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EXPERIMENTATION OF A NEW ADAPTIVE MODEL FOR ENVELOPE SYSTEMS

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Abstract
In recent years, the construction sector is pushed to accelerate the development of technical solutions to increase building envelopes' performance compared to the various climatic changes that involve the built environment. The contribution illustrates ongoing experimental research whose intent is to address a design methodology through adaptive design techniques responding dynamically to contextual conditions of reference. The operating methods are based on the construction of dynamic simulation scenarios to create a highly adaptive model, which can be used as a component for advanced envelopes. With the support of the TCLab section of BFL, the model's development and testing intend to implement technical solutions with possible explanations of prototype lines.

Keywords
climate change, environmental quality, adaptive components, building envelope, adaptive design

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For years, the effects of climate change[1], if on the one hand, negatively affect the general quality of the built environment and represent a fertile field of experimentation of innovative design processes and methods. In this sense, there is an increasing demand for methods and processes capable of calibrating the phenomenal interactions and the effects suffered and induced by the building system on the dynamics of climate change at the various scales of the built environment. By this, the building is assimilated to a living organism (Dal Buono and Scodeller, 2016), able to receive the environmental influences of the context and, on the other hand, is itself a relevant instrument of the modification of the physical environment, consisting of several coexisting and interacting elements and factors. In particular, the building envelope is not a static and passive system concerning the context. Still, it becomes a control surface of the performance offers according to the thermodynamic balance between inside and outside; therefore, 'influencing' turns the relationship's environmental context. In terms of the flow of matter and energy in the envelopes, the synergistic reading of the effects and relationships pushes innovation to define new performance criteria different and articulated corresponding to the performance of individual technical elements that contribute to the definition of internal and external environmental quality.

The contribution is part of this framework and is related to ongoing PhD research, in line with the European Directive on Energy Efficiency 2012/27/EU (Directive 2012/27/EU of the European Parliament, 2012) and the recent 2018/844/EU (Directive EU)2018/844 of the European Parliament, 2018), to achieve zero-emission buildings by 2050 and the integration of smart technologies to ensure that buildings operate and consume as efficiently as possible. The research scenario, financed with funds POR Calabria FESR/FSE 2014-2020 (Axis 12, Action 10.5.6), should also be read about the Strategy S3-Region Calabria[2]. It is placing itself within the Sustainable Building trajectory related to the development of specific technologies and materials with higher performance and the simulation and evaluation of buildings' environmental impacts. The research project wants to investigate the performance and control aspects of the components of the building envelope. The project results from the latest innovations, identifying and defining new technological solutions that express additional levels of response and environmental compliance, and the ultimate goal of verifying the possibility of arriving at prototype lines. The opportunity to have the TCLab Section of BFL[3] – Building Future Lab of the 'Mediterranea' University of Reggio Calabria – is strategic in examining the various scenarios of adaptability of the building envelopes, directing different design strategies concerning the environmental context of reference.

Starting assumptions | The research's reference scenario in progress highlights the building envelope's role in constant etymological and functional-performance evolution. An element able to control the interactions between the internal and external environment (and vice versa) as the different contextual conditions change and, above all, respond to the multiple needs of users who 'live' the confined environment. The acclaimed attention to environmental issues, energy, and comfort conditions has oriented innovation towards developing technical elements, innovative multifunctional components (Milardi and Mandaglio, 2019), and high-performance materials that organize the envelope. The envelope transformed from a protective 'shield,' with insulating and sealing properties, to a surface of dynamic interaction between the external space and the confined interior. According to Wigginton and Harris (2002), the building envelope can be designed to operate as part of a holistic building metabolism and morphology and will often be connected to other parts of the building, including sensors, actuators control cables from the building management system. The complex management and regulation between parameters with high impacts on buildings (Bitan, 1988), such as air temperature, humidity, ventilation, and envelope elements, challenge declining new technical configurations that induce less variation in the context.

In line with these considerations, adaptive design[4] techniques, applied to the envelope, assume today a primary role in the function of programmable performance responses, useful to affect the quality of the built environment and, at the same time, modulate the effects generated by it. In general, adaptive behaviour combines sensors and movement mechanisms classified as pneumatic actuators, hydraulic actuators, and drives based on electric motors. Thus, these systems make the envelope responsive, interactive, dynamic, intelligent and increase its ability to change its structure to regulate the flows of thermal, light, and sound energy passing through it (Banham, 1969). The results of numerous research and initiatives concerning the panorama of programmatic policies in Europe[5] often reveal methodological gaps and applicative difficulties for the correct evaluation of the balance of technological and environmental parameters, thus pushing the designer to acquire different qualitative approaches to control the project. Against this, assessing the envelopes' adaptive behaviour is a challenge because of the building envelope's adaptive components' performance, which doesn't sufficiently characterize through static performance indicators such as U-value, g-value, T-vis, etc (Attia et alii, 2015). Moreover, these indicators' variability cannot be ignored, given the changing external and internal environmental conditions, leading to mismeasurement of building envelopes' adaptive characteristics.

In this sense, the innovative character of the current research aims to understand the envelopes' microclimatic functioning in the built environment, which is crucial in defining information that can increase the level of contextual relationship of new strategies of adaptive type. On the other hand, in constant development and experimentation, adaptive design technologies are linked to single architectural design cases, limiting the large-scale application of innovative envelope systems that contribute significantly to the control of microclimatic variations that trigger between building and context. From an initial analytical investigation, the following issues are identified: i) the demand for high degrees of environmental compatibility cannot disregard a valid but difficult analysis of technological processes, which continuously transform incoming and outgoing matter flows and dependent on the microclimatic conditions of the context and environmental comfort; ii) the evaluation of the performance quality of adaptive envelopes is not ensured by a specific regulatory apparatus, underlining the need to classify the behaviour of adaptive technologies according to the environmental context of reference; iii) it emerges the need to investigate the building's energy operation in its technical components, considering that the quality control cannot take place ex-post, to address and simulate its dynamic process.

Adaptive building envelopes | The interest for an architectural project-related both to new languages and to themes of interaction (today, more and more 'intelligent') with the environment has led to conceive the envelope as a dynamic epidermal layer that changes, mutates, and adapts to different microclimatic conditions and the needs of users. In line with the literature, the research wants to position itself as a tool capable of supporting the panorama of building interventions, innovating the architectural language with elements endowed with new technological values aimed at improving the functioning of the system to the totality such as the world's first passive envelope powered by algae (Conato and Frighi, 2018), the Smart Material House BIQ in Hamburg (Figg. 1, 2) and the Media TIC in Barcelona (Figg. 3, 4). It combines high safety standards with a visual image of openness and transparency through ETFE panels, examples that contribute to the formulation of new approaches to adaptive governance, in its continuous feedbacks from the urban to the building scale and vice versa.

The envelope technologies' innovation involves transitioning from a single function of insulation/protection to adaptivity. These are capable of satisfying many interdependent requirements relating to specific environmental contexts. Therefore, according to this paradigm shift, adaptive building envelopes can interact with the environment and the user by reacting to the external output and adapting their behaviour and functionality accordingly: the building envelope insulates only when necessary, produces energy when possible, and shades or ventilates depending on the internal comfort requirements (Luible et alii, 2015). In particular, the focus is on the building envelope, which takes on a strategic role in achieving energy and living comfort goals. The new technological language of the envelope system enshrines a new relationship with the environment, dictated by the ecological burden of the materials used. Thus, the building envelope enters into symbiosis with the environmental context in which it places, thanks to intelligent control systems, overcoming the traditional passive bioclimatic architecture through integrated strategies.

Given the complexity of parameters and components that constitute an envelope, the development of an adaptive envelope requires the integrated contribution from other disciplines, such as to manage the factors on which its adaptive operation depends. In this direction, we add the decisive contribution of SMART systems for intelligent enclosures that, reading the user's reactions, monitor the environmental and technological performance with optimized information. This scenario opens the way to dynamisms that, depending on the envelope's configuration, direct low-material choices, generating controlled systems during the life cycle. As expressed by Benyus, taking nature as a model, measure, and mentor (Benyus, 2002), the biomimetic approach investigates the adaptive requirements of building envelopes, which directs the research and development sector towards the realization of materials and components that respond to external stresses organically and passively.

Aims and objectives | The desire to research with a strong experimental character highlights how this must leverage more in the perspective of overcoming the frontiers related to the management of the processes of adaptation and transformation, necessary prerequisites in the development of responses in terms of maintenance and improvement of functionality and performance quality of the elements and systems. How can the building envelope system's technical elements generate systemic responses such as to capture the effects useful to maintain and improve its functioning, contributing to the definition of the internal and external environmental quality?

It seems clear that one of the theoretical-operational strategies is the definition of processes and technologies of performance control of the envelope to improve the quality of the built environment. The envelope means the totality of the parts that define an internal environment (characterized by relatively stable environmental conditions) to an external environment (variable by nature). The studies focus on the possibility of developing a controlled and reliable vision of building envelopes capable of adapting to different needs, exploiting changes as an opportunity to raise environmental and performance quality. Specifically, the research wants to address technological innovation's adaptive functional aspects of the envelope, offering the possibility to mediate the thermal and energetic loads induced by the building's same technical elements. The need for a measurable control leads to the realization of a model/adaptive element, with the ultimate goal of verifying the possibility of realizing prototype lines, implementing the technology transfer from science to production.

The difficulty in constructing a detailed performance-environmental profile of the envelopes poses a general objective of the research, the definition of technical tools to promote interventions on the built environment towards adaptive strategies related to the envelope system's performance control. This scenario of intent is aimed at the expectations of quality control, translating environmental requirements into technological performance, contributing to the mitigation of impacts. Thus, the research activities are directed to developing scenarios/simulation models and application testing through the proposal of an adaptive model that can become, through the implementation and application testing, a real example of the possibility of offering guarantees aimed at energy containment and mitigation of environmental impacts. The research project is, therefore, aimed at: i) classify the building's technical elements concerning their operating characteristics and performance requirements to be asseverated, providing a complete picture from the technical point of view; ii) identify the features of

Figg. 1, 2 | Smart Material House BIQ in Hamburg by Splitterwerk Architects and Arup, 2013. The most significant element is the integration, on the south-east and south-west building façades, of flat-screen bioreactors, made up of microalgae (source: syndebio.com/).

components, materials, and adaptive systems -in production or already built buildings- that allows the envelope to be understood as an environmental moderator (López et alii, 2017) to assume variable configurations; iii) identify design and performance criteria that facilitate the reading and the most suitable adaptive functions for envelope systems to specific environmental conditions.

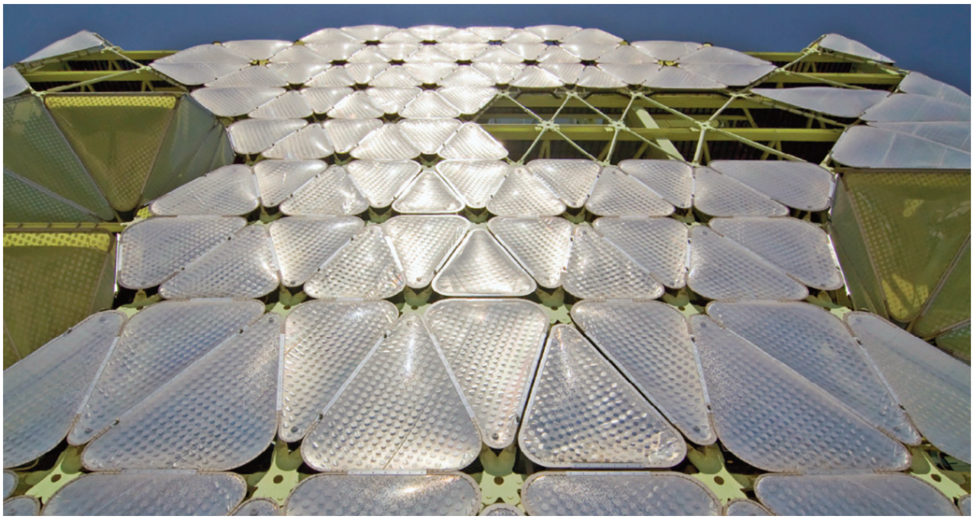
Methodology and actions aimed at experimentation | Starting from an analysis of the performance functions of the envelope, it emerges: i) the complexity of the technological elements constituting the envelope makes it difficult the correct reading of their behaviour, given by the summation of the different performances of the components of which they are made, influencing the climatic-environmental conditions of the area in which it places; ii) the difficulty in assigning adaptive characteristics determines a wrong measurement of adaptability, given the lack of specific indicators that combine environmental and adaptive parameters.

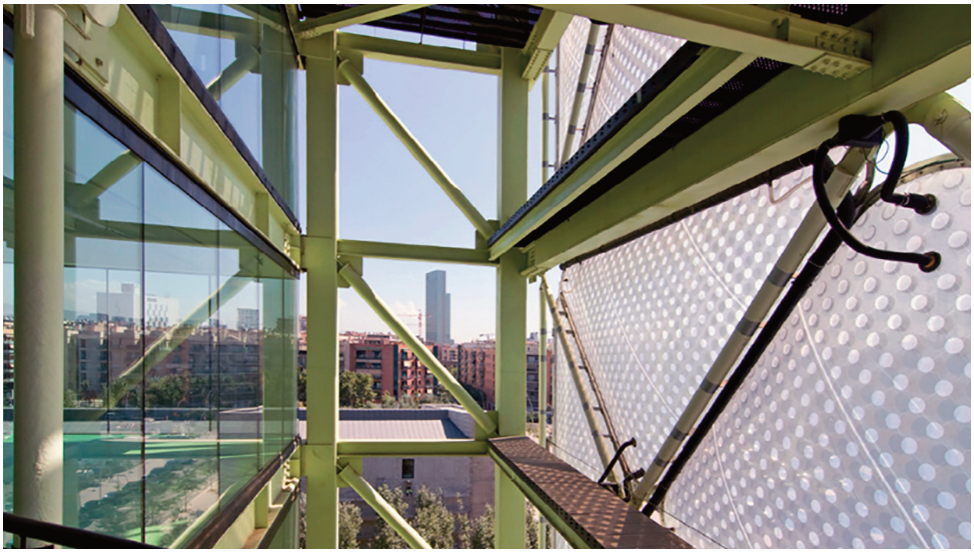
According to the above scenario and to study the modalities and the effects induced by the 'activities' of the building envelope on the microclimatic context, the research activities is articulated following a methodological procedure structured according to sequential phases, activating a process of validation/implementation of the partial results obtained. It is also expected a strong integration with different disciplines, thus implementing a qualified contribution and a sharing of resources in the field of architectural technology and other scientific areas involved. Specifically, we report below the sequential phases.

Analytical-knowledge phase: analysis of the technical-performance scenario related to the building system to identify which technical elements affect microclimatic variations; the building is broken down into its parts – opaque surfaces, transparencies, and roofing – focusing on the control of thermal, luminous, and visual fluxes to understand the technical systems' potential and criticality the functions to which they must necessarily respond to environmental requirements.

Analytical-critical phase: it intends to promote a straightforward reading of the incidence of the building's technical elements on the effects of microclimatic performance compared to effects-phenomena to control; the investigation of the state of the art will focus on the mechanisms of adaptive systems movement, made in recent years, defining a synthetic picture of the possible configurations that an envelope can assume automatically.

Critical-propositional phase: definition of an adaptive model-component, with the possibility of contributing in a verifiable way to improve the quality of the built environment and identifying those adaptive functions of movement, concerning microclimatic variations of context to which it subjected. In this phase, the role of TCLab is strategic for the execution of the model and to confirm that the requirements are satisfied; within the experimental activity, based on standardized protocols (UNI/EN, ASTM[6], AAMA[7]) will be carried out all the verifications that meet the requirements of industry standards.





Figg. 3, 4 | Media ICT in Barcelona by Enric Ruiz Geli Architect and Cloud 9, 2010. The envelope is characterized by a counter-facade in Etfe (Ethylene tetrafluoro-ethylene), which, being able to be blown with air and nitrogen, becomes inflatable or deflatable according to the environmental stresses external (credit: Cloud 9).

Expected results | The integrated reading of the effects and phenomena induced by the building, to varying degrees on the context, defines how adaptive solutions can contribute to reshaping physical-environmental requirements in terms of design flexibility, technological and experimental innovation. When considering methodological aspects, the field of future opportunities widens considerably because a basis has been laid for approaching problems related to adaptive technologies and their functional completeness in building envelope systems.

In particular, with respect to the phases listed above, the following expected results are hypothesized: i) construction of performance repertoires on the elements of the building system to understand how they affect microclimatic parameters, through an investigation of technological and material characteristics; ii) elaboration of computerized sheets that relate phenomena, effects to be controlled with the identification of possible adaptive strategies, able to control the operation and behaviour of the envelope for the purpose of environmental comfort; iii) instruction and construction of feasibility checks useful to the development of prototype/s (of components or if possible of envelope elements) and possible simulation of the experimental adaptive solution – able to guarantee a positive response of environmental quality that becomes function of the level of technological complexity – with the support of the TCLab section of BFL with specific competencies for monitoring, testing and prototyping; the verification activity is necessary to allow to test the adaptability levels of the model, carrying out simulations of climatic conditions in urban environment and of the effects connected to them. The partial results of the investigation activities conducted so far (always in continuous validation and updating) are identified in the first elaboration of tabs on effects-phenomena to control the building system and adaptive systems that allow the envelope to assume variable configurations.

Conclusions | It is well established that adaptive design modes contribute significantly to the design process's dynamic organization, aimed at de-intensifying the urban system's performance in its components (complex urban elements, buildings, open spaces, infrastructure). About its effective functioning, the urban system can reduce climatic vulnerability also due to the dependence on in-stream processes that characterize conventional operating conditions. Therefore, planning and designing future interventions can instruct within them procedures of analysis/evaluation and verification design appropriate to the phenomena' complexity. In support of the design decision, these tools contribute in a verifiable way to the increase and improvement of the built environment's adaptive capacity, where the ability of dialogue and control of the envelope system respond efficiently and responsibly in the dynamic contexts in which they relate.

To respond to these demands, research efforts, though still ongoing, are directed toward designing the optimal combination of the adaptive model, focusing on the most appropriate adaptive efficiency, to specific environmental contexts. However, it is highlighted that the performance responses of building envelopes, linked to the environmental variables with which they relate, will need to intelligently and systemically regulate these variables' effects. Simultaneously, it is necessary to satisfy a wide range of needs (Del Grosso and Basso, 2010) by implementing their thermophysical and mechanical characteristics. According to this approach, it is possible to offer reliable efficiency levels because of the interventions on the envelopes calibrated to the contextual conditions that determine the technological choice but react to the same context through 'dynamisms' useful to increase the environmental quality.

The research's study and analysis activities cannot be considered exhaustive due to the complexity of the issue and innovation fields to investigate. Moreover, the experimental approach is functional to define the following potential applications: i) scientific impact – it determines an advancement in the definition of products, characterized by a robust, innovative content and methodological and operational tools for climate-change mitigation; ii) technological impact – the experimental content makes it possible to test levels of adaptability to climate change of technical solutions, carrying out simulations of climatic conditions in an urban environment and the effects related to them, assessable in terms of industrial spin-offs (these intentions are made possible through equipment and machinery that the TCLab section of BFL has); iii) social impact – activities such as workshops and symposiums are indispensable to involve the main stakeholders and overcome impediments in the adaptation process; the project highlights how qualified scientific information and adequate technical skills are essential so that it can rest on a solid knowledge base and be well-calibrated concerning the actual environmental needs; iv) economic impact – it is expected that the coherence of the objectives places the relationship between public and private investment-benefits in a short and medium-long term perspective, establishing a new mission focused on the improvement of business know-how, centered on the realization of innovative products aimed at market trends and efficient enclosures.

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Notes

1) The Intergovernmental Panel on Climate Change (IPCC), established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP), provides a scientifically based view of the current state of climate change and its potential environmental and socio-economic impacts. For more details see the website: ipccitalia.cmcc.it/climate-change-and-land/ [Accessed 13 October 2020].

2) S3 Calabria – Smart Specialisation Strategy – Regional research and innovation strategy systematized at national and European level. For more details see the website: calabriaeuropa.regione.calabria.it/website/s3/areeinnovazione/ediliziasostenibile/ [Accessed 13 October 2020].

3) The BFL (Building Future Lab) is a laboratory infrastructure of advanced testing at the 'Mediterranea' University of Reggio Calabria, which supports creating new components with high performances through simulations with standardized protocols. In particular, the TCLab Section (scientific responsible Prof. M. Milardi) bases its activities on standardized and experimental tests, having as object the envelope in its technological and material structures. For more details see the website: unirc.it/ricerca/laboratori.php?lab=69 [Accessed 23 October 2020].

4) Current design paradigm is oriented to technological-sustainable performance with the implementation of materials with integrated reactive properties (Shahin, 2019).

5) EU Adaptation Strategy has among its primary objectives qualitative improvement of the environment through adaptive design processes. For more details see the website: ec.europa.eu/clima/policies/adaptation/what_en [Accessed 25 July 2020].

6) ASTM International, the acronym for American Society for Testing and Materials International, is a U.S. standards organization and leader in defining materials and test methods in almost every industry.

7) AAMA, the acronym for American Architectural Manufacturers Association, was established in the U.S. in 1936 and is one of the most prestigious associations operating in the industrial world of windows and components of windows.

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