Chapter 62
Adaptive Building Technologies for Building Envelopes Under Climate Change Conditions

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Abstract Following the widespread recognition of the urgency of environmental and energy issues, cities, now under the influence of the pandemic crisis, are called to cope with them through adaptation strategies to future scenarios that are constantly changing. At the same time, the implementation of adaptive building envelopes seems to be a promising alternative to achieve higher quality levels in the built environment, especially to counter and mitigate climate change, in line with EU directives. Adaptive envelopes can modify physical or chemical characteristics, exploiting environmental stimuli such as solar heat, temperature, airspeed, or atmospheric humidity. In this scenario, the experimental research in progress wants to define a new adaptive model by using innovative materials. It can be applied to curtain wall systems, intended as an element vulnerable to the effects of extreme events in a Mediterranean climate and more stressed by external energy flows. In this work, the author presents some parts of the research results, in which a necessary phase involved the reasoned recognition of adaptive materials for extreme applications or materials that can respond actively to possible external stresses. Research efforts are focused on the choice of the most suitable material to define the levels of environmental adaptability of the model, its constructability, and technological characterization. Finally, the performance verification of the adaptive model will be carried out at the TCLab section of the BFL of the Mediterranean University of Reggio Calabria to develop prototypical lines that can facilitate the new approach to high environmental quality adaptive envelopes.

Keywords Climate change · Building envelope · Adaptive model · Curtain wall · Testing

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62.1 Introduction

The current environmental and energy issues affecting the scenario of this time, accentuated by the effects of climate change, such as global warming (IPCC 2021) and the increase in CO_2 emissions, highlight the pressing need to define concrete and measurable responses, moving from a phase considered to be one of transition to one of transformation of the built environment.

This challenge has led to a systematic review of the design modalities, transferring performance issues away from the traditional physical and static properties of building enclosures to a broader discourse in defining how they behave.

For this reason, innovative concepts such as adaptive building façades could play a role in the near future, as their dynamic behavior could optimize the performance of a building in its complex system of internal and external relations (Milardi et al. 2021). In recent years, the climatic conditions of the Mediterranean areas, characterized by islands and heatwaves, extreme rainfall phenomena such as water bombs, micro-typhoons increasingly frequent and known as Medcane, represent a critical point of the building envelope, becoming a specific field of application for research activities.

The contribution refers to ongoing research, financed by funds POR Calabria FESR/FSE 2014–2020, with the ultimate aim of addressing a design methodology related to the concept of adaptability of the building envelope.

The research is in line with the European Directives on energy efficiency 2018/844/EU and is part of the Strategy S3-Region Calabria, related to the development of specific technologies and materials with higher performance and efficient and economically sustainable solutions. Research activities are directed toward the development of simulation scenarios/models and application experimentation, the aim of which is to develop an adaptive model using innovative materials, elements, and components applied to curtain wall systems (Kazmierczak 2010). The latter is vulnerable to the effects of extreme events, such as rising temperatures and precipitation, and more stressed by external energy flows.

This scenario directs experimentation toward realizing efficient and adaptive envelopes through advanced tests conducted at the TCLab Section of the BFL—Building Future Lab, Mediterranea University of Reggio Calabria. It represents a fertile opportunity for research and development of activities and skills to control the overall quality of the building and the urban context of reference.

The laboratory is one of the 40 partners of the project called Metabuilding Labs of Horizon 2020 to create easy access to an extensive network of high-value testing facilities that enable them to develop and test innovative envelope solutions for next-generation buildings.

In this work, the author presents some parts of the research results, on the reasoned recognition of adaptive materials for extreme applications or materials that can actively respond to possible external stresses.

62.2 Adaptive Materials

A review of the state-of-the-art shows how innovative materials, in the construction industry, are those existing materials that, through chemical-physical and electrical changes, acquire adaptive characteristics, offer more advanced performance, and even very different uses from the so-called "starting point" (Buanne 2015).

They belong to two macro-categories: those whose variability is linked to the variability of the shape and configuration, using sensors and handling mechanisms classifiable in pneumatic actuators, hydraulic actuators and drives based on electric motors (Wigginton and Harris 2009), and those whose variability is linked to the intrinsic properties of the material.

The study activities focused on the second macro-category, active materials, which represent the most advanced frontier of innovation.

Within this category, smart and shape-memory materials (SMMs), such as shape-memory alloys (SMAs) and electroactive polymers (EAPs) control and product performance at the level of material shape capable of stretching, bending, or folding, depending on the environmental stimulus, without the need for complex electromechanical systems or energy supply (Elattar 2013).

Thermo-reactive SMMs and SMAs perceive the thermal stimulus and show actuation or some predetermined response, making it possible to adjust different technical parameters such as shape, position, deformation, stiffness, and other static and dynamic characteristics (Wei et al. 1998). An input of thermal energy alters the microstructure through a crystalline phase change, allowing multiple shapes to environmental stimuli (Addington and Schodek 2012), making them promising materials for integration into adaptive façade applications.

The dynamic behavior of electroactive polymers, on the other hand, is triggered when an electric current, the stimulus, flows through the laminate, increasing the electrostatic forces that generate a contraction of the elastomer (Villegas et al. 2020). A typical dielectric electroactive polymer (DEAP)—a type of electronic EAP—consists of a dielectric elastomer membrane placed between two electrodes. When an electric field is applied, the membrane compresses and stretches, causing the material to change shape (Zhao et al. 2016) with the ability to store a large amount of energy.

Based on the analysis done, shape-memory materials, whether alloys or polymers, are identified as adaptive materials that contribute to a more complex and intelligent system. These materials, used for components design for the building envelope, absorb, and dissipate energy, deriving from a rise in external temperature, giving great adaptive response capacity to the entire system.

The direct impact examined in this research concerns the solar radiation reflected directly from the curtain wall surface into the urban microclimate. An adaptive façade improvement could, therefore, reduce the environmental temperature and the impact of the building and, consequently, decrease the magnitude of the phenomenon.

This activity was necessary for knowledge acquisition about material innovation and experimentation and the identification of the most congruent material of the adaptive model.

62.3 Objective and Results

In line with the technical-scientific literature on the difficulties in reconstructing a unique performance profile of the envelopes, the research intends to position itself as an effective tool capable of overcoming the possible criticalities dictated by environmental dynamics. The general objective is to identify operational tools capable of directing interventions on the built environment toward adaptive design with the contributions deriving from technological innovation to respond to the expectations of environmental control.

On the other hand, experimentation with adaptive systems is currently tied to individual cases of architectural design, limiting the large-scale application of innovative envelope technologies that contribute significantly to the control of climate variations. The systems currently on the market are scarcely applicable or used only in buildings with a particular use or size or value that justifies the adoption and thus the cost of such systems (Conato and Frighi 2018).

At the same time, there is a knowledge gap in the literature on future trends and main concepts of adaptive façades. There are knowledge gaps in terms of adaptive façade market share, including the main concepts, the most promising technologies, their categorization, their best use, and the distinction between short-term and long-term structural trends in adaptive façades (Attia et al. 2020).

The research aims at defining an intervention model that can guide design choices toward the elements that make up the building envelope, characterized by an adaptive component.

This study wants to satisfy the need to improve the performance of curtain walls by reducing the impacts of extreme climate change events, through the development of an adaptive model—the result of the research—able to react synergistically to different climatic conditions, ensuring high-quality performance.

Specifically, the following partial and expected results are listed:

- typological classification of curtain walls systems, on construction characteristics, operating principles, and performance requirements to be certified, with respect to critical elements that may be damaged during an extreme event;
- systematization of data and case studies relating to adaptive design through technological elements and systems capable of responding to external environmental conditions;
- elaboration of performance repertoires to guide the design of components with adaptive criteria and reasoned recognition of innovative materials for extreme events;

- identification of the current performance (without the adaptive model) of the curtain wall system with mullions and transoms, which will be chosen for experimentation, by conducting laboratory tests, thanks to the support of the TCLab section of BFL, relating to air permeability and watertightness;
- definition, through a synthesis framework, of the performances to be improved for the adaptive behavior of the façade system, with respect to the increase in temperature and precipitation, and of the materials that will constitute the adaptive model;
- instruction and construction of feasibility checks useful for the development of the prototype to be used for experimentation and testing activities;
- design experimentation through simulation and verification of the adaptive behavior of the model applied on a curtain wall to improve its performance.

The experimentation will focus on the analysis of a type of mullion and transom façade with respect to its adaptive stress behavior with respect to climate change phenomena. The investigations conducted on the study of materials for extreme events, summarized in the section on adaptive materials, allow us to consider the possibility of applying an intelligent material with shape-memory capabilities for the experimental phase. The final phase of the experimental research project will involve the comparison and superimposition of the results obtained from the laboratory tests on a curtain wall system, with and without the adaptive model.

62.4 Methodology

In accordance with the illustrated scenario, the research and its activities are organized in thematic sections to identify advanced technologies and materials for the adaptive management of curtain walls and to arrive at a model idea and the verification of its technical feasibility, which can be implemented through experimentation and evaluation of the results obtained (Grillo and Sansotta 2021).

The first phase concerns the investigation of the state-of-the-art, the European and national regulatory framework and, therefore, the identification of the open problems shaping it. In particular, the focus is on some key assumptions, based on the need for a renewed building design responding to the pressing demands of "new quality." Subsequently, a critical analysis of adaptive components, systems, and materials is useful to highlight the problematic aspects and resolve the criticalities emerging from the conception of the new adaptive model for curtain wall systems.

The experimentation phase is started thanks to the support of the TCLab section (Trombetta and Milardi 2015), carrying out simulations of climatic conditions in an urban environment and their related effects to test the adaptability levels of the model applied on a mullion and transom curtain wall system. The behavior of the curtain wall (mock-up on a 1:1 scale), with and without the adaptive model, in situations of climate change identifies and configures new adaptive scenarios, directing design decisions toward the optimal option for the different reference contexts and relationships.

For this reason, with respect to the climate change phenomena to be examined, the following procedure is identified for the experimentation activities:

- heatwaves: Experimentation is carried out by reproducing a wind flow, through an AAMA/ASTM fan, capable of verifying the performance behavior of the materials of the external façade of the mock-up subjected to a strong pressure and in accordance with ASTM E 283-04 (2012);
- pluvial flooding: The experimentation is carried out by reproducing a constant rain directly on the external façade of the mock-up, through a sprinkler system, with respect to three simulations of the water jet, through a sprinkler network with calibrated nozzles: in the absence of wind, in the presence of wind, and in extreme wind conditions (hurricane power) (Fig. 62.1) and in accordance with ASTM E 331-00 (2009), AAMA 501.1-05-00 (2007) and ASTM E 330-02 (2010).

The experimentation will have double feedback in the progress of the research: one, to test the performance characteristics of the curtain walls according to American standards with respect to extreme events; the other to verify, according to the normative requirements, components of the system, able to guarantee acceptable levels of safety with respect to environmental flows and external stresses, which relate to the building envelope.

Fig. 62.1 Example of hurricane simulation on a curtain wall. *Credit* TCLab

62.5 Conclusions

Research focuses efforts on the assumption that curtain walls guarantee constant performance thresholds calibrated to the average values required by the standards, resulting in envelopes that perform the same even in different contextual conditions.

Therefore, the research, even if still in progress, is oriented toward the design of the optimal combination of the adaptive model, using shape-memory material aiming at the most appropriate adaptive efficiency, calibrated to specific environmental contexts. Incorporating these principles in the prototyping of the adaptive model to be applied to new or existing curtain walls becomes an essential activity for an architecture that must continuously adapt to the effects of climate change.

In this perspective, the prototype to be developed represents the physical element of mediation between the external and internal environment, able to regulate and react to the signals that qualify the external environment, contributing to becoming an element of transformation and control. In this sense, the study and analysis activities of the research cannot be considered exhaustive due to the complexity of the subject and new fields of innovation are still to be investigated, but the experimental approach is functional to define application and simulation potential in the construction sector.

Therefore, it is strategic to pursue the approach based on measurement tests and performance evaluation in a "simulated" regime. The testing process is intended as an adaptive control tool for climate change, based on measurements and performance evaluation concerning specific environmental reference contexts. The coherence of objectives establishes a new mission focused on improving the company's know-how, centered on the realization of innovative products addressing market trends and efficient and adaptive envelopes.

The activities and perspectives of applied research and experimentation can outline concrete solutions on a theoretical and operational level, referring to current and future challenges, moving toward an increasingly controlled vision in the relationship between innovation and architectural design. Work in progress.

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