Materials and science for great Architecture

1. Introduction

Throughout the course of history discovering materials and new techniques in the building technology and science lead to great breakthroughs in buildings. The genius technique of moving large blocks of stone and granite create the pyramids of Giza. Also, the invention of tongue and groove in stone made it possible to crate the Parthenon. Not to mention the technique of optical correction to create the awe and humbleness that the building possesses till this day. The discovery of concrete by the romans and mortar that created the rules of modern build ting techniques

But while materials hold a great aspect of the success of a building the technique of how the building is built is very important as it can be seen in modern buildings like the concrete casting in *Burj Khalifa* where the problem was not a material related problem. It was the way to move liquid concrete and cast it above the ground and keeping it in its liquid form before it starts to harden

Architects have always searched for new techniques and materials even if the materials where not invented for the building industry. Titanium was initially produced and manufactured for the use of ballistic missiles and air space travelling industry. However, it was used by *Frank Gehry* at the *Guggenheim* museum in Bilbao Spain. Not only did he use a new material in architectural cladding but he also used a program called Catia that was initially made for *NASA* to design, fabricate and simulate the space shuttles that saves a lot of raw material and time through the manufacturing process.

This article focuses on some of the materials that where recently used and some of the techniques used to make them a material that works in building industry. Also, the article focuses on 2 main materials (*ETFE* and *Phase changing material*) and computational and digital fabrication techniques to create buildings that consider their environment and that provides a better quality of indoor spaces.

ETFE a polymer material that was invented to act as a wire insulating material for airplanes and space shuttles and was used by architects in pneumatic structures to create bigger and more efficient canopies for buildings. On the other hand, phase changing materials are materials that change their phase with respect to an environmental aspect and how these materials where used to create better thermal mass and shading element for buildings. Also, the integration of computational and digital fabrication in minimizing the materials usage. the simulate the indoor environment quality and to reduce the carbon foot print of the building

2. ETFE Material

ETFE stands for *Ethylene tetrafluoroethylene* which is a polymer is one of the most used polymer nowadays. Basically, it was designed and developed as a coating for aerospace industries structure in the early 1970's (Le Cuyer 2008) but the fabrication of the polymer and its welding produced relatively small sheets as it was used in the inner coatings of airplanes and space shuttles by *NASA*. However, *ETFE* was also used as a good insulator for chemical containers, electrical cables and radiation proofing because of exceptional insulating capabilities (Lamnatou et al. 2017).

Figure 1 The Eden project at Cornwall-Uk source edenproject.com

Later in 1981 scientist discover a way to extrude the raw material to create *ETFE* foil (a very thin layer of sheets). *ETFE* foil used a drop welding bar technique that it possible for the cladding of buildings creating large surface areas of *ETFE*. However, by the mid 80's the material was accepted and widely used in schools and shopping malls across Europe

Soon *ETFE* foil was used in the Eden project (*Figure 1*) (Hu, Chen, Zhao, et al. 2017) this project was considered the breaking point for *ETFE*. Since then, various types of *ETFE* emerged to suit the building industry. Hence, the need of development on the new material made a lot of discoveries and techniques to widen and make the use of ETFE more popular. Over the past few decades ETFE gained appealing characteristics that made it an appealing material for architects not to mention the large spans that it can carry without structural limitations.

Some of the benefits gained by using ETFE are

A. Clarity as it has transparency value of 90% and it allows the passing of the ultra violet rays to pass UV's that can also be controlled through using *ETFE* air cushions
B. Shading and solar control ETFE foil has a vast number of patterns that can be engraved in the film to provide semitransparent, opaque and clear. As well as grooves (*Figure 2*) that help in the refraction and distribution of light in the internal space creating a more uniform indoor light. Finally, EFTE films can come with various types or filters that can filter specific rays or shed a certain color hue in the indoor environment(Cremers and Marx 2017)

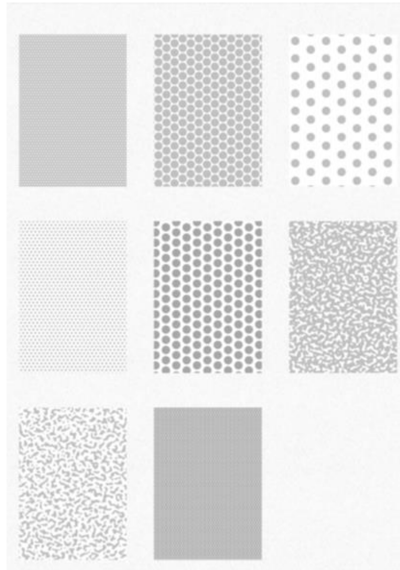

Figure 2 types of ETFE patterns source: Badir.com

C. Elasticity ETFE has a very elastic material that is up to 600% at the breaking point (LeCuyer 2008). Also, ETFE has a limit of plasticity that reaches 23 N/mm^2 and a tensile strength of 52 N/mm^2 but the factor of safety marge is $20N/mm^2$
D. Recyclable material ETFE is easily recycled as t can remolded to create new films or create ETFE products such as tubing components, wires or patches for torn panels
E. Cost effectiveness compared to concrete and steel ETFE has a relatively low cos that can go up to 150$ per sqf this includes the tubing and air inflation systems(Hu, Chen, Zhao, et al. 2017)
F. Sustainability and energy efficiency the manufacturing and the transportation of the film has low impact on the environment as it's a bio degradable material and has a low cost compared to other cladding materials not to mention the low cost of transportation as ETFE film has neglectable weight per square meter compared to concrete and metal (Hu, Chen, Liu, et al. 2017)
G. A material with a long-life span ETFE is a very durable material that does not degrade from external environmental factors and it can withstand harsh chemicals or extreme temperature variation (Cremers and Marx 2017)

To conclude, *ETFE* has what it takes to be a cutting-edge material that saves energy and improves the quality of indoor environment if fused with phase changing materials. Also, *ETFE* proved to be a successful material when it comes to aesthetics

3. Phase changing materials

Phase changing materials *PCM* are materials that change their state at a certain temperature. *PCM* have a very distinctive characteristic which is storing and releasing vast amounts of energy at this certain temperature(Kenfack and Bauer 2014). *PCM* can cycle but only solid liquid and vice versa are the most effective type of materials. *PCM* where initially developed as inner insulating material for *NASA* astronauts to keep them comfortable in space it was used in their Suits, Blankets and even space gloves. However, *PCM* were introduced to buildings creating a thermal mass for buildings (Raoux 2009).

The benefits of using *PCM* that it gives the wall the same heat coefficient value but in a thinner and lighter wall. The energy utilization to meet the space conditions and the difference between the temperatures between the inner and external spaces (*Figure 3*) where proved to be reduced using *PCM* (Wahid et al. 2017). Hence, the reduction of electrical usage in buildings that uses *PCM* versus conventional buildings. Also, using *PCM* in the insulation of the roof resulted in a considerable decrease in heat transfer in the upper floors leading to creating better indoor environment in buildings (Sharma et al. 2009)

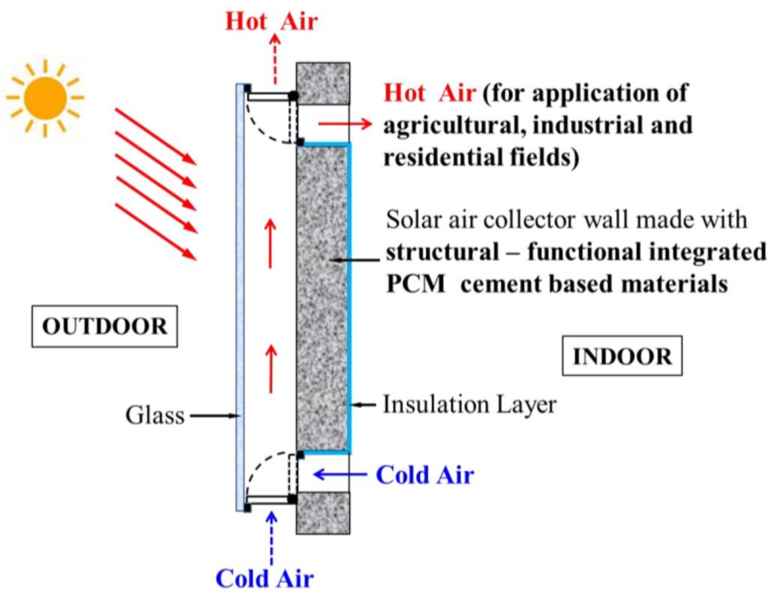

Figure 3 using PCM as a thermal mass for buildings source: dissertationwritings.com

The future of the building industry lies in merging *PCM* with new building techniques such as computational designs. On the other hand, *PCM* are known for their large energy storage capacity that have shown promising results through environmental simulation in the past few years and are being imbedded on buildings all over the world. However, the main problem of *PCM* materials are the possibility of explosion during the change of status phase as the store and exhale large amount of heat energy to change their phases. But with the proper isolation of the material these problems are reduced to minimal (Zalba et al. 2003)

4. Meta materials

Metamaterials (*MM*) are engineered structured materials that have properties and characteristics that are not found in natural materials (Schaedler et al. 2014). However, the creation of *MM* is depended mainly on two techniques Nano technology and digital fabrication. Where nanotechnology deals with replicating and aligning the material structure in sub wave length scale in order to evade a certain phenomenon in nature(Zheludev and Kivshar 2012). And digital fabrication makes it possible to simulate and fabricate the material giving the user control over its architectural molecular structure *Figure 4*.

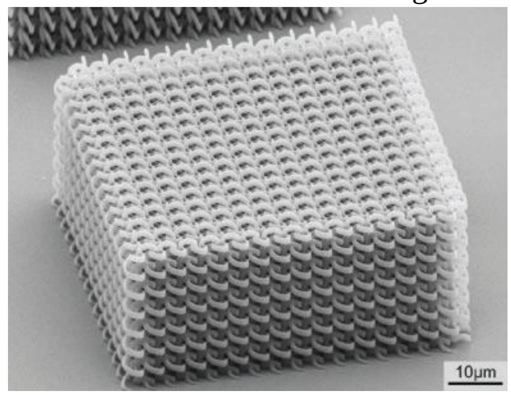

Figure 4 MM in 3D visualized simulation source: advancedsciencenews.com

Though there are various ways for structural alignment that qualifies a fabricated and engineered material to have the label MM. But, the most common of them are the materials with spacing arrangement of the material is much smaller than the size and spacing of phenomena. Hence making the material invisible to the phenomena and evading it(Boltasseva and Shalaev 2008). Thus, creating more complex material and more sophisticated materials that will aid the advancement of humanity.

The continuous development in the data transferring industry made it possible to meta materials to emerge. Where, NASA placed a big research and development to create materials that make astronauts more comfortable in their travels. Hence, the creation of materials that can perform faster when it comes to communication and storing data not to mention the technology embedder in the astronaut's space suits that is practically their life support system in vacuum

There are many types of meta materials but perhaps the most controversy material till this day is what is known as the zero-refractive index material known as (the cloak of invisibility). The material is structured to let the light passes through without any refraction making the object practically invisible (*Figure 5)* (Tsakmakidis, Boardman, and Hess 2007).

Figure 5 a Concept of the invisibility cloak source Lifeboat.com

To conclude though these materials are futuristic materials and are in the phase of research. An example of these materials also is something called the air gel which is in development phase and its said that it has the ability keep or retract heat and cold. As their applications are countless MM will aid the advance of building science to aid architects create a better indoor environment.

5. New Construction Technologies

Using new materials is important but creating new techniques that improve the material and save the material usage is not less important than the material itself. In the past few decades new machines and methods have been used to make the fabrication and construction of materials easier. The technological breakthrough in computer programs have created new forms and geometries that architect could not do before(Mahmoud and Elghazi 2016). The increase usage of parametric and computational design program lead to the creation of what is known nowadays as smart geometries. Smart geometry is a geometry that response to a certain parameter like light, shading and glare (*Figure 6*) (Sakamoto and Ferré 2008).

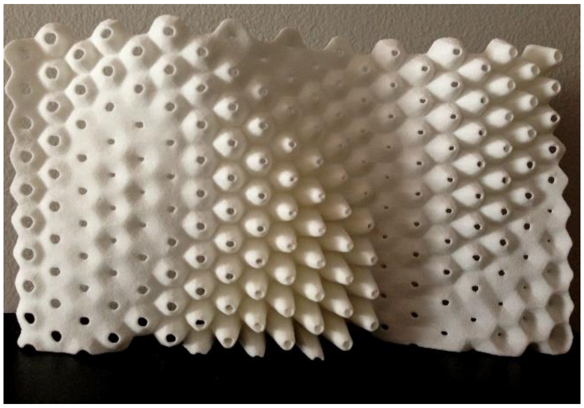

Figure 6 smart geometry created by computational design programs source: digital fabrication in architecture book

Figure 7 Digital fabricated cement based screen source: UC Berkeley

The geometries generated by architects through computational design needs precision in fabrication and cannot rely on hand made fabrication. Hence, *3D* printers where introduced and used to create these geometries with precision and with factor of error and variation to the computer-generated model known as digital fabrication *(Figure 7)*. On the other hand, the expenses of *3D* printers are decreasing opening a new era of fabricated facades and architectural elements in the building. Also its becoming a prerequisite in architectural study to get the knowledge of using such printers to prepare architects for professional life (Dunn 2012)

Another method to create theses geometries is to use the CAD/CAM technique which involves sending the files created to a *Computer Numerical Control* / CNC machines. These machines are used widely in the fabrication of watches machine parts and lots more. The concept of the machine is based upon a gantry utilized by a milling head that moves across this gantry *(Figure 8)* in different axes to create the desired shapes to conclude the combination of construction technologies along with materials is the ideal way to create better indoor quality

Figure 8 CNC machines source tehno-design.ro

6. Applications in architecture

While materials and new buildings techniques are two different faces of the same coin. Architects should utilize their usage together to achieve better indoor quality. However, this section of the article deals with an architectural precedent that utilized material and computer simulation to create a building that responds to the environment

The media tic is an office build that was designed by the firm *CLOUD9* in 2000 till 2005 and the construction was finished in 2007. The architect went through a long analysis period to come up with the existing building as he had to analysis the great *Gaudi* elevations and the came up with a modern iron grid that went with the same proportions of the building *(Figure 9)*

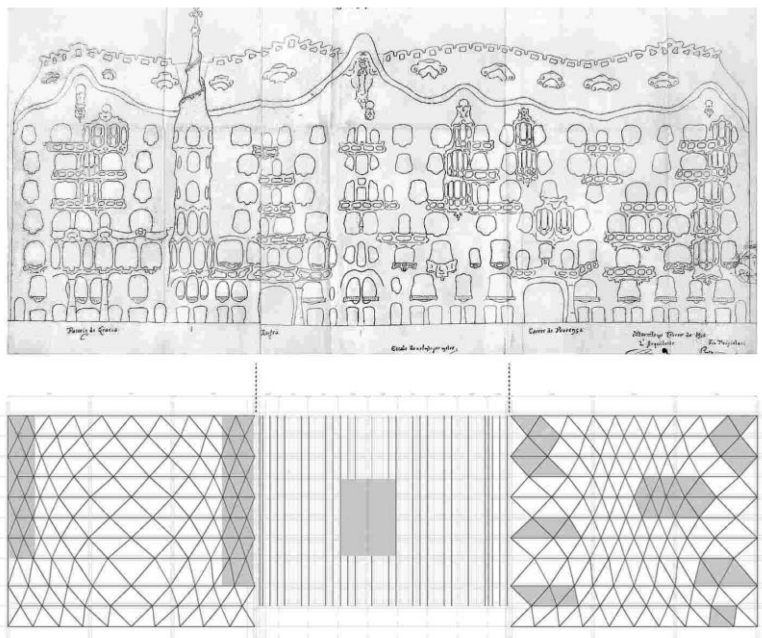

Figure 9 The analysis of facade source Cloud 9

The building traded the conventional curtain walls with a parametric designed façade that was fabricated and design with respect to the solar impact on the elevation. Also, the panels that where installed where triple layered *ETFE* with a metallic lattice panel inside to filter the daylight *Figure 10*.The *ETFE* panels are inflated with both air and a nitrogen vapor. As air works as an insulating material to decrease the heat transferred to create a better indoor environment the nitrogen vapor acts as a phase changing material that cycles between transparent and translucent material to provide the interior space with indirect light *(Figure 11)*

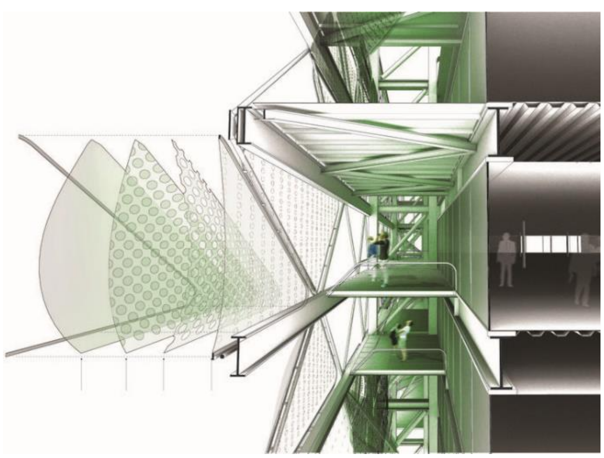

Figure 10 The skin Techtronic

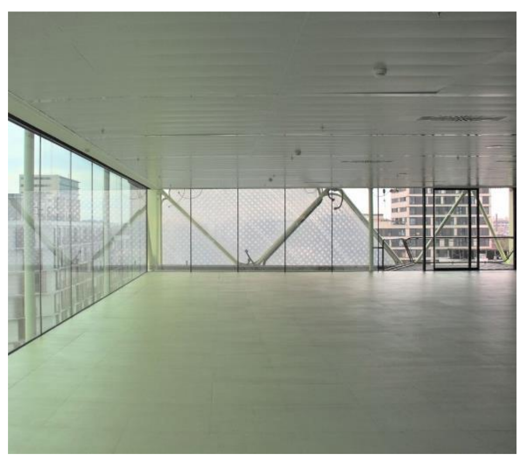

Figure 11 indoor environment

The air cushion *ETFE* panel has three layers with 3 air gaps (*Figure 10*) 2 outer gaps enclosing an inner gap. The two outer gaps are mainly filled with air and they act as a thermal insulator for the building. They are inflated using a sensor that measures the outside temperature and determine whether the insulation is needed or not. The inner gap is filled with nitrogen vapor and it is inflated using a light sensor that senses direct solar light beams. Once the gap is inflated the material turns translucent thanks to the opposite pattern engraved in the *ETFE* air cousin in the middle section *(Figure 12)*

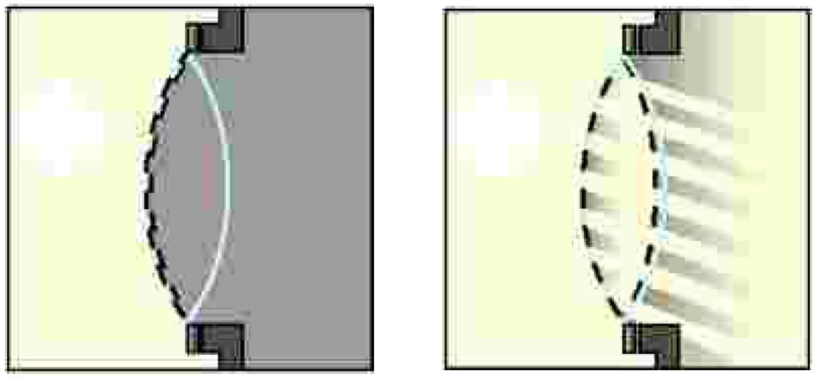

Figure 12 the pattern of the ETFE air cushion

Finally, these panels where designed and simulated using computational design programs. The panels where then sent to the manufacturer where sophisticated 3D printing, milling, welding and fabrication robots started assembling the panels and numbering them to be shipped to the site for fixation

To conclude, the impact of digital fabrication techniques on architecture is visible. Where the integration of digitally generated models with data collection and computational aspects of assembly create complex geometries. On the other hand modern materials and engineered materials are a byproduct of such advancement of fabrication and computer generated models. Hence, the integration of new materials alongside computer generated panels and computational assembly are an important ingredient to create a better indoor environment for users. Also, the usage of such techniques and materials reduce the carbon foot print of the building, material usage and material wastage fulfilling the term sustainability in buildings finally, the architectural projects currently enrolls and encourage the described work frame that encourages creativity and make our buildings more efficient and pleasant

7. References

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