermo, Photo and Electro-chromic nano glass**

Nanotechnology could be used in reducing heat loss and heat gain through thin-film coatings, (will be explained later) and thermo-chromic, photo-chromic and electro-chromic technologies.

-<u>Thermo-chromic</u> technologies have been studied to react to changes in temperature and provide thermal insulation to give protection from heating while maintaining adequate lighting.

- <u>Photo-chromic</u> technologies react to changes of light intensity by increasing their light absorption.

- <u>Electro-chromic</u> technologies react to changes in applied voltage by using a tungsten oxide layer, becoming more opaque by the touch of a button.

All these applications are intended to reduce energy that used in cooling buildings, and could help bring to down energy consumption in buildings.[90]

Electro-chromatic materials are defined as a reversible colour change of a material, caused by application of an electric current.

This product is not one material; it is multi-layer assemblies of different materials working together.

This glass is classified under which is called colour-changing materials, these materials do not really change colour, they change their

[90] Mann, S., "**Nanotechnology and Construction**", Institute of Nanotechnology, 2006, P10

optical properties under different external stimuli (heat, light or a chemical environment), which we perceive as a colour change. [91]

Traditional electro-chromic glass was widely used before and is available in the markets. However, one of its disadvantages is that it needs constant electric current to be effective, this does not help save building energy. The advent of nanotechnology has provided a new means of integrating electro-chromatic glass in buildings. The electrical energy required to colour the ultra-thin nano coating is minimal. The primary difference to the earlier product is that a constant electric current is no longer necessary. Just a single switch is all that is required to change the degree of light transmission from one state to another, one switch to change from transparent to darkened, and a second switch to change it back (Figure 3.35). Different levels of light transmission with various darkening effects are also possible, either as a smooth gradient or clearly differentiated.[92]

Many companies have been developing and producing this technology, starting from small residential building windows to large buildings curtain walls.

**Figure 3.35 Electro-chromatic glass with an ultra-thin nano coating.**

**Source; Sylvia Leydecker, 2008**

### 3.3.3.2 **Heat storing glass**

Glass X AG is the trade name of heat absorbing glass. It contains a salt hydrate fill material that functions as a latent heat store for solar heat, and protects outdoor spaces. The latent heat store has a thermal absorption capacity equivalent to a 15 cm thick concrete wall. The glass panel is transparent when the fill material has melted and milky-white when frozen. The material's change of state is therefore immediately reflected in the building's appearance, function and aesthetics are inseparably connected.[93]

This sort of nano products will be applicable, especially in cold areas. The next figure shows the using of heat storing glass in the south façade of a residential building located in Swiss Alps.

[91] Addington, M. and Schodek, D., **Smart Materials and new technologies** , Architectural Press, 2005
[92] Leydecker, S. **, Nano materials in Architecture, Interior Architecture and Design**, Birkhauser, Basel, Switzerland, 2008, P 143
[93] op. cit., P 140

**Figure 3.36 The south-facing glazing of a residential building, Swiss Alps.**

**Source; Sylvia Leydecker, 2008**

## 3.3.4 Coatings

### 3.3.4.1 Definition of coatings

Coatings are thin coverings that are deposited on a base material to enhance its surface characteristics or appearance. This broad definition includes coatings used to improve durability or wearing characteristics, provide corrosion resistance, or otherwise protect the base material. They might also be used for change adhesion qualities, colour, reflective qualities, or a host of other reasons.[94]

**Figure 3.37 Anti-graffiti coating.**

**Source; Nano magazine, The Magazine for Small Science, www.nanomagazine.co.uk, Retrieved August, 2012**

There are many fascinating examples of nanotechnology applications in new materials, for example; polymer coatings are easily damaged, and affected by heat. Adding only 2% of nano-particulate clay minerals to a polymer coating makes a dramatic difference, resulting in coatings that are durable and scratch resistant. Nano coating has important role for situations where a material fits a particular application in terms of its weight and strength, but it needs protection from an external corrosive environment, which a reinforced polymer nano-coating can provide. Other nano-coatings can prevent the adherence of graffiti (Figure 3.37); enabling them to be easily removed by hosing with water once the coating has been applied. This has the important influence on improving urban environments.[95]

Nano coatings materials have many forms, alloys, composite, multi-layer-functionally graded, and textured (Figure 3.38). Its nano particles which

[94] Schodek, D. L., Ferreira, P., & Ashby, M. F., **Nanomaterials, Nanotechnologies and Design**, Butterworth and Heinemann,2009
[95] **Nano magazine, The Magazine for Small Science**, http://www.nanomagazine.co.uk/, Retrieved August, 2012

create a layer bound to the base material. Types of nanoparticle coatings can achieve a wide variety of other performance characteristics, including[96]:

- Self-cleaning
- De-polluting
- Scratch-resistant
- Anti-icing and anti-fogging
- Antimicrobial
- UV protection
- Waterproofing

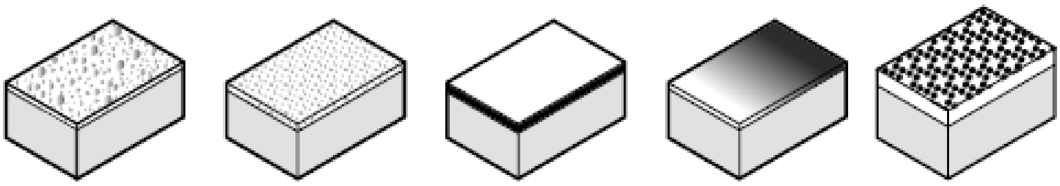


**Figure 3.38 Nano coating forms.**

**Source; Daniel L. Schodek, 2009**

### 3.3.4.2 **Self-cleaning photo catalyst** [97] [98] [99]

Nano particles can control a process in which dirt is broken down by exposure to the sun's ultraviolet rays, and washed away by rain. So, sun rays, humidity and air are required for this process. A further advantage is that **light transmission for glazing and translucent membranes** is improved as daylight is less obscured by surface dirt and grime. As a result, energy consumption and lighting costs can be reduced.

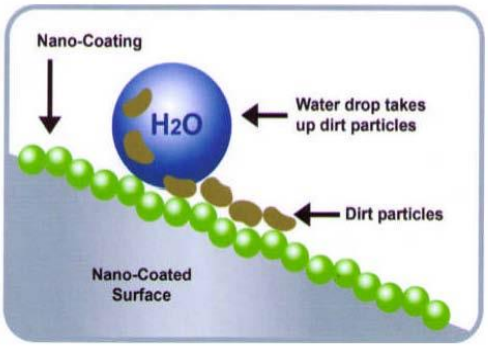


**Figure 3.39 Surface with self-cleaning material.**

**Source;http://blogs.dickinson.edu/mindmeetsmatter/category/glass/, Retrieved December, 2013**

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[96] Elvin, G. ,**Nanotechnology for Green Building**, Green Technology Forum, 2009, P21
[97] op. cit.
[98] Leydecker, S. , **Nano materials in Architecture, Interior Architecture and Design**, Birkhauser, Basel, Switzerland, 2008, P 72
[99] **Self-cleaning coating for building exteriors**, http://phys.org/news146916753.html Retrieved March, 2014

**Figure 3.40 Left, organic dirt and grime is broken down by exposure to sunlight and left clean surface. Right; self-cleaning effect on surface.**

**Source; Sylvia Leydecker, 2008**

Such coatings will greatly enhance building maintenance, especially for skyscrapers, since they reduce the need for costly surface cleaning.

### 3.3.4.3 **Self-cleaning-Lotus effect**

This represents a way of **transitioning natural laws** into architectural application. This is one of the best-known means of designing surfaces with nanomaterials. Self-cleaning surfaces were investigated back in the 1970s by Wilhelm Barthlott; (the researcher at the University of Heidelberg). He examined a self-cleaning effect, he exhibit a microscopically rough water-repellent (hydrophobic) surface, which is covered with tiny knobbles or spikes so that there is little contact surface for water to settle on. Due to this microstructure, surfaces are less wet-able. The effect of the rough surface is strengthened still further by a combination of wax (which is also hydrophobic) on the tips of the knobbles on the Lotus leaves, which results in a perfect, super hydrophobic self-cleaning surface. Water forms tiny beads and rolls off the leaf and disposing of any deposited dirt.[100]

**Figure 3.41 The Lotus plant with its natural self-cleaning.**

**Source; Sylvia Leydecker, 2008**

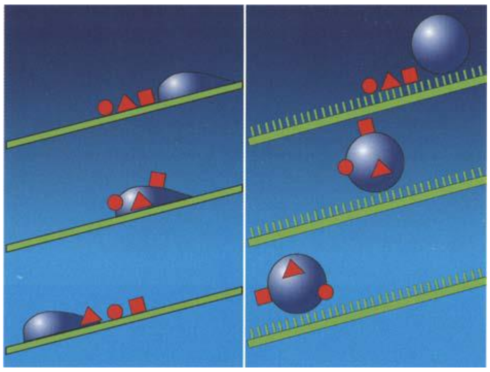

**Figure 3.42 The difference between a flat surface and self-cleaning surface.**

**Source; Sylvia Leydecker, 2008**

[100] Leydecker, S. , **Nano materials in Architecture, Interior Architecture and Design**, Birkhauser, Basel, Switzerland, 2008, P 58

### 3.3.4.4 Easy to clean materials (ETC)

Confused with other self-cleaning functions, such as the lotus-effect, easy-to-clean surfaces are smooth rather than rough. These surfaces have a lower force of surface attraction due to a decrease in their surface energy. As a result it reduces surface adhesion, this results in water to be repelled and in forming droplets and running off. Easy-to-clean surfaces are therefore hydrophobic, water-repellent and often also oil-repellent, making them well suited for use in bathrooms.

The easy-to-clean function of surfaces is also often confused with other photo-catalytic self-cleaning functions. The primary difference here is that easy-to-clean surface coatings do not require UV light to operate, and their hydrophobic surface properties cause water to run off in droplets rather than forming a thin film of water.[101]

The next Figure 3.43 shows the difference between easy to clean, lotus effect and photo catalytic.

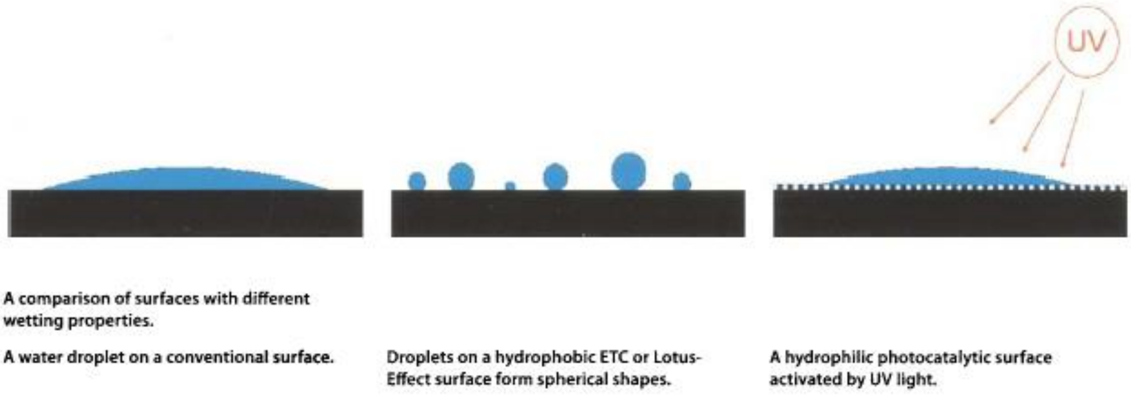


**Figure 3.43 Comparisons of surfaces with easy to clean, lotus effect and photo catalytic.**

**Source; Sylvia Leydecker, 2008**

## Application:

This technology can be applied to a variety of base materials, including concrete, metal, cement, plaster ceramics, polymers and textiles.
It could be applied to historical buildings, commercial buildings (hotels, shopping malls, offices, convention centres), conservation projects, educational institutes.

## Advantages:

Self-cleaning and easy to clean surfaces are offering an environmentally friend technology, it reduces maintenance cost and effort and keep buildings surfaces clean with its colour retention.

[101] Leydecker, S. , **Nano materials in Architecture, Interior Architecture and Design**, Birkhauser, Basel, Switzerland, 2008, P 92

### 3.3.4.5 **Anti-graffiti**

Anti-graffiti coatings can be applied to surfaces in order to reduce the adhesion of graffiti. New means are offered by anti-graffiti nano coatings. They are highly effective, and are used to make building materials water-repellent. These extremely hydrophobic properties mean that with appropriate detergents graffiti can be removed more easily. Even porous and highly absorbent materials such as brick, lime sandstone, concrete and other similar materials can be protected efficiently by using such nano-based coatings.[102]

**Figure 3.44 Historic monuments such as the Brandenburg Gate in Berlin are protected with an anti-graffiti coating.**

**Source; Sylvia Leydecker, 2008**

Numerous application areas are conceivable for both new constructions and in building conservation, Figure 3.44. In Egypt, and with the repeated attempts to distort the heritage buildings (Figure 3.45) ; anti-graffiti coatings offer a practical solution to easy- clean walls rather than re-paint it, or the use of chemicals that can detriment building's material.

**Figure 3.45 Graffiti on Alnahda statue.**

**Source; http://www.tamecom1.com/mareya/t16341.html, Retrieved December, 2013**

### 3.3.4.6 **Temperature regulation: Phase change materials (PCMs)**[103]

Phase change material (PCM), can be used as an effective means of regulating indoor room temperatures. It is also known as latent heat storage materials.

The idea is similar to ice cube, it has a high thermal capacity, it begins to change to liquid at 0°C, but the energy required for this change of state is equivalent to that required to heat liquid water from 0°C to 80°C. The same idea used here with PCMs.

Regulating the temperature of buildings consumes huge quantities of energy, for both heating and cooling. With the help of **nanotechnology**, PCM consists of microcapsules in a nano scale, and its contents are working on absorbing heat; the energy consumption can be significantly reduced. This latent thermal storage is too large, so it can absorb extremes in temperature, keeping indoor areas to remain cooler for longer time.

[102] Leydecker, S. , **Nano materials in Architecture, Interior Architecture and Design**, Birkhauser, Basel, Switzerland, 2008, P 152
[103] op. cit, P 136

### 3.3.4.7 Air purifying material[104]

Figure 3.46 PCM plaster applied on Interior walls provides thermal insulation.

Source; Sylvia Leydecker, 2008

The usage of nanomaterials makes it possible to improve the quality of air; it enables unpleasant pollutants to be eradicated. The air-purifying properties of nanomaterials are beneficial in both cases, and play an important role both for indoor as well as increasingly for outdoor environments.

<u>A- For interior application</u>

The indoor air quality is particularly important in industrialised nations, where people spend a large amount of time indoors. For interior spaces, air purification technology is increasingly being used for textiles and paints. It should be noted that although it is possible to improve the quality of air, factors such as oxygen content and relative humidity also contribute to the air quality and should not be neglected when using air-purifying products.

**Figure 3.47 The European headquarters of Hyundai Motor Europe in Offenbach, Germany, Is lined with air-purifying plasterboard panels.**

**Source; Sylvia Leydecker, 2008**

<u>B- For exterior application</u>

Photo-catalytic air purifying surfaces could reduce air pollutant, but it is depending on the respective conditions, it is possible to eradicate between 20% and 80% of airborne pollutants. It could be applied to paving stones, road surfaces and paints. Pedestrians walking in the vicinity of treated walls breathed in fewer airborne pollutants. At present these materials are still expensive, but a start has been made.

[104] Leydecker, S. , **Nano materials in Architecture, Interior Architecture and Design**, Birkhauser, Basel, Switzerland, 2008, P 108


**Figure 3.48 Concrete paving panels with photo catalytic air purifying properties used as a design element in a car park. Source; Sylvia Leydecker, 2008**

### 3.3.4.8 Anti-fogging and anti-bacteria:

**Anti- fogging:**

The fogging of glazed surfaces (glass- mirrors) is due to condensation. Condensation can be prevented by heating the cold surface. A team of researchers at the Fraunhofer Technology Development Group TEG in Stuttgart, Germany have developed a nanotechnology coating that warms the surface; it is a transparent coat of carbon nanotubes. When electrically charged, coating acts as a continuous heater uniformly covering the cold surface without wires of other visible heating elements.[105]

**Anti- bacteria:**

Anti-bacterial products have been used in order to provide more protection especially in medical and health facilities; however, conventional antimicrobial products can contain different active ingredients, including biocides, which may release into the environment. Antimicrobial nano-coatings reportedly offer the benefits of conventional anti-microbial products without these environmental and health concerns. Various products are already commercially available, and the product palette ranges from floor coverings, curtains, paints, textiles and clothes.[106]

### 3.3.4.9 Ti colour (electrolytic method for colouring titanium and titanium alloys)[107]

Titanium and its alloys are widely used due to their chemical resistance and high mechanical performance; it has traditionally been finished in dark gray wrought or silver polished states.

Nano surface's controlled electrochemical process allows titanium to produce unusual colours such as pink, blue, brown, green, and yellow (Figure 3.49) with many different intensities and finishes. These colours are chemically resistant, may be applied to complex shapes, and are suitable for **interior and exterior applications**. When exposed to sunlight, the colours become particularly intense and vibrant.

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[105] Berger, Michael, "**Anti-fogging windshields through nanotechnology**," Nanowerk News, Article, December 15, 2006, http://www.nanowerk.com/news/newsid=1157.php, Retrieved December, 2013

[106] Elvin, G., **Nanotechnology for Green Building**, Green Technology Forum, 2009, P29

[107] Brownell, B., **Transmaterial**, Princeton Architectural press,2006, P 74

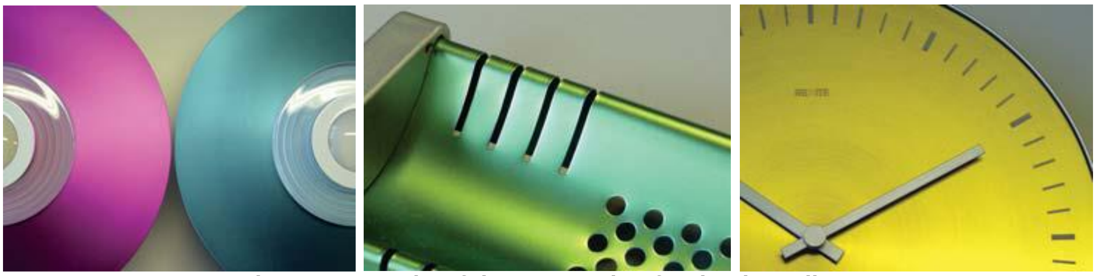


**Figure 3.49 Colourful Nano coating for titanium alloys.**

**Source; Blaine Brownell, 2006**

### 3.3.4.10 **Nano textile**

**Textile in architecture:**

The use of textile in architecture has become increasingly popular in recent years. The term Architextiles appeared; it describes the using of textile techniques, materials and ideas in architecture.

Most of the examples of textile and fabric architecture are horizontal covering either roofs or enclosing structures. These structures can be seen to have reached their maturity in the 1970s and 1980s, (the Kassel music Pavilion). After that the facades were covered with textiles and fabrics fairly late in 1990s, British Pavilion, 1992 (Figure 3.50).[108]

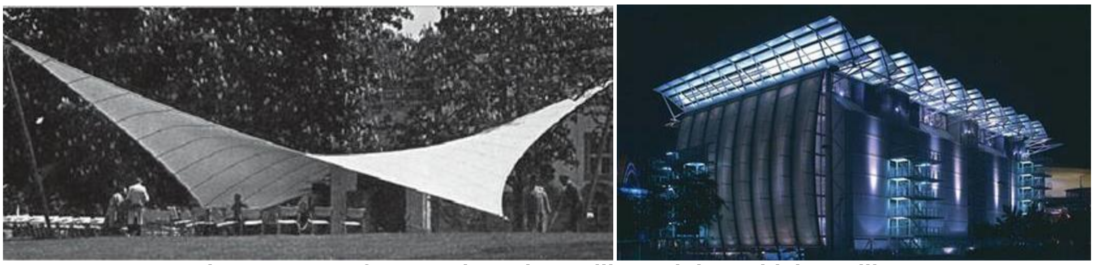


**Figure 3.50 Left; Kassel music Pavilion. Right; British Pavilion.**

**Source; Terhi Kristina Kusisto, 2010**

Nanotechnology introduce wide matrix of textile products and builds permanent spill and stain resistance into the molecular structure of these fabrics, in order to make it anti rain, sleet, snow and any other liquids. It could be applied to exterior and interior applications (Figure 3.53 ); it offers durable, light weight and water-repellent textiles.

<u>How does it work?</u>[109]

One way to understand nano textile is to imagine how you could assemble bricks into a ten foot high barrier; you could pile them up ten feet high, while this is easy to do and requires little skills, it is not durable or efficient. This barrier would erode over time and needs a large foot print in order to reach ten feet high. Or you could align and stack the bricks to create a wall. This is much more efficient and durable and analogous to the way

[108] Kusisto, T., **Textile in Architecture**, master, Tampere University of technology, 2010, P 45

[109] **Nano textiles** http://www.protectbeauty.com/publicpages/InfoCenterNanotech.aspx, Retrieved December, 2013

nano- tex applies technology enhancements to fabric (Figure 3.52).The strategy that used here is called "cross linking", and it is similar to the brick barrier. Nano-tex manipulates the polymers so that they can align themselves on the surface of the fiber, resulting in an efficient treatment that does not affect the look or the feel of the textile.

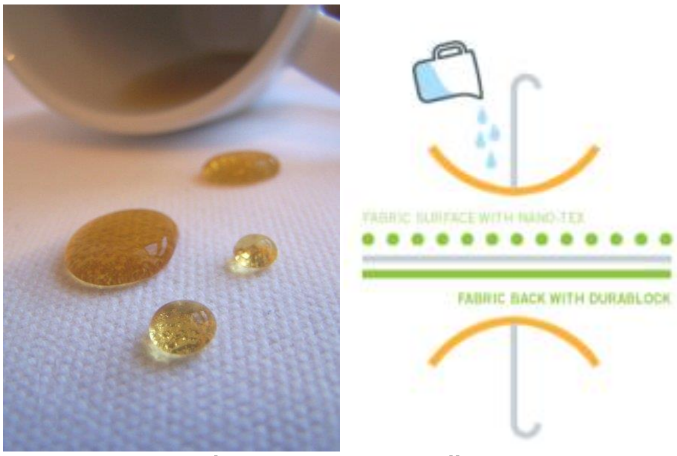



**Figure 3.51 Nano textile.**

**Source; http://www.protectbeauty.com/publicpages/InfoCenterNanotech.aspx, Retrieved January, 2013**

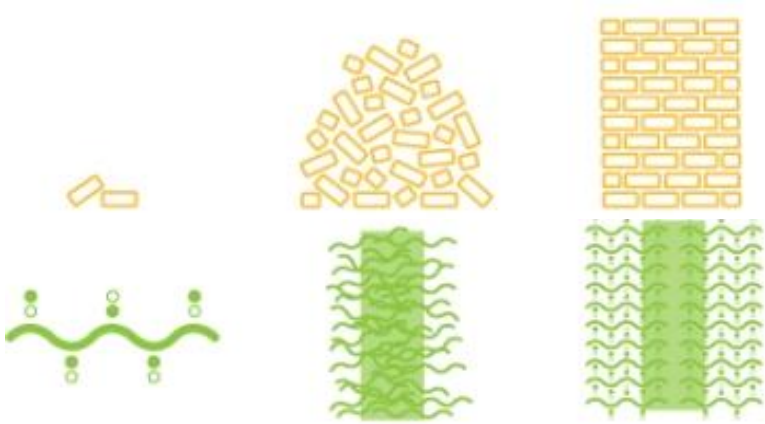


**Figure 3.52 The idea to align and stack bricks to create a wall is the same as nano-tex way of work.**

**Source; http://www.protectbeauty.com/publicpages/InfoCenterNanotech.aspx, Retrieved January, 2013**

**Figure 3.53 Carpet produced by Nanolia Textile, with waterproof properties.**

**Source; Ramy A. Bakir, The Impact of Nanotechnology on the Environmental Design Process, paper, Building Simulation Cairo, 2013**

## 3.3.5 **Lighting**

Lightning in architecture affects our perception and adds a visual experience to both exterior and interior spaces. Pattern of light and dark helps in gathering information about the physical world .Economically, lightning considered approximately as one third of the energy used in building running operation. LEDs lights (Light Emitting Diodes) were one of the best solutions in the last few years to save energy that is used in lighting. [110]

LEDs are semi-conductors that have the capability to change electricity into light. Once the light switch is turned on, electrons journey through an area with larger numbers to an area with lesser numbers, and release small pools of energy or photons (which is the lowest form of light). The best part about LED lights is that they don't release any heat unlike traditional tungsten bulbs.

The colour of the LED lights is dependent on the type of semiconductors used, probably seen LED lighting in colours like green, yellow, blue, and white. [111]

Nanotechnology offers new techniques that could be applied in order to improve the performance of current LEDs, investigating new lighting products which are lighter, brighter, cooler and more efficient.

### 3.3.5.1 **Nanotech LED Lighting**

Companies like NANOSYS are using semiconductors of remote phosphorous to develop LEDs, The phosphorous used in this experiment is created from 'nano-materials.' This strange semiconductor material changes the colours of those LEDs, resulting in a rainbow of hues that are brighter. So it will be able to design LEDs in just **about any colour** (Figure 3.54), which is going to be a huge leap forward from the currently used LED displays, in addition to other electronic devices that emit stronger hues.[112]


**Figure 3.54 Nano semiconductor LED cause rainbow colors.**

**Source; http://dvice.com/archives/2010/01/nanotech-trick.php, Retrieved December, 2013**

[110] Fouad, F., **NanoArchitecture and Sustainability**, master thesis, Alexandria University,2012, P 65

[111] **Nano LED lighting,** http://dvice.com/archives/2010/01/nanotech-trick.php, Retrieved December, 2013

[112] **Use of Nanotechnology in Lighting**, http://nanogloss.com/nanotechnology/use-of-nanotechnology-in-lighting/#axzz21INm5BYp, Retrieved July, 2012

### 3.3.5.2 **Organic light emitting diodes (OLEDs)**

**Figure 3.55 OLED lighting.**

**Source; http://www.digitaltrends.com/green-technology/new-oled-light-mimics-natural-phases-of-the-sun-claims-researchers/, Retrieved December 2013**

OLED is a light-emitting diode (LED) whose emissive electroluminescent layer is composed of a film of organic components. This layer of organic semiconductor material is formed between two electrodes, where at least one of the electrodes is transparent (glass).[113]

The organic LEDs which developed by nanotechnology are designed to be formed into thin, flexible sheets that presage a new generation of lighting fixtures and flexible electronics displays. [114] . It is manufactured on glass and metal substrates; it is extremely thin, lightweight and come in various sizes from 25 cm2 up to 225 cm2 active areas. Depending on the substrate material and device structure chosen, it can be transparent, have a diffuse appearance or behave like a mirror in the off state.[115]

All of this makes OLEDs an attractive solid-state lighting that is a compelling candidate to replace conventional lighting systems for large area illumination.

What is interesting about OLED is that it has the possibility to be at **any shape,** which offers a large variety in design, also **controlling its colour as well.**

Scientists recently developed OLEDs that are transparent. Transparent OLEDs could be embedded into laminated glass, enabling windows to switch between transparent glazing and informational display panels, or act as both simultaneously.[116](Figure 3.56).

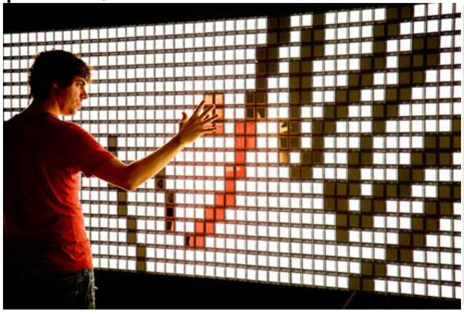


**Figure 3.57 Interactive wall using OLED light and sensors.**

**Source; http://inhabitat.com/reader-tip-philips-special-edition-lumiblade-now-available/, Retrieved December, 2013**

**Figure 3.56 OLED possibilities (transparent-Semi-transparent-solid light).**

**Source; http://www.oled-info.com/oled-light, Retrieved December, 2013**

Figure 3.58 shows Organic Light

[113] OLED, http://en.wikipedia.org/wiki/Organic_LED, Retrieved January, 2014
[114] **Science daily,** http://www.sciencedaily.com/releases/2007/03/070319175617.htm Retrieved December, 2013
[115] **Novaled to introduce ultraflat OLED luminaires at Light + Building,** article, OLED association press, March, 2010, http://www.oled-a.org/press_details.cfm?ID=41, Retrieved January, 2014
[116] Elvin, G. ,**Nanotechnology for Green Building,** Green Technology Forum, 2009, P 45

Emitting Diodes (OLED) - developed by Lomox company- which are affixed to the surface of the wall and can create various lighting effects. The wall becomes a flat screen of light or can be programmed to display light patterns. [117]

**Figure 3.58 Wallpaper with OLED light developed by Lomox.**

**Source; http://www.ubergizmo.com/2010/04/oled-lighting-wallpaper/, Retrieved December, 2013**

**Properties:**[118]

What is interested about OLEDs is the ability to cover large areas; they are extremely thin and applied to substrates of virtually any shape.

This high level of flexibility and efficiency in terms of design, energy saving and application make them highly appealing for lighting designers, manufacturers and consumers.

- Various colours are available and the quality of the emitted light is high.

## 3.3.6 **Insulations**

Building insulations reduce the amount of energy required to maintain a comfortable environment, in addition, it reduces carbon emissions from energy production. Insulation is the most cost-effective means of reducing carbon emissions which is available today. The demand from both public and private enterprise for more energy efficient buildings will lead to significant growth in the insulation sector in the next few years.

### 3.3.6.1 Nano gel

Nano gel is a lightweight nano-porous material, that delivers unsurpassed thermal insulation and light transmission. Nano gel weighs only ninety grams per liter, which makes it the **lightest solid material in the world**. Compared with other insulation materials, nano gel provides a superior combination of thermal and sound insulation, in addition to light transmission and diffusion characteristics. These benefits offer new design solutions for architects, where both optimum natural daylight uniformity and energy efficiency are required.[119]

[117] **Organic Light Emitting Diode (OLED) Paint**, http://nice.asu.edu/nano/organic-light-emitting-diode-oled-paint-lomox, Retrieved Juan, 2013

[118] Mohamed, A. , **Zero Carbon Architecture, The future challenges & the Nanotechnology solutions**, master thesis, Alexandria University, 2010, P 56

[119] Brownell, B., **Transmaterial**, Princeton Architectural Press, 2006, P 38

Figure 3.59 Insulated roof by using nano gel at County Zoo, Milwaukee, WI. USA.

Source; Blaine Brownell, 2006

## 3.3.7 **Nanomaterials versus smart materials**

To study the relevance between nanomaterials and smart materials we should firstly define what are smart materials?

**Smart materials:**

Smart material has many definitions, some refers to it as a substance, other refers to its series of actions, what we concern about it as architects is it's responsively to the external environment and conditions.

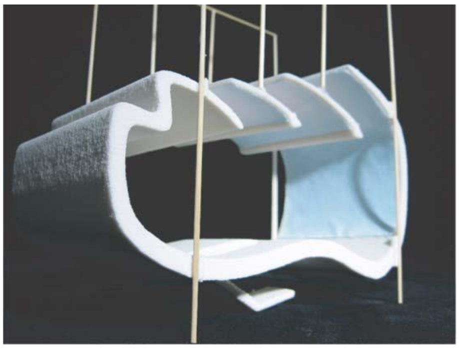


**Figure 3.60 Interior panels of a physical model are covered with photochromic cloth that changes from a base color of white to blue upon exposure to sunlight.**

**Source; Michelle Addington and Daniel Schodek, 2005**

*Smart materials:* The name smart means that a structure –or a material-should be able to respond to environmental exchanges or external impacts to keep it in a safe condition, without substantially changing its original functionalities.[120]

*Smart materials:* are materials that have one or more properties that can be significantly changed in a controlled fashion by external stimuli, such as temperature, moisture…etc [121]

**Mechanisms of smart materials**[122,123]

All smart materials are common in their actuation behaviour (response); however there are two kinds of smart materials with two different mechanisms.

-Property change:

The Property-changing class of smart materials has the greatest number of potential applications in architecture. These materials undergo a change in a property or properties – chemical, thermal, mechanical, magnetic, optical or

[120] Lau,K, **Smart Composite Materials** ,paper, International Conference on Multifunctional Materials and Structures (MFMS 08),Hong Kong, July, 2008

[121] **Smart materials,** http://en.wikipedia.org/wiki/Smart_material , Retrieved October, 2012

[122] Addington, M., and Schodek, D., **Smart Materials and new technologies** , Architectural Press, 2005, P 80

[123] El Sayed, L.**, Dialectics of technology and form- application of smart and nanotechnology in bioclimatic architecture**, master thesis, Cairo University, 2011, P 70

electrical – in response to a change in the conditions of the environment (Figure 3.60).

<u>-Energy exchange:</u>

The next class of materials that is expected to have large penetration into the field of architecture is the energy exchanging class. These materials, which can also be called 'First Law' materials, change an input energy into another form to produce output energy in accordance with the first law of thermodynamics.

The next table shows material classification according to its smartness in behaviour:

| Classification | Description |
|---|---|
| Traditional materials and high-performance materials | Fixed responses to external stimuli (material properties remain constant under normal conditions) |
| Type 1 smart materials: Property-changing | Intrinsic response variation of material to specific internal or external stimuli |
| Type 2 smart materials: Energy exchanging | Responses can be computationally controlled or enhanced |
| Smart devices and systems | Embedded smart materials in devices or systems, with intrinsic response variations and related computational enhancements to multiple internal or external stimuli or controls |

**Figure 3.61 Distinguishing materials according to its smartness and intelligent.**

**Source; Michelle Addington and Daniel Schodek, 2005**

Many nanomaterials are considered to be smart materials; on the other hand other nanomaterials couldn't apply the notion of responding and interaction in its behaviour, so we can't consider it as a smart material. However it might be called high performance materials and they often have what might be called selected and designed properties. For instance the additives that can optimize properties like stiffness and strength.

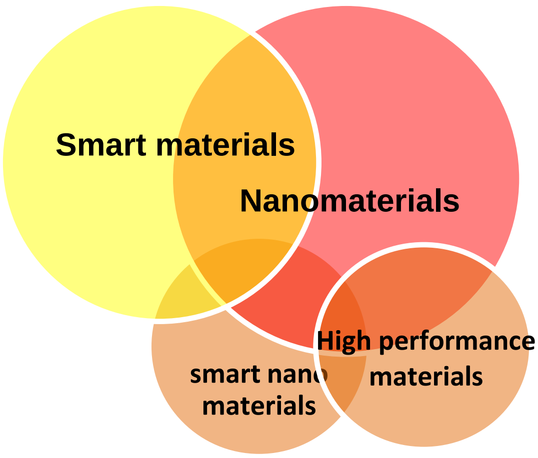



**Figure 3.62 The relationship between smart materials and nanomaterials.**

**Source; by the researcher**

### 3.3.8 **Summary**

Nanotechnology provides a whole new palette of both smart and high performance materials that could potentially have profound effects on building design; emphasising on material role in the design process.

At present the most promising application could affect architectural form is structural materials; indeed material like carbon nanotube is expected to be a leap in construction materials field due its magnificent possibilities, moreover, significant advancements include the ability to improve the performance of conventional materials, especially steel , concrete and composite materials through the addition of nanomaterials in production phase. Also, nano coatings, lighting and insulations directly affect building's performance and its technicality functions.

Regarding nanotechnology applications in architecture, we can clarify that according to the timeline in which the first products available in market are nano insulations and coatings. However there are many applications under development such as nano lightings and nano devices, furthermore, new structural materials and systems which are under research and are expected to affect architectural form and functions.

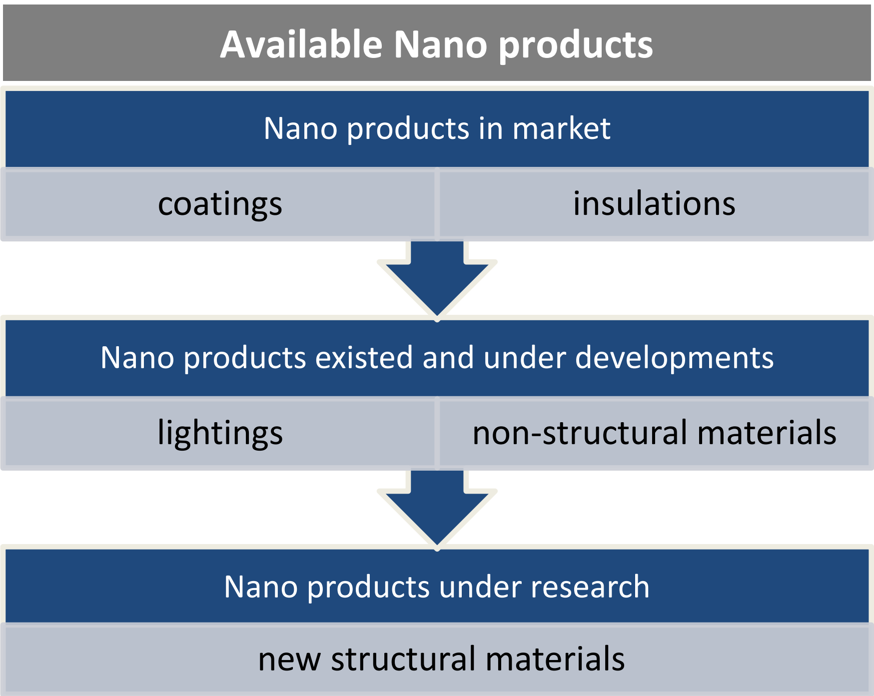



**Figure 3.63 Nanomaterials products timeline layout.**

**Source; by the researcher**

# Chapter 3

- Nanotechnology
- Nanoarchitecture (NA)
- Nanomaterials in architecture
- **Nano systems and devices in architecture**

# Part 2 Nano systems and devices:

## 3.4 Nano systems and devices in architecture

### 3.4.1 Introduction

Inspirations from nature and living systems have been combined with architecture thousands years ago. As it mentioned in chapter 2, it was limited to transmit external shapes and structures, and then it goes beyond that to include natural performative behaviour, involving its ability of sensing and actuation. This behaviour needs an advanced technology in order to enable our today's buildings to be an interface which gather data from outside conditions and inside needs and response to it, imitating living systems and its actuation.

### 3.4.2 Nano systems (Biological Nanoarchitecture)

Nano scientists are now examining how the living world 'works' in order to find solutions for problems in the 'non-living' world. Investigating this could be achieved through observing natural adaptation, conditioning and how organism's behaviour becomes dependent on the occurrence of a stimulus in its environment. As a result; this suggests a careful calibration between behavioural and performative scope in relation to specific ranges of environmental conditions. The capacity for this can be embedded in the makeup stage of materials and in the logic of **material assemblies** (Which is the core of how nanomaterials are built). Self-organizational and behavioural capacity of the built environment can thus be facilitated by a related material, fabricating, manufacturing and assembly approach.[124]

Engaging with biological architecture, which is discussed in chapter two; nanoarchitecture could offer systems and methodologies that could simulate living system's growth and behaviour. It will allow having designs that interact better with the human senses. Experiencing this type of architecture could feel more "natural" and less forced than many of the designs we experience today. [125] This will be achieved through systems that depending on nano devices which will add the ability of sensing and actuation to buildings, making building's envelope act as responsive interface between inner spaces and external conditions.

[124] Castle, H., **Techniques and Technologies in Morphogenetic Design**, Wiley, 2006, P11

[125] Lehman, M., **The Future of Architecture with Nanotechnology,** article, sensing architecture magazine, 2009 http://sensingarchitecture.com/1347/the-future-of-architecture-with-nanotechnology-video/, Retrieved December, 2013

#### 3.4.2.1 Molecular Nanotechnology (MNT) [126]

Molecular Nanotechnology (MNT) represents a new phase in the evolution of manmade structure. With co-operation with NASA, many researches are in progress to investigate MNT and its potentials. MNT is capable of producing almost any chemically stable structure that can be specified. It is possible to assembly materials in a molecular scale with particular patterns. The molecular structure harnesses the energies from chemicals and electricity rather than current major power resources.

William Katavolos[127] at Pratt Institute remarks, "We are rapidly gaining the necessary knowledge of the molecular structure of these chemicals with the necessary techniques that will lead to the productions of **materials that will have a specific program of behaviour built into them**." The word ‘growth” is extensively used in the field of MNT; the molecular growth brings us back to natural form.

These performative behaviours until now are known to exist only in living organisms. In future molecular nanotechnology will add the ultimate organic factor, which is; the growth process itself.

The **notion of growing** in architecture is not new; it was proposed in 1961 by Katavolos and expanded by the architect and morphologist Vittorio Giorgini in “Early Experiments in Architecture Using Natures Building Technology” in 1997.

Designing a material with a specific behaviour could exist with mimicking DNA. Biologists claim that the *artificial DNA* is possible, at this time, to transfer the exact pattern of DNA to an artificial code. Architect-morphologist Haresh Lavani states, "Coupled with biological (DNA based) or other (chemical-physical) building processes, the artificial genetic code enables**, growth, adaptation, evolution, and replication** of buildings permitting architecture to design itself”.

It is important to understand that this kind of growth is a **mechanical one and not biological** case. As physicist Eric Delexler[128] wrote “The great difference is that nanotechnology use not living ribosome but robotic assemblers, not veins but conveyor belts, not muscles but motors, not genes but computers, not cells dividing but small factories producing products and additional factories”.

The British cybernetics, John Frazer speaks to architects of the future of a new design process as "the New Genetic Language". Architects will start with the usual conceptual sketch. Secondly it must be redesigned by a computer; thirdly, engineered; then molecularly modelled, converted to

[126] Johansen, J., **Nanoarchitecture: A New Species of Architecture**, Princeton Architectural Press, New York, 2002, P 151, 154

[127] **W. Katavolos,** has been part of the Architecture School at Pratt Institute since the sixties. He is co-director of the Center for Experimental Structures. His manifesto, Organics, published in Holland in 1961 became the basis for chemical architecture.

[128] **Eric Delexler**, An American engineer best known for popularizing the potentials of molecular nanotechnology, he was involved in NASA studies 1975 and 1976,his 1991 doctoral thesis at MIT(Massachusetts Institute of Technology) was published as the book **Nano systems**, which received Association of American publisher award for best computer science book of 1992

software, and finally constructed into a code. The code will replace all blueprints and specifications.[129]

**Coding:**

MNT products can't grow by themselves; it must be re-designed, engineered, molecularly modelled and translated in to functional software and **coded**. As certain buildings familiar to us have already been coded as to schema, plan, section, mass, dimension, material, details and construction strategy, same goes to newly designed building concepts which can be easily coded as well.

Carbon nanotube CNT will be the main material used in this technique, because of its strength, light weight and transparency. It could be able to produce clear sheets of diamond, a few millimetres thick, to form the exterior membrane of a building. This creates a structure which will be integral with building shell, walls and enclosure.

The American architect John Johansen[130] proposes these following projects in his book "Nanoarchitecture", 2002. However, till now we are dealing with theoretical studies and their applications doesn't exist yet, but in contrast John Johansen argue that he is just an architect, he doesn't have any illusion what it might be, he just listen to scientists, they say that you can do this or that in this particular way so he goes through this knowledge and design these previous proposals. As architects; we should be more aware about new technologies and its potentials, and believe that everything is possible.

**Examples**

A- Molecular-Engineered House (The house of leaves) for the year 2200[131]

John Johansen imagines the molecular engineered house in 2200; he conceptualizes material growth stages day to day. It is a theoretical proposal to investigate how material behaviour could be. The designer claims that the building will go through several stages (a stage per day).

**The first three stages:** Excavation begins on site, and then vats delivered to building site with bulk materials in liquid form. The various materials are then pumped into the vats. After that the code developed from an architect's designs and then engineering and molecularly modelled, is ceremonially placed in the vat.

**Stage four and five:** Molecular growth starts with roots stemming from the chemical composite. Reaching up and out of the vat to ground level, the roots form grade beams extending horizontally to the edge of the house, where they grow upward in curvature forms to support the superstructure.

[129] Johansen, J., **Le Nuove specie dell'archiettura**, article, L'ARCA, issue210, http://issuu.com/zirak/docs/131111101453-6f5b6d01c50049ea984ec9f3c431d49a#, Retrieved December, 2013

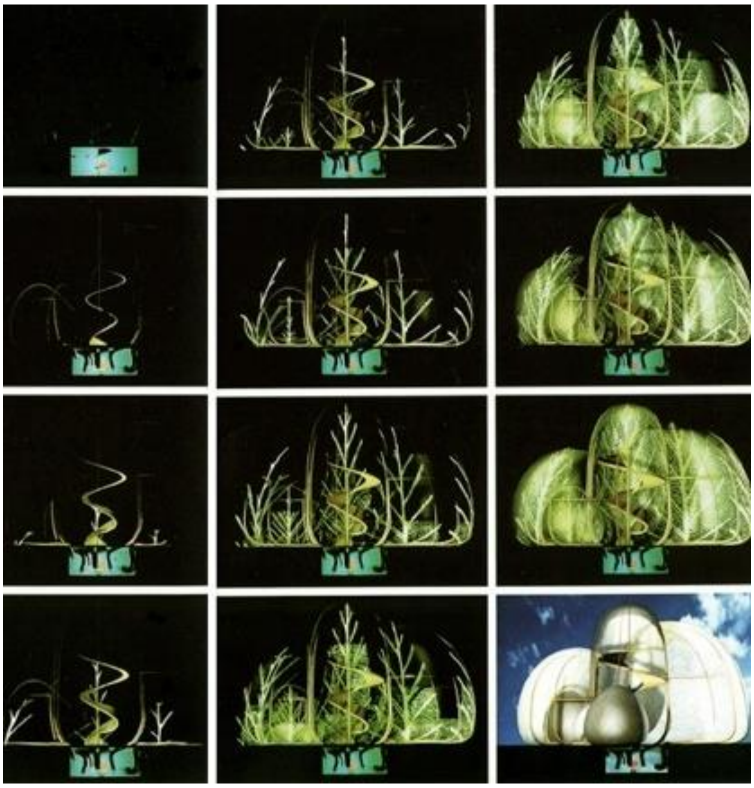
[130] **John M. Johansen**, an architect and a member of the "Harvard Five", he was taught the fundamentals of modern architecture by Walter Gropius, the founder of Bauhaus, he is the author of **Nanoarchitecture** book.

[131] Johansen, J., **Nanoarchitecture: A New Species of Architecture**, Princeton Architectural Press, New York, 2002, P 133

Cross ribs connect the grade beams and form the ground floor platform (Figure 3.67).

Superstructure starts with the extension of primary exterior and interior vertical ribs in order to creating the lattice (outer skin).

The lattices (building skin) are of varied densities, and are programmed to adapt and meet stress requirements—being less dense and more open in pattern where door openings are specified.



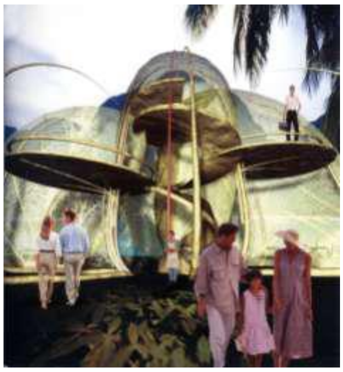


**Figure 3.64 Exterior view of the molecular engineered future house.**

**Figure 3.65 Molecular-Engineered House strategy of growth.**

**Source; Johansen John M., 2002**

**Figure 3.66 The natural walls of the molecular engineered future house.**

## Stage six, seven and eight:

Ethereal light glows and appear through the translucent membranes. These membranes change from translucent to opaque with a signal, providing a view anywhere at any time according to users request. Interior furnishing grow; "Body support," which known previously as sofas, chairs, tables, and beds, are springing up from the floor, out from the wall ribs, and hanging from the arched vault. Furniture will be as an extension of the structural system.

The membrane responds to outer conditions of the immediate environment to make an interaction between internal and external space. Finally after six stages of molecular growth, the house becomes ready to anticipate our changing needs.

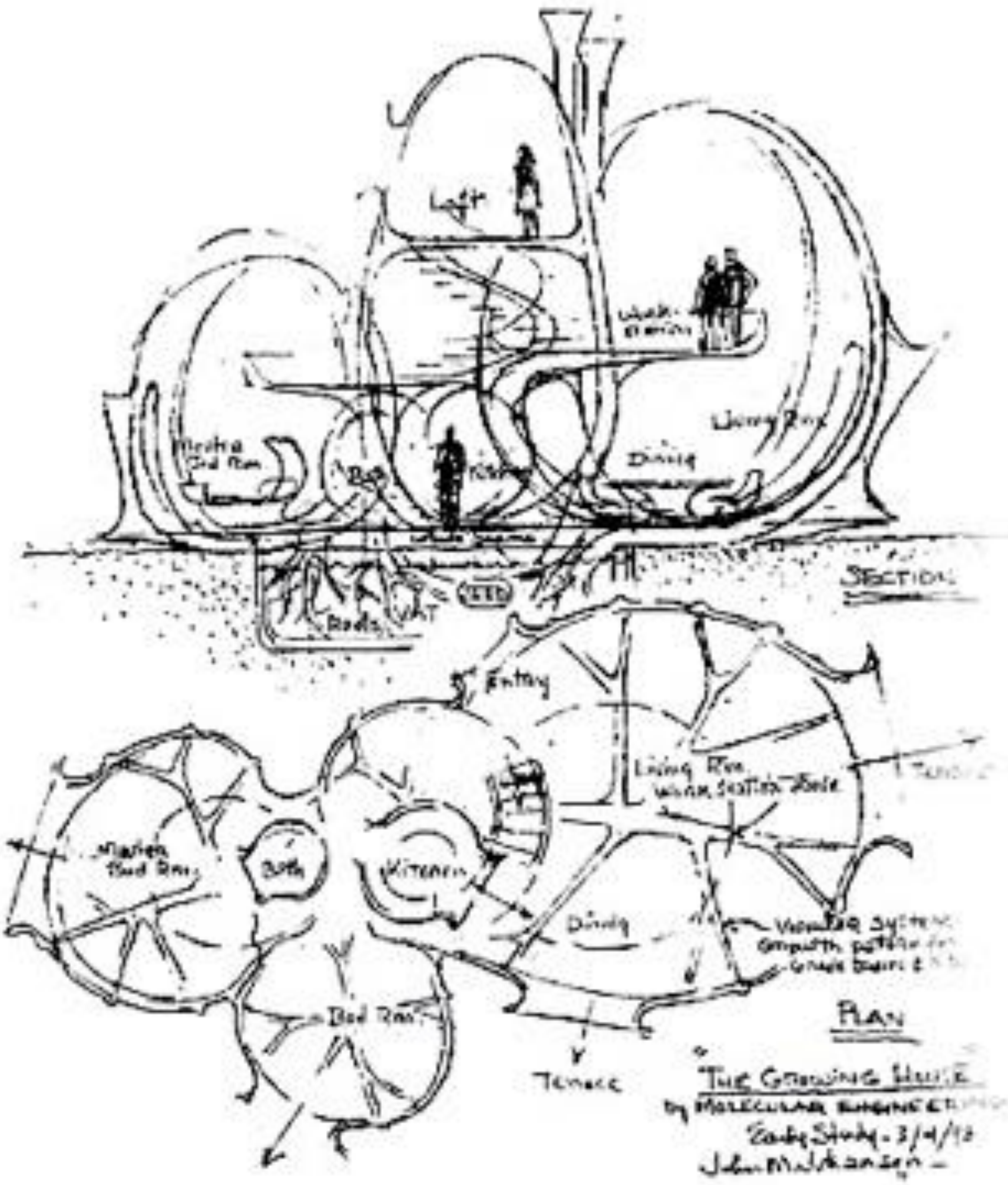



**Figure 3.67 A Plan and longitudinal section of the growing molecular-engineered house.**

**Source; Johansen John M., 2002**

B- Metamorphic Capsule

The metamorphic capsule is one of proposals that designed by John Johansen depending on molecular nanotechnology; it is an enclosure nano (skin). Its surface consists of a fixable thin-film membrane whose form, opacity, and colour are controlled by electromagnetic field. It controls nodes on the object with surrounding field. Here, this surrounding field is formed by a system of nodes attached to a structural framework, with corresponding nods placed on the outer surface of a fabric capsule place within the field.

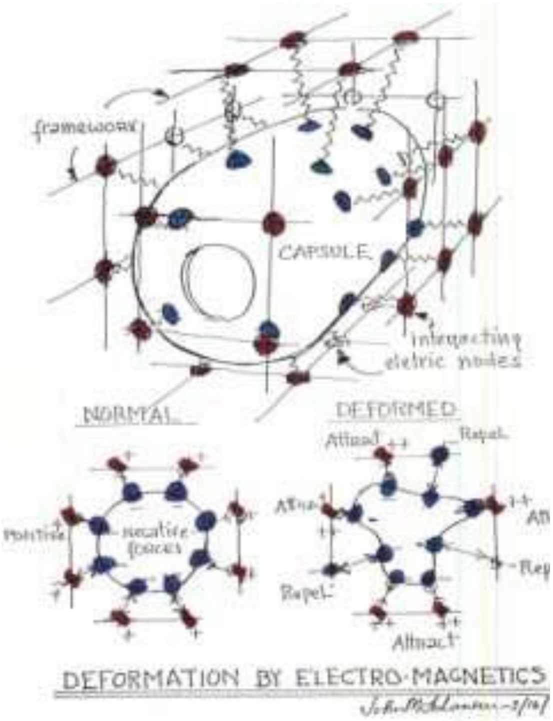



**Figure 3.68 The deformation that occurred by electro-magnetic of the metamorphic Capsule.**

**Source; Johansen John M., 2002**

Continuous air pressure is required to sustain the form of the capsule. The power of the attraction and repelling forces sent to each node determine the overall shape of the capsule. By changing the power which is sent to the nodes and its amount it will cause the capsule to undulate and change colour and the degree of opacity or transparency as well, this ability to morph skin from opaque to transparent is termed 'morphability' one of the quintessential aspects of molecular nanotechnology. Other visual and audible stimuli can also be controlled.[132]

This idea presents a new concept of liveable spaces that could adapt with its users density and also controls the whole volume of space. Human movement could motivate the visual effects of the capsule which can add a memorable visual experience to the users.

**Figure 3.69 3D visualization for the outer frame controlling the nodes with electromagnetic field.**

**Source; Johansen John M., 2002**

[132] Johansen, J., **Nanoarchitecture: A New Species of Architecture**, Princeton Architectural Press, New York, 2002

C- The Air Quilt

This project consists of two layers forming the space in an order established by a geometric pattern of hexagons and pentagons. Each are quilt of spherical air malleable chambers. This project present an adaptive building that can adjust its interior volume to accommodate changing needs which is created by distorting the chambers into desired configuration.

Distortion of the quilt surface is achieved by the variable expansion and contraction of the two layered strata of hexagonal-air chambers. Transferring air from the chambers in the outer skin to the inner skin results in a deformation and bending actions which cause a convex form. Conversely, air passing from the inner skin to out creates a concave form as seen from the interior (Figure 3.70). The air pressure sustains the envelope. Small air pumps, which prompted by a computer system used to power the air transference, by substituting helium gas for air, this structure would lift off. To keep the structure stable it could be tethered by cables to the ground. Small jet motors also could be used in order to lift and lower it and to make it stable against wind, control its motion and navigate it. [133]

Air chamber material is suggested to be from carbon nanotube or its derivatives. Material scientists are working on mixing carbon nanotubes and grapheme into more traditional substances to create hybrid materials that are much stronger, or are conducting, while still being malleable.[134] Also nano-sensors (will be explained later) could be embedded to the two skins in order to transfer data about occupant's needs.

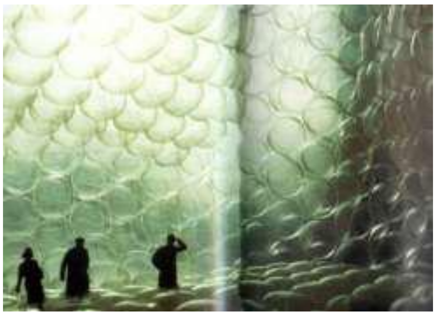


**Figure 3.70 Left; a sketch for air chambers. Right; the internal view.**

**Source; Johansen John M., 2002**

[133] Johansen, J., **Nanoarchitecture: A New Species of Architecture**, Princeton Architectural Press, New York, 2002, P 97
[134] Der Zande, A., **Carbon Nanotubes and Graphene, Fabrication, Measurement and Applications**,paper, Cornell University

#### 3.4.2.2 **Digital fabricated nanomaterials**

Introduction

The knowledgement of novel trends in design such as nanoarchitecture and tools like digital fabrication, make us understand the integration between nanotechnology and digital fabrication in order to create new materials for building skins with new potentials. Designing new materials from nano and macro scale in addition to select specific properties which we need are now available with digital fabrication techniques.

The experience that gained from natural laws (behaviour, adaptation) which could be transfered into technical solutions in architecture is more important than superficially transition; it goes beyond that to involve living organisms systems, for instance; the structural properties of wood are not unlike most biological materials, hardness and strength is not same, it can widely vary when it is measured with the growth grain or against it. This is dependent on wood structure, so if we could control –with the help of digital fabrication-the architecture of each material starting from its nano scale with the help of nanotechnology to build it atom by atom, we could gain novel and improved materials for construction that have sense of adaptation instead of our current material strategies that appear to be much less effective, and mostly wasteful.

In addition we can consider nanomaterials itself as a digital fabricated material, which using nanoscale to build it atom by atom. This is exactly the core of **materialisation.**

What is digital fabrication?

Digital fabrication is a design tool. Enabling the calibration between virtual models (produced by computational design tools) and physical artefact, it is a digital practice which has the potential to narrow the gap between representation and building; affording a hypothetically seamless connection between design and making. Laser cutters, CNCs and 3d printers are the used tools. It is not only an architecture tool, it ultimately the method to form almost anything.

Digital fabrication used during the development of the glass fixings for the roof of Zaha Hadid's stations in Austria, 2007 (Figure 3.71), where (Bollinger + Grohmann) was responsible for the structural design and the facade engineering to be executed. The connection of the steel structure and the double-curved glazed skin required a solution which embodies the logic of digital design and manufacturing. The structural system is based on a series of ribs that follow the curvature form of the skin.[135]

[135] Castle, H., **The new structuralism**, Wiley, 2010, P 38


**Figure 3.71 Left; Innsbruck railway station, Australia. Right; a 3d fabricated structural model.**

**Source; Helen Castle, 2010**

Variable property design (VPD)

It is a design approach, a methodology and a technical framework by which to model, simulate and fabricate material assemblies with varying properties designed to correspond to multiple and continuously varied functional constraints.

**Figure 3.72 3D printing technique enables to print multi materials with specific distribution.**

**Source; http://www.creativeapplications.net/objects/neri-oxman-and-mediated-matter-at-the-mit-media-lab/, Retrieved December 2013**

Neri Oxman -the founder of Materialecology at MIT (Massachusetts Institute of Technology) -explains VPD that it depends on digital fabrication technology, it is inspired by nature, and as every organism grow to get their functions, the same to architectural design; "*we tend to work with elements, put them together to create a large amount of functions as a result of growth*" Neri Oxman. This could be produced by using digital fabrication tool; 3D printing, that uses multi materials in order to control the material composition to get multi functions in one material alloy (Figure 3.72).

Example:

Neri Oxman, Beast: Prototype for a Chaise longue, Museum of Science, Boston, Massachusetts, 2009:

The chaise combines structural, environmental and corporeal performance by adapting used materials thickness, pattern density, stiffness, flexibility and translucency to human body load, curvature and skin-pressured areas respectively. The multi-materials pattern was fabricated with five different materials, colour-coded by elastic moduli (Figure 3.73).

Stiff and soft materials are distributed according to the user's structural load distribution; soft silicon 'bumps' are located in regions of higher pressure.[136]

**Figure 3.73 A Prototype for a Chaiselongue, Museum of Science, Boston.**

**Source; Helen Castle, 2010**

Digitally fabricated nanomaterials for breathable building skins

By using digital fabrication; Holcim foundation (Holcim Next Generation Award for Sustainable Construction, North America, 2008) , explores and offers a novel approach to design, fabricate and maintain building skins by controlling the mechanical and physical properties of spatial structures inherent in their micro and nano structures. The method offers construction without assemblies, such that material (alloy) properties vary locally to accommodate for structural and environmental requirements. This methodology stands in contrast to functional assemblies and kinetically actuated facades, which is required more energy to operate. Next generation construction materials offer spatially-differentiated material compositions and structural forms. These facilities are combination of structural, optical and fluidic behaviours which are governed by the material architecture.

Such material architectures could simultaneously bear large structural loads; change their transparency so as to control light levels within a space, and open and close embedded pores so as to ventilate a space.

Holcim foundation suggests an exemplary material architecture that developed by **nanotechnology** which can be enabled by hierarchical combinations of carbon nanotubes (CNT), polymers and traditional building materials such as steel, wood and glass. The growth process for CNTs can be controlled to give hierarchical organization of CNTs into functional networks, which act as base material of the functional matrix materials that interact with the CNTs to give a multifunctional skin. Holcim demonstrate the notion of a breathable façade by controlling passive material distribution and actuation that is ideally and potentially self-powered by the façade itself.[137]

[136] Castle, H., **The new structuralism**, Wiley 2010, P 83
[137] **Construction in vivo,** http://www.nanobliss.com/constructioninvivo/ , Retrieved December 2013

### 3.4.2.3 Kinetic nanoarchitecture

Introduction:

Kinetic Architecture:

New systems will allow the realization of buildings which is able to create a dynamic relationship with environmental factors and with its users. These systems add a possibility of modifying material performance, appearance and even their shape in relation to external stimuli, in order to ensure environmental control and energy savings strategies. Architecture itself will be used as a communication “interface” that enhancing the capability of information exchange and mutual interaction.[138]

Buildings envelop design and manufacture uses different layers of smart materials in order to achieve a wide array of functionality, and to get adaptive buildings that response to external and internal conditions: heat, humidity, light, sound and wind. This movement in building skins design surly brings new forms and functionalities that will add new dimension in building design, and its reactivity level with environment and human-environment relations.

Kinetic architecture represents a new design trend that could make our building more smart and interactive. Kinetic building skins could be achieved not only by a physical movement of the occupant, but also by a sense of movement due to the optical effects of changes in light or the presence(Figure 3.74) .However many definitions of kinetics, such as Jules Moloney’s definition of kinetics, are limited only to four geometric transformations in space – translation, rotation, scaling – and movement via material deformation (Figure 3.75). Considering the incorporation of motion graphics via projection screens, LEDs or visual effects, are not included in the scope of kinetics.

**Figure 3.74 Electro chromic glass creates an interactive architectural facade.**

**Source: http://www.interactivearchitecture.org/dvitral-electrochromic-glass.html, Retrieved December 2013**

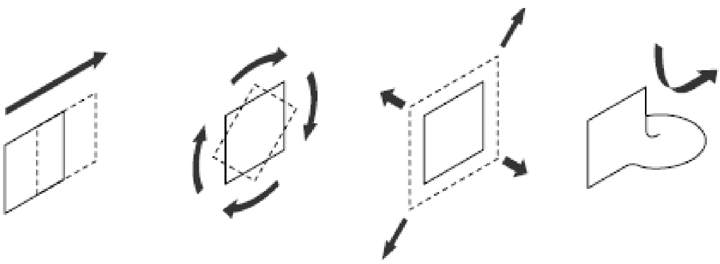


**Figure 3.75 Definition of kinetics as three spatial transformations and material deformation.**

**Source; Jules Moloney, 2011**

[138] Leone, M., **Nanotechnology for Architecture. Innovation and Eco-Efficiency of Nanostructured Cement-Based Materials**, paper, Architectural Engineering Technology conference, 2012, P 4

There has been much speculation on the possibilities for nanotechnology in spatial deformation through controllable variance in material property.[139] this could be through nano properity-change materials or nano devices.

The next example will illustrate how the ability of sensing and actuation (smartness) with the capability of being both morphed and movement could be achieved by the using of nanotechnology's methodologies in building's façade.

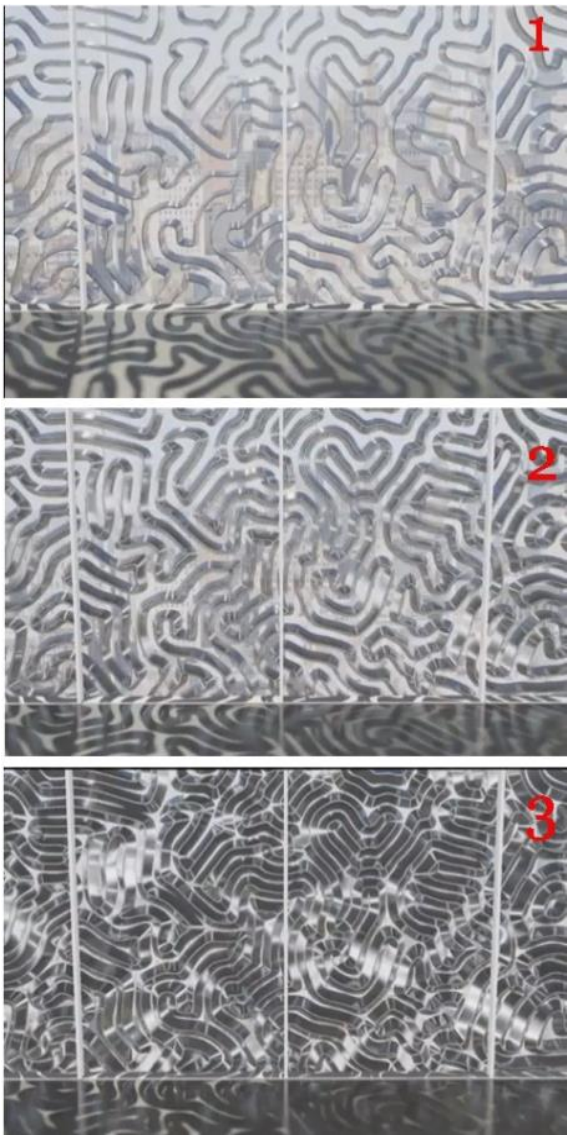



**Figure 3.76 The morphed skin expands due to sunlight amount.**

**Source; [http://www.fastcodesign.com/1662975/mighty-building-facade-beats-solar-heat-with-mechanical-muscles](http://www.fastcodesign.com/1662975/mighty-building-facade-beats-solar-heat-with-mechanical-muscles), Retrieved December 2013**

Kinetic Nanoarchitecture

1. Homeostatic façade, China:

Many examples have applied a responsive, passive solar control in the form of natural behaviuor; like irises movement, (Arab institute- Figure 2.16). Homeostatic building façade (designed by Decker Yeadon) is applying same concept but with using a different system, that is translated hydrophobic surface properties of the acacia leaf into a building façade, it uses a property-change material based on nanotechnology (dielectric elastomer that uses temperature or electricity to change shape). Heat from sun flex and relax a swirly system of polymer fins. The fins are coated in a silver film (Figure 3.78). When the sun hits it and heats it up, the fins material expand to create more shade; when it cools down, it contracts to let in more light. No computer programing or physical adjustments required. The whole system would be sandwiched between two sheets of glass.[140][141]

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[139] Moloney, J., **Designing Kinetics for Architectural Facades**, Routledge, 2011, P 7

[140] **Mighty Building Facade Beats Solar Heat With Mechanical Muscles,** http://www.fastcodesign.com/1662975/mighty-building-facade-beats-solar-heat-with-mechanical-muscles ,Retrieved November, 2013

[141] Saxl, O., "**Nanotechnology – for sustainability across the board**", article, Nano magazine, issue 19,August, 2010 http://issuu.com/nanomag/docs/nano_light

Besides its function as a UV protector, this system provides a morphed façade that changes building appearance from solid to transparent, providing an advantage of privacy to its users.

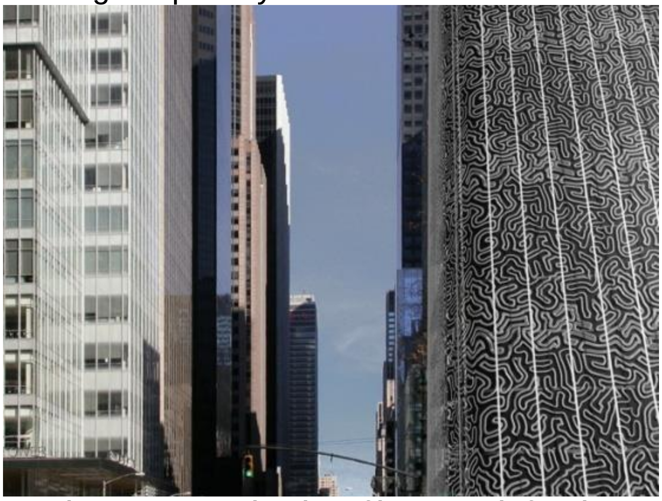


**Figure 3.77 Exterior view of homeostatic façade.**

**Source; http://www.fastcodesign.com/1662975/mighty-building-facade-beats-solar-heat-with-mechanical-muscles, Retrieved November, 2013**

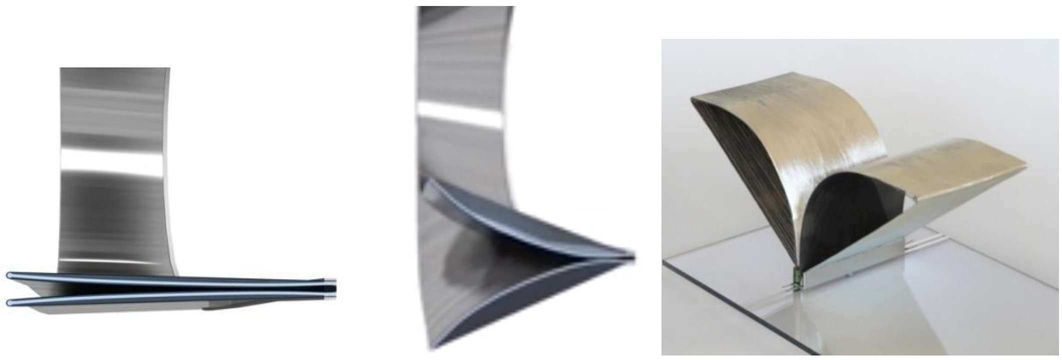


**Figure 3.78 Homeostatic façade's elastomer unit which flex and relax.**

**Source; http://www.fastcodesign.com/1662975/mighty-building-facade-beats-solar-heat-with-mechanical-muscles, Retrieved November, 2013**

**Figure 3.79 Homeostatic façade from inside.**

**Source; http://www.fastcodesign.com/1662975/mighty-building-facade-beats-solar-heat-with-mechanical-muscles, Retrieved November, 2013**

2. Light caterpillar cabinet (LC2)Project:[142]

LC2_Project has been shortlisted for WA Architecture Awards 8th Cycle in September 2010, and announced as a winner by WA Awards 2010s last cycle.

Over all view, designer imagines that in the future surrounding environment will embrace dynamic and spontaneous architecture, in the sense that has not been planned or organized, but happens by itself, it will apply all aspects of responsively.

The project consists of a group of cabinets connected together. The designer resembled these cabinets with butterfly's caterpillar.

In this project; buildings will be as bodies, bodies of a species. These bodies are self-justified and adapt to the places where they fix. The structural coloration of butterflies is depending on nanotechnology to produce paints and LEDs. In the future paint will be a nice coating of energy generating by solar cells on flexible sheets using carbon nanotubes, that becomes superconducting which leads to a metallic behaviour. In their desire to adapt they can be of any colour and multiple skins to generate light, shadow, worm, cold, in order to supply the needs of the environment and to deal with sustainable development to a green self-production cycle in a sort of self-sufficiency, letting architecture species act as shelters.

This project is emphasisng the acceptance that architecture is a living and dynamic system, with a wide range of species, that adapts and develops itself, even with the acceptance that architect role in this process is radically changing.

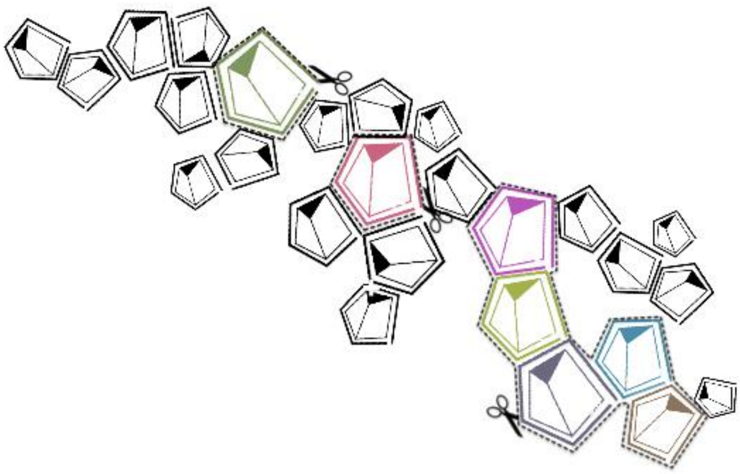


**Figure 3.80 A group of cabinets connected together to form LC2 project.**

**Source, http://archiactivity.wix.com/mafalda_carmona/lc2#!__lc2, Retrieved January, 2014**

[142] **LC2Project**, http://archiactivity.wix.com/mafalda_carmona/lc2#!__lc2, Retrieved January, 2014

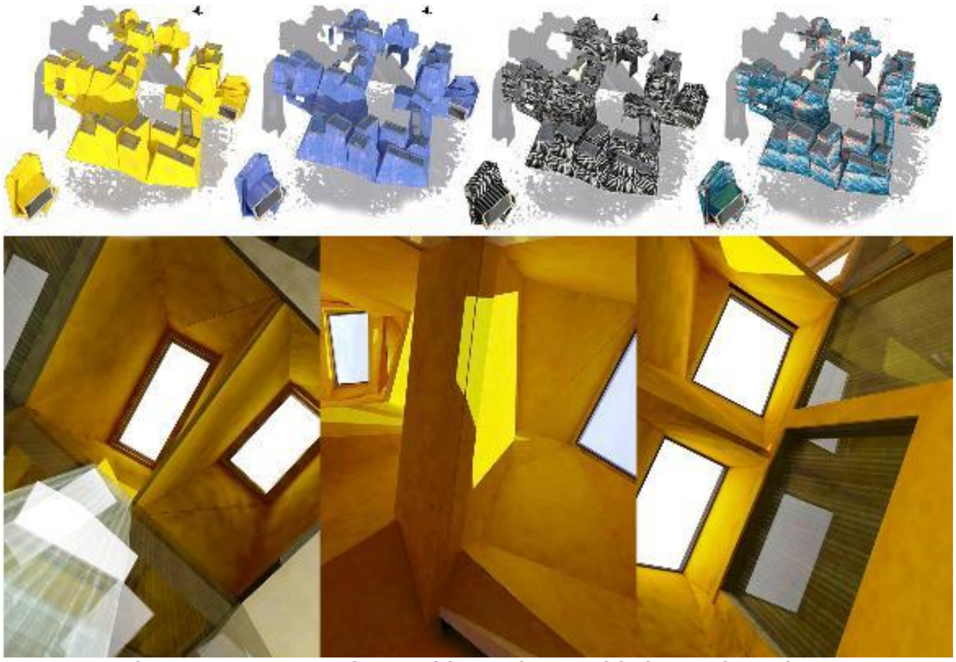


**Figure 3.81 LC2 project, cabinets that could change its colour.**

**Source; http://www.worldarchitecture.org/world-buildings/vhzc/lc2-project-light-caterpillar-cabinet-building-page.html, Retrieved January, 2014**

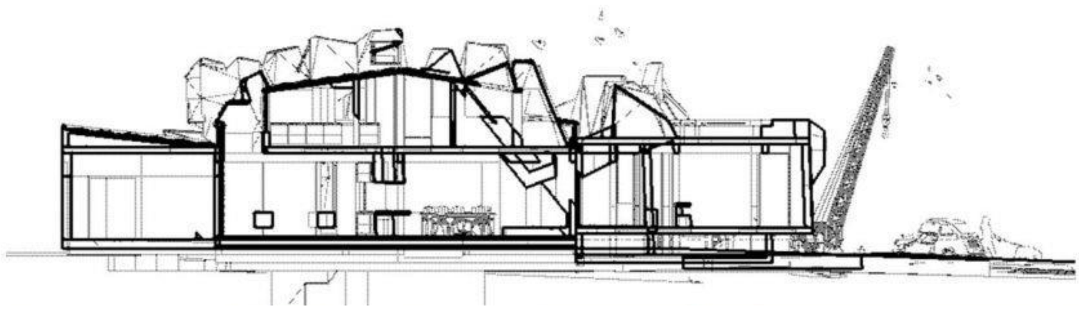


**Figure 3.82 Section at LC2 project.**

**Source, http://archiactivity.wix.com/mafalda_carmona/lc2#!__lc2, Retrieved January, 2014**

## 3.4.3 **Nano devices**

### 3.4.3.1 **Nanotechnology and smart nano sensors**

The term sensor derives from the word sense, which means to perceive the presence or properties of things. A sensor is a device that detects or responds to a physical or chemical stimulus (motion, heat, etc.). A sensor directly interacts with the stimulus field. In normal usage, the term sensor also signifies that there is an output signal or impulse produced by the device that can subsequently be interpreted or used as a basis for measurement or control.[143]

Nano sensors

Nanotechnology will affect sensor's technology by producing a new generation of nano sensors. These tiny sensors can be embedded into building skins or the structural elements in order to gather data about the environment, building's users and material performance. In this case there will be an interaction between buildings and their users. Initially building components will become smarter, gathering data to make our buildings behave as a network of intelligent.

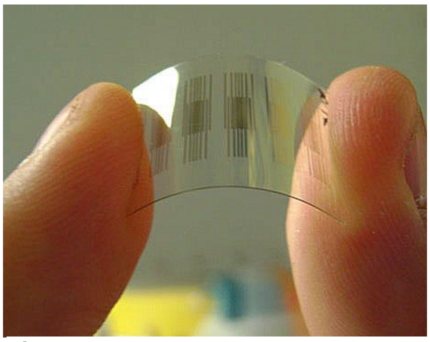


**Figure 3.83 Nano sensor.**

**Source; http://www.azonano.com/news.aspx?newsID=13822, Retrieved December 2013**

Nano sensors building components will become smarter, by gathering data on temperature, humidity, vibration, stress, cracks, decay, and a host of other factors. This information will be invaluable in monitoring and improving building maintenance and safety.[144] Moreover, in the near future it is expected that road surfaces, bridges and tunnels may be able to count act pollution.

**Figure 3.84 The Confederation bridge in Canada.**

**Source; http://msride.ca/tag/confederation-bridge/, Retrieved December 2013**

Wireless nano sensor

Wireless nano sensors are devices equipped with storage, processing, sensing, and communication units, with size ranging from one to few hundred of nanometers.[145]

According to the international journal of materials and structural integrity study, wireless sensors based on nanotechnology could be used as an alert to cracks and damages in buildings, bridges, tunnels and other structural elements.

[143] Addington, M. and Schodek, D., **Smart Materials and new technologies** , Architectural Press, 2005, P 114
[144] Elvin, G., **Nanotechnology for Green Building**, Green Technology Forum, 2009, P85
[145] Piro, G., Grieco, L. A., Boggia, G., & Camarda, P. **Simulating Wireless Nano Sensor Networks**, paper, NS-3 conference, 2013, P 1

It will allow engineers to monitor deterioration and cracking without any physical intervention. Similarly, sensors in bridges could monitor vibrations and loads, enabling researchers to assess weaknesses and fix them long before they are apparent to human inspectors. Road sensor networks could gather and provide data to transportation operators to manage congestion and incidents better and detect fast-changing weather conditions.[146]

Example: The Confederation Bridge in Canada has a length of 12.9km, making it the longest bridge over iced water in the world. Sensors were built into advanced composite materials to measure corrosion risk on the bridge (Figure 3.84). [147]

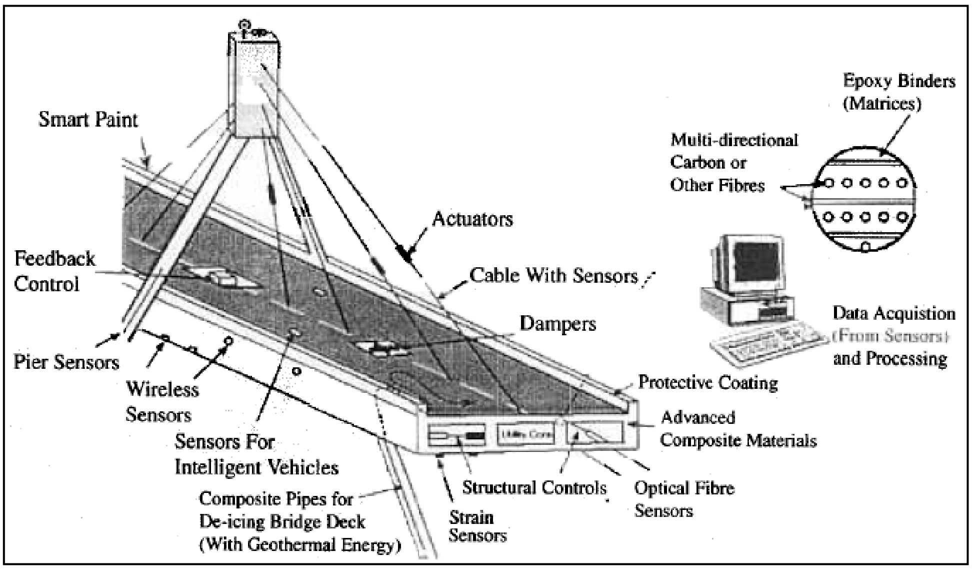



**Figure 3.85 Using smart nano-sensors that are monitoring the performance of structural elements.**

**Source; Mulenga, D.M. & Robery, 2010**

[146] Mulenga, D.M. & Robery, "**Can Nanotechnology Address Today´s Civil Engineering Challenges**?", paper, Fifth International IABMAS Conference, Philadelphia, USA, 2010, P 4

### 3.4.3.2 **Nano solar cells**

Flexible solar cells

Revolutionary thin nano solar cells are now entering the market, and are expected to be significantly less expensive than current silicon-based solar cells. Its nano-structured materials that makes fabricating solar cells which is more efficient, and enables solar cells to be available in various colours. The other dramatic advantage of organic thin films is their flexibility, which will enable their integration into far more building applications than conventional flat glass panels. This creates more possibilities of combining solar cells with windows, roofs, and facades, and overcomes the aesthetic concerns that some architects hold against rigid flat panels, which can hardly be integrated into building facades. It could be integrated into windows, roofs, and facades, potentially making almost the entire building envelope a solar collector.[148]

**Figure 3.86 Flexible solar panels.**

**Source; Dr. George Elvin, 2009**

Colored nano solar panels

Solar cells have been known as a smart solution to save buildings energy; however nanotechnology produced new techniques which embedded into solar panels and make it more efficiency, because of the lack of need to direct sun light, which differs from traditional solar panels which require direct sun light. With normal solar cells, you need direct sunlight for them to generate power, and if the panels are at all shaded the efficiency drops significantly. A new type of solar cell is making huge waves because it can generate power from diffuse light using a specialized colored panel.[149]

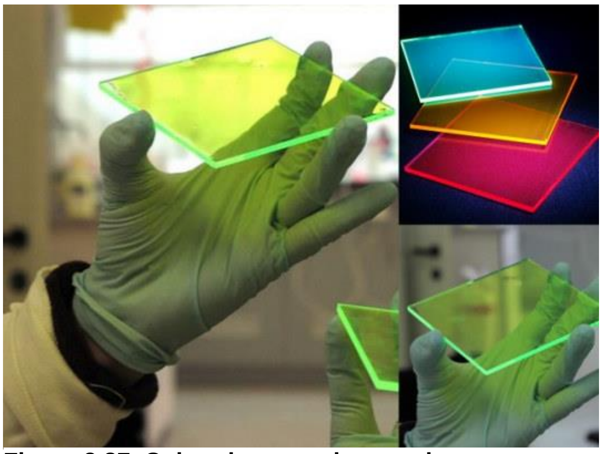


**Figure 3.87 Colored nano solar panels.**

**Source;http://inhabitat.com/colored-solar-panels-dont-need-direct-sunlight/, Retrieved December, 2013**

[148] Elvin, G. ,**Nanotechnology for Green Building,** Green Technology Forum, 2009, P52
[149] **Colored Solar Panels**, http://inhabitat.com/colored-solar-panels-dont-need-direct-sunlight/, Retrieved December, 2013

### 3.4.3.3 Nano turbines (Nano Vent Skin)[150][151]

NVS is multifunction skin, which will be able to generate energy for buildings, by using organic photovoltaic to capture sun and micro-wind turbines to capture wind. It makes existing objects greener by covering them with a skin made out of micro wind turbines (25mmx10.8mm), which generate energy from wind and sunlight. (Figure 3.88), it uses round supply units found in each panel's corner (Figure 3.90).

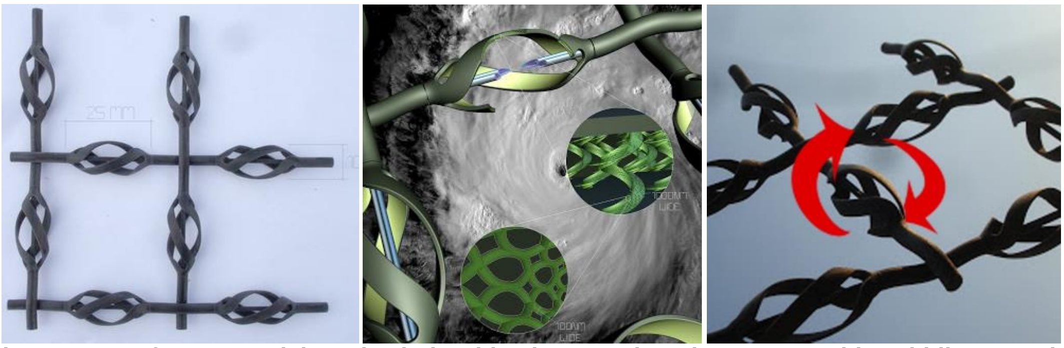



**Figure 3.88 Left; NVS model, each wind turbine is 25mm long by 10.8mm wide. Middle; zoom in showing the scale of nano engineered structures. Right; turbine movement.**

**Source; http://nanoventskin.blogspot.com/, Retrieved June, 2013**

The outer skin of the structure absorbs sunlight through an organic photovoltaic skin and transfers it to the nano-fibers inside the nano-wires, which then are sent to storage units at the end of each panel. [152]Also the inner skin of each turbine works as a filter absorbing $CO_2$ from the wind.

NVS can be used to coat train tunnels around, uses the wind generated from the speed of trains to power the lights of the station.

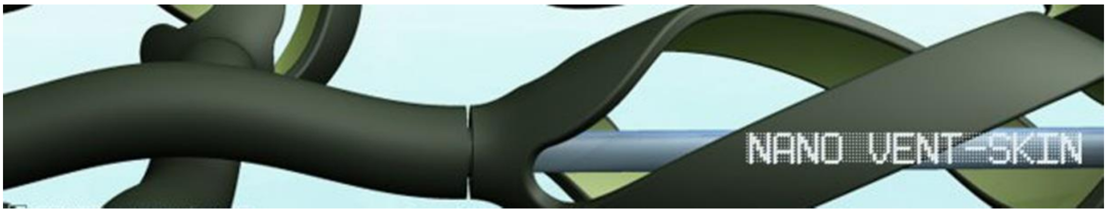



**Figure 3.89 NVS turbines.**

**Source; http://nanoventskin.blogspot.com/, Retrieved June, 2013**

[150] **Nano vent skin**, http://nanoventskin.blogspot.com/ , Retrieved June, 2013
[151] Hemeida, F., **Green nano architecture,** Master thesis, Alexandria University, 2010, P 90
[152] **Nano vent skin**, http://www.jetsongreen.com/2008/06/nano-vent-skin.html , Retrieved June, 2013

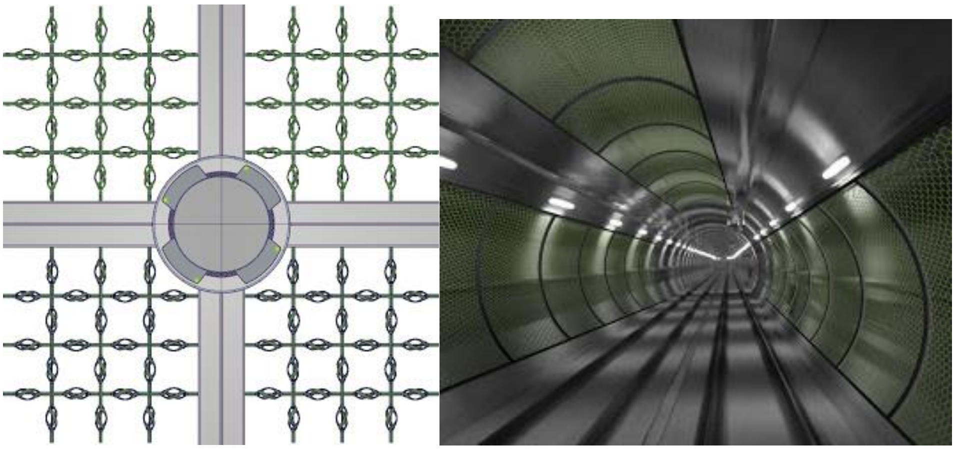


**Figure 3.90 Left; rounded supply units. Right; inner train's tunnel is coated by NVS.**

**Source; http://nanoventskin.blogspot.com/, Retrieved December, 2013**

### 3.4.4 <u>Summary</u>

Nanotechnology offers systems and devices that could be merged with today’s buildings in order to improve the level of their performance, creating more livable buildings that respond to their user’s needs. These systems emerge as new systems such as MNT, or through re-submitting existed systems such as kinetics and digital fabrication techniques:

a) <u>MNT molecular nanotechnology:</u>
Molecular nanotechnology (MNT) presents a liveable architecture that could apply sensing and actuation to its performance and explores new ideas that would show a building's ability to have means of growth and could interact with its user's needs.
Exploring this technology and its ability to control spaces outlines and configurations will lead to a continual dialogue between the users and spaces. This ability of controlling could be through using electromagnetic fields, or designing a material with specific behaviour, or creating internal spaces that could interact with users by changing its colour and size. All of this is promoting a significant architectural future.

b) <u>Digital fabricated nanomaterials:</u>
This part shows the ability of using digital fabrication techniques in order to explore material architecture that is developed by nanotechnology. This aims to create a multi nanomaterials alloy that have multi functions, and to control passive material distribution based on its function to reach the maximum level of performance.

c) Kinetic nanoarchitecture
This part shows the integration of nanotechnology and kinetic systems; this could be achieved through using both nanomaterials

and devices; (property-change material based on nanotechnology or nano sensors).

In addition, improved devices which could be embedded to buildings are offered by nanotechnology, it shows high performance compared with conventional one, especially with regard to its size and the capability of being integral with building elements and skin. These devices are:

a) Nano sensors
b) Nano solar cells
c) Nano turbines

## 3.5 **Nanotechnology risk**

Generally, new technologies always face public fears due to their risk, especially if the products have not been tested yet. However, as we care more about the benefits we have to figure out new methods to help us use such new technologies like nanotechnology. Recent discussions have been concerned about the possible dangers, related to genetic engineering and molecular nanotechnology (MNT), such as its possible emissions. For example, nano particles are more readily absorbed into the body than larger particles. Therefore, scientific organizations and governments are working on researches in order to minimize its risks.

The potential impact of nano structured particles and devices on the environment are perhaps the most high profile of contemporary concerns. Quantum dots, nano particles, and other nano devices may constitute whole new classes of non-biodegradable pollutants that scientists have very little understanding of.[153] At present, the National Institute for occupational Safety and Health only offers guidelines for workplace safety for workers in contact with nanomaterials[154]

[153] Arnall, A. **,Future Technologies Today's Choices** ,Greenpeace Environmental Trust, 2003, P 36

[154] Howard, J., **Approaches to Safe Nanotechnology: An Information Exchange with NIOSH,** National Institute for Occupational Safety and Health, 2009

## 3.6 Conclusion

Nanotechnology is the most promising technology in recent architecture. Integrating this technology with architecture is presenting (Nanoarchitecture). Methods of this integration are through **nanomaterials** and **nano systems and devices**.

i. Nanomaterials

Nanotechnology offers a new palate of novel and modified materials, these materials are varying in classification:

a) Structural materials
b) Non-structural materials
c) Coatings
d) Lightings
e) Insulations

ii. Nano systems and devices

Among the trials of mimicking nature and, as a result, the emergence of new design trends and methodologies that using natural laws and transferring its principles into architectural design; nanotechnology takes place through providing systems and devices that making our buildings more liveable and becomes dependent on the occurrence of stimulus in its environment. Therefore, besides nanomaterials; nanotechnology offers systems and devices that could be integrated with buildings elements and skins. These systems are:

a) MNT molecular nanotechnology
b) Digital fabricated nanomaterials
c) Kinetic nanoarchitecture

Applying molecular nanotechnology MNT in architecture raise the performance of buildings to unexpected levels, indeed, buildings will be capable of responding to multiple states rather than being fixed to one. In this meaning, architecture is transforming its spatial condition to the world of kinetics. The notion of growth-ability will be proposed, and as a result, the performative behaviour.

Combined with digital fabrication techniques, creating a multi functions alloy materials with specific distribution-using multi materials- and; as a result, functions; could be fabricated and employ it in façade's passive design, instead of assembled materials and kinetic (or automated) elements which could need more energy to be operated. In addition, kinetic systems will be re-introduced by nanotechnology.

Therefore; the diffusion of these innovative methodologies presented by nanotechnology would result in a new building system that will no longer be associated with some restricted functions, but there will rather be different ways to achieve the desired performance.

# 4 Chapter 4 the effect of nanomaterials and nano devices on form and functional performance (An analytical study)

# 4. The effect of nanomaterials and nano devices on form and functional performance

## 4.1 Introduction

According to nanotechnology timeline, recent products (which are available in market) are nano insulations and nano coatings; however there are many applications under research and development such as nano lightings and nano devices, which could be embedded into buildings skins or structural elements to respond to external and internal stimuli. Furthermore; new structural materials and systems are expected to be a novel in architectural future.

The following selections of representative case studies show how far could these new materials influence architectural design and help to get more possibilities to achieve more functional needs.

In this chapter; the research is going to analyse a group of nanoarchitectural buildings, this will include the different nano-functions in building materials; exploring nanotechnology effect on building's **form elements** and building's **functional performance.**

**- Intention of both form and functional performance in the analytical study:**

The impact of nanotechnology on the architectural form will be specifically on the **form elements** which are: shape, colour, size and texture. On the other hand any form of energy saving capability, for example using products like nano solar cells and OLED, beside environmental control ability will be considered as **functional performance** (for example using self-cleaning or anti-pollution nano coatings).

By analyzing these cases it is important to point that numbers of these case studies already existed, others are proposals.

## 4.2 Case studies

### 4.2.1 Carbon Tower

| |
|---|
| **Project:** carbon tower |
| **Architect:** Peter Testa Architects |
| **Description:**<br>The Initiative is led by the University of Technology, Sydney through its Institute for Nanoscale Technology, jointly with Commonwealth Science and Industrial Research Organization.<br>The Carbon Tower Prototype is a 40-story mixed-use high-rise that incorporates five innovative systems (Figure 4.1): 1-pre compressed double-helix primary structure, 2- tensile laminated composite floors, 3- two external filament-bound ramps (Figure 4.5), 4- breathable thin-film membrane, 5- virtual duct displacement ventilation. Studies suggest that, if built, the tower would be the lightest and strongest building of its type.[155] |

[155] Mcquaid, M.**, Extreme textile-Design for high performance**, Princeton Architectural press, 2005, P 112

**Product:** Carbon nanotube

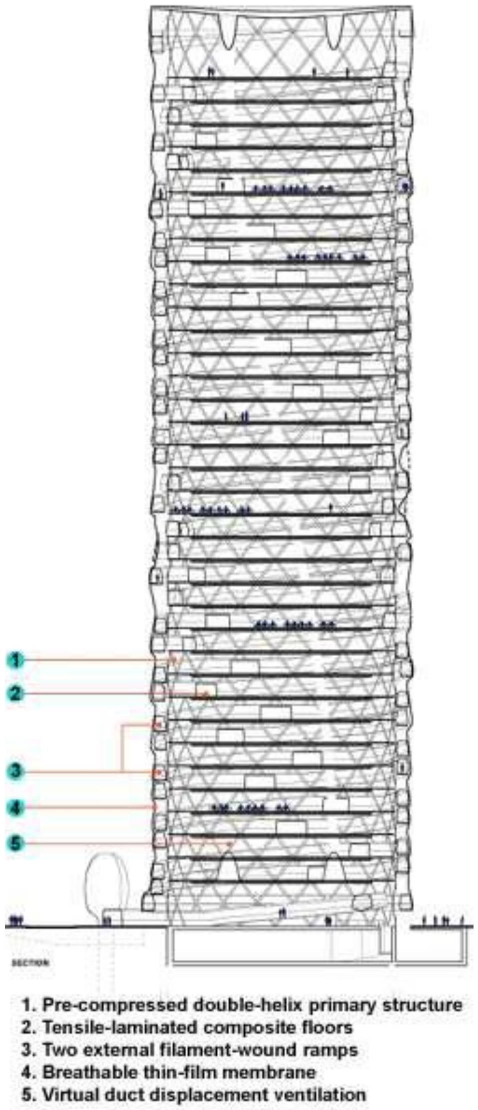



**Figure 4.1 Left; a longitudinal section of the Carbon Tower. Right; a model of a carbon tower, National Design Museum in New York.**

**Source; http://www2.ljworld.com/photos/2005/may/22/58189/, Retrieved December, 2013 and Matilda Mcquaid, 2005**

**Figure 4.2 Carbon tower, exterior shots.**

**Source; Matilda Mcquaid, 2005**

| Material effect: |
|---|
| • **Form elements:**<br><br>The primary structure is the double helix of twenty four twisted strands of braided carbon fiber, stabilized by continuous braided tendons within floor plates; the ramp is designed to contract with cables along its length to form active lateral bracing.<br>**Carbon nanotube** makes the perimeter double helix structure applicable in the 40 story building without internal columns, **it makes building structure act as its skin as well**. In order to create woven effect to ramp geometry-pattern- Testa has designed special software titled (waver to assist visualization of the structure), the program allows for geometry morphologies to make woven patterns for external ramps.[156] |
| • **Functional performance:(None)** |

The **carbon tower** suggests a number of future benefits of the construction industry. **Carbon fibers** offer many advantages over traditional material, it is strong and light, and manufacturing carbon fiber and resin requires half the energy of steel. In a construction of a large building project, much of the cost of materials lies in the expense of transportation to the site. And here too there is substantial saving, many components in the carbon tower including the core elements, are manufactured on site and others are very light components that are easily transported. The advanced materials have the last longer and require less maintenance than many conventional materials currently in use.

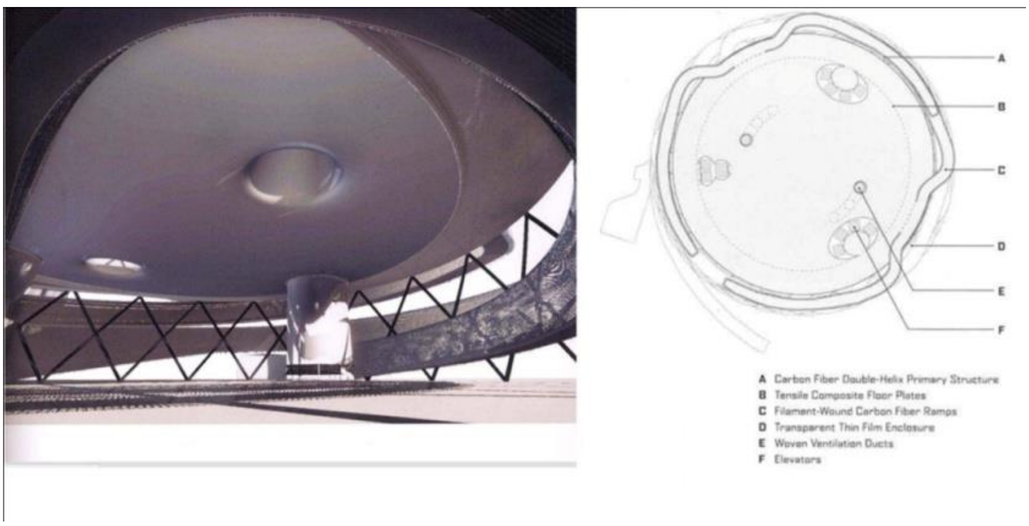



**Figure 4.3 Left; carbon tower internal view. Right; plan.**

**Source; Matilda Mcquaid, 2005**

[156] Mcquaid, M.**, Extreme textile-Design for high performance**, Princeton Architectural press, 2005, P 112

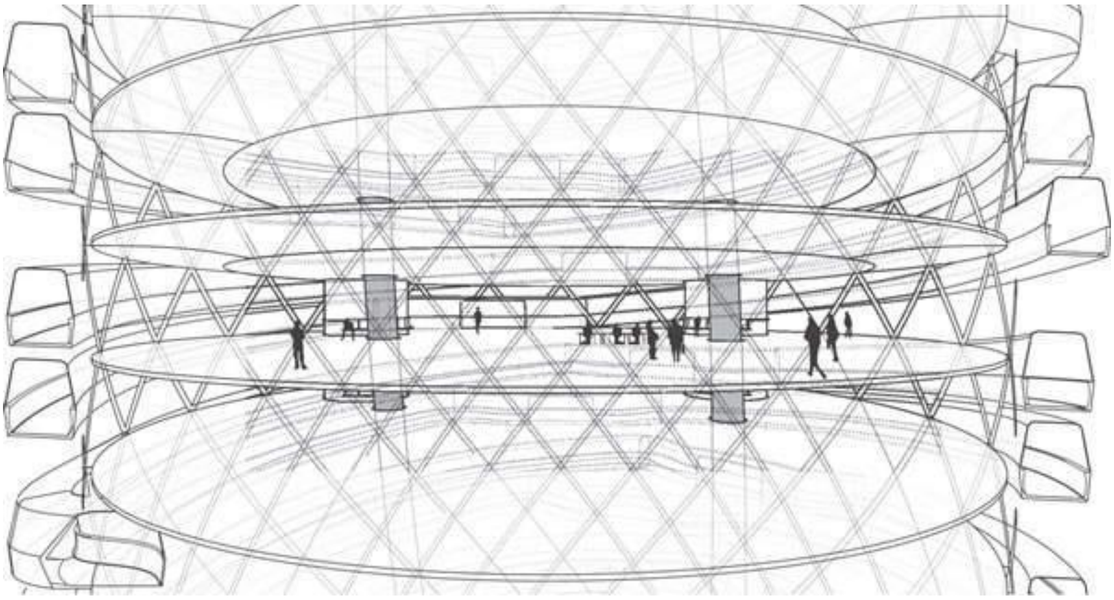


**Figure 4.4 Carbon tower,3d model.**

**Source; http://www2.ljworld.com/photos/2005/may/22/58189/, Retrieved December, 2013**

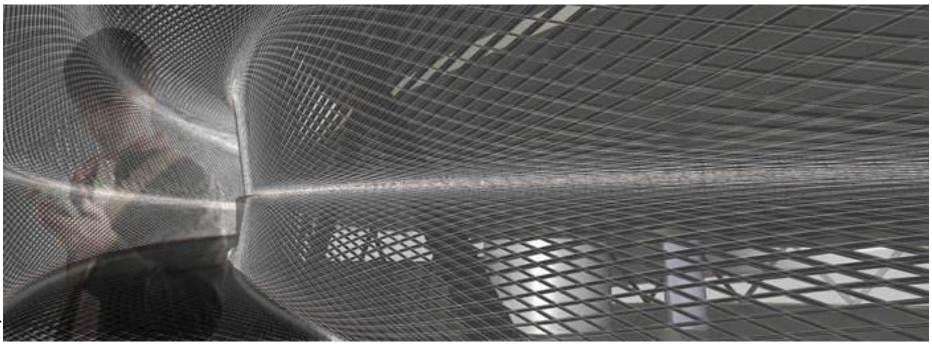


**Figure 4.5 Carbon tower, view of one of two external filament-bound ramps.**

**Source; http://www2.ljworld.com/photos/2005/may/22/58189/, Retrieved December, 2013**

## 4.2.2 The New World Trade Center

| |
|---|
| **Project:** The New World Trade Center (proposal) |
| **Architect:** Marwan Al-Sayed Architects |
| **Location:** New York, USA |
| **Description:** It is one of many proposals submitted to the new Trade Center competition. It is an international memorial contest, initiated by the Lower Manhattan Development Corporation (LMDC) in April 28, 2003.<br>The project consists of five slender towers emerging from the sites perimeter instead of the old two towers. |
| **Product:** Nano photo and thermo-chromic |

The designer imagines the towers being able to change their inner and outer skin. Weather, time of day, mood of the occupants, holidays and events around the world; all of these could influence its skin. The site can become a kind of monumental marker, a sort of urban, collective receptor and transmitter of the state of things.

*"My idea is to create a building structure and skin that begins to reflect the true emotional content of structures and the latent expressiveness cumulatively contained within buildings and the lives they house "*Marwan Al Sayed.[157]

**Figure 4.6 The New Trade Center.**

**Source; http://www.masastudio.com/2012/, Retrieved December, 2013**

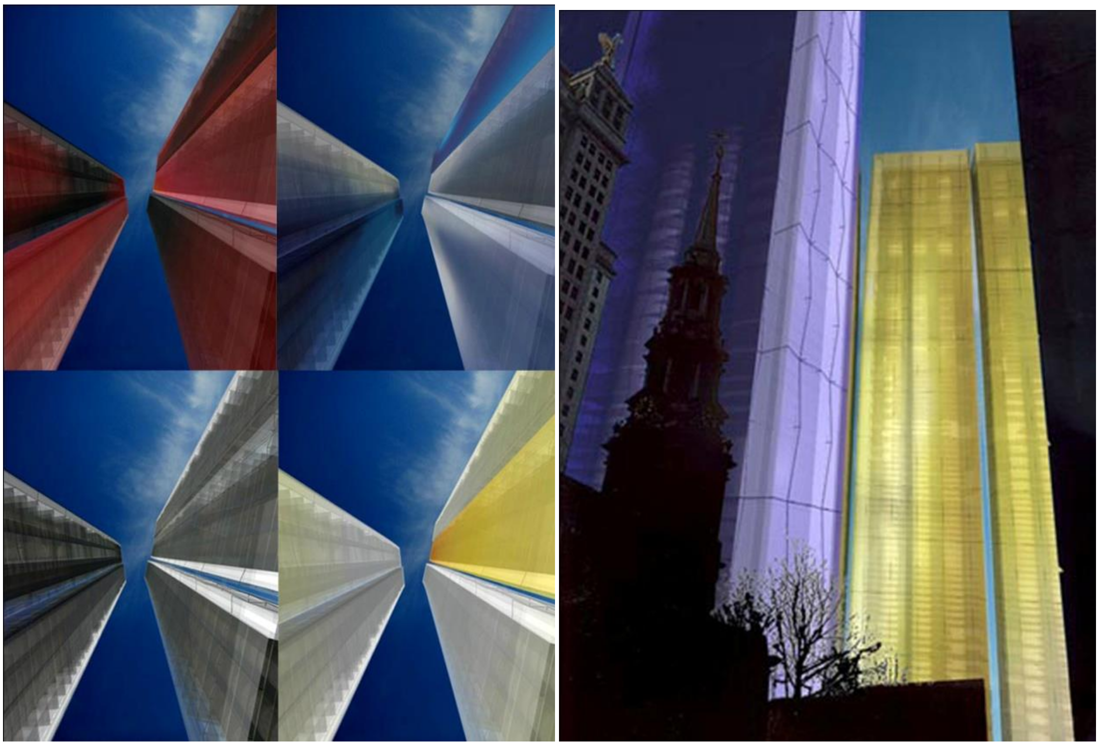


**Figure 4.7 The New Trade Center, colour morphing.**

**Source; http://www.masastudio.com/2012/, Retrieved December, 2013**

[157] **Marwan Al Sayed architects**, http://www.masastudio.com/2012/, Retrieved December, 2013

| **Material effect:** |
|---|
| • **Form elements:**<br><br>The architect designed a skin that begins to reflect the true emotional content within the building. This skin could change its colour to be (steely black, red or yellow) (Figure 4.7), in addition to the depth of transparency. This colour morphing is responsive to the external environmental conditions and to internal activity with occupants. And in the same time it represents an urban scale landmark. |
| • **Functional performance:**<br><br>Thin thermo and photo-chromic film coatings filter out unwanted infrared light to reduce heat gain in the building; in addition it reacts to changes in light intensity by increasing their light absorption. |

### 4.2.3 **Utopia One tower**[158]

| |
|---|
| **Project:** Utopia one tower |
| **Architect:** Cesar bobonis-zequeira, Ivan perez-rossello and Teresita del valle |
| **Location:** Dubai |
| **Description:**<br>The tower and its elements are composed of materials that resemble a smooth sculptural piece that are integrated into outer park. The base behaves as a single unit housing the proposed spaces, entry areas and existing walkways. Tower form creates a courtyard intended for gatherings and general leisure. |
| **Product:** nano solar cells |

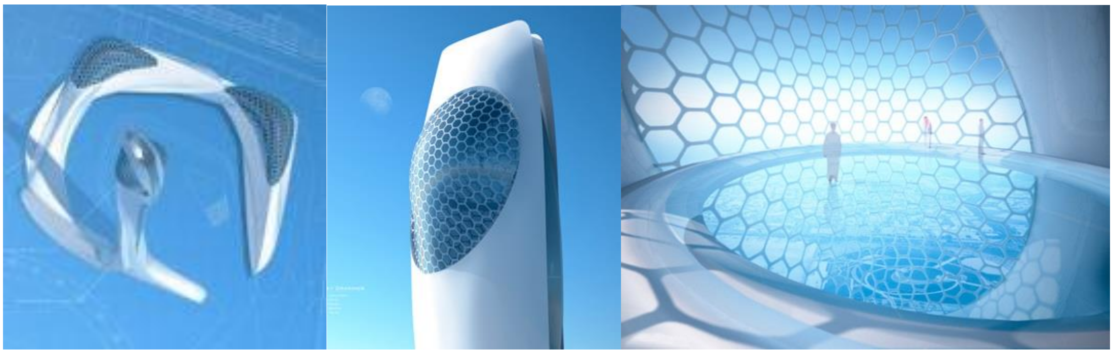


**Figure 4.8 Utopia one tower.**

**Source; http://www.designboom.com/architecture/utopia-one-dubai-tall-emblem-structure/, Retrieved December, 2013**

[158] **Utopia One tower**, http://www.designboom.com/architecture/utopia-one-dubai-tall-emblem-structure/, Retrieved March, 2013

**Material effect:**

- **Form elements: (None)**

- **Functional performance:**

Nano-cell technology is a thin photovoltaic film bonded to metal surfaces. It will be integrated to the building exterior façade, providing a portion of the used energy to run the elevator systems, HVACs systems and electrical systems. Heat sensitive glass reacts to the sun's position and controls the heat gain in the glassed surfaces.

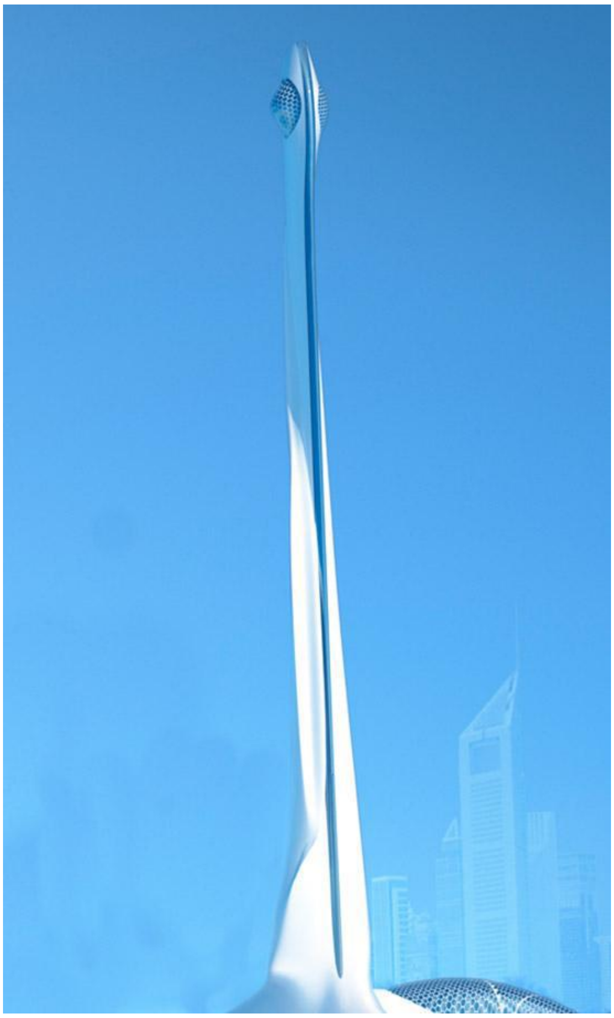


**Figure 4.9 Utopia one tower.**

**Source; http://www.designboom.com/architecture/utopia-one-dubai-tall-emblem-structure/, Retrieved December, 2013**

### 4.2.4 **Shimizu Mega City Pyramid** [159160]

| |
|---|
| **Project:** Shimizu Mega City Pyramid |
| **Architect:** Dante Bini |
| **Location:** Tokyo, Japan |
| **Description:**<br>The Shimizu Mega City Pyramid is a proposed project for construction of a massive pyramid over Tokyo in Japan.<br>The proposed hyper-structure has a footprint of approximately 8 square kilometres. It contains office buildings, residential complexes, and other facilities and It would house 1,000,000 people. The structure would be about 14 times higher than the Great pyramid at Giza which is 146 m, and it would be 2000 meters height. This pyramid would help answer Tokyo's problem of limited areas, although the project would only handle 1/47th of the Greater Tokyo Area's population.<br>Housing and office spaces would be provided by twenty-four or more 30-story high skyscrapers suspended from above and below, and attached to the pyramid's supporting structure with nanotube cables. |
| **Product:** carbon nanotubes |

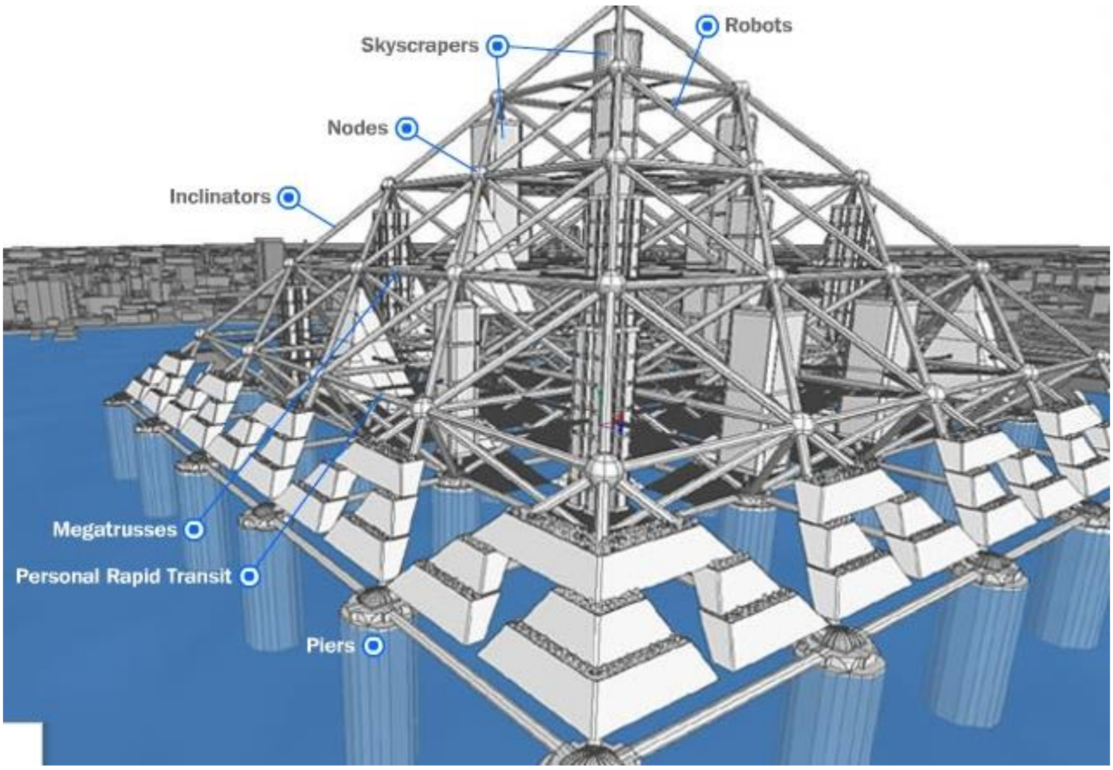



**Figure 4.10 A 3 dimensional model for Mega City.**

**Source; http://www.shimz.co.jp/english/theme/dream/try.html; Retrieved July, 2013**

[159] **Shimizu Mega City,** http://www.shimz.co.jp/english/theme/dream/try.html , Retrieved July, 2013
[160] **Shimizu Mega City,** http://pinktentacle.com/tag/environment/ , Retrieved July, 2013

## Circulation:

To move vertically within the city, people will use a continuous transportation system that incorporates elevators in diagonal shafts. Users will use a new linear-motor transportation system set up inside the horizontal shafts to move laterally. (Figure 4.12). Walkways, escalators, or corridors will be used to move from a node to a building. The trusses would be coated with photovoltaic cells which collect sunlight and convert it into electricity and help in energy saving strategies.

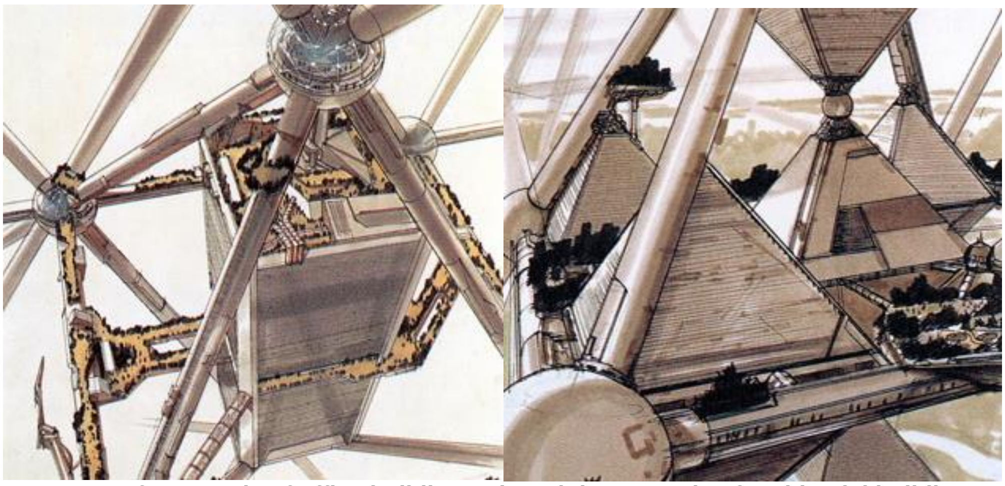


**Figure 4.11 Left; example of office building units. Right; example of residential building units.**

**Source; http://www.shimz.co.jp/english/theme/dream/try.html , Retrieved July, 2013**

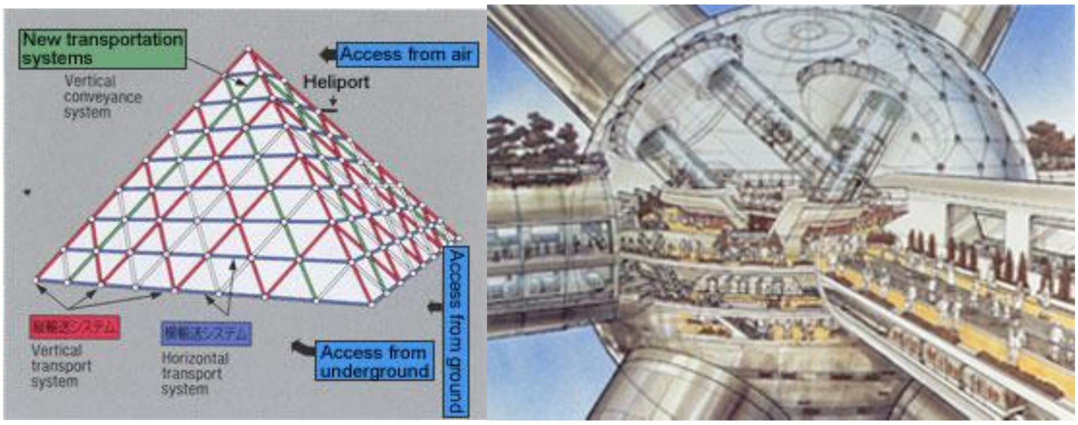



**Figure 4.12 Left; mega city transportations. Right; truss node.**

**Source; http://www.shimz.co.jp/english/theme/dream/try.html , Retrieved July, 2013**

## Material effect:

- **Form elements:**

The proposed structure is so large that it cannot be built with currently conventional materials, due to their weight. The design relies on the future availability of super strong lightweight materials based on carbon nanotubes which is 100 times stronger and 6 times lighter than steel.
-The pyramid's foundation would be formed by 36 piers made of special concrete. Due to Pacific and Japan's location which is seismically, the

external structure of the pyramid would be an open network of mega trusses (Figure 4.10). Supporting struts will be made from carbon nanotubes to allow the pyramid to stand against high winds, and survive earthquakes and tsunamis.

- Spheric nodes at the connections between trusses would provide structural support and serve as transfer points for travellers.

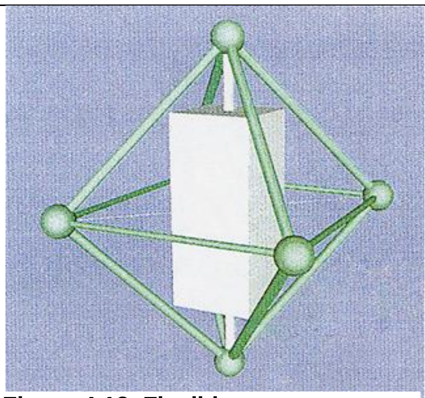


**Figure 4.13 Flexible-space octahedron's unit.**

By comparing with the great pyramid, the forming units are different, in great pyramid the assembly unit was the stone blocks but in Mega city the used units will be the octahedral geometry, which will be connected together, each measuring 350 meters per side, These units are then combined both vertically and laterally to enable flexible expansion to suit specific purposes (Figure 4.13). The main construction material is (Carbon Nanotubes) which will make this form possible to be executed due to its light weight and strength.

- **Functional performance: (None)**

### 4.2.5 **Indigo Tower**

| |
|---|
| **Project:** Indigo Tower |
| **Architect:** 10 Design Architects Team: Ted Givens, Benny Chow, Mohamed Ghamlouch |
| **Location:** Qingdao, China |
| **Description:**<br>It is a three high-rise building which takes an active stance and attacks the problem of polluted air, by aiming to help purifying the air of our cities. The tower keeps out dirt, grease, and bacteria out of the air. The tower is split into three bars in order to:<br>1) Increase the amount of surface area.<br>2) Provide more light to the south face of each bar.<br>3) Focus and increase wind speed.<br>The tower will be a glowing indigo object at night varying in intensity according to the amount of solar energy collected during the day. This glow will become symbolic of the cleansing, counteracting the yellow haze that appears during daytime hours.[161] |
| **Product:** Air purification nano coating |

[161]**Indigo Tower,** http://www.theurbanvision.com/blogs/?p=652, Retrieved May, 2013

**Figure 4.14 Left; Indigo skin. Right; towers at night.**

**Source; http://www.evolo.us/architecture/indigo-bio-purification-tower-with-titanium-dioxide-facade/, Retrieved December, 2013**

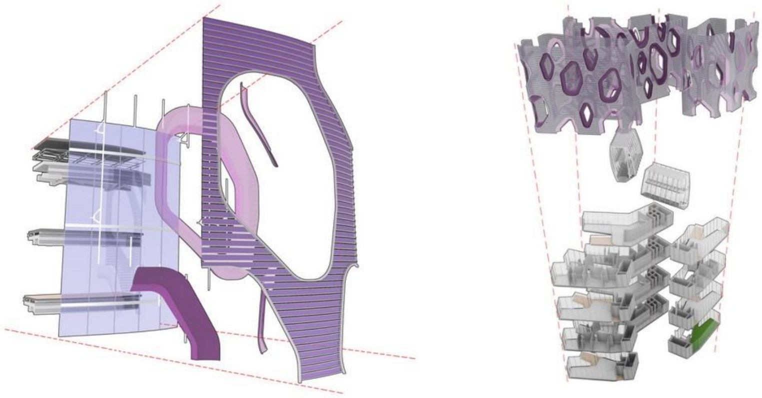


**Figure 4.15 Left: Indigo tower layering skin. Right; towers unit's orientation**.

**Source; http://www.evolo.us/architecture/indigo-bio-purification-tower-with-titanium-dioxide-facade/, Retrieved December, 2013**

**Material effect:**

- **Form elements: (None)**

- **Functional performance:**

Nano material used to decrease the amount of pollution. The reaction is triggered by the use of air purification nano coating on the outer skin of the project.
The used coating based photo-catalysts can trigger a series of chemical reactions to generate hydroxyl radicals when exposed to sunlight or ultraviolet light.[162]
The reaction is naturally powered by sunlight acting on the titanium dioxide during the day and supplemented by ultraviolet light at night. These ultraviolet lights are powered by energy collected through PV (Photo voltaic) panels during the day.

162 **Indigo Tower**, http://www.evolo.us/architecture/indigo-bio-purification-tower-with-titanium-dioxide-facade/, Retrieved May, 2013

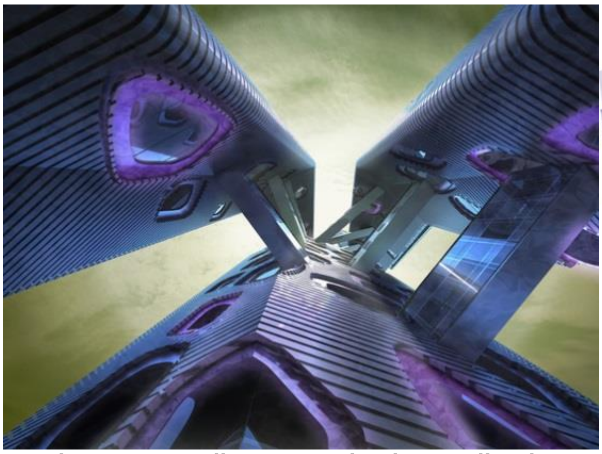


**Figure 4.16 Indigo tower; the three splitted towers.**

**Source; http://www.behance.net/gallery/Indigo-Tower/2676325, Retrieved December, 2013**

**Figure 4.17 Indigo tower is consisted of three bars.**

**Source; http://www.theurbanvision.com/blogs/?p=652, Retrieved May, 2013**

## 4.2.6 London Art Fair

| |
|---|
| **Project:** London Art Fair |
| **Developer:** developed in collaboration with Philips company. |
| **Location:** London |
| **Description:** London Art Fair design is depending on many internal visual effects. Organic LED (OLED) is one of them; it is used in an interactive art work called" You Fade To Light ". The project is developed with Philips company by using a total of 1064 bulbs to create a suspended wall of light. When people walk in front of the wall, it will react to people's movement. The hundreds of small mirrored screens reflected people's own images perfectly, until they moved; then an array of light spreads across the wall responding to their movement. The transition from mirror to bright white light which then fades gently through the grey scale to dark again reflects people visual experience in the space. (Figure 4.18).[163] |

[163]**London art fair**, http://www.treehugger.com/sustainable-product-design/incredible-interactive-oled-installation-lights-up-london-art-fair.html , Retrieved March, 2013

| **Product:** OLED lighting |
|---|

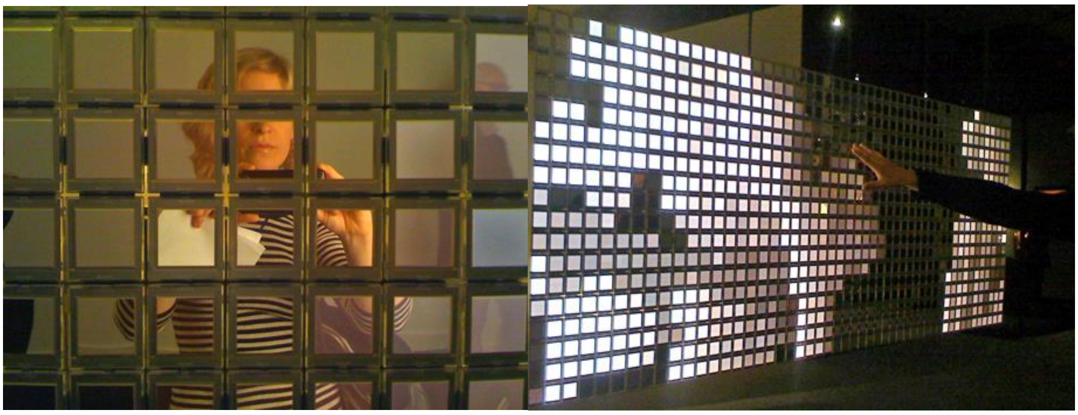


**Figure 4.18 Interactive OLED wall, London Art Fair.**

**Source; http://www.treehugger.com/sustainable-product-design/incredible-interactive-oled-installation-lights-up-london-art-fair.html, Retrieved March, 2013**

| **Material effect:** |
|---|
| • **Form elements:** This art work represents unique characteristics and capabilities that can redefine lighting. Visual effects of lights and colours influence its unusual experience. |
| • **Functional performance:** The used OLEDs have the potential to achieve substantial energy savings and low heat emission as well. |

## 4.2.7 **NVS Tower**

| **Project:** NVS Tower |
|---|
| **Architect:** Agustin Otegui |
| **Location:** Mexico City |
| **Description:** The skin of this tower consists of nano vent skin (NVS) panels. About using nanotechnology in this tower Otegui said "*Why not start thinking about a small scale and use green innovation to the existing buildings, structures, bridges and tunnels?*" The tower explores new potentials at energy saving fields. |
| **Product:** Nano vent skin (NVS). |

**Figure 4.19 NVS tower, external view.**

**Source; http://nanoventskin.blogspot.com/, Retrieved June, 2013**

**Figure 4.20 View from internal space.**

**Source; http://nanoventskin.blogspot.com/, Retrieved June, 2013**

As it was explained in chapter three; NVS contains very tiny turbines built in the skin itself. Nanotechnology changes the size of usual wind turbines dramatically. This brings us the possibility of merging these turbines in many external elements of buildings to achieve the principles of energy saving.

| Material effect: |
| --- |
| • **Form elements: (None)** |
| • **Functional performance:**<br>NVS uses organic photovoltaic cell to capture sun, and micro-wind turbines to capture wind and reuse it to generate energy. |

### 4.2.8 Nano House[164] [165]

| | |
|---|---|
| **Project:** Nano House. | |
| **Developer:** The Nano House Initiative conceived in 2002 by the Institute of Nano-scale Technology. Visualized and implemented by architect James Muir. | |
| **Location:** Australia | |
| **Description:**<br>It is an initiative to achieve more sustainability in our houses models based on nanotechnology materials and techniques.<br>The University of Technology at Sydney (UTS) have developed a model house that shows how new materials, products and processes that are emerging from nanotechnology researches and developments might be applied to our living environment. | |
| **Products:** Self-cleaning coated glass, electro chromic glass, photovoltaic cell, in addition to wide range of nano based materials. | |

**Figure 4.21 A 3D model for the proposed nano house.**

| Material effect: |
|---|
| • **Form elements:** the used electro chromic glass is able to change its transparency degree from opaque, semi- transparent to transparent. |
| • **Functional performance:**<br>Self-cleaning glass will reduce maintenance cost and effort and keep buildings surfaces clean. Cold lighting systems and the photovoltaic solar cell will be used too in order to reduce building's Energy consumption.<br>In nano house, electro chromic glass can be used more liberally in optically tuned to block heat and UV; It would be possible to construct a building with many more, larger windows than is currently. |

[164] Rahman, K., Fazli, M. and Noman, S. M., **Nano Technology in Buildings to save the Material Resources**, paper, Green chemistry conference, 2011 , P4
[165] Hemeida, F., **Green nano architecture,** Master thesis, Alexandria University, 2010, P68

### 4.2.9 **Tornado House**[166]

| | |
|---|---|
| **Project:** Tornado House | |
| **Architect:**10 Design Architects<br>Team: Ted Givens, Trey Tyler, Mohamed Ghamlouch, Shane Dale, Dougald Fountain | |
| **Location:** Tornado zones | |
| **Description:**<br>Every year hundreds of people's lives and residential buildings are lost because of tornados (Figure 4.22); The architects at 10 Design have tried to come up with a specially created building(Tornado House) that may offer residents of these areas a sturdier and more protective living solution. It is a sort of underground shelters that can protect people from twister's hits, with other efforts that exploring the potential of kinetic architecture and nanotechnology to reach high protection needed. House structure will be elevated by hydraulics levers that can control house's body movement up and down according to tornados seasons and external stimulus. | <br>**Figure 4.22 Storm's hit, Oklahoma City.** |
| **Product:** Carbon nanotubes, solar cells, photo catalytic coating. | |

**Figure 4.23 The Tornado House.**

**Source; www.10design.co, Retrieved August, 2013**

**Figure 4.24 Section at Tornado House.**

**Source; www.10design.co, Retrieved August, 2013**

[166] **Tornado House** , www.10design.co , Retrieved August, 2013

**Material effect:**

- **Form elements:**

House's structure will be constructed from Carbon nanotube. Material choice would help the concept of hydraulics levers which will hold the structure up and down (capability of moving) due to its property as the lightest and strongest construction material ever.

- **Functional performance:**

Photo catalytic coatings will absorb and clean pollution .In addition; series of solar cells on the outer skin rotate and flex to attain maximum solar intensity.

## 4.2.10 Light tree

| |
|---|
| **Project:** light tree |
| **Architect:** Omar Ivan Huerta Cardoso |
| **Location:** USA |
| **Description:** Light tree is a smart solution for streets lighting design, pedestrian paths and public parks. Nano LED lighting was used with nano solar cell technology. Organic nice trees will be rooted inside these units, the seeds are in the upper extremities of the tree and they can be removed, transplanted or just left in there to have a nice tree. |
| **Products:** NanoLED and Nano solar cell |


**Figure 4.25 Left; light tree. Right: light tree base.**

**Source; http://www.evolo.us/architecture/light-tree-a-very-green-solution-to-pedestrian-lighting/#more-3336, Retrieved December, 2013**

**Material effect:**

- **Form elements:**

  Green light that works efficiently will be generated by several ultra-bright LEDs.

- **Functional performance:**
  The Light Tree “uses a Highly-Efficient 3-Dimensional Nanotube Solar Cell for visible and UV Light which enables light absorption from visible and ultraviolet light and double the efficiency of light to energy conversion. This solar panel is located at the base of the Light Tree and it is designed to work in shady or cloudy conditions (Figure 4.26).[167]

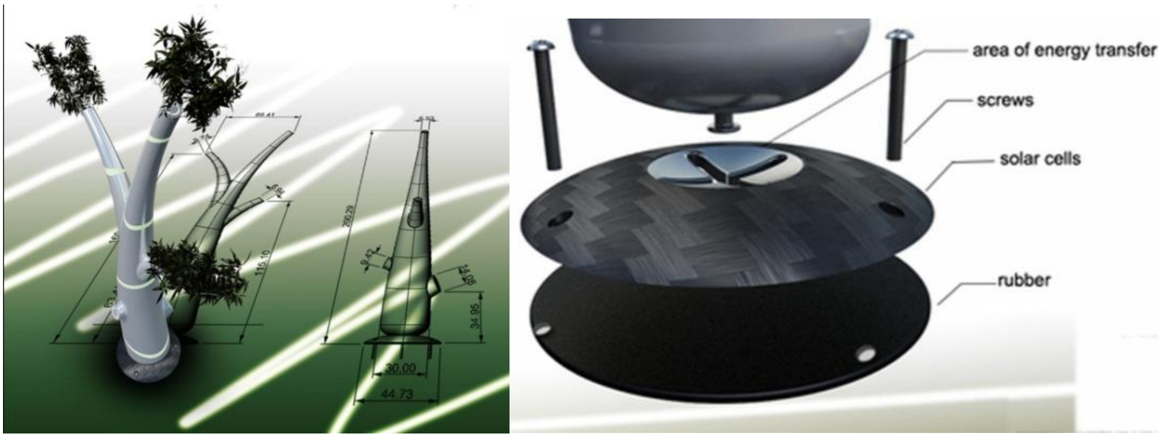



**Figure 4.26 Left; light tree dimension. Right; light tree base.**

**Source; http://www.evolo.us/architecture/light-tree-a-very-green-solution-to-pedestrian-lighting/#more-3336, Retrieved December, 2013**

## 4.2.11 Epiphyte pavilion

| |
|---|
| **Project:** Epiphyte pavilion |
| **Architect:** Marvin Bratke + Tor-Magnus Horten |
| **Location:** Munich, Germany |
| **Description:** Epiphyte is a pavilion, created to travel around the world and the structure is designed to be transmitted and collected at any site. The main idea is to explain modern and ecological building systems in one architectural experience. It is to provide an interesting space of exhibitions and art installations included media shows for public users which depend on collected day time energy.[168] |
| **Products:** air purification nano coating |

[167] **Light tree**, http://www.coroflot.com/omarhuerta/Light-Tree, Retrieved March, 2013
[168] **Epiphyte pavilion** , http://www.evolo.us/architecture/epiphyte-.travelling-pavilion-marvin-bratke-tor-magnus-horten/, Retrieved December, 2013

**Figure 4.27 Epiphyte model, exterior and interior shots.**

**Source; http://www.evolo.us/architecture/epiphyte-.travelling-pavilion-marvin-bratke-tor-magnus-horten/, Retrieved December, 2013**

| **Material effect:** |
| --- |
| • **Form elements: (None)** |
| • **Functional performance:** The cladding is covered by air purifying nano coating that reacts to ultraviolet rays enabling the reduction of air pollution, cleaning the atmosphere around the pavilion. |

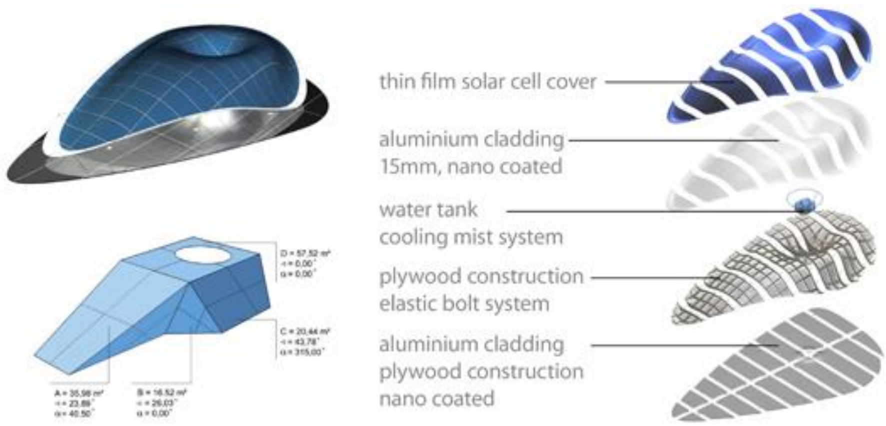



**Figure 4.28 Construction layering system, including nano coating layer.**

**Source; http://www.evolo.us/architecture/epiphyte-.travelling-pavilion-marvin-bratke-tor-magnus-horten/, Retrieved December, 2013**

## 4.2.12 Mohammed Ali center (MAC)[169]

| |
|---|
| **Project:** Mohammed Ali Center (MAC) |
| **Architect:** Beyer Blinder Belle Architects & Planners LLP, in cooperation with Lee H. Skolnick Architecture + Design Partnership, New York, USA |
| **Location:** Kentucky, USA |
| **Description:** This building considered as a Museum, caters for seminars, lectures, films and exhibitions. The building has a striking appearance, in particular due to its facade. Ceramic tiles with different colour glazing are arranged on a 30 X 60 cm grid according to a particular pattern. From a distance it appears as an oversized mosaic depicting typical boxer stances and a likeness to Muhammad Ali. |
| **Products:** photo catalytic self-cleaning ceramic tiles. |

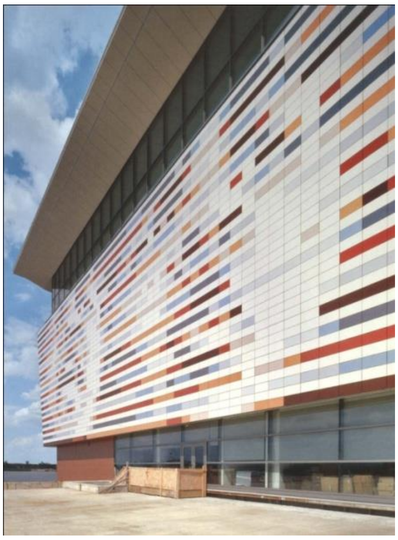


**Figure 4.29 Mohammed Ali Center façade.**

**Source; Sylvia Leydecker, 2008**

| **Material effect:** |
|---|
| • **Form elements: (None)** |
| • **Functional performance**: To maintain a consistently good appearance and to keep down the cost of cleaning, the tiles are equipped with a photo-catalytic self-cleaning surface coating. The coating is baked onto the glaze of the tiles and is therefore cause permanent durability. |

[169] Leydecker, S. , **Nano materials in Architecture, Interior Architecture and Design**, Birkhauser, Basel, Switzerland, 2008, P 78

### 4.2.13 **Jubilee Church**

| |
|---|
| **Project:** Jubilee Church |
| **Architect:** Richard Meier & Partners, New York, USA |
| **Location:** Rome, Italy |
| **Description:** Three giant sails reaching up to 36m into the sky give this church and community centre its unmistakable appearance. Made of prefabricated high-density concrete, their white colour is achieved by adding Carrara marble and self-cleaning cement to the mixture. |
| **Products:** photo-catalytic self-cleaning cement. |

**Figure 4.30 Jubilee Church, Italy**.

**Source; Sylvia Leydecker, 2008**

| **Material effect:** |
|---|
| • **Form elements: (None)** |
| • **Functional performance:** The photo-catalytic self-cleaning additive enables the building to achieve its trademark white colouring in an urban environment that is heavily polluted by car exhaust gases. The building not only remains clean, the large surface area of the sails also helps combat pollution by reducing the amount of volatile organic compounds in the air.[170] |

[170] Leydecker, S. , **Nano materials in Architecture, Interior Architecture and Design**, Birkhauser, Basel, Switzerland, 2008, P 116

## 4.3 Summary of the analytical study

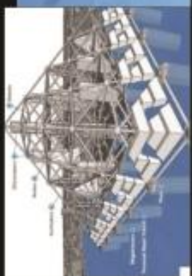
| No. | Case study | | Status | The used Nano product: Nanomaterials | The used Nano product: Nano devices | Nanotechnlogy Impact – Form elements: shape | Form elements: colour | Form elements: size | Form elements: texture | Technical function: Energy saving | Technical function: Environmental control |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Carbon Tower |  | Proposal | Carbon nanotube | | Structural elements shape ● | ○ | Structural elements size ● | ○ | ○ | ○ |
| 2 | The new world Trade Center |  | Proposal | Nano photochromic glass<br>Nano thermo- | | ○ | Changing skin's ● | ○ | ○ | ○ | Absorbin g sunlight ● |
| 3 | Utopia one |  | Proposal | | Nano solar cells | ○ | ○ | ○ | ○ | Generating energy ● | Absorbing sunlight ● |
| 4 | Shimizu Mega City Pyramid |  | Proposal | Carbon nanotube | | structural elements shape ● | ○ | Structural elements size ● | ○ | ○ | ○ |
| 5 | Indigo Tower |  | Proposal | Air purification nano coating | | ○ | ○ | ○ | ○ | ○ | Anti-pollution ● |
| 6 | London Art Fair |  | Existed | OLED lighting | | Fixable shapes ● | Multi-colour lightings ● | ○ | ○ | Energy saving ● | ○ |

**Table 6 Summary of the analytical study and results.**

| 13 | 12 | 11 | 10 | 9 | 8 | 7 |
|---|---|---|---|---|---|---|
| Jubilee Church | Mohammed Ali center | Epiphyte pavilion | Light tree | Tornado House | Nano House | NVS Tower |
|  |  |  |  |  |  |  |
| Existed | Existed | Proposal | Proposal | Proposal | Proposal | Proposal |
| self-cleaning cement | Photo-catalytic self-cleaning ceramic tiles | air purification nano coating | Nano LED | Carbon nanotube<br>Photo catalytic coating | Self-cleaning coated glass<br>Nano electro chromic glass | |
| | | | Nano solar cell | Nano Solar cells | Nano photovoltaic cell | Nano Vent Skin (nano turbines, photovoltaic cells) |
| ○ | ○ | ○ | ○ | capability of dynamic moving ● | ○ | Skin shape ● |
| Colour retention ● | ○ | ○ | Multi-color light ● | ○ | changing glass transparency ● | ○ |
| ○ | ○ | ○ | ○ | ○ | ○ | Turbine's size ● |
| Material texture ● | Material texture ● | ○ | ○ | ○ | Material texture ● | ○ |
| ○ | ○ | ○ | Generating energy ● | Generating energy ● | Generating energy ● | Generating energy ● |
| Self-cleaning coatings ● | Self-cleaning tiles ● | Anti-pollution ● | ○ | Absorbing sunlight ● | Self-cleaning glass ● | Absorbing sunlight ● |

# 5 General Conclusion and Recommendations

## 5.1 Results and conclusion

### 5.1.1 Discussion

To monitor the impact of nanotechnology on both; the building's form elements and functional performance, it was important to predestine, in general, the impact of nanotechnology (divided into nanomaterials and nano devices) -which were illustrated in chapter 3- on each form element (shape, size, colour and texture) and functional performance (energy saving and environmental control). This will be through using a relation diagram that shows links between different aspects, that expresses strength or weakness of the relationship. But before discussing this diagram, it is necessary to summarize the results of selected case studies and find out the percentage of the impact of nanotechnology on each form element and functional performance.

After analysing the previous case studies; between the selected cases there are 11 cases used nanomaterials as (structural- non-structural materials- coatings and lightings), on the other hand only 5 cases used nano devices.

Next tables illustrate that among 13 of selected different cases; 11 cases are affected by nanotechnology in its functionality, 10 cases are affected in its form elements.

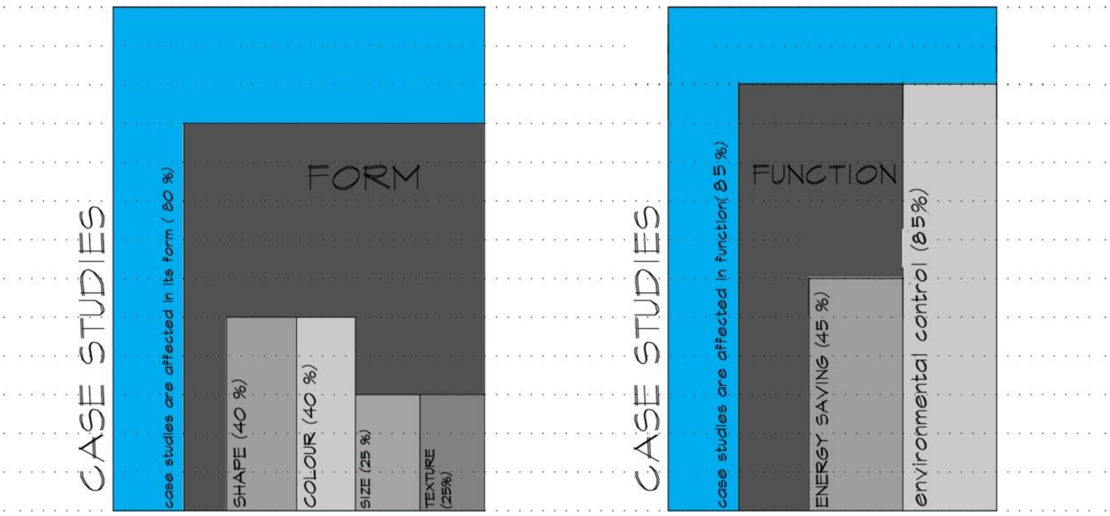



**Figure 5.1 The selected case studies and nanotechnology effect on its form (left), and functional performance (right).**

**Source; by the researcher**

This result shows that the impact on building's functional performance is over the impact on building's form (12 cases to 11 cases); perhaps this is due to the diversity of products that support building functions (coatings, lightings, nano solar cells,…), on the other hand the majority of the products that can directly affect the architectural form (nano structural materials is more recommended) are still under development, no sufficient experience with it, beside others that are hardly tested in architectural applications.

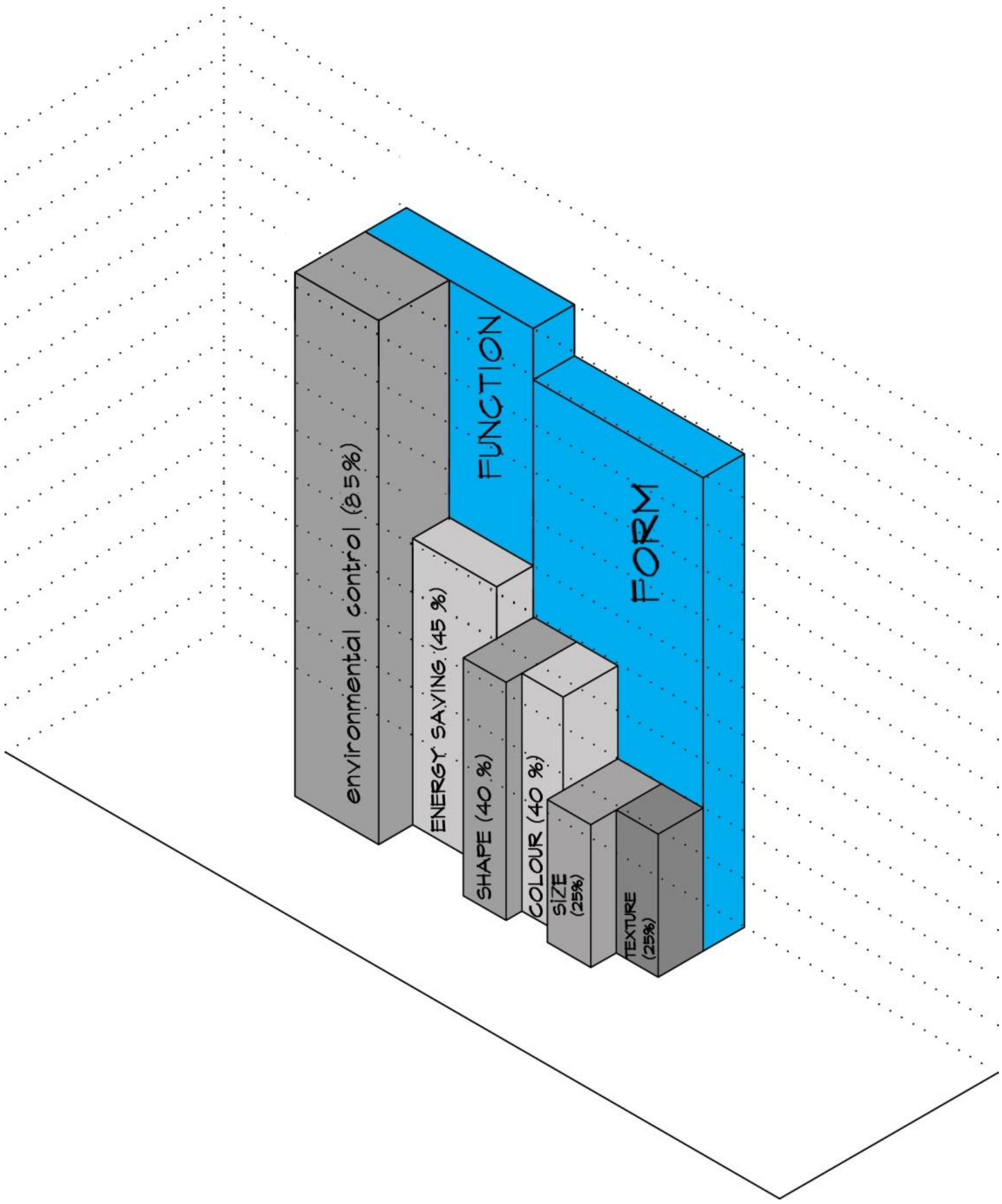



**Figure 5.2 Final results.**

**Source; the researcher**

## Relation diagram:

The relation diagram is a matrix diagram that shows (cause and effect) relationships. It helps a group analyse the natural links between different aspects of a complex situation. By using this analysis tool of analysing; the next figure will illustrate the influence of nanomaterials and nano devices on architectural form and functional performance. Line's thickness is an indication of strength or weakness of that influence.

The next relation diagram shows nanotechnology effect on both form elements and building's function:

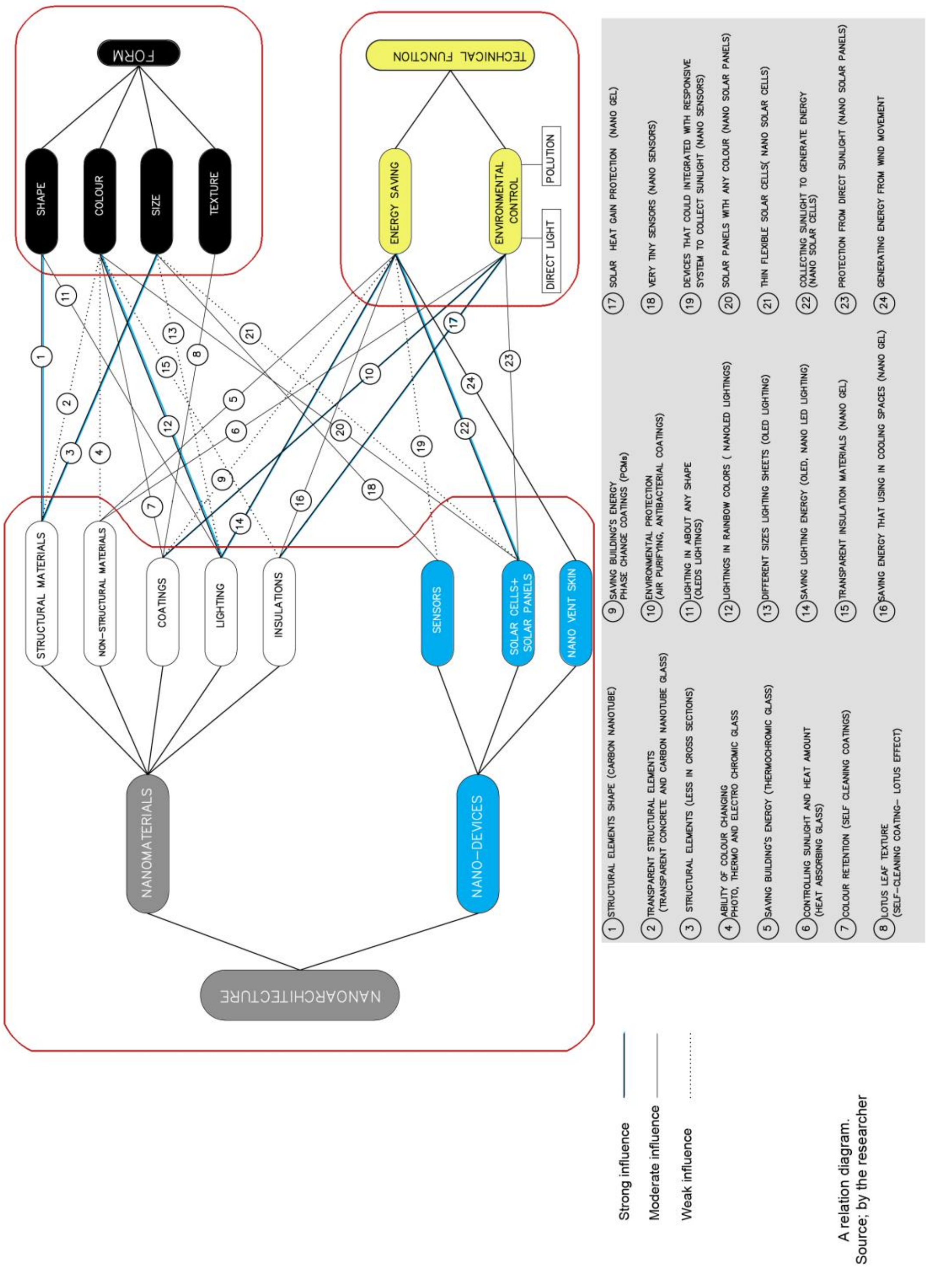



**Figure 5.3 A relation diagram summarizes the results.**

**Source; by the researcher.**

### 5.1.2 **General Conclusion**

Architecture is about human, building and the environment, here the research discusses the issue from the standpoint of building systems. As a sub-system; material is a strong variable factor which influences the design process, it is our focusing area to be investigated.

This change in the role material plays during the design process reflects the way we addressed and accommodated it, not as an appearance or superficial covering, but as an initiative giver which generates form. Digital material, as a design methodology, considers material characteristics and behaviour, this design methodology runs combined with the ideologies that gained from natural laws. In this new methodology, material could outline how the form will be; this could be achieved by form finding operations which consider material characters in its early design stages, by applying material to a digital model, and exploring its behaviour and performance, let material orient form evolution which adds new dimensions to architectural design.

Digital materiality requires a deep understanding of material characters and an awareness of new designed material. Assembling strategy is required to design a material or a multi-functional material with a specific property or behaviour, in order to transfer performative behaviour of living systems into the make-up stage of materials, the logic could be applicable by assembling it at the micro and nano scales.

Furthermore, due to the advancements that occurred in form generation methodologies and designing complexity forms; the gap between these operation's products and the available implementation techniques is increased, which spurs looking for new technologies and methodologies that could bring new possibilities for architecture. Therefore; the interest in new design methodologies such as **digital materiality** could narrow this gap, because the considerations relating to material characteristics make complexity forms executable. Besides, the exploration of modern technologies in the science of manufacturing materials brings **nanotechnology**, which promises architecture with new pallet of (new and modified) construction materials, new systems and devices, which also helps in narrowing this gap.

Investigating this integration between nanotechnology and architecture raises building performance; boundaries between internal and external spaces will be eradicated, building skin will act as an interface that collect data and response to external stimulus. Nano buildings will apply the conception of interaction with different levels of smartness and responsively, building envelope will be converted from façade to skin, from static to dynamic, structural system also will be integrated with the building shell, walls and enclosure, leading to investigate new spatial configurations and arrangements which will adapt building and user’s needs. Imagining this new generation of architectural collective buildings could lead and govern consequently urban fabric.

By focusing on how architectural form and function will be impacted due to this integration, research investigates nanoarchitectural case studies and analyses them, this shows that building form elements and technicality function are greatly affected as a result of merging nano materials, systems and devices.

As a result; user's needs, building system and environmental conditions will be interwoven, which means that the whole design process will be impacted according to a variety of materials that are brought by nanotechnology.

| Interrelation in building design | | | | | |
|---|---|---|---|---|---|
| Environmental system | | Building system | | Human system | |
| Cultural context | Physical context | Building technology | Internal ambience | User requirements | Client objectives |
| social | Climatic | Available resources<br>Material<br>equipment | Structural mass | Organic | Security |
| Economic | topographical | Structural systems | | Locational (static/ dynamic) | Profit |
| Technological | Constrains (land use- existing built..) | Services system | Sensory environment (lighting/ sound control/ heating/ vent) | Spatial | The ability to change |
| historical | | Fitting system | | | |
| political | | | | | |
| aesthetic | | | | | |
| religious | | | | | |

**Table 7 Material as a sub- system is affecting the design process.**

**Source; by the researcher**

## 5.2 **Recommendations**

**Recommendations for those interested in the domain of academic architectural studies:**

- As a result of today's new design methodologies; an extended academic course for undergraduate students is recommended to be aware of novel nanomaterials, this course could focus on the potentials of nanomaterials compared with conventional materials.
- It is very important to spread the knowledge of material design and the ability to use nanotechnology to design our own materials, and the capability of improving current construction materials properties as well.
- Exploring computational design methodologies which are integrated with material physics in the early stage of the design process, in order to get executable forms.
- The collaboration between architects and material scientists is required to solve design requirements depending upon material.
- Advanced studies are needed to focus on the possibility of merging nanoarchitecture with new architectural trends such as biological architecture, kinetic architecture, responsive architecture….

**Recommendations for general architectural and construction community:**

- Focusing on new nano-applications and its potentials, and what distinguishes it from other conventional materials.
- Inform the Egyptian architectural community about the basic concepts of nanoarchitecture through publications, conferences and exhibitions.
- Prepare a list of available nano-materials in the Middle East market and Egyptian market, which can be used in the construction field.

**Recommendations for the concerned authorities in the field of historical buildings preservation:**

- Nano coatings such as (anti-graffiti- self- cleaning), which is already in the market, are highly recommended to be used in historical buildings in Egypt to overcome the continuous attempts to distort these buildings and monuments.

**Recommendations for those working in the field of sustainability and energy conservation:**

- Further studies are recommended for participating nanotechnology in the sustainability principles; this could be through using energy-saving products such as OLED lightings, nano insulations, nano coatings and nano solar cells.

## 5.3 Future avenues of research

- Integrating nanomaterials with digital fabrication techniques.
- Towards more integration between nanotechnology and structural materials.
- Nano building skin.

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**الملخص العربى**

موضوع الرسالة يتناول عمارة النانو، احد الاتجاهات التصميمية الحديثة التى ظهرت نتيجة دمج تكنولوجيا النانو بالعمارة، ويهدف البحث الى رصد تأثير تكنولوجيا النانو على التشكيل المعمارى والاداء الوظيفى للمبانى.

مشتملات الرسالة:

**تتكون الرساله من 5 ابواب رئيسية:**

الباب الاول : ويشتمل على مقدمة البحث والمشكلة البحثية واهداف البحث ومجاله ومحدداته، بالاضافة الى منهجيات البحث المتبعة وهيكل البحث.

الباب الثانى : يتناول الباب الثانى دور المواد فى العملية التصميمية وفى تشكيل المنتج المعمارى، وكيف أدى ذلك الى ثورة فى التشكيل المعمارى خاصة بعد الثورة الصناعية واستخدام مواد جديدة فى البناء، يستعرض هذا الجزء بعض المنهجيات الرقمية الحديثة فى التصميم المعمارى وكيف ان هذه المنهجيات تؤكد على دور مواد البناء واشراكها فى العملية التصميمية فى مراحلها الاولية .

الباب الثالث: يركز هذا الجزء على تكنولوجيا النانو واهميتها ومواد النانو وأهمية هذه المواد من حيث تضمنها على خصائص فائقة مقارنة بالنسبة لمواد البناء التقليدية ، ثم التطرق الى تطبيقاتها فى العمارة والذى أدى الى ظهور اتجاه معمارى جديد (عمارة النانو).

سوف يعرض هذا الجزء من البحث سبل دمج تكنولوجيا النانو بالعمارة واساليب هذا الدمج والذى سيكون من خلال طريقتين رئيسيتين:

دمج مواد النانو بالعمارة فى صورة

- مواد انشائية Structural materials
- مواد غير انشائية Non-structural materials
- كسوات Coatings
- اضاءة Lightings
- مواد عازلة Insulations

واما دمج أنظمة وأجهزة النانو بالعمارة لرفع اداء المبانى ودرجة استجابتها للمتغيرات.

الباب الرابع : يستعرض هذا الباب حالات الدراسة التى تم اختيارها فى البحث وتحليلها وتحديد تأثير تكنولوجيا النانو على تشكيل هذه النماذج وعلى اداءها الوظيفى.

الباب الخامس:

تنتهي الدراسة في هذا الجزء بتقديم أهم النتائج التي توصل إليها البحث من خلال الدراسة التحليلية والتحليلية المقارنة، والتوصيات المقترحة.

**المستخلص العربى**

للتطور التكنولوجى والمواد الحديثة تأثير كبير على العمارة منذ أن بدأ الانسان القديم الاشتغال بالبناء فالمواد الحديثة لها تأثير كبير على المنتج المعمارى حيث أنها تؤثر على الشكل المعمارى بالاضافة الى تاثيرها على الاداء الوظيفى للمبنى ،فى الوقت الحالى اصبح للمواد دورا كبير فى العملية التصميمية يتعدى دورها كمجرد عنصر نهائى لتحقيق الشكل المعمارى وانما تقدم دورها فى العملية التصميمية ليصبح أحد أهم المدخلات التى يجب أخذها فى الاعتبار عند البدء فى التصميم مع الاخذ فى الاعتبار خصائصها ، من هذا المنطلق فان الترتيب النمطى والذى يبدأ بالشكل المعمارى ثم تطويع كلا من النظام الانشائى والمواد المستخدمة لتحقيق هذا الشكل لم يعد هو الطريقة المثالية للتطوير للشكل المعمارى خاصة بعد ظهور منهجيات جديدة فى التصميم تعتمد على الحسابات وتحليل المدخلات لتطوير الشكل المعمارى شاملة المواد وخصائصها كأهم هذه المدخلات ، ولهذا فالاهتمام بمجال علم المواد ومتابعة التطوير فيها شيء مهم للمعماريين والمصممين.

تعد تكنولوجيا النانو واحدة من أهم التطورات العلمية والتى يتوقع أن يكون لها أثر كبير على العديد من المجالات بما فيها العمارة حيث أنها تقدم موادا وأنظمة جديدة من شأنها أن تؤثر على مواد البناء ومن ثم على الشكل المعمارى ووظائفه. هذه المواد يمكن أن تكون مواد جديدة تماما بخصائص فائقة التطور أو تكون مواد تقليلدية تم تحسينها وتطويرها باستخدام تكنولوجيا النانو.يناقش البحث هذا الدمج ما بين العمارة وتكنولوجيا النانو من خلال ثلاث نقاط رئيسية:

- دراسة العلاقة بين كل من الشكل المعمارى والهيكل الانشائى ومواد البناء وتأثير كلا منهم ودوره فى العملية التصميمية ، كما يتم اسقاط الضوء على مواد البناء كعامل مهم أصبح أساسيا فى العملية التصميمية من بدايتها، يتناول هذا الجزء ايضا تصنيفات المواد المعروفة وتأثير مواد البناء على تطور التشكيل المعمارى منذ عصور الانشاء الحجرى الى وقتنا هذا .

- يتناول الجزء الثانى من البحث تكنولوجيا النانو وتأثير دمجها بالعمارة ، هذا الدمج الذى سيظهر فى عدة صور اما عن طريق دمج مواد النانو بالعمارة ( فى صورة مواد انشائية او غير انشائية، كسوات، اضاءة، مواد عازلة) أو عن طريق دمج أنظمة جديدة وأجهزة تم تطويرها باستخدام تكنولوجيا النانو تساهم فى رفع أداء المنتج المعمارى كما سيتم الاشارة فى هذا الجزء من البحث الى الدمج بين أنظمة النانو واتجاهات تصميمة حديثة مثل العمارة المحاكية للبيئة و العمارة الحركية.

- الجزء الاخير سيتم فيه تحليل بعض حالات الدراسة التى تم استخدام تكنولوجيا النانو فيها، مع توضيح تأثير تكنولوجيا النانو فيها على كل من الشكل المعمارى والوظيفة.

جامعة الأزهر
كلية الهندسة
قسم الهندسة المعمارية

# استخدام تكنولوجيا النانو فى العمارة

## تأثير تكنولوجيا النانو على الشكل المعمارى والوظيفة

مقدمة من

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لنيل درجة التخصص "الماجستير" فى هندسة العمارة

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**يوليو ٢٠١٤**

**جامعة الأزهر**
**كلية الهندسة**
**قسم الهندسة المعمارية**

# استخدام تكنولوجيا النانو فى العمارة
## تأثير تكنولوجيا النانو على الشكل المعمارى والوظيفة

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**2014**