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Dynamism and Soft Robotics in the Intelligence of the New Design of Lightweight Envelopes

Consiglia Mocerino
Already contract professor in the Faculty of Architecture, Sapienza University of Rome - Miur, Rome, Italy

Abstract: The innovation of building envelopes is densely characterized, in the new design process, by new products of the building industry and intelligent robotic systems, making them efficient and dynamic in an eco-efficient environmental context and spatial flexibility. The goal is that of energy efficiency and environmental sustainability that invest above all the building production sector, pushing towards a circular economy with the use of clean energy resources and new artificial intelligence systems. The intelligence is highlighted through the optimization of the performance of new lightweight envelopes, in the technological design and the new building process, through Lean planning and Lean construction, Mass customization, with application of criteria, methods and tools. So there are innovative technological solutions, for environmental comfort and energy saving, and typological solutions with high performance level, with the use of innovative, adaptive, advanced, light materials with nanoproducts, intelligent IT systems, etc. We highlight the effectiveness of design with natural passive use of renewable energy and energy efficiency of the envelope as "skin" and relative increase in performance levels, in the interaction with the internal environment and natural dynamic flows and in the conversion of thermal and electrical energy. The methodologies are aimed at the application of digital technologies and soft robotic systems for the management and quality of services with technological and constructive solutions for dynamic interactive envelope and intelligent systems of double or triple skin, curtain walls, etc. The challenge is new design models of dynamic enclosures, on criteria and methods that guide the new rules on energy efficiency in buildings, for environmental sustainability and housing quality with the integration of soft robots.

Key words: Innovation, process, digital technologies, envelopes, soft robotic systems, sustainability.

1. Introduction

The design of buildings is changing according to the emerging needs that consider climate change with the development of digital and biocompatible technologies, while respecting the environment, focusing on quality and budget containment on sustainability and efficiency criteria.

For this reason, we aim at approaches of systemic sustainability in Architecture and related technical feasibility with the control of quality and management, of the various design choices, of a new building process with its impact on the environment, the know-how of techniques and technologies, and product innovation, and tools for evaluating the performance characteristics of interventions.

In fact, the objectives of the new design are based, above all on the low environmental impact and on the quality of building interventions with construction efficiency, necessarily conforming with project choices and requirements, with related alternatives, also depending on the resources available to combat climate change.

So we aim at a conscious approach to the new design, with in-depth knowledge of the choices made and aimed at new construction and the built, to the sustainable urban and territorial contextualization, in which the control and maintenance of building quality are fundamental in relation to the phases of life cycle. Designers must know how to interpret the new requirements, through the innovation of the design and construction process with design industrialization, prefabrication off-site, the digitization of new

Corresponding author: Consiglia Mocerino, Arch. Ph.D., professor, research fields: technological innovation, sustainable and smart systems, energy and environmental requalification of buildings.

construction models by integrating passive systems of renewable resources into lightweight dynamic envelopes Fig. 1 [1].

They are characterized by technological systems of highly performing façades, with double or triple skin types, through an efficient design that gives dynamism and efficiency to the envelope, both for the architectural configuration, according to an aesthetic request and for the technological and constructive solutions adopted with energy efficiency and relative savings.

The methodologies are distinguished in the application of digital technologies and intelligent soft robotic systems, collaborative algorithms that enable digital transformation and make efficient systems adopted in dynamic moving and energy efficient envelopes.

They comply with European standards with new Directive 2018/844/EU updating the two previous directives 2010/31/EU and 2012/27/EU, respectively on energy performance and efficiency [2].

In these political and regulatory strategies, the construction is a determining factor for CO_2 reduction, as it accounts for around 40% of the pollution, so the types of dynamic lightweight envelopes are successfully adopted by denouncing the technological transfer, of a synthesis between science and practice, and aimed at energy efficiency.

In fact, the passive solutions that replace the efficiency of the systems, through the design with shaded areas and light, realize the interaction with the internal and external environment as a ventilation filter of natural dynamic flows, reducing the installation energy plant.

The types of reactive envelopes play a crucial role in the different urban and landscape contexts, reacting with kinetic energy to the local climate and determining the optimal internal microclimate.

This involves the advantage of reducing CO_2 through the configuration, with components and materials (glass, composite aluminum, nanomaterials, multilayer layering textiles, vertical green, PTFE-Polytetrafluoroethylene, FRP-polymer matrix fibers, EFTE-Ethylene tetrafluoro-ethylene, copper, etc.) of lightweight envelopes with moving facades, as they are equipped with digital sensors and advanced smart materials and engineered materials [3]. For this purpose there are different types including User-Control Dynamic Façade, such as the Centercity Gallery by UNStudio in Korea with Moire effect, Seasonal Green Dynamic Façade, Wind Responsive Dynamic Façade, Light Control Dynamic Façade, etc.

So lean planning and lean construction strategies are adopted in the technological design and of the new building process, with criteria of modular design and of process innovation, for the implementation of a production method with variations for techniques, technologies, equipment and/or software.

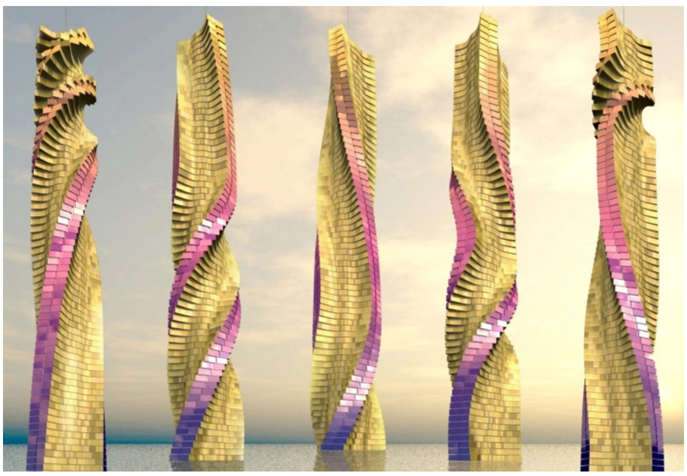

Fig. 1 Dinamic Skayscrapers-Project, by 2020. Dubai. Project with rotation of the shapes. Source: Ref. [4].

Mass customization strategies that overlap the industrial production, with the use of computerized systems, 3D printers, achieve customized results according to the needs of users for the production of complex shapes with innovative products, and representing an added value, depending on the needs flexibility in the construction sector. To this are added criteria of both radical and incremental process innovation, of a product for the improvement of technical functionalities, for components and materials, of embedded software, for ease of use or other functional features, etc.

So application of artificial intelligence robots in prefabricated or off-site constructioned and use of responsive dynamic systems, and then recourse to IT technologies, with actuator and sensor arrays in the new configurations of lightweight envelopes in a professional interoperability according to STEM (Science, Technology, Engineering and Mathematics).

2. The Dynamic Typologies

Process innovation indicates for integrated design, lean planning strategies in which both off-site building production and the use of BIM (Building Information Modeling) represent the fundamental tools to ensure efficient and effective execution in construction by signaling a revolution in AEC (Architecture, Construction and Engineering).

The new processes indicate the Lean Construction [5] that pushes to interoperability and denotes the development with the methodologies of innovation with LPS (Last Planner System), in which a team leader decides how long an activity must last on the construction site and not on the site manager.

So strategic methodologies are highlighted with the aim of new technological design, for dynamic kinetic enclosures, which is based on low environmental impact, both summer and winter comfort, and considers contextual, architectural and climatic indicators, calculating static values and transmittance indices, depending on the conductivity and thicknesses of the materials.

For this purpose, in order to design the dynamic kinetic envelopes, static and transmittance values are considered, as a function of the conductivity of the materials in self-sufficient and prefabricated building systems. Usually envelopes of the same average transmittance and the same configuration correspond to the same energy balance, even if they find disparities, between winter and summer season, in calculation models, in semi-stationary regime.

The criteria are those of new production models with awareness of the impact, of economic activity, of the environment, using fewer resources, as an index of sustainability, at a level of production and development parity using more resources.

Furthermore, they are identified the criteria of process innovation are radical, conceived as a new method or production system, such as to have no parallel in past history, which incremental process, considered as the improvement of an already existing production process, improving production efficiency and using a different combination of production steps or a technology. So tools with an off-site construction and application of intelligent construction technologies, according to the ISO 8402 and UNI 10838 standards and the new European directives on energy efficiency 2018/844/EU that update the two previous directives 2010/31/EU and 2012/27/EU, with targets for the reduction of greenhouse gases by 2050 and production of 32% of renewable energy by 2030.

The European Commission also establishes the identification of the smart indicator, by the end of 2019, as a tool capable of identifying the capacity of buildings, of improving network and operational interconnection, and finally adapting energy consumption according to the real needs of individual users. Therefore, through the control with intelligent devices of automation systems integrated by soft collaborative robots, they improve the functionality and capacity with energy saving features of buildings.

In particular, self-sustaining and prefabricated construction systems methodologies of lightweight dynamic envelopes, which guarantee an optimal internal microclimate and reacting to summer and winter climatic excursions, maximize efficiency, guarantee environmental safety control and minimize demolitions with ecological recycling.

In this constructive typology of light prefabrication systems, we highlight the performance capacity of systems and products with durability of the same and of the components, in the eco-sustainable control of energy production and building automation, with intelligent energy solutions and incentives for companies and reduction of costs.

In fact, for the dynamic typologies some design and constructive technological solutions are adopted with actuator matrices, through responsive dynamic systems, unlike physical dynamical systems that without electrical or control devices interact passively with the external environment.

These envelopes include passive energy systems in façades, such as blackout slats for the optimization of energy performance by converting solar radiation into thermal and electrical energy, with a relative reduction in energy consumption or mobile modular systems equipped, with sensors that react to the climate temperature and identify themselves in different forms and then restore the main form. Or installations of interactive devices capable of involving visitors through a dynamism of components with lights, interactive paintings of nanomaterials that control and reflect light, etc. From the different types of envelopes such as Insitut du Monde Arabe, Jean Nouvel in Paris to the most daring and efficient, Kolding Campus in Denmark, to the restyling of the SFMOMA (San Francisco Museum of Modern Art) realized by Snøhetta studio, with panels of a polymer fiberglass-reinforced (Fig. 2), integrated in surface by silicate crystals, and variable sunlight. This new architecture is the requalification project with integration and expansion of the MoMA Museum designed by the architect Mario Botta in 1995

As at the Hyundai Pavilion of Asif Khan Designs—The World's First Super-Black Building for the Pyeongchang 2018 Olympics, South Korea, as the pilot project of the House of Natural Resources with the adaptive solar façade, of ETH Zurich, Media-TIC Building in Barcelona with covering in EFTE material, etc. They are integrated with the User-Control Dynamic

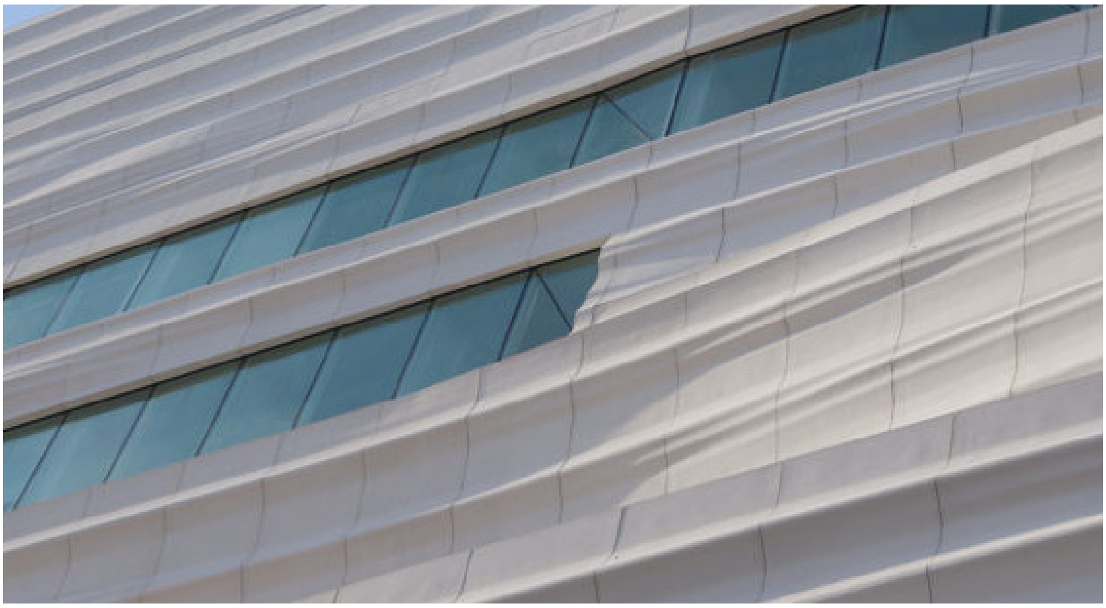

Fig. 2 SFMOMA by Snøhetta studio. San Francisco, CA-USA. Detail of panels of a polymer fiberglass reinforced. Source: Ref. [6].

Facade typologies in which users, through electronic devices, control the operation of blinds without using reactive systems, to Light Projection Dynamic Façades that generate optical illusions of light dynamics, through the articulation of an efficient mix of design both vertically, horizontally, obliquely, etc.

This last typologie is indicated in some architectures as in the Centercity Gallery, by UNStudio in Cheonan in Korea, on which trompe d'oeuil model, a double skin glass case and aluminum profiles, simulates moire fabric effects, with monochromatic light by day and multicolored at night, distinguishing itself as an urban lighthouse. The same UNStudio realizes a dynamic BIPV envelope, for the redevelopment of a HQ Hanwha skyscraper in Seoul, a system of sustainable interaction between inside and outside. Instead with the Light Control Dynamic Façade typology, the envelopes, as in the work of J. Nouvel of the Institut du Monde Arabe in Paris, with a centralized automation system that controls the modular diaphragms in the south façade, inspired by Mashrabiya, Arabic geometry and other architectures , including the Al-Bahr Towers in Abu Dhabi, by UNStudio, are equipped with components that, through an intelligent design, constitute shading systems on the façades, sensitive to solar radiation, with the advantage of energy saving, environmental comfort and C02 reduction of up to 40%.

In particular the Mashrabiya system consists of dynamic self-regulating modules (that open and close) and sensitive to sunlight, as in the case of the Al-Bahr Towers are coated with an innovative design in PTFE (polytetrafluoroethylene) material which improves the environmental performance of the envelope by reducing solar radiation by about 20%.

In addition, they stand out the Wind Responsive Dynamic Façade, with self-regulation of the façade components dominated by the wind directions, the Adaptive dynamic facades, of many architectures such as the MAC 5-7 Offices, in Milan, by Sauerbruch & Hutton [7] whose casing is covered with a dynamic system of solar shading in glass slats, which responds to variations in the intensity and direction of solar radiation, and controlled by a network of sensors with automated management of BEMS (building energy management systems) of the building, Homeostatic Façade System, with nanotechnologies of a double glass and an air chamber in which a dielectric elastomer is integrated, it reacts to the temperatures by self-regulating, opening and closing, and forming a shielding, which also contributes to energy saving, etc. These typologies of dynamic envelopes are integrated in the city with configurations highlighted by new construction systems and innovative technologies, which improve the built environment with the potential to connect to IoT, smart networks, facilitating the services and quality of the inhabitants.

In fact the environment is the crucial node for the design and construction of dynamic envelopes, whose skin becomes a filter between the inside and outside of buildings for the purpose of indoor environmental comfort and energy efficiency.

2.1 Efficient Stratifications and Soft Robotics Application in Envelopes

For these dynamic envelope typologies, both adopt adaptive and intelligent component and material including PCM (Phase Change Material), exploiting the natural phenomenon of the phase transition by modifying their behavior according to the climatic conditions, also robotic membranes, as chromocene materials (liquid crystals, electrochromic, photochromic, thermochromic) sensitive to external stimulations for which they change their optical characteristics, etc.

Also with the integration of intelligent systems as TMA (thermal mass activation), EC (earth coupling), DIS (dynamic insulation systems), AIF (advanced integrated facades), in particular to such components and intelligent systems of lightweight and dynamic envelopes in architecture, they apply, in integrated design, soft robotics to increase, specially, the balance of energy requirements from renewable resources in buildings, to reduce noise in the built environment, and in making the management of technological and plant systems more secure and independent. Inspired by the shape of origami, and contributing to the greater strength of soft robots, it is experimentation, also according to Wyss Institute of Harvard University and MIT's CSAIL (Computer Science and Artificial Intelligence Laboratory), of artificial muscles (Fig. 3) or artificial actuators—Exoskeletons—with a skeleton of material metallic, like metal springs, or plastic devices, etc.

These artificial muscles, forged with water or air and then sealed by a fabric or plastic skin, through the introduction of internal emptiness, manage to move autonomously, guided by the shape and the skeleton, without human help or energy force, in natural environments and with low environmental impact.

To this end, research has advanced in multidisciplinary fields, experimenting with prototypes and innovative models for solar adaptive façades in which to combine a dynamic, interactive aesthetic model, with energy efficiency and by eliminating in the envelope, in large part, the local climatic and environmental problems, both for new buildings and for the built.

So the prototype of adaptive solar façade as part of the EU Climate-KIC Building Technology Accelerator project, at ETH Zurich, is the interface between user and environment in which energy is monitored, through the adjustment of the individual façade modules, equipped with thin-film copper solar cells (CIGS) and located south of the natural resources house (HoNR) and managed by soft robots.

They act on the principle of the compressed chamber (three chambers supplied for each actuator) chasing the solar radiation and with the unfilled chambers the expansion inhibition takes place. The hysteresis is determined by the non-linearity of the pressure in the chamber and the inclination of the module so that it becomes one of the phenomena of careful research for the energy transition.

To these types of envelopes of integrated design, additive manufacturing methods are applied to which intelligent soft robots [8] collaborate which, through some of their components, including actuators and sensors of composite material, generate movement to the modular components and on which intelligent materials are added, of energy efficiency like PV, etc.

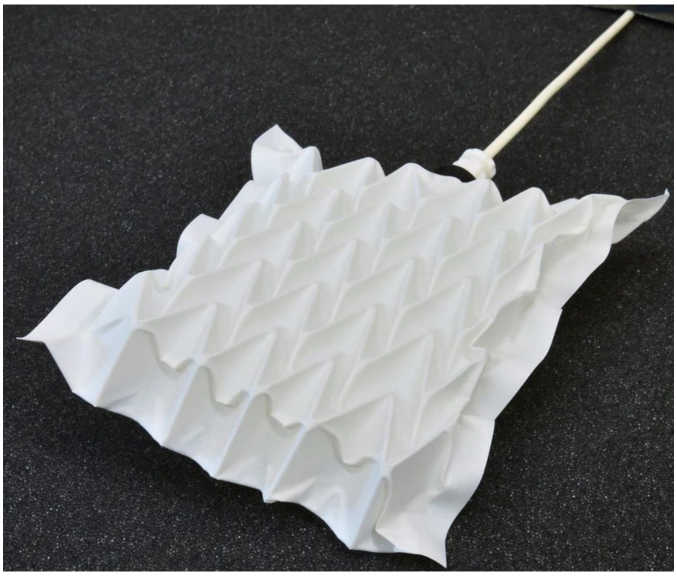

Fig. 3 Artificial muscles inspired by fluid origami. Source: Ref. [9].

In fact, the soft robots of the broad sector of artificial intelligence and learning machines, belong to one of the emerging sectors of bio robotics and are flexible, soft-structure systems that interact securely with the natural environment and the user, distinguishing themselves from rigid-structure robots.

Soft robots, usually widespread in hydrogel or silicone rubber, in which nanotechnologies are inserted, ferromagnetic, react to magnetic fields, heat or light, change shape and apply in the biomedical field, in architecture, etc. They can be lengthened, deformed and twisted taking inspiration from the forms of invertebrate plants and animal species, fluids with integrated parts, without the traditional assembly of mechanical parts of a robot and 3D printing products, such as Octobot, one of the first completely autonomous soft octopus, according to the shape of the octopus, and tested by the University of Harvard with biocompatible materials. This example of a soft robot is a pneumatic (powered by gas under pressure) type whose operation is based on a circuit which, like an electronic oscillator, controls the transformation of a small amount of hydrogen peroxide into gas, generating movement in the components of the robot.

For the power supply we used control cards, sensors, pumps, etc., instead for the modulation of the pressure inside (Fig. 4) the actuators and for movements and force, we choose feedback, finally we also resort to analytical models for the control of the state variables, when estimation difficulties arise.

According to these methods, the pressure forces, of the external objects and the internal pressure of the soft actuators, are monitored using soft sensors that are miniaturized and incorporated into the actuators themselves.

3. Case Study

Even nanotube, based coatings that cover surfaces, develop dynamism and efficiency of the envelopes, contextualizing them in the landscape or urban environment as an architectural and community focus, as well as for the Hyundai Pavilion (Fig. 6) designed by Asif Khan Designs, the world's first super black building for the Pyeongchang 2018 Olympics, in South Korea. The building with a block configuration based on criteria of Lean Construction and off-site, is developed on a 35 × 35 m square plan, 10 m high, with the space divided into five rooms that represent virtually, the water, solar energy, electrolysis, hydrogen fuel stacks and water recreation with multi-sensory installation and covered with translucent white Corian (aluminum hydroxide and acrylic resin) in interior design. The outer envelope is completely coated with a Vantablack VB×2 [12], spray

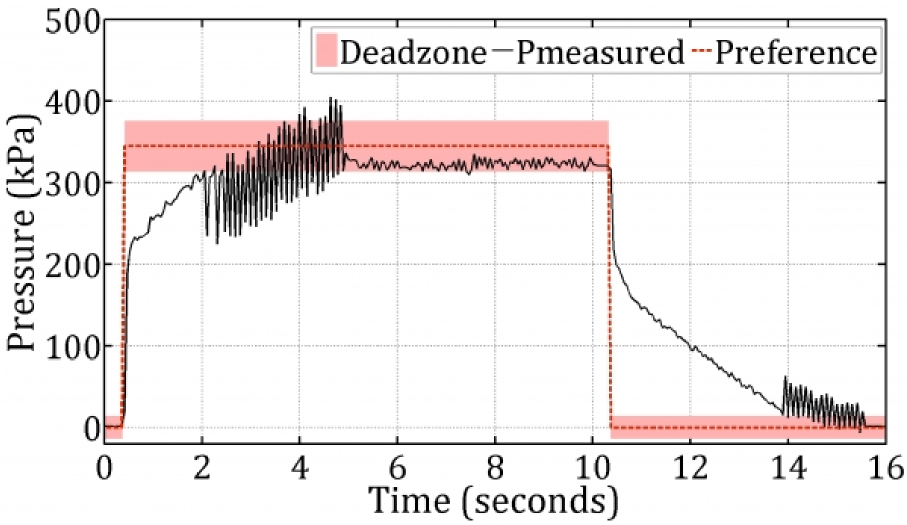

Fig. 4 Pressure graph in soft actuators through soft sensors. Soft robots-sensing and control. Source: Ref. [10].

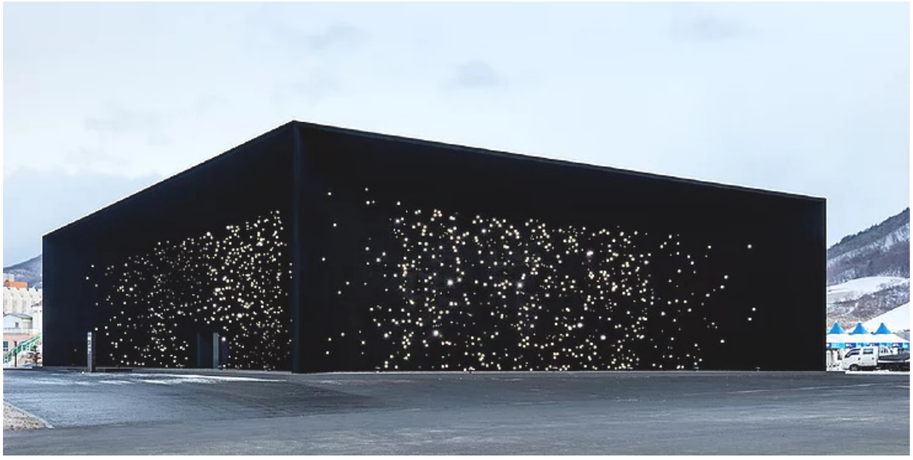

Fig. 5 Hyundai Pavilion designed by Asif Khan at PyeongChang Winter Olympics 2018. Source: Ref. [11].

paint made by Surrey NanoSystems that absorbs 99% of sunlight creating a virtual black space void, in which thousands of bright stars spread. This nanomaterial of spray paint with THR (total hemispherical reflectance) of 1%, is adopted in architecture on different surfaces including metal, wood, polymers, ceramic, concrete, plasterboard, glass, etc. and it can also be applied to internal partitions of the building. The pigmented coating is biocompatible solvent-based dispersed in carrier solution, it is the recent version of Vantablock (a thin film of carbon nanotubes-CNT), but VBx paints do not use nanotubes.

4. Conclusions

In architecture there is an evolution of both technological and constructive systems with the increase of the fundamental know how of materials and components, with their behavior with the environment and aimed at indoor comfort and energy efficiency with the use of renewable resources.

For this purpose, scientific research and construction production, highlights in the construction sector a series of products and systems that are adopted in various building works, supported by experimentation and prototyping in which the interaction between users and dynamic enclosures integrated in particular environmental conditions occurs. The objectives of achieving sustainability with quality of interventions, low environmental impact and energy efficiency with parametric design, for light and dynamic, adaptive envelopes are the drivers of this process innovation and digital revolution. In it the innovative materials, the nanomaterials, etc. the new construction systems with the adoption of IT, artificial intelligence soft robots, improve the performance of buildings, balancing needs and energy savings. Digital fabrication methods with intelligent systems and digital technologies that enable digital transformation, according to lean planning and lean construction and mass customization strategies, highlight in the integrated design and off-site construction of the new radical, incremental and product process, signaling a revolution in the AEC. And just in architecture the challenge is the creation of new dynamic envelopes with performance soft robots, safer, durable and sturdy that integrate with innovative technologies and materials, according to user needs, especially for the quality of the habitat with indoor comfort, energy saving and better performance of the buildings contextualized both with the built and the environment.

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