Case Studies – Adaptive Facade Network

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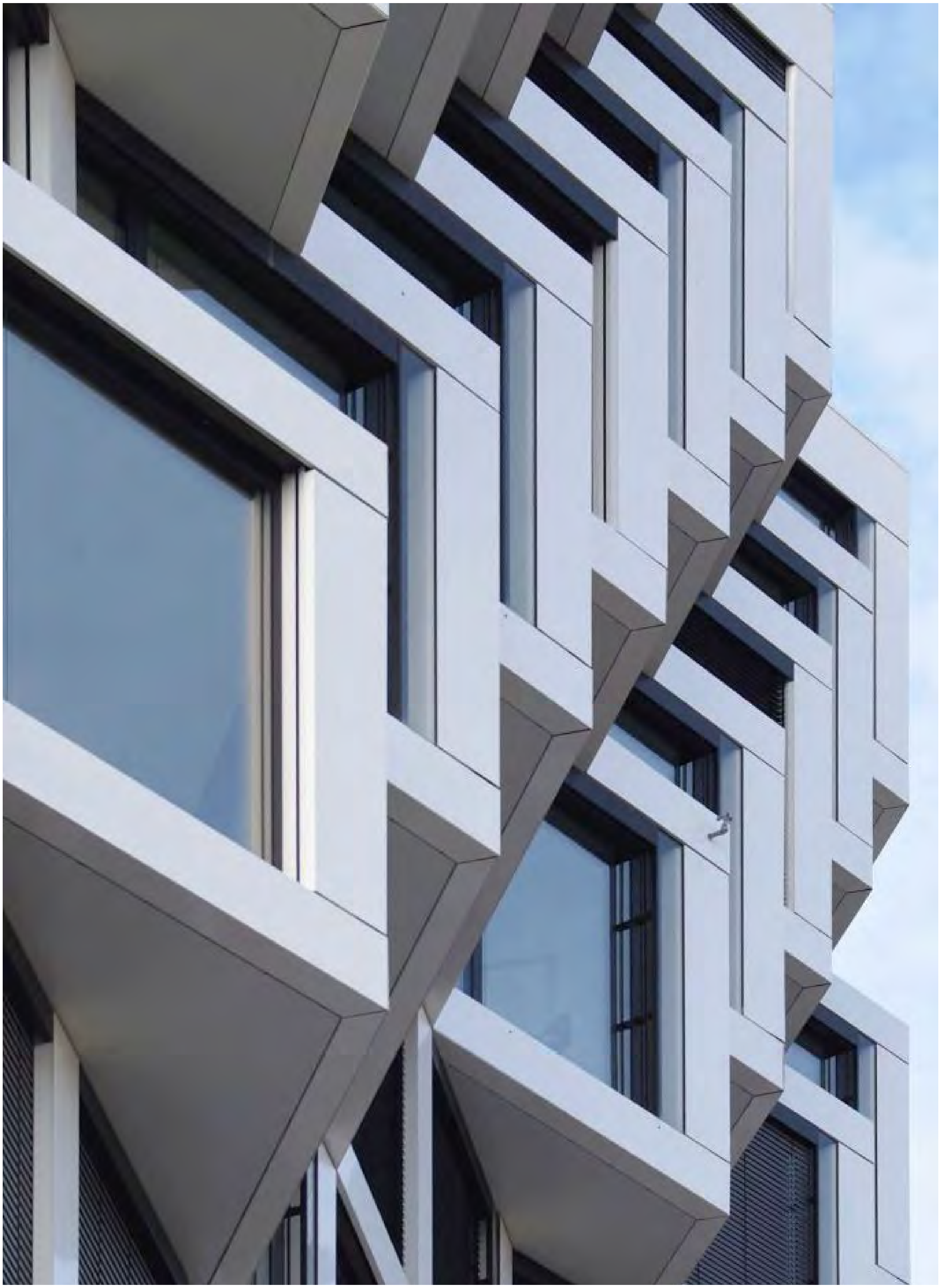
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Preface

Adaptive building envelopes can provide improvements in building energy efficiency and economics, through their capability to change their behaviour in real time according to indoor-outdoor parameters. This may be by means of materials, components or systems. As such, adaptive façades can make a significant and viable contribution to meeting the EU´s 2020 targets. Several different adaptive façade concepts have already been developed, and an increase in emerging, innovative solutions is expected in the near future. In this context the EU initiative COST Action TU 1403 aims to harmonize, share and disseminate technological knowledge on adaptive facades at a European level.

According to the definition given by this COST Action, an adaptive façade is a building envelope consisting of multifunctional and highly adaptive systems that is able to change its functions, features, or behaviour over time in response to transient performance requirements and boundary conditions, with the aim of improving the overall building performance.

In order to explore the available and emerging technologies focusing on adaptive façades, Working Group 1 of the COST Action undertook research to form a database of adaptive façade case studies and projects structured in accordance with a simple classification – materials, components and systems. In addition to this, details of the purpose of the systems/components/materials with adaptive features and the working principle of each technology were also collected together with data regarding design practice, technology readiness, and economical aspects, among others.

The information was collected with the help of a specific online survey (structured in the following main sections: detailed description - metrics- characterization- economic aspects – references). The database includes 165 cases of adaptive façade systems, components, and materials that allowed a variety of analyses to be carried out. According to the classification adopted within WG1 (materials, components, systems), each of the classification terms are introduced together with examples from the case study database in the following sections. This volume ends with a section dedicated to future developments, where different issues are addressed such as embedded functionality and efficiency amd biomimetic inspirations. The importance of adaptive façades through their flexibility, and intelligent design within the context of smart cities is also discussed.

The work within Working Group 1 - Adaptive technologies and products was developed within four distinct sub-groups (SG) in order to provide outputs according to the objectives of this WG and the COST Action: SG1 – Database, SG2 – Educational Pack, SG3 – Publications and Reports and SG4 – Short Term Scientific Missions (STSM).

This work was possible due to the strong commitment and work of all WG1 members: Laura Aelenei, Aleksandra Krstić-Furundžić, Daniel Aelenei, Marcin Brzezicki, Tillmann Klein, Jose Miguel Rico-Martínez, Theoni Karlessi, Christophe Menezo, Susanne Gosztonyi, Nikolaus Nestle, Jerry Eriksson, Mark Alston, Rosa Romano, Maria da Glória Gomes, Enrico Sergio Mazzucchelli, Sandra Persiani, Claudio Aresta, Nitisha Vedula, Miren Juaristi.

Laura Aelenei

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Cubus Office Building / Gigon Guyer Architekten (image: M. Brzezicki)

Future Developments

Innovations for the next generation of adaptive building envelopes

Susanne Gosztonyi, Enrico Sergio Mazzucchelli, Rosa Romano, Nikolaus Nestle, Marcin Brzezicki, Christophe Menezo

Introduction

The adaptability of façades is actually nothing new. The façade has always had a variety of static and dynamic tasks. For example, manually controllable openings or sun protection devices are traditional “adaptive” components - and yet these components in particular have experienced a considerable leap in innovation in recent years. Under the collective term “Future Developments”, this chapter would like to provide a glance into ongoing research and development topics for new technical solutions of adaptive façades. The focus is on innovations that are not yet established on the market and are being touched by the COST TU1403 Adaptive Façades Network at the time of writing. It can certainly be assumed that there are many more innovations in the field of adaptive façades. The COST TU1403 publications refer in this sense to further topics, which are not illustrated here.

Goals for adaptive facades: Future technical developments for façades will focus on the material design criteria for outdoor applications, concerning increased durability and mechanical resistance, as well as on the responsiveness of the components. Among all features that are expected, reliability is one of the key issues that asks for caution due to the intensive use of e.g. mechanical or embedded controls. With active devices, as it was the case in earlier years, there is often a loss of adaptability in the event of a breakdown, or when these have to be ‘restarted’ several times before being abandoned. According to Bridgens, Holstov and Farmer (2017), the main typologies of future applications within architectural design focus on: functional devices/ components (actuators, micro-generators, sensors, locomotion engines etc.), performance-oriented adaptive systems (enhanced occupant comfort, energy efficiency, etc.), formal/ aesthetic/ spatial experience values (e.g. enhanced visual appearance of a dynamic façades) and contextual/location-specific values (buildings as a physical representation of local environment and climate). Inspirations from other domains, such as from nature, are a huge potential to support the development of such typologies in an innovative way.

From adaptive façades to intelligent buildings in the framework of smart cities: Following the outlines of the Smart Cities and Communities Initiative of the European SET Plan, the concept of *Smart City* is clearly focused on the promotion and dissemination of a new generation of innovative, intelligent and energy-efficient building envelopes. In particular, the Smart City represents a new generation of built environments, where energy efficiency is not exclusively achieved by a single building but rather involves the entire energy infrastructure network of the city, and where building envelopes represent essential and strategic nodes for reducing the energy consumption and increasing the production of renewable energy (Arbizzani et al., 2015). For decades, architects and building scientists have envisioned the possibility of the envelopes of future buildings replicating human skin's adaptive response to changing environmental conditions (Davis, 1981; Wigginton and Harris, 2002). Advances in material technology and building automation are drawing these parallels between adaptive envelopes and the intelligent response of human behaviour and skin to environmental stimuli. It is seen as an increasingly feasible way of regulating energy flows through a building's thermal barrier in a controlled way that promotes energy reduction and users comfort. Over time, this concept has been defined as an envelope able of changing shape in relation to external thermo-physical stresses, shifting from transparent to opaque, altering its colour, and varying its optical properties. These characteristics can be determined by choosing materials that offer advanced solutions in relation to their chemical composition or the ongoing application on the envelope of dynamic elements. Michael Wigginton and Jude Harris (2002) in their text on Intelligent Skin define this concept as an adaptive and dynamic control system able of regulating the interchange of energy between an internal and external environment, ensuring an excellent level of comfort through the possibility of automatically varying the building's structure. A large number of sensors should regulate the system with precision, turning the building into a smart building. The variability of the façade system makes it possible to regulate heat and light energy flows through its conformational layers, and has led to an evolution in research related to phase change materials, advanced glass surfaces (such as electrochromic and/or photochromic glass) and mobile (horizontal and vertical) external screening systems. Therefore, in the next years, the concept of smart building will be closely linked to that of adaptive envelope, as the façade itself is the main element able of changing its structure to ensure the required performance, emphasizing its resemblance to human skin. Finally, the future envelope will become a real organism connected to the building's central control system, where the air conditioning system can be compared with the human circulatory system. In this context, the novel concepts of adaptive envelopes developed in the last years by Doris Sung and Ingalill Wahlroos-Ritter (Bloom installation), Achim Menges (HygroSkin), Hoberman Associates (Tessellate™), Ned Kahn and Koning Eizenberg Architecture (Articulated Cloud), Simone Giostra (Sol Pix), etc. are interesting. These are innovative approaches able to not only to increase the building energy performance and to produce renewable energy at the same time, but also to improve the environment of our cities.

This chapter touches some developments for these objectives, such as innovations for e.g. components that are independently adaptable due to smart material or construction properties.

The digitalization potential: Another topic is the digitalization of design, planning, production and operation, which seems to be particularly advantageous for the performance-oriented combination of complex systems with flexible designs. The virtual planning environment enables also a holistic consideration of the life cycle of a façade and its components. Even passive systems can become then somewhat adaptive. Using parametric, multi-criteria planning methods, a façade construction can be designed in such way that it is adapting to changing local climatic conditions by its specific design. The performance potential of this approach might be higher than currently used. The economic effort for such is then shifting from high costs in the production and implementation of a multifunctional system towards more complex design and planning efforts. Ultimately, it seems beneficial to bring active and passive components together in a complementary way: The more intelligently the passive and active properties of a façade interact, the more robust the desired output is in terms of maintenance and performance.

Smart devices: The development of smart control systems for adaptive façades will be another technological challenge. In this regard, the transition from centralized to decentral distributed models, often more coherent with properties and behaviour of smart materials, shows huge potential. One of the advantages of active systems is their intelligent interaction ability with the building energy management. Combined with renewable systems, the required operating energy may not only be generated by the façade, but also support the total building operation. Intelligent façade management, coupled with building energy management, may then enable economic optimisation and contribute to the smart living features.

Only few of these challenges can be addressed in the following pages. The chapter draws a picture from the role of adaptive façades in the future smart city, to development approaches of its intelligent components by applying new materials and methods, up to the need for new production processes and new integration requirements for the adaptive functionality in the building context. Many more topics are elaborated and addressed throughout the COST TU1403 activities, which are provided in the booklets and proceedings.

Material systems – embedded functionality and efficiency

The integration of building services functions and renewable energy systems into façades shall increase the total performance efficiency of a building while providing individual comfort in zones (adjacent to the respective façade). This idea undergoes currently a fundamental change, starting from the first multifunctional façades to new adaptive systems. The vision is to merge the various functions of an element, such as e.g. structural or building services requirements, into an intelligently designed façade system without applying the additive approach. So-called '*material-systems*' (Hensel, Kamvari and Menges, 2008) and corresponding structures contribute to this vision: Material-systems are materials that are designed on the basis of performance-orientated, formal and structural criteria in combination, with the aim of reacting dynamically and autonomously to varying conditions and at the same time being able to take on other functions, such as serving as structural elements. The difference is that only one or a few raw materials are used for this. The various functionalities are embedded in the geometry of the designed material-system. Instead of the additive assembly of mono-functional subsystems to a complete system, as we build multifunctional façades today, material-systems reduce the application of various materials and components and the associated problems coming with composites. Using parametric computational design methods, the morphogenetic potential of materials can thus be utilized in such way that they provide e.g. shape-varying, thermo-adaptive, light-emitting, energy-generating or -storing properties.

An interesting approach herein is the utilization of physical properties embedded in material properties by nanotechnologies or micro-structuring: For example, colour change mechanisms in squid skins (achieved through active and fast shape changes of colour-containing vesicles in the skin) could provide technical inspiration to control glare and solar gain. Structural colours and photonic crystals are used in nature to change colour appearance without any change of the material structure or properties at all (cp. Gosztonyi, 2015). Ferrofluids or electro-wetting mechanisms might be another, low energy-consuming approach in this context. For example, ferrofluids could be arranged by using transparent micro-coils to shade areas, which would then have electrostatic, constant power consumption in contrast to electromagnets.

However, these developments ask for a further obligatory criterion, which should be applied in the future investigations to allow a real innovation step: The sustainable use of raw materials and the reduction of (non-recyclable) composite materials. Material-systems ideally use only one or a few raw materials to fulfil several functions, but the type of raw material is not refined towards sustainability. In order to follow sustainable goals, this would also have to be considered, since not all current material-structure solutions are recyclable and therefore sustainable.

Biomimetic inspirations

A possible source of inspiration for the development of sustainable, performance-oriented material-structures is the systematic analysis of biological principles in nature. By analysing functional phenomena in nature, as nature is using the logic of material-systems, the functions, dependencies and properties can be probed and processed for applications in technology. The transfer potential of biological solutions is huge, as many recent research projects demonstrate (Shimomura, 2010) (Gosztonyi, 2013). Whether for plants or animals, the interfaces between the outside and the inside of living organisms, such as the epidermis or cuticle, play a major role in overcoming physical and physiological problems related to an ambient environment (by radiation, temperature, humidity, wind, etc.). Even if these interface properties are complex and based on physicochemical principles that are currently largely non-duplicable, certain structures, materials and processes can still serve as inspiration for technical innovations. In order to highlight the main functional evolutions related to the climate, it is therefore essential to study living organisms in their climatic environments.

Bio-inspired solutions – air conditioning and wood-related construction components

A possible bio-inspired topic concerns the implementation of organic gaseous exchange systems in buildings, such as decentralized air-conditioning systems already applied in selected buildings. Decentralized air-conditioning systems can be compared with gaseous exchange systems in insects, where the air is sucked directly into the tissue through a system of tracheal tubes and spiracles. The air exchange system of Capricorn house in Düsseldorf (designed by the architects Gatermann and Schossig in 2008) was modelled on this principle. The façade modules are independent ventilation/cooling and heating elements that suck the air directly from the surrounding into the rooms. A central air-conditioning system does not exist in the building. The advantage of this system is the unique possibility to maintain very different climatic conditions in adjacent rooms and to switch off the system when rooms are not occupied. The disadvantage is a high level of complexity and maintenance of each façade module that practically are single air-conditioning units.

Some bio-inspired material-structures targeting wood have already been tested for practical applications, as e.g. the elastic bending behaviour of wood fibre materials in relation to the relative moisture content of the environment in the research project HygroSkin of the ICD, University of Stuttgart (Krieg et al., 2014). In doing so, the morphogenetic functional potential of the wood was exploit, by means of which the proven material is once again elevated to a new dimension of intelligent adaptive materials. And incidentally, wood itself would fulfil the criteria of sustainability and resource efficiency. The development of such therefore offers the opportunity to innovatively combine high-tech functions and sustainability. Similar applications on wood-based, responsive building skins have been recently deepened by Bridgens, Holstov and Farmer (2017) and Mazzucchelli and Doniacovo (2017). Because these components can be used as cladding panels, sunscreen, passive layer for photovoltaic systems and others, the maintenance and durability aspects that usually depend on wood species must be taken into account. In this regard, it is important to note that the vapour phase transport is not disturbed by non-sealing, hydrophobic treatments (oil- and wax-based).

Cellulose is another material within this category: It is used, for example, by insects, like e.g. hornets, for the manufacture of the combs and the entire nest shell, which is designed to dissipate heat in hot periods or to limit heat loss in cold periods. These flexible and lightweight envelopes also provide the UV and water protection function by cellulose fibres taken from tree barks or dead wood. These fibres are processed into a cellulose mass, which the hornets use as cement to build larger scales, each layer of which is interspersed with beige and brown. This composition is comparable to 3D printing (Merlin and Ménézo, 2018).

Digital design and production potential

Digital design and production process chains, such as the coupling of parametric design and additive manufacturing (AM), enable a flexible, material and time-saving design process of complex shapes and functional components. In addition, it allows nearly any type of embedded functionality that enables the product to become smart and responsive.

The starting point is to create a computer-based, three-dimensional model: this model is created by the combination of static and dynamic parameters, and input/output conditions and target variables, in a parametric design environment. Thus, the design development is no longer created 100% manually, but developed based on dynamic data and generic algorithms. As the environment is dynamic and allows variation studies and optimization loops, the results can be manifold (Wang, Zmeureanu and Rivard, 2005). With digital production methods, it is then possible to realize some of the chosen results while maintaining the quality and - in the near future - producing any quantity in cost- and material-efficient manner.

AM products can be designed of single raw materials, such as polymers, fibres, metal or minerals, which also promise simplification in terms of re-use and recycling. Their quality in function and production is already at a very high and mature level on the prototyping scale (Lim et al., 2012). It is expected to reach economic feasibility for prefabricated modular components of a façade in sooner future. Today, AM techniques or rapid prototyping are particularly suitable for the production of complex connections or for the rapid realisation of prototypes on small scales (testing and design phase).

Smart controlled

A major challenge in making optimal use of adaptive façade elements is their appropriate consideration in the building control system. This is not only true for elements responding to extrinsic stimuli (and thus can be actively controlled) but also for elements responding to intrinsic stimuli (which cannot be controlled but nevertheless need to be considered by anticipating their adaptation effect for an optimal control of other building components by the building control system). This requires sufficiently simple, fast and robust models for energy and material flows through the adaptive façade components. The models can be run as a routine in an optimization kernel, which continuously calculates the energetically optimal operation of all building components based on sensor data and anticipative information, such as the weather forecast and energy quantities available in smart grids for electricity and heat. If run together with a simulation of a non-adaptive benchmark model building, such a building control system can also be used to validate and quantify economic and energetic gains from the use of the adaptive façade.

The lack of plug-in solutions for both aspects of the building control system is probably a major factor in the slow market penetration of adaptive façades up to now. The development of appropriate building control systems capable of dealing with adaptive building skins will therefore be a key challenge in developing adaptive façade solutions to their full potential. This pivotal role of building control systems for the operation of adaptive façade component is likely to have a substantial impact on the future development of value chains and business models in the field of adaptive façades. Open and extendable standards and a good integration with BIM solutions are desirable to facilitate further development of new adaptive façade components. Due to its interdisciplinary and complex nature, this topic is probably best approached in the context of large research cooperation and thus should be considered as a high priority for future EU-funded research in the field of adaptive façades.

Conclusions

The future technical developments in the area of adaptive façades will be strongly related to digital production and design processes, smart controls, intelligent components and dynamically reacting materials that open new potential research fields. The development of appropriate materials and systems, capable of dealing with adaptive façades, appear therefore as the technical key challenge in future research and industrial development activities. Particularly smart materials may replace current building services technologies or structural elements by intelligently designed material-systems and bio-materials. Moreover, their development may offer the opportunity to innovatively combine high-tech functions and sustainability. This objective follows the outlines to reach the Smart City targets, where energy efficiency is not exclusively achieved by a single building but rather involves the entire infrastructure of a city network.

Other challenges in the field of adaptive façades are not touched in this chapter, but are likewise important. One is the evaluation of adaptive components in a façade, which poses another major challenge in the future. Adaptive façades, allowing to damp external effects or even to match external flux (energy, water, gas) with internal needs, require a complex assessment framework to be reliably used in new buildings or in building refurbishment, depending on the type of construction and building type. The performance evaluation of adaptive components is herein a criterion that must be considered and established in practice in order to predict the full performance capacity of adaptive façades. The question is to what extent can the dynamic behaviour of adaptive façades be made predictable and quantifiable? Do adaptive components require an extended characterization of its properties and new “dynamic” reference values? In any case, there is a need for enhanced standards and test procedures of dynamic components and behaviour in the building sector. To date, standards from other areas are used to evaluate adaptivity, such as material characterizations without integration into the façade system, electrical measurement and control standards, monitoring technologies for safety logging of intelligent control measures, and many more. It requires a combination of these evaluation methods with new approaches to investigate adaptive façades in the context of actual operation.

Modularity and standardization of components are another aspect in the development of adaptive façades. Both promise higher planning, operational reliability, and economic efficiency. “Keep it simple” is often expressed as a concern in this context. Especially with adaptive façades, the desire for simplicity and robustness of the components raises many questions: How can fully integrated, adaptive components be replaced in the event of a change in use of the building? What about the interaction between several active components? Can interfaces and connections of active components be standardized? To what extent can existing constructions be supplemented with high-tech products? And, to what extent can active façades take over building services tasks? Another critical factor herein is surely the cost-effectiveness of adaptive façades. In contrast to passive systems, i.e. static systems and manually operable components, active systems - systems with automatic reactivity - are nowadays usually cost-intensive high-tech products.

Finally yet importantly, the challenges of adaptive façade systems ultimately go far beyond the technical-constructive requirements; they demand new economic models, production methods and a high degree of interdisciplinarity in planning and development. Those who interact with the “intelligent” system on a daily basis - the inhabitants - must also be taken into account. They finally decide whether adaptive façades are successful in practice or not. A close-up towards user acceptance and monitoring while operation is thus another essential development field.

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