NANOTECHNOLOGY PROVIDES NEW DYNAMICS IN ARCHITECTURAL DESIGN

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ABSTRACT
Materials have been affecting architectural design since the beginning of human civilization and architectural expression. The use of advanced technology has provided a wide range of possibilities in implementing architectural design. Nanotechnology has already revolutionized a lot of industrial fields. The advantages through the implementation of nanotechnology in architecture are multidimensional as they do not limit to the sustainability and energy efficiency of buildings. Furthermore, nanotechnology provides architecture with new, innovative and revolutionary materials that can alter design and performance of buildings. This has led to the launch of Nanoarchitecture, offering new possibilities that affect both architectural design and architectural applications. Nanotechnology integration in Architecture concerns not only the use of nanomaterials and manipulation techniques but also the reconsideration of forms and design methods. Flexibility and dynamics of forms and aesthetics, adaptation in external and internal requirements, protection of quality in living conditions and ad hoc control of microclimate are now feasible. Structures adopt mechanisms from nature and begin to mimic living organisms. Throughout research in existing and potential applications of nanotechnology and use of smart materials in architecture, this study demonstrates the level of influence of nanomaterials on architectural design and attempts at proposing an innovative system of high-performance buildings.

Keywords: Nanotechnology Materials, Construction Applications, Architectural Design

INTRODUCTION
One of the basic human activities from the beginning of civilization was the creation of a shelter. Basic natural materials found in proximity were the first components of human structures. Those conventional, traditional, per se, materials are still in use in architecture creation and construction. The unique characteristic of human nature has always been the ability not only to adapt to the environment but also to adjust environment to their needs. In accordance to the latter, technology has become the infinite manipulation tool. Nanotechnology in particular is a rapidly developing field with numerous current and potential applications in various other fields. Many possibilities that nanotechnology can offer, if combined together, they can promote architectural creation and project realization. Reduced time in implementing architectural plans diminished negative environmental impacts through low emissions from materials production, as well as increased energy efficiency of buildings -that can produce sustainable energy and even perform air purification and water filtering. Even increased positive performance of structures, due to self-assembly and self-repairing features, are some of the objectives to be met.
Smart materials and new techniques have already been used, i.e. self-cleaning and air-purifying surfaces, insulating and anti-microbial coatings, sun radiation protection and fireproof membranes. Further ahead, as research is progressing in bio- and nanotechnology, we could combine new features in order to develop systems that mimic nature in the field of construction. The concept of our research represents an effort of combing these new dynamics of nanotechnology in order to create an intelligent system of external bearing structure that can perform multiple functions. A system that will be able to carry structural load and at the same time produce energy and filter the air, one that will have the capacity to transform according to external climatic conditions in order to regulate internal climate and that will have aesthetic dynamics through colour shifting and transparency switching. All this approach is part of the conceptual framework of a dissertation study that aims at concluding in implementing an experimental model system.

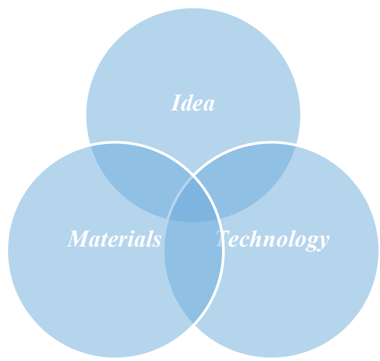

Figure 2. A structure is a result that comes from combining three forces.

Technology in Architecture

A positive effect of technology in architecture is the computer aided design and the creation of 3D models (CAD, modelling, 3D rendering, and 3D printing). The next step is realized by the introduction of genetic architecture in combination with nanotechnology. Computer design techniques strengthen the interdisciplinary relationship between architecture and other sciences. Also, new building techniques and construction methods have rendered project implementation easier and more efficient. New organic forms inspired by nature can now be digitally produced and constructed.

Nanotechnology

Nanotechnology is the design, characterization, production and application of forms, mechanisms and systems through controlled manipulation of shapes and dimensions at nanoscale that produces forms and systems with at least one improved or new property [1].

The development of nanomaterials will bring benefits to society [2]:

- research on nanomaterials has major influence on health, information technology, energy and other areas, where much economic benefit lies on commercialization of new technologies,
- regarding energy efficiency, the research of nanomaterials will lead to new materials that will lead to more efficient operation of power plants and enable the development of new energy systems based on renewable sources,
- development of nanomaterials will cause reduction of negative environmental impact from the production process of materials (less pollutants) and form the presence of waste (efficient and enhanced materials don't need to be replaced often).

Nanotechnology is very diverse area and ranges from conventional material-matter manipulation to completely new approaches. It is a rapidly developing field with numerous current and potential applications in various other fields. Many possibilities that nanotechnology can offer, if combined together, can promote architectural creation and construction. Innovative new nanomaterials and nanosensors have already been giving the architect a new tool palette. Properties such as self-cleaning, self-repair and self-assembly have promoted the performance of architectural projects.

Functions of nanomaterials, which have high potential for innovation, include:

- improved mechanical properties,
- new electronic functions,
- new magnetic functions,
- enhanced thermal properties,
- improved chemical properties,
- new optical functions,
- biological properties.

Nowadays, nanotechnology has already been applied to construction materials such as concrete (stronger, greater durability, easy assembly), steel (stronger) and glass (self-cleaning). The use of nanotechnology in the material industry leads to efficient use of raw materials and also reduction of negative environmental effects which emerge from material production processes (less pollutant emissions, less raw materials used [3]).

Architecture

Architecture in simple words means the science that translates human needs into functional three dimensional structures, the art of synthesis that is the effective way of combining elements to create more complex forms. Architectural evolution has brought up new demands in performance and energy efficiency of structures and sustainability of buildings.
The term Architecture refers to both the process and the product of planning, designing, and constructing buildings and other structures. Architectural works are often perceived as cultural symbols and/or works of art. Civilizations are often identified with their surviving architectural achievements. The word "architect" comes from the combination of two Greek words «αρχή» and «τέκτων» which means "master constructor". By others, architecture means the origin of arts and crafts.
Architecture encapsulates the style, design and construction of buildings and other physical structures, the knowledge of art, science, technology and humanity, the design activity of the architect, from the macro-level (urban design, landscape architecture) to the micro-level (construction details and furniture). Architecture deals with planning, designing and constructing form, space and ambience to reflect functional, technical, social, environmental and aesthetic considerations. It requires the creative manipulation and coordination of materials, technology, light and shadow. Often, conflicting requirements must be resolved. The practice of Architecture also encompasses the pragmatic aspects of realizing buildings and structures, including scheduling, cost estimation and construction administration. Documentation produced by architects, typically drawings, plans and technical specifications, defines the structure and/or behaviour of a building or other kind of system that is to be or has been constructed. Thus, nanotechnology employed in architecture leads to "Nanoarchitecture", a promising endeavour.

Nanoarchitecture
The integration of nanotechnology in architecture has led to the launch of Nanoarchitecture, where nanotechnology integration concerns not only the use of nanomaterials and manipulation techniques but also the reconsideration of forms and design methods – ultra high performance buildings (dynamic, interactive) [4].
The process of designing structures is changing, as a material can perform differently and play alternative roles. The size of materials required is smaller, the necessary assembly time is less and the life cycle of structures becomes larger due to the enhanced properties of materials and the use of innovative protective coatings. Material properties control to this extend, evolve architectural design and construction. Thus, construction methods can change as well. Most structures can be created "bottom up", i.e. from material unit to structure elements as some materials have the ability to self-assembly. Augmented features release design, making possible even the most unrealistic solutions. Forms evolve and often mimic living organisms. Architecture operates at optimum levels as it offers innovative solutions. Transformable usage of architectural elements which is at user's discretion, such as control of transparency of windows or partitions (interior and exterior), give the building a more dynamic form. Furthermore, improvement of living conditions by controlling the quality of internal environment (air purification, thermal comfort, reduced solar radiation, antimicrobial surfaces, effective security and protection against external adverse conditions) restores the role of the architect as a quality supplier of living environments beyond functionality and aesthetics.
Ultra high performance buildings retain stability through negative feedback interactions and promote their development by applying positive feedback [4]. In this sense, buildings and structures can be programmed to monitor the environment (internal and external) and to adapt or change their form so that it will be in harmony or symbiotic relationship with nature and man. To a future extend the cooperation of sciences of biology and nanotechnology can provide biological characteristics in materials, structure and morphology. Surfaces will be able to metabolize, respond and adapt to the environment, will have the properties of self-assembly, self-healing and self-repair. All text paragraphs should be single spaced. The position and style of headings and.

Sustainability and Innovation
Nanotechnology in Architecture involves of course two major areas that nowadays accompany the meaning of technology, i.e. sustainability and innovation.

Sustainability
Sustainability as a general term refers to the capacity to endure. Sustainable development is the development that meets the present needs without compromising the ability of future generations to meet their own needs [5].
Currently it is considered as an infinite process through the ecosystem, a dynamic evolutionary way towards the improvement of management of human and natural resources. In the construction field, sustainability is a matter of grave importance. In architecture sustainability describes environmentally conscious design

techniques, minimizing negative environmental impact and enhancing efficiency in the use of materials, energy and space.
The principles for sustainable design include:

- low-impact materials (non-toxic, sustainably produced or recycled),
- energy efficiency (less energy in manufacturing and production),
- quality,
- durability,
- reusability and recyclability [6],
- bio-mimicry[1],
- service substitution[2],
- renewability and
- provision of healthy environments.

Thus, sustainable architecture aims to design and produce sustainable buildings.

Innovation
Innovation enhances sustainability with the following features:

- adaptability,
- symbiosis,
- environmental interaction,
- intelligent systems and materials,
- ultra high performance structures and
- creation of in other circumstances unrealistic projects.

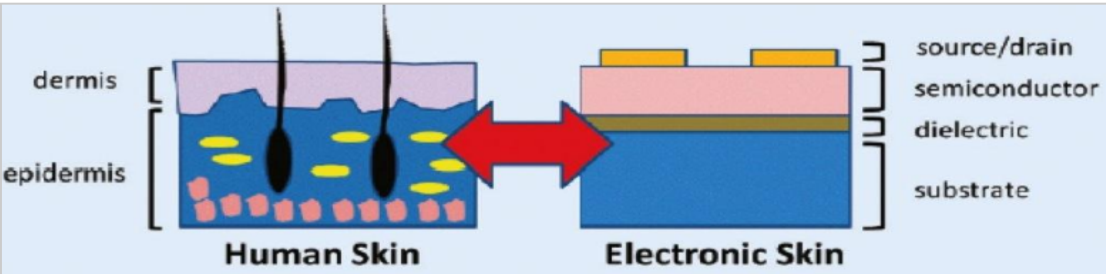

Figure 3. Using organic materials to create artificial skin: Scientists are using organic field-effect transistor (OFET) architecture to build electronic material that mimics human skin. The electronic skin I s a stretchable 2D array of tactile sensors that collect environmental signals and translate those signals into information [9].

Nanomaterials and Applications
Materials reduced to nanoscale exhibit different properties compared to those on the macro scale. They tend to be more chemically reactive. Opaque materials become transparent, stable turn combustible, semiconductors become conductors and solids turn to liquids at room temperature.

Basic Nanomaterials
Carbon nanomaterials are an enabler for technology with seemingly endless potential applications: self-repairing buildings and bridges, creating strong and lightweight structures, filtering water, powering mobile devices from body heat or movement, improving corrosion resistance of conventional materials. Carbon nanotubes are 100 times stronger than steel at one-sixth of the density and 10,000 times smaller than one human hair. Graphene is a carbon membrane that, at just one atom thick, is stronger than steel and can tolerate wide temperature and pH ranges. Carbon nanotubes, single or multi-walled, have tubular form with a

[1] Bio mimicry is an approach that seeks sustainable solutions by emulating nature's time-tested patterns and strategies [7].
[2] Service substitution: shifting the mode of consumption from personal ownership of products to provision of services which provide similar functions - Such a system promotes minimal resource use per unit of consumption [8].

diameter of about 1nm – a graphene sheet is rolled into a tube. According to their geometry, they exhibit different properties (armchair geometry shows metallic behavior, zigzag shows semiconducting behavior). A carbon nanofiber has a diameter that ranges at a billionth of a meter and therefore has a large surface-volume ratio.

Nanocoatings can be applied as thin films on glass or fabric in order to block solar radiation, as paint in order to attribute insulating properties [10] and as layers of nanoparticles that interconnect with the substrate material, achieving properties such as insulating, stain-resistant, self-cleaning, scratch-resistant, anti-microbial, anti-corrosive and water-proofing.

Nanosensors can be integrated into conventional construction materials in order to continuously check for the presence of chemical or biological agents and interact with the control sensor to provide the information to the monitoring system.

Nanorobots (or nanobots) have been developed as a means of engineering molecular products. A nanorobot is a controllable nanoscale robotic device (autonomous or semiautonomous) [11], composed of elements at nanoscale and possesses characteristic abilities such as:

- swarm intelligence,
- cooperative behavior,
- self-assembly and replication,
- information processing and programmability,
- interface architecture and
- durability.

Organic nanorobots are ATP and DNA based molecular machines whereas the inorganic ones are based on tailored nanoelectronics.

Organic electronic devices can do more than transport electronic information. They can also transport optical, magnetic, and thermal information. Indeed, many of the organic electronic devices already on the market are multifunctional. For example, organic light-emitting diodes (OLEDs) and organic solar cells are multifunctional optoelectronic devices, i.e. electronic devices that use or produce light in addition to using or producing electrons. As chemists gain better control over the synthesis of organic materials, they and their engineering collaborators will be able to build increasingly sophisticated optoelectronic and other multitasking devices with multiple inputs and multiple outputs. For example, researchers envision multitasking window glazing that function as solar cells that generate electricity and as OLEDs that generate light [9]. There are many advantages of organic electronics. In addition, the development and encapsulation of organic electronic devices in flexible polymer substrates in large scale and with low cost production processes will enable their market applications in numerous fields such as monitor devices, lighting, photovoltaic systems, frequency identification circuits [12] etc.

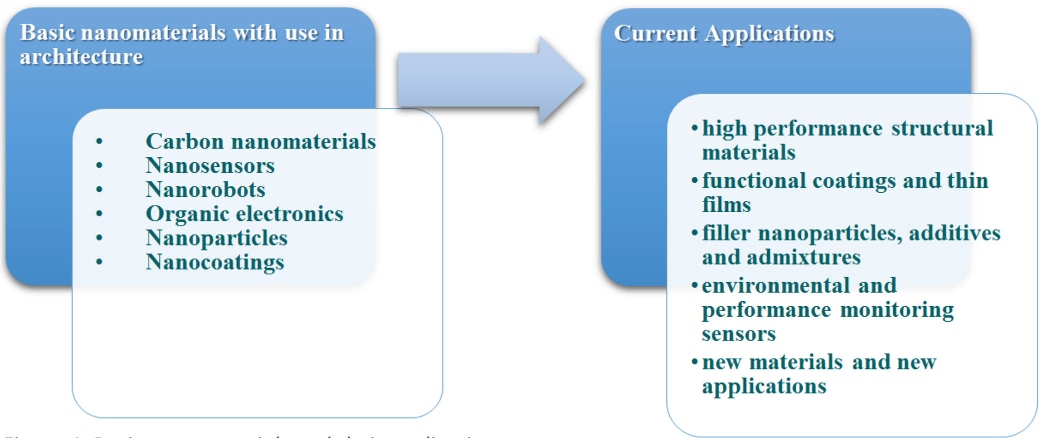

Figure 4. Basic nanomaterials and their applications.

Applications overview

Nanomaterials and techniques have already been under use, such as self-cleaning and air-purifying surfaces, insulating and anti-microbial coatings, self-healing additives and strength admixtures, sun radiation protection and fireproof membranes. Further ahead, as research is being made in bio- and nanotechnology, we could combine new features in order to develop systems that mimic nature in the construction field.

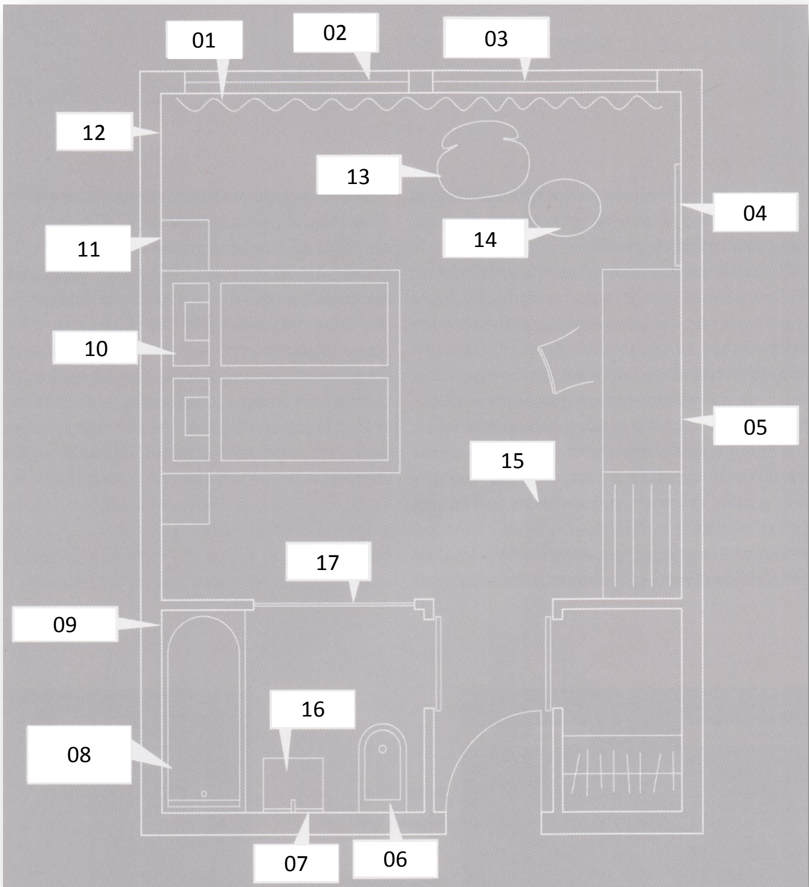

Figure 4. A typical plan of a hotel room, with the application of basic nanotechnology materials [21].

01. Curtains: air-purifying nanocoating
02. Window: photocatalytic coating – self-cleaning
03. Window: electrochromic - self-cleaning
04. TV: antiglare
05. Wall painting: air-purifying
06. W.C.: easy-to-clean
07. Mirror: anti-fogging
08. Bathtub: easy-to-clean
09. Walls: ceramic nanoparticle coating
10. Bedding: anti-bacterial
11. Switches: anti-bacterial
12. Wall painting: air-purifying
13. Wall paper: air-purifying
14. Glass table: anti-fingerprints
15. Carpet: air-purifying
16. Sink: anti-fingerprints

Reality or Fiction?

The increasing development of technology will lead to intelligent systems such as self-assembled structures, buildings even entire cities. What seems now science fiction can be feasible tomorrow through the leaping advances of technology. Multifunctionality and innovative properties can be ad hoc combined towards serving the human needs. Some interesting examples are given bellow.

Self-assembly: Scientists who are focusing their study on nanotechnology have recognized that some properties of atoms and molecules enable them to arrange themselves into patterns. There are a variety of applications where self-assembling of nanoparticles can be useful. For example, developments of building sensors that detect chemical and biological molecules. In addition, it can also be used on creating computer chips with smaller component sizes, which can then allow more computing power to be stored on a chip. Natural ability of nanoparticles to self-assemble can be replicated in systems that do not intrinsically self-assemble. Directed self-assembly (DSA) attempts to mimic the chemical properties of self-assembling systems, while simultaneously controlling the thermodynamic system to maximize self-assembly. Templates made of microstructures like carbon nanotubes or block polymers, can also be used to assist in self-assembly. They cause directed self-assembly (DSA) in which active sites are embedded to selectively induce nanoparticle deposition. Nanoparticles are often shown to self-assemble within distances of manometers and micrometers, but block copolymer templates can be used to form well-defined self-assemblies over macroscopic distances. By incorporating active sites to the surfaces of nanotubes and polymers, the functionalization of these templates can be transformed to favour self-assembly of specified nanoparticles.

Structures that build themselves: a top-down concept of building from nano to meter scale has been developed following certain suppositions. These suppositions suggest the following conceptual solution [13]:

The fundamental building process is occurring at the nanolevel by multifunctional nanodevices (nanorobots), which are capable of capturing CO_2 from the air and extracting C molecules from it, releasing O_2 back to the air, and building 3D carbon nanotubes arrays with certain characteristics required for a specific area of the building.

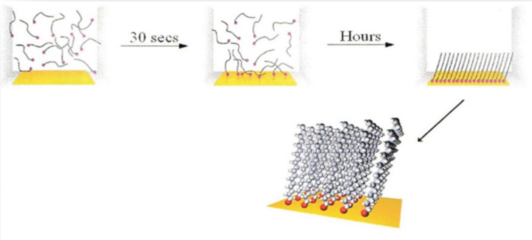

Figure 5. The self-assembly process. [31].

Nanorobots are controlled and powered externally by light. Instructions are coded using specific wavelengths.

Light is emitted by a projector installed above the site. To avoid interference with light emitted by other sources, an adequate wavelength spectrum has to be chosen.

The projector uses the detailed BIM (Building Information Model) as input, and continuously projects the horizontal section, which is constantly moving from the bottom to the top of the model.

Openings of the final model are temporarily filled with unstable carbon nanomaterial, which transforms back into CO_2 after a specific time period (or under specific conditions), when its function as a supporting structure is fulfilled.

All utilities and coatings (if necessary) are built at the same time, together with the bearing structure (e.g. pipelines, power lines, communication lines), and are part of the building.

This concept is feasible in theory but it will require many more years of research in the areas of biotechnology (bionanorobots), nanomaterials (3D CNT arrays), physics (light projector), and construction informatics (detailed and appropriate building information models and modeling tools, building technology system) [13].

Interactive material: “living kitchen” is a project in concept. It is in fact about a matter made out of a multitude of small intelligent robots, able to stick and communicate to each other. This would create a shape-shifting, programmable matter, able to transform into whatever shape desired. The matter being reactive to exterior stimuli, people would just have to touch the walls to make faucets, sinks (Figure6a) or cutting-boards appear. The volumes could be stretched, twisted and bend by the user to perfectly fit his needs. Also new shapes could be invented by drawing their silhouettes on the surfaces [14].

Concrete mimicking human skeleton (Figure6b): inspired by the bone's morphology defined by the Wolff's law, adapting the material to force, a reinforced concrete structure becomes truly sustainable using half the material whilst more efficient to withstand heavier earthquakes. As the bone morphology, the concrete skeleton adapts to the environmental inputs [15].

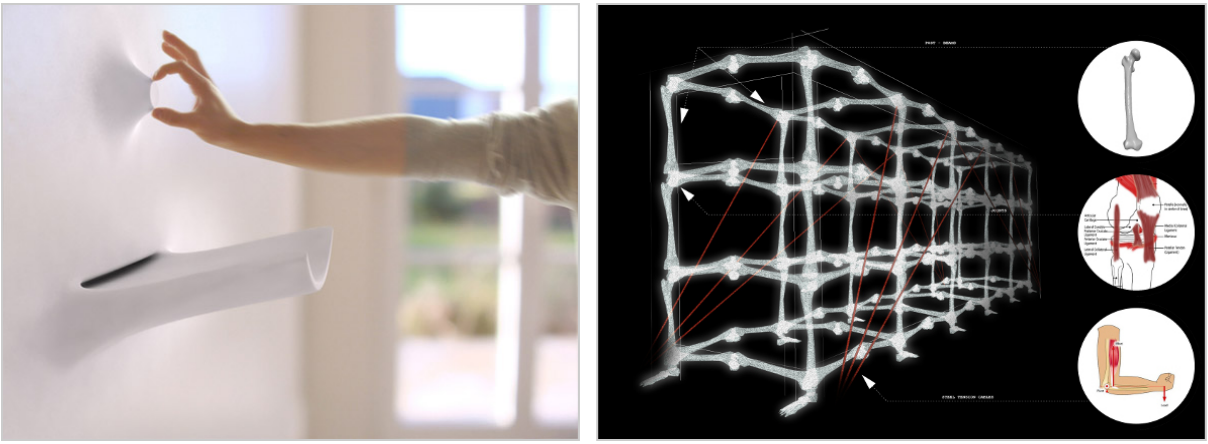

Figure 6. (a) The "Living Kitchen" –a sink and a faucet is made [14]. (b) Bearing structure of a building as bone skeleton [15].

Innovative Architectural Applications

There are numerous examples of design projects that make use of nanotechnology, most of which are still in conceptual stage. Some Innovative Architectural Applications (that have been constructed) are the following: Soft House (created by KVA Matx, Hamburg, 2013): The SOFT HOUSE project in Hamburg, Germany is a winning competition entry for the International Bau Austellung (IBA), a prestigious German building tradition that dates to 1901. Completed in March of 2013, it is a set of live/work row house units which offer a new model for low carbon construction and an ecologically responsive lifestyle that can be personalized to meet homeowner needs. The Soft House demonstrates how domestic infrastructure can become 'soft'—engaging flexible living concepts, carbon-neutral solid wood (brettstapel) construction, and wireless building controls with responsive and performative textiles which create the public identity of the architecture. Through the conceptual reframing of 'soft' and 'hard' materials and the integration of architecture, mobile textiles, and clean energy infrastructure the SOFT HOUSE transforms the German Passive Haus typology, offering a more flexible living experience [16].

Figure 7. (a) PV curtains [16]. (b) Front view [16].

They have created a mobile system of PV curtains (Figure 7a) that harvest solar energy while offering solar protection externally and serve lighting purposes internally. They have revolutionized interior design by replacing traditionally steady interior elements with PV curtains.

The structure consists of wood panels and flexible solar nanomaterials in a light, smart textile that bends in order to achieve the best angel for solar energy harvesting. The PV curtains offer coverage on a large glass façade (Figure 7b). A three-storey atrium brings daylight deep in the ground floor and regulates inner air circulation with a system of windows and curtains. LEDs in the movable curtains are playful and engaging—allowing people to make new connections between the domestic and natural environments. The Soft House smart curtain LED lighting system allows for real time monitoring and visualization of outside wind and climate conditions. The solid state light that moves along the Soft House curtain surface in relation to exterior wind

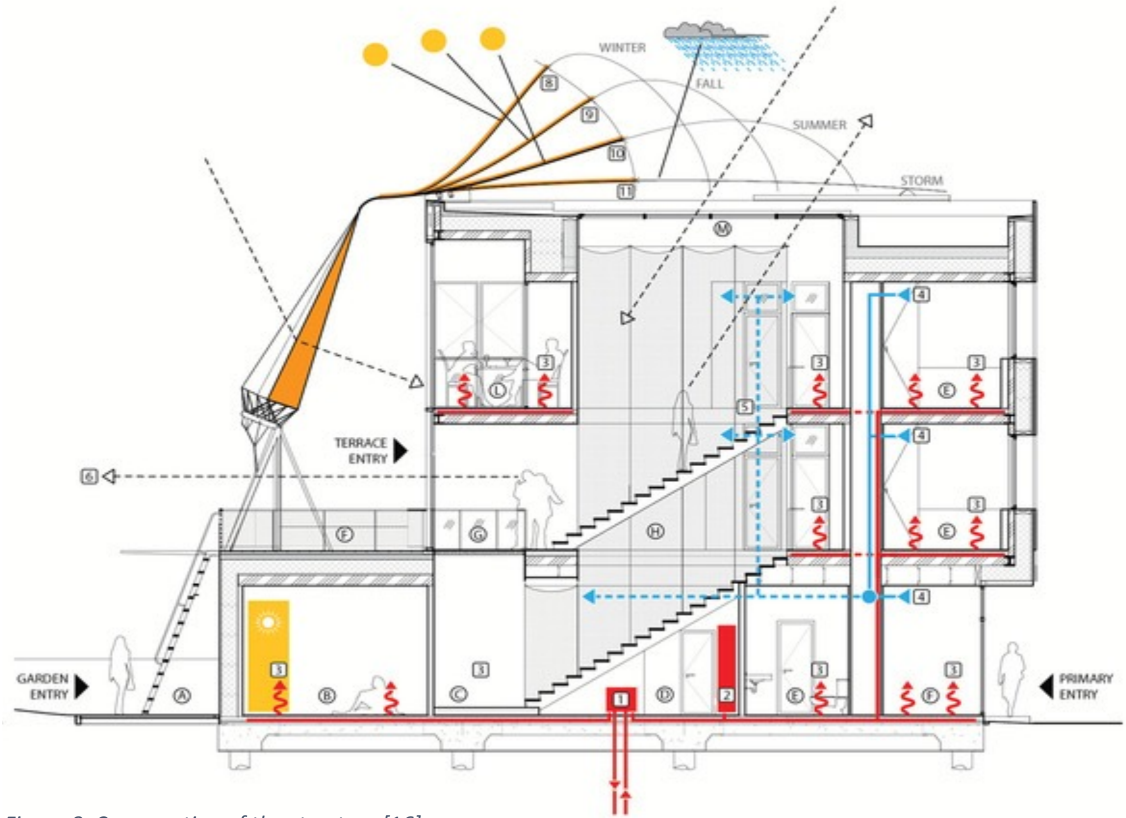

Figure 8. Cross section of the structure [16].

levels creates a Visual Breeze— an ambient interior luminous expression of the external environment. The PV curtains channel the produced energy in common household devices [16, 17, 18, 19].

<u>Glass Façade Sur Falveng (Schwarz Architects, Alps, 2006)</u>: The "Sur Falveng" (Figure a) building is a house for the elderly in the Swiss Alps and offers 20 rooms with access for the disabled. The south elevation glass façade heats actively or passively the rooms and changes according to climatic conditions. The glass panels consist of 8cm composite glass element - this contains in the middle a hydrated filler material which functions as a latent solar heat storage medium and protects the room from overheating. The glass structure is composed of four plates of 6 mm safety glass, with three intervals. The interval that is located outwardly contains a prismatic plate; it is filled with a noble gas, as the middle one. The gap located inwardly is filled with a latent accumulator: a salt hydrate. With this internal interval containing the salt hydrate, the glazing GlassX provide the necessary heat storage. The integrated prismatic glass protects against summer heat and the latent accumulator is used for winter storage of energy; both are an innovation. In the summer, an integrated prismatic glass prevents overheating by refracting light. Developed by architect Dietrich Schwarz, this glass has solar accumulation rate efficiency up to 40% in winter. Solar radiation is directly converted in a pleasant radiant heat [20].

The heat capacity of that element is equivalent to the heat capacity of a concrete wall with a thickness of 15cm. The glass façade becomes transparent when the material passes from the state of solid to liquid (Figure b) [21]. Therefore, the change of state of the material has a direct impact on the appearance of the building.

With the rise of external temperature, the material absorbs heat. As outer temperature drops, the Phase Changing Material will return to its solid phase and reject the absorbed heat. The hydrated salt that is encapsulated in polycarbonate containers has much more latent thermal capacity than conventional materials. This means that solar energy is stored until nighttime (when the temperature drops), reducing the average inner temperature and thus reducing the use of air-conditioning systems [22].

Figure 9. (a) "Sur Falveng" glass façade [21]. (b) Changing states of the PCM [22].

Jubilee Church (Richard Meier & Partners - Arup Guy Nordenson & Associates, Rome, 1996-2003): The Jubilee Church (La Chiesa del Dio Padre Misericordioso) (Figure 9), conceived as part of Pope John Paul II's millennium initiative to rejuvenate parish life within Italy, is located outside central Rome. The proportional structure of the entire complex is based on a series of squares and four circles. Three circles of equal radius generate the profiles of the three concrete shells that, together with the spine-wall, make up the body of the nave. The materials used in the portico—the paving, the wall cladding and the liturgical furniture—allude to the body of Christ's church while referencing the fabric of the adjacent residential area. Glazed skylights suspended between the shells are lit by zenithal sidelight, and the nave is enlivened by a constantly changing pattern of light and shade. The light is diffused over the inner volume of the church and varies according to the hour, the weather, and the season, imparting a particular character to the aspects of the interior [23].

Self-cleaning surface systems have been applied here. This church consists of 256 precast and prestressed concrete elements that are assembled into curved white shells of 25m. The concrete elements are made of high performance concrete mix with white Portland-type cement, metakaolin and white Carrara marble. This mixture creates a bright, clean and white concrete. The objective was to create a structure with clean surfaces and pure white color, features that are maintained. This was achieved with the use of TiO_2 in the concrete mixture, offering self-cleaning and smog-eating properties [24]. "Italcementi" developed and patented a new type of white self-cleaning cement, called Bianco TX Millennium. The cantilever reached is impressive, related to the thickness and extension of the "sails" [25, 26].

Figure 10. The Jubilee Church in Rome [24].

Figure 11. Discovery Gardens [24].

Discovery Gardens (Dubai): paints enhanced with Ag nanoparticles were used. Bioni paints achieve their anti-microbial properties from microscopic nano-silver particles. Silver has been used as medicine and preservative by many cultures throughout history. Today, germs, bacteria or fungal spores brought into contact with surfaces coated with Bioni paints are very quickly destroyed when the integrated nano-silver particles react with proteins in the outer membranes of the microorganisms. Unlike other microbial paint systems, where the incorporated anti-bacterial function will lose its effect over time, the nano-particles used in Bioni paints are solid bodies, allowing the paint to retain its antimicrobial effect permanently. Bioni façade paints and roof coatings may also be used to protect the exterior of buildings from attack by algae and moss.
When used as an exterior coating, Bioni's nanosilver technology is also claimed to reduce air conditioning bills due to the low thermal conductivity of the nano-silver particles, and their ability to reflect 93% of incident sunlight. Due to the high demand for a permanent anti-bacterial solution, Bioni has already been used in a number of significant projects worldwide, including the spectacular 26 million square foot freehold residential community, Discovery Gardens, located in Dubai (Figure 11) [24, 27].

Frost Art Museum (Yann Weymouth of Hellmuth Obata & Kassabaum, Miami, 2008): The structure features a soaring three-story glass atrium entrance and a dramatically suspended staircase leading to the second and third floors containing over 9,000 sq. ft. (840 m^2) of exhibition space. Three of the nine galleries are dedicated to the permanent collection, while the remaining six galleries will feature temporary exhibitions. Among various interior design highlights is the prominent use of natural daylight in the galleries. Large "leaves" or "petals" are constructed to diffuse ultraviolet by preferentially scattering light to the walls. This unique gallery lighting was designed by ArupLighting. The glass surfaces are coated with Hydro-NM-Oxide[3]. It is a nanocoating that is used for reducing heat transmission in buildings. Other than insulating properties, it offers effective protection from mildew and corrosion. It can be applied as paint and is transparent or white. The objective for the use of this material was to allow light while preventing the penetration of heat [24].

Figure 12. The Frost Art Museum in Miami [24].

[3] Nansulate® coatings are a patented insulation technology that incorporates a nanocomposite called Hydro-NM-Oxide, a product of nanotechnology. This material is documented as having one of the lowest measured thermal conductivity values.[28, 29]

Solar Ivy: Mimicking the form of ivy and its relationship with the environment, this system is called SolarIvy. It was designed by Samuel and Teresita Cochran and consists of thin solar photovoltaic panels (Figure 13b) that resemble the leaves of ivy and generate power. This "skin" can be incorporated on the side of a building. When the sun is shining or the wind blowing, it can generate power [32]. SolarIvy enriches the appearance of a building / structure (Figure 13a), when it is applied on a façade, and simultaneously has the ability of providing energy functioning as photovoltaic system. It is a bi-functional decorative element for external surfaces.

The Living Glass [33,34]: created by "the Living" - the silicone surface embedded with Dynalloy Flexinol wires contracts due to the electrical stimulus, allowing the "gills" to breathe and regulate air quality when carbon dioxide levels are high (Figure 14).

Figure 13. (a) Example of application – 3d model. (b) Form of Ivy leafage [32].

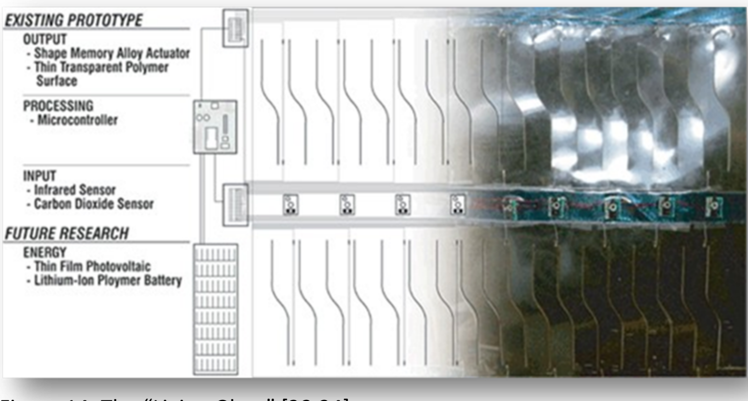

Figure 14. The "Living Glass" [33,34].

Potential Applications

Throughout research we came across various interesting materials and innovative properties that we plan to exploit:

- n2m construction with the use of nanobots - self-assembly of simple parts [13]
- intelligent systems: react – interact – adapt, adjust
- organic electronics: photovoltaic, lighting, textiles
- flexible organic electronics: flexible compounds, filling materials
- MM-CNT: stable, strong, light weighted bearing structure
- enhanced materials with nanoparticles for aesthetic properties: cleanliness, transparency – opacity, color changing
- energy efficiency: thermal conductivity, insulation, production of energy
- health: organic and printed materials as microbial indicators, use of sensors for atmospheric pollution
- nanosensors: failure feedback

Ending this paper, let's imagine a structure that uses some of the revolutionary properties mentioned before. The exterior of the structure will have skeleton and skin properties. This means it will serve load bearing purposes and protection, isolation – insulation and interaction. We have an oversimplified schematic representation of a structure (Figure 15a) which roughly consists of three parts:

1. Metal structure with joints

- MM-CNT
- anticorrosive coatings (i.e. TiO2)
- nanosensors (feedback)

2. Filler Materials (glass, Plexiglas)
- flexible organic electronics (PV)
- self-cleaning coatings
- microbial indicators (printed)
- sensors (best solar beam angle)
- PCM, TCM (solar protection, passive heating)
- flexibility (shape and size changing)

3. Inner Environment
- indicators for climatic changes
- PV textiles and lighting elements
- antimicrobial surfaces (Ag2O)
- easy-to-clean surfaces.

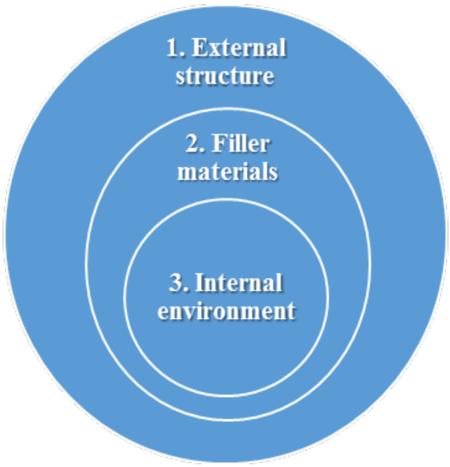

Figure 15. (a)Schematic representation of a structure. (b)Metal structure with joints.

All the materials that are mentioned above could grant energy efficiency, sustainability, high performance features and also aesthetic dynamics. Having that in mind one can imagine how deeply nanotechnology has already influenced architecture.

CONCLUSIONS

Architecture is considered as a form of artificial life, subject, like the natural world, to principles of morphogenesis, genetic coding, replication and selection. The aim of evolutionary architecture is to create within the built environment symbiotic behaviours and metabolic balance that are characteristic of the natural environment [30]. Nanomaterials constitute a new “language” for architectural expression. New possibilities have emerged in such a sense that we could create bio-mimicking and responsive buildings in the near future and, furthermore, buildings that build themselves. Similar to Le Corbusier, who once quoted that “a house is a machine to live in”; we are able now to describe a house as a living machine or even a living organism. There are nevertheless two important challenges for future research: achieve to combine properties in real life and manage to produce large scale structures within viable cost limits.

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