Parametric design for technological and "smart" system. Adaptive and optimized skin

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ABSTRACT

The goal of this research is to develop technological and "smart" complex building skin systems, particularly façades, through the development of "emerging technologies" and of a reputable multi-disciplinary approach. The awareness that innovation in architecture, but also generally in science, is essential to provide concrete answers to issues of general interest, such as energy resources consumption and the obsolescence of construction systems that have been used so far, makes research fundamental and priority. It is necessary that architecture becomes adjustable to the environment, like living organisms, through a new multi-disciplinary approach: studying not only the morphology but investigating also the generative process starting from the physical characteristics of materials and components as well as analyzing bio-inspired systems, resulting in an architecture that is increasingly adopting the form of a living organism. In order to achieve this, efficient technologies and mutually collaborating systems are required that can only be achieved through research in the field of emerging technologies. Specifically the approach presented in this paper provides the basis for the development and prototyping of a "light" dynamic and adaptive façade system that is able to synthesize the different contributions that these new technologies are able to provide. In the second step of the research thus a new methodology and a new design process had to be defined (involving major innovations in the design and prototyping of technological systems to be transferred to the industrial sector), with the intent to ensure the necessary product innovation to compete at a global level and to establish a standardized and repeatable design process also for other smart façade systems.

The knowledge of the "state of the art" and critical, directs research towards a prototype system of flexible façade based on pre molded components and achievements obtained by the nonstandard and avant-garde processes, even experimental, which contains sub-systems able to collect input from outside and rework them to provide an adaptive and optimized response.

Keywords: Parametric modeling; computational design; adaptive; optimized; high performance skin system.

INTRODUCTION

The term "emergent technologies" - defined by M. Hensel, A. Menges and M. Weinstook in the book "Emergent technologies and design. Towards a biological paradigm for architecture" (2010) - indicates a new science that - on the basis of the study and the understanding of the mathematical complexity of natural systems - aims to transfer such complexity within technological systems to achieve optimized and adaptive performance.
Given the importance it plays worldwide, nowadays, the innovation and the research for new strategies and new technological systems in construction industry is a necessity. Construction industry is one of the biggest sectors of industry in the world in terms of employment, earnings, influence and energy resources use. Indeed, in EU countries this sector "consumes" 30-40% of the energy resources and 50% of the global resources only during the construction process. Similarly it is possible to say that the construction industry and the technologies and components used in manufacturing processes, are still linked to the use of standard materials that dominate the market - such as reinforced concrete, steel and glass - and obsolete constructive and productive systems. The industrial revolution of the 19th-20th century, based on the serial process, produced very efficient but very expensive systems in terms of energy demand and need for raw materials. Today this process has definitely to be rethought involving experiments on new materials and new production and realization technologies such as robotics, additive processes, morphing and especially 3D surface printing.

![Figure 1](image)

**Figure 1** Robotic fabrication printing «ICD/ITECH research pavilion 2012»

One of the elements that affect more buildings, in terms of cost of construction and maintenance, energy demand, thermo-hydrometrical and acoustic comfort, is the “building skin” understood as a complex element capable of modifying inputs from the surrounding environment. Technology evolution, particularly in expansion in recent years, has transformed the “building skin” from passive to active, resulting finally, in a hybrid skin, in which building and plant technologies become complementary to each other and the building skin becomes part of an integrated building-plants, equipped with devices of regulation and control that placed it at the center of experimental processes in prototype models of futuristic living field.

![Figure 2](image)

**Figure 2** Material deposition 3d printing «D-shape 3d printing»

If research on the topic of “building skin” has reached a level of development on the energy and environmental side, on the other side today we need to introduce new variables in this process affecting the generative process in architecture. The adaptive aspect of architecture related to the variable conditions of the surrounding world such as social needs, climatic conditions and human iterations, forms the basis for future testing: analyzing how everything variable and dynamic can affect architecture and its technological components. Besides the three, now consolidated, macro-categories which characterize passive, active and hybrid façades we have to introduce a fourth category being “intelligent and dynamic” façades.
METHODS AND EXPERIMENTATION

This new approach to intelligent technological systems, in particular regarding façades, needs a different methodological approach and needs to introduce new systems of experimentation able to reduce the current gap between practice and research. This research consists of two experimentation works focusing on intelligent façades for innovative building prototypes. The chosen typology is “tower buildings”, characterized by almost zero energy consumption, high adaptability and high energy efficiency and locate in the Mediterranean area. The new bottom-up approach allows to optimize the processes of analysis and to obtain optimized results. The interaction between architecture and environment, leads inevitably to analyzing natural systems. The analysis of the system in relation to the external inputs is the basis of the creation of the genotype (generative algorithm) and of the analysis of the phenotype (physical model). Both experimentation works are localized in the area of Ascoli Piceno, Italy lat. 42° 51’ - long. 13 ° 35 ’. The climate files were carried out by Meteonorm and Ecotect software.

The first experimentation work aims at optimizing the energy performance of the building skin in tower buildings in order to identify, their “energetically active parts”, through the definition of a range of values and to determine their annual gain in terms of energy production. Specifically, after defining the reference weather conditions and the object geometry, the environmental analysis was conducted using a software able to optimize the skin behavior. Thanks to parametric design tools in Rhinoceros software - in particular the link between Grasshopper and its plug-ins Geco and Ecotect - it was possible to evaluate in real time the effects of any changes made in the designed building skin.

Figure 3  Adaptive and optimized surface «ICD/ITECH, Hygroscope meteosensitive pavilion, 2012»

Figure 4  Tower’s design concept: double skin development and conceptual design of the tower building in an urban context.
It was decided to use a dynamic double skin façade. As a first step, the geometric pattern of the outer skin was defined through its panelling with the plug-in Launchbox\textsuperscript{2} in Grasshopper environment. In the second step the skin was analyzed from an environmental point of view with the software Ecotect. Among the analyzed parameters, special importance was given to the solar irradiation on the outer surface, expressed in kWh/year. In this way it was possible to define the “energetically active” part of the outer surface and to obtain an early pre-dimensioning of the façade system and an estimate of its energy production.

In addition, the methodology of this experimentation and work can be repeated for different climatic zones and for different architectural configurations by replacing the weather file in input stage.

![Figure 5](image1.png)

**Figure 5** Bottom-up process for skin optimization: process for the evaluation of incident annual solar radiation through the link between Grasshopper and Ecotect.

The second experimentation work aims at defining an intelligent and adaptive technological system to be applied to tower buildings, able to ensure an optimized response to inputs coming from the external environment. Specifically, after identifying the adaptive system, the analyzed surface “was panelled” using the software package Grasshopper inside Rhinoceros, and then the result were evaluated using the software Ecotect and Geco. Once input process, climate files and geometry were defined, the surface behavior was analyzed in response to the inclination of the solar irradiation, in order to study its dynamic and adaptive potentiality.

![Figure 6](image2.png)

**Figure 6** “Panellization to adaptation” process: adaptation of daylight system in Mediterranean area.

In particular the image shows the adaptation of the skin surface in relation to the inclination of the suns’ rays and the process:

The dynamic analysis of an adaptive device is preparatory to the creation of the technology scheme of the

\textsuperscript{2} Launchbox is a free plug-in for Rhino-Grasshopper, for the surfaces panelization. With this plug-in it is possible to define a geometrical pattern and to analyze it in all its parts (nodes, rods, panels).
façade. In the first phase of this second experimentation work the components of the façade are identified and classified into two types:

- Fixed parts: primary structure composed of panels of varying sizes (maximum extension 1.95 x 1.75 m) realized with innovative production systems, robotics and CNC fabrication,
- Moving parts: extensible cables to ensure the correct dynamic operation of the panels made from innovative materials including bioplastic and fibro elastic textiles.

**Figure 7** Skin design: a possible development of the skin system for the environmental rehabilitation of buildings in the Mediterranean area.

**EXPERIMENTATIONS AND RESULTS**

Both experimentation works aim at studying the behavior of surfaces in response to specific environmental and climate input changes; in the first case the incident solar radiation on the entire surface, measured in kWh/year, is used to define the energetically active parts of the surface and assess the need of technological devices able to shield and avoid its overheating. In the preliminary project phase, better don’t underestimate the possibility to assess the energy gain derived from the surfaces energetically active parts.

**Figure 8** energetically active parts of the buildings surface and assessment of the need of technological devices able to shield and avoid its overheating through the definition of a range of values.

In order to define the energetically active part of the skin and in accordance with the climatic characteristics of the project site and with the chosen HVAC system a range of annual energy demand between, < 290 and >290 kWh/year was established. Thanks to the use of the LUA script COMMAND - present in Geco - it was possible to estimate the production of electricity, expressed in kWh/year. The script "0: Calc.resource, solar" allows to calculate these gains through the link with Ecotect, panel analysis and resource consumption, and to estimate the area of application and the number of used elements. The direct connection between skin geometry, geometric pattern and analysis software environment, allows also to have a real-time update of the analysis with respect to geometric variations typical of the early stage of architectural and components design.
Thanks to Geco and Lua Command Script we can underestimate the possibility to assess the gain derived from the surfaces energetically active parts.

In the second experimentation work the adaptive capacity of the buildings external surface was tested in relation to the solar path, angle and incidence on the surface. The process aims particularly at defining a dynamic surface able to open and close in an adaptive way according to the variation during the time of the external conditions inputs, in particular of natural lighting. The optimization as a guide in complex processes. Main difficulties, until a few years ago, resided in the technological know-how that would allow to consider architecture as a living and adaptive organism. Each architecture would have its genetic composition and a specific combination of genes. The genotype will represent the intrinsic characters while the phenotype would be the character set that the architecture shows clearly. In biology it’s well known: the phenotype depends on the genotype but also by iterations between genes and environment.

The ability to analyze the dynamic behavior of building skin technological components is fundamental in the preliminary phase of the design as it allows to significantly reduce the gap between digital design and physical experimentation.

Considering the large amount of available data, commonly called “open data”, it is not difficult to imagine how such a process can bring substantial advantage, especially in building retrofitting, where is necessary to add new parts or components in order to reduce the energy demand and ensure a adequate indoor comfort level compatible with the actual standards and regulation.
APPLICATION IN EXISTING BUILDINGS

In Italy, the country chosen as a case study for this research, in fact, there is no need to build many new buildings, while a big problem consists of existing buildings, mostly made in the years 60'-80’ and characterized by a high energy consumption and a low level of environmental comfort inside. Therefore, it is necessary to find a solution to this problem, mainly caused by building envelopes of poor quality and obsolete buildings in general. A dynamic and adaptive technology device (e.g. a building skin designed to respond to specific input from the external environment), can formally design in an innovative way the existing façades and also reduce the problems arising from excessive solar radiation, e.g. overheating of the exterior walls and of the interior spaces.

The developed adaptive envelope system has been applied in existing tower buildings, located in Ascoli Pieno and realized in the 80’s. This application is actually in a test-phase, but the experiments made so far are giving very good results.

Figure 11 The image show the possible application of dynamic façade in Ascoli Piceno area, Italy lat. 42° 51’ - long. 13 ° 35’.

CONCLUSION AND OUTLOOK

The presented research proposed a new bottom-up process for developing a new type of building’s dynamic façade. Skin becomes a technological intelligent system that interfaces with the external environment and its inputs. In this way the technological system is equipped with artificial intelligence able to collect and process data from the environment in order to return an optimized and adaptive response. If at the dawn of the modern movement response the slogan was “form follows function” today, thanks to the developed digital technology, it is possible to safely talk about “form follows energy flows”. The use of parametric modeling software combined with assessment tools and simulation of environmental performance, allows the development of technology components which record and respond to climate change creating a further project phase. In addition the skill of ensuring the kinetic movement, through the use of nanotechnology and smart materials and the possibility of strongly reducing the manufacturing imperfections through the digital manufacturing, can further reduce the gap present between digital and physical experimentation and production and ensure a better relationship between construction costs and performance of device.

In the next step of research the main objective is a territory research of companies able to invest and ensure technical and financial support for the realization of the prototype. The final goal is to create a database, clear and easy to read, able to make the know-how available immediately and to reduce the gap between the research subject and the industrial production world.
Figure 12  Model prototype of dynamic skin for physical analysis with Arduino board «Eth Zurig, Adaptive System Lab».

REFERENCES