Chapter

# Adaptive Textile Facade Systems-The Experimental Works at D1244

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## Abstract

Adaptive facade systems are a promising approach to achieve a dynamic response to varying weather conditions and to individual user demands. Within the framework of the Collaborative Research Center (CRC) 1244 at the University of Stuttgart the use of adaptive systems and the related architectural potential is explored with the aim of reducing the consumption of natural resources as well as waste generation and hazardous emissions. The targeted parameters for the facade design include solar radiation, temperature, wind speed, relative humidity, daylighting, and user interaction. To generate an experimental platform for the research work, a 36.5 m high adaptive experimental tower, D1244, has been designed and built on the University campus. The temporary facade of the tower is currently being replaced floor by floor, in order to validate different research approaches. The first implemented facades focus on textile systems, because of their lightweight and the different functions that can be easily integrated. Further material systems will be investigated in the next future.

**Keywords:** adaptivity, textile solutions, resilience, interaction, kinetic architecture

## 1. Introduction

The Collaborative Research Center (CRC) 1244 "Adaptive Skins and Structures for the Built Environment of Tomorrow" at the University of Stuttgart has been working since 2017 on the question of how future built environments can be created reducing the use of resources and the associated greenhouse gas emissions (GHG). The building sector is responsible for more than 50% of global resource consumption and for more than 38% of global $CO_2$ emissions [1]. The target of the interdisciplinary program is the development of new design strategies and technologies, which enable structures and envelopes to be adaptive against loading and environmental actions. The research group comprises architects as well as structural, mechanical, control, and aeronautical engineers and computer scientists.

Within the scope of CRC 1244, adaptive structures and facades are understood as systems whose physical properties are actively manipulated by means of control systems. The state of the system is monitored by sensors. In the specific case of facades, the overall target is the design and validation of systems that enable the manipulation of transparency, reflectivity, humidity rate, insulation, cooling and acoustic properties, in order to control indoor as well as outdoor conditions in the vicinity of the building envelope.

Conventional envelopes can only provide a very limited range of reactions to varying external agents or to changing user needs. When using such systems, facade engineers often can achieve sub-optimal design [2]. While other researchers have been in the past investigating performances and design methods of adaptive skins in general [3], in this chapter the focus is on a specific field: adaptive textile facades. The reason for this focus is the lightweight character of such facade types and the potential of integrating and combining different functions while keeping a low ecological footprint.

CRC 1244 has set a strong experimental background for the research work. A 36.5 m high adaptive experimental tower, called D1244, has been built to test the proposed approaches on a large-scale experimental structure that offers real-world conditions (**Figure 1**). D1244 is the world's first adaptive high-rise building [4]. The unique feature of this demonstrator is the integration of sensors and adaptive components into the load-bearing structure and skin. All elements are assembled in such a way that they can be later substituted without generating any waste. The adaptive components in the load-bearing structure enable it to react autonomously against external disturbances such as winds and earthquakes. The building envelope currently consists of a single-layer recycled membrane that is being gradually replaced by adaptive facades as the research projects unfold.

This chapter focuses on three systems: *HydroSKIN* on the tenth floor, addressing rainwater collecting strategies and the potential of evaporative cooling; *FiberSKIN* and *MagneticSKIN* on the ground floor which are targeting the interaction between

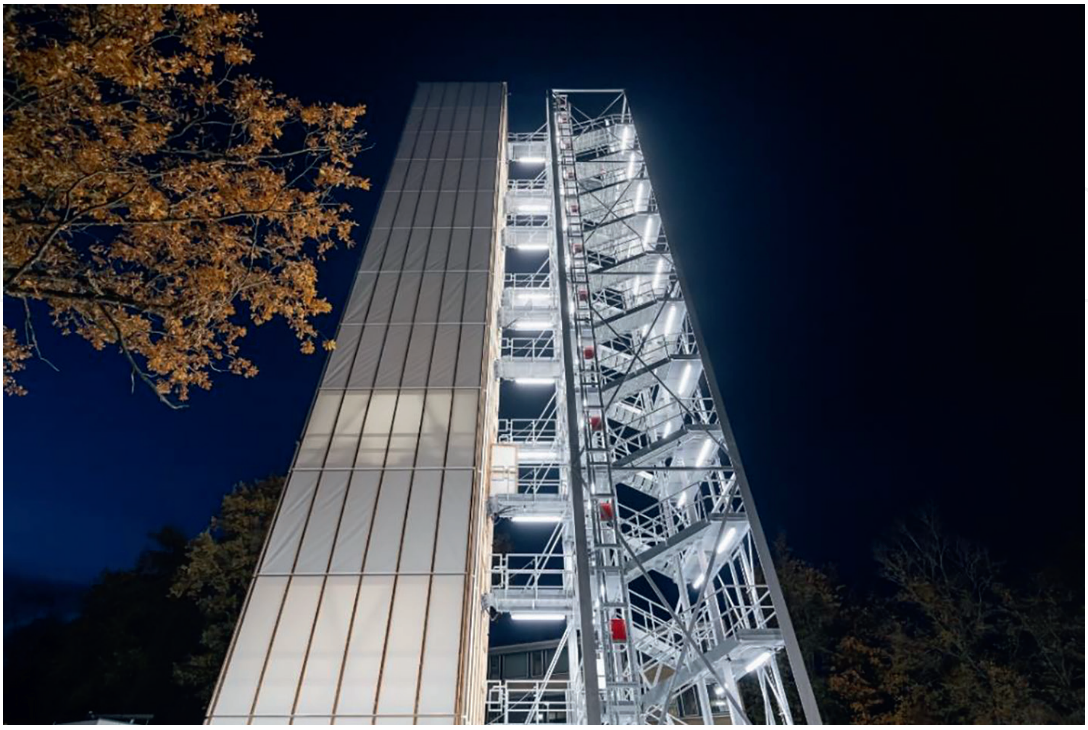

**Figure 1.**
*View of the experimental high-rise building D1244, Stuttgart © R. Müller.*

people with inside and outside spaces. Additionally, it provides an overview of further textile systems such as *KineticSKIN,* which is currently in the design stage.

## 2. HydroSKIN

*HydroSKIN* represents the first lightweight building skin, that collects the wind-driven rainwater hitting the building facade and releases water in heat periods to cool the interior and exterior environment by evaporation (**Figure 2**). The aim is a drastic reduction of urban inundation and heat risks by relieving the sewage infrastructure as well as providing natural microclimate regulation with a minimal amount of embedded mass, energy, and emissions.

### 2.1 Climate context

Heavy rainfall events and extreme heat are becoming more intense, frequent, and long-lasting [5]. The increasing urban densification with coherent surface sealing in urban agglomerations enhances precipitation runoff on the one hand, as well as solar radiation absorption, thus causing urban heat island effects on the other hand. While social developments lead to increasing urban densification, surface sealing, and the construction of high-rise buildings, the effects of climate change, such as extreme heat and heavy rainfall, require the opposite: the creation of more permeable surfaces and buffer areas for reducing inundation and heat exposure. The average annual ratio between evaporation and runoff for non-built-up surfaces, such as green areas, is

**Figure 2.**
*HydroSKIN prototypes at the D1244 experimental high-rise building in Stuttgart © S. Cichowicz.*

about 60% evapotranspiration, 25% groundwater recharge, and 15% rainwater runoff. In comparison, sealed surfaces demonstrate an average runoff of over 90% [6]. In conclusion, the aim is to approximate the water balance of built-up areas to that of non-built-up areas by reducing the precipitation runoff after heavy rainfall events, as well as by increasing evaporation and latent cooling in urban areas.

To avoid irreversible damage to humans and the environment, the Intergovernmental Panel on Climate Change is pursuing two complementary approaches, based on the concepts of mitigation and adaption. The first aim is to reduce climate change by significant and sustained reductions in greenhouse gasses (mitigation). However, since climatic consequences are to be expected even with zero manmade $CO_2$ emissions, strategies and technologies for adaptation to the expected climate situation are being developed [5].

The combination of climate mitigation and adaptation strategies, by addressing both climate challenges of urban heat islands as well as pluvial inundation risks, is seen to have great potential for dealing with global environmental issues sustainably and effectively.

### 2.2 Concept

Most facade systems only focus on the building-physical performance. *HydroSKIN* faces the current climatic challenges by addressing both climate mitigation and adaptation strategies with a new type of functionalities in the building skin (**Figure 3**). The incorporation of textile and foil-based materials into the building skin opens a revolutionary new spectrum of performances in the facade: with a minimal weight per unit area, the use of a special, functionalized, multi-layered textile enables integration of decentralized rainwater harvesting into the facade, with time-delayed evaporative cooling of the building and its environment. The aim of the *HydroSKIN* is to improve drastically and sustainably the climate resilience of buildings and cities by simultaneously reducing precipitation runoff and inundation risks as well as urban heat island effects; achieving this with a minimum amount of technical effort, resource and energy consumption [7].

During heavy rainfall events accompanied by wind, the *HydroSKIN* add-on element absorbs the wind-driven rain striking the building facade. Thereby the

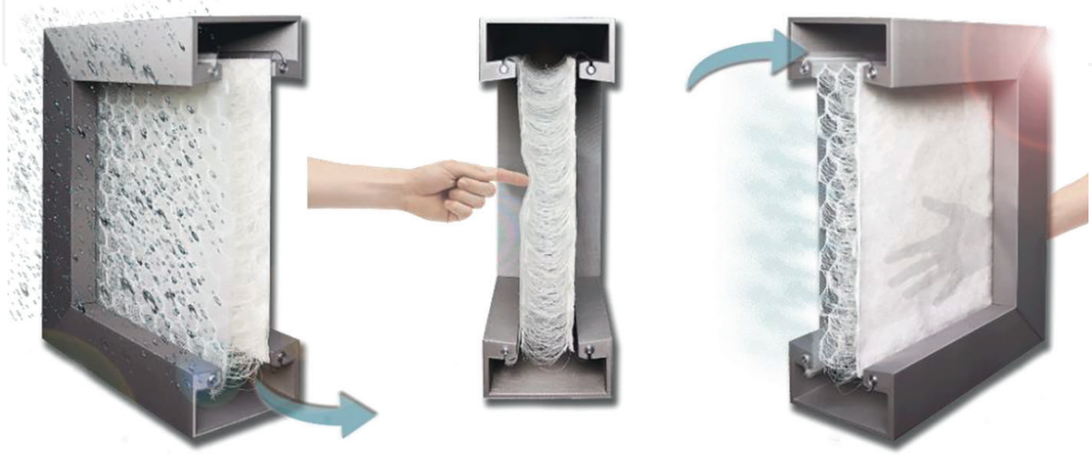

**Figure 3.**
*HydroSKIN concept for rainwater harvesting of wind-driven rain and for evaporative cooling © C. Eisenbarth/ILEK.*

minimal material facade element reduces the load on urban sewage infrastructure and decreases the risk of flooding. Wind causes rain to have a horizontal velocity component and therefore increases the water impact on the facade. During hot periods, the absorbed rainwater can be targeted and time-delayed and released by wetting and evaporating on the facade. This improves the urban microclimate by cooling the building envelope and causing a down-flow of cold air into the urban area around the building thereby mitigating urban heat islands. The hybrid component addresses both rising climatic impacts of heat and inundation risks on urban architecture in a single hybrid envelopment solution. Depending on the prevailing climatic conditions, *HydroSKIN* can also be configured to perform only as one mono-functional device for rainwater harvesting or evaporative cooling [7–9].

### 2.3 System design

*HydroSKIN* is designed as a multi-layered textile structure to fulfill the multiple requirements of water absorption, storage, transport as well as evaporation (see **Figure 4**). The first layer provides a water-permeable filter facing to the outside. It protects the structure behind it from accumulation of dirt particles, insects, etc., thus favoring the water permeation into the multi-layered system by splitting the incoming raindrops. The second layer consists of a three-dimensional water-transporting spacer fabric whose pile threads on the one hand transport the incoming and outgoing water droplets and on the other hand favor air circulation by an open porous structure with large surface area, thereby enhancing the evaporative cooling performance.

An intermediate layer with high water absorbency can optionally be integrated to increase water storage capacity and evaporation duration of the textile multi-layer system in very hot and dry regions. The water-bearing layer, consisting e.g., of a foil, is on the inside and serves to provide water drainage and collection into the lower profile system. The individual layers are assembled by a force fit and are fixed in a frame profile system by means of textile joining techniques. The polymer-based textiles can be manufactured out of recycled material. Besides the textile mono-material system

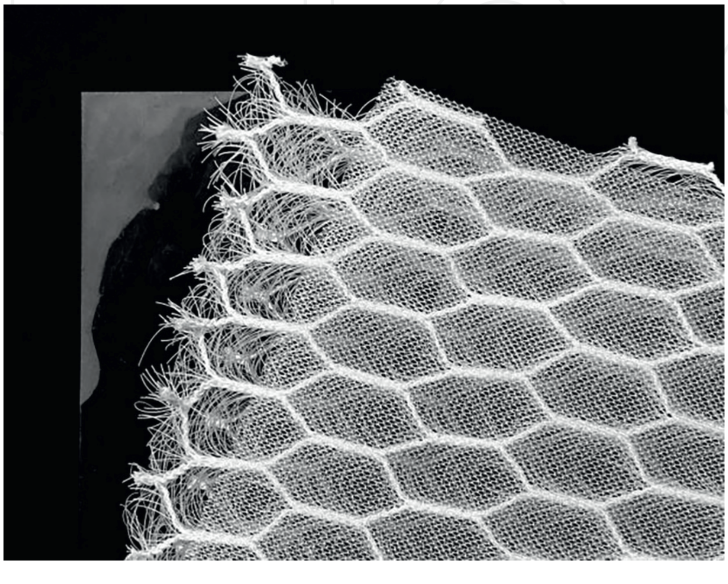

**Figure 4.**
*Multi-layer system design of HydroSKIN © C. Eisenbarth/ILEK.*

can be easily detached from the enclosing frame profile to return all system components to the material cycle. The water supply and discharge conduits are connected to the frame profile, enabling both the wetting of the *HydroSKIN* during hot periods and water drainage of the absorbed precipitation yields [9].

### 2.4 Potential

The advantages of facade-integrated rainwater harvesting consist not only in relieving the load on urban sewage infrastructure but also in reducing global freshwater consumption of residential buildings by up to 46% as well as in saving energy by up to 26% [7, 10].

Compared to conventional hard building surfaces, such as glass, optical investigations of the droplet impact behavior indicate a high permeability of textile materials. Evaporative cooling is one of the oldest and simplest principles of air-conditioning technology: the phase transition of water from the liquid to the gaseous state at temperatures below the boiling point extracts heat energy from the surrounding air. Frescoes from around 2500 BC show the fanning out of ceramic vessels filled with water, whose large pore content allows a large amount of water to be absorbed and evaporated on its surface [11, 12]. By the specifically adjustable surface structure and porosity of textiles, one can obtain a maximum surface area for water evaporation with a minimum amount of material. Thus, textiles are of particular interest for their application as evaporative cooling materials. The development of synthetic fibers since 1945 has even increased their evaporative cooling potential, since their large surface structure can be functionalized precisely [9, 13].

The evaporative cooling potential of water-saturated textile fabrics shown in **Figure 5** was investigated by empirical test series on an evaporation test bench under laboratory conditions of approx. 35°C room air temperature and 20–30% room air humidity. Humidification of the textile results in an immediate temperature reduction of 8–12 K, which under real weather conditions including wind velocity increases to

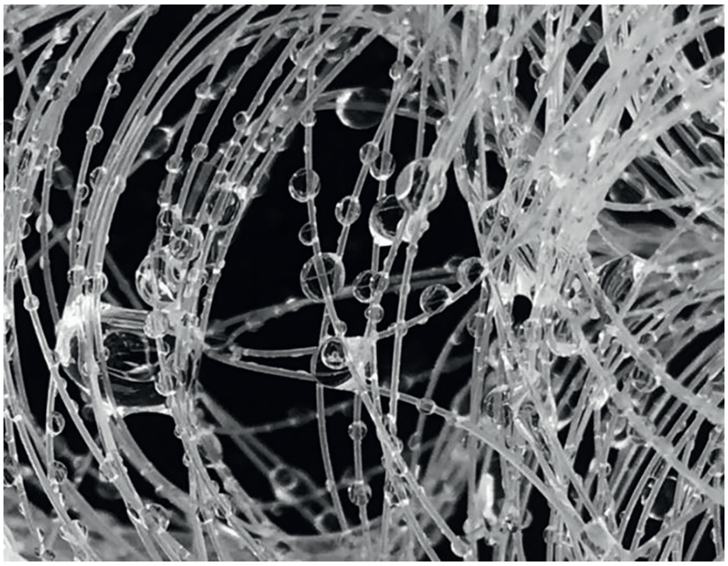

**Figure 5.**
*Water droplets accumulating in three-dimensional spacer fabric © C. Eisenbarth/ILEK.*

a facade surface temperature reduction of more than 20 K. The temperature decrease is accompanied by a coherent cool downdraft of about 0.2–0.4 m/s, which indicates a potentially useful implementation in tall buildings providing a cooling tower for the urban space below.

### 2.5 Implementation

*HydroSKIN* elements are designed to be applied to both new and existing buildings. Retrofitting of existing facades is limited to the static restriction of reducing the additive loads to a minimum, as these were not considered in the original design of the existing construction. The lightweight elements comply with such a constraint, still allowing for a wide range of design options and performance scenarios. The multi-layer design of *HydroSKIN* can be individually customized to the respective climate conditions, user requirements, and design guidelines. Creating a unique translucent esthetic effect with a textile, tactile surface texture, these climate-adaptive textile facades can be applied in a huge variety of design options, such as printed, colored, illuminated, 3D-shaped, or kinematic elements, that provide different states of shade and visibility in the facade from opaque closing over partial shading to fully transparency. The multi-layered collector and evaporator element provides a minimal weight per unit area of only approx. 1 kg/m$^2$ in a dry state and approx. 5 kg/m$^2$ in a water-saturated state, allowing it to be retrofitted to most conventional facade systems.

Further development of the *HydroSKIN* leads to a completely textile and film-based, multi-functional facade system [14]. In combination with an automated control and regulation strategy, the use of adaptive *HydroSKIN* facades can significantly improve indoor conditions and user comfort while reducing the consumption of water, materials, and energy at the same time [15].

Conventional high-rise buildings are characterized by a significant consumption of material and energy as well as high emission values, offering at best only marginal qualities for urban climate resilience. As Fazlur Khan once pointed out by his expression "Premium for height," the material consumption, as well as the embedded amount of "gray" energy bound up in the building, increases disproportionally with the building height due to the rising wind loads acting on the building facade [16]. On the other side, benefits result from the implementation of the *HydroSKIN* facades on high-rise buildings, as the first prototype facades at the D1244 building in Stuttgart demonstrate.

The facade surface of tall buildings such as skyscrapers offers not only a much larger absorption surface than its horizontal roof or ground surface. Simulations show, that above a building height of approx. 30 m, the amount of wind-driven rain yields per square meter facade surface is even greater than the amount of vertically falling precipitation per square meter on horizontal roof or ground surfaces. With the building height, wind speed rises, thus causing a stronger horizontal deflection of the precipitation drops and increasing wind-driven rain yields hitting the building facade [7]. During hot days, such wind velocities cause higher evaporation of water and enhance the cooling performance. Considering this potential of vertical retention and evaporation surfaces as a new "benefit for height" we wish for a new era of climate-adaptive and climate-resilient high-rise buildings (**Figure 6**).

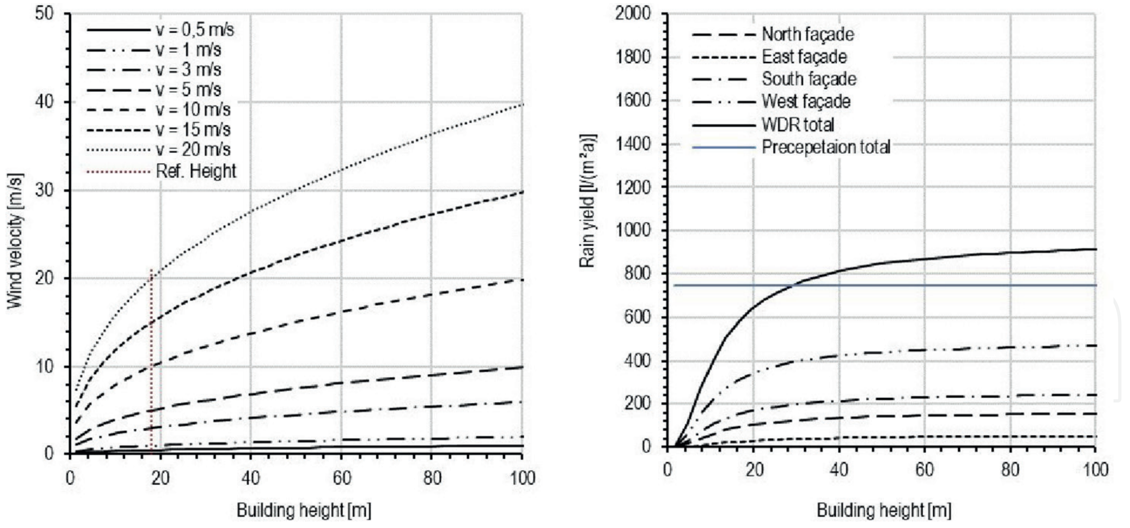

**Figure 6.**
*Increase of wind speed (left) and wind-driven rainwater yields per square meter in comparison to vertically falling precipitation per square meter (right) with the building height [7].*

## 3. FiberSKIN

### 3.1 Concept

The idea behind the design of *FiberSKIN* is a moving screen on the ground floor that allows for a smooth transition from the interior space, where the hydraulic structural system of D1244 is showcased, to the surrounding platform area, where events and various activities take place. An interdisciplinary team of architects, structural engineers, and mechanical engineers came up with a customized veil-like screen made of lightweight and fully recyclable glass and basalt fibers [17]. The project was also a methodological test to validate early interdisciplinary collaborations in the field of adaptive facades [18]. The tight link to the panel manufacturers allowed for a highly customized solution, especially in the definition of the fiber pattern. The developed solution has a wide range of potential applications where no thermal insulation is required and lightweight and movable panels are required.

Featuring the integration of lightweight textiles and a double-sliding mechanism, *FiberSKIN* blends the conventional notions of curtain wall and curtain (see **Figures 7** and **8**): it prevents water penetration into the interior and regulates light transmission while generating special visual effects. The fiber panels cover three sides of the ground floor: two fixed panels clad on the southwest and northeast sides and two layers of movable panels clad on the southeast side. During the opening sequence, the permeability of the screen varies, creating an extraordinary spatial experience as the overlapping patterns of the two sliding panels constantly change. When closed, the panels overlap to provide a semitransparent screen; when fully open, the interior space is visually linked to the outdoors.

### 3.2 Panel design

The design is based on a geometric pattern radiating from intentionally placed clamping points. The number of clamping points differs depending on the function of the panels: the two 5.2 m wide movable panels are clamped with 17 nodes along the horizontal edge to glide smoothly along the curved corners, while the 6.6 m long

**Figure 7.**
*View of FiberSKIN at the south corner of D1244 © M. Jeong/ILEK.*

**Figure 8.**
*View through the SW fixed panel from inside D1244 © M. Jeong/ILEK.*

fixed panels only need 10 nodes to withstand wind forces (see **Figure 9**). In order to achieve a consistent pattern across all sides, a geometric rule is applied. This rule affects the pattern parametrically in response to variations in distance between nodes.

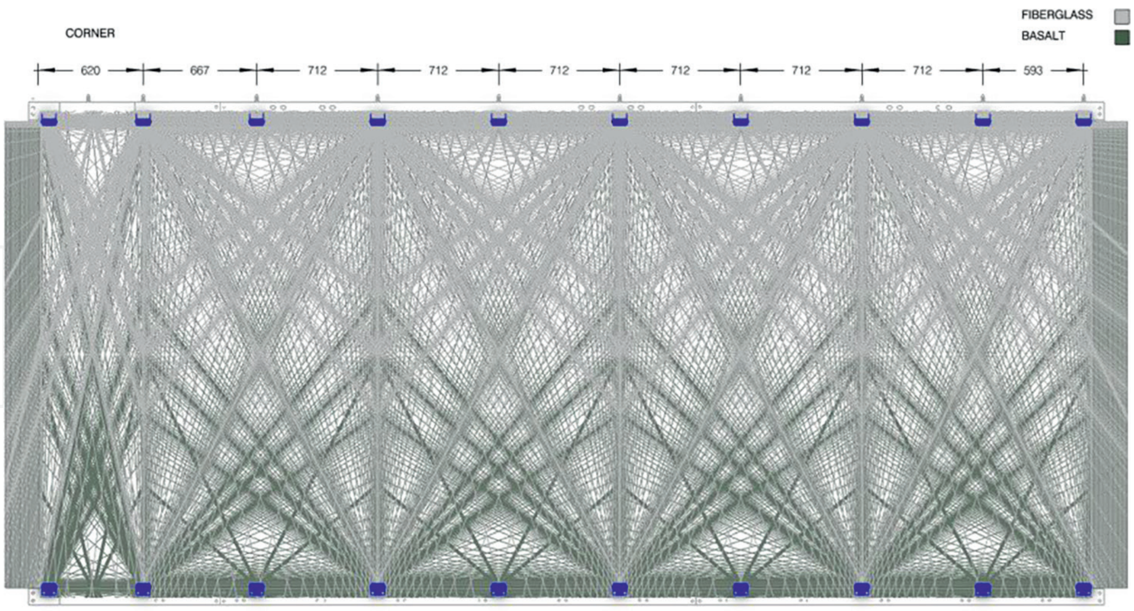

**Figure 9.**
*Drawing for fixed panels and clamping pockets © M. Jeong/ILEK.*

The resulting pattern design leads to an extraordinary spatial experience indoors and outdoors based on the way the shadows are cast and the angle at which they are cast.

A color scheme inspired by the constituent materials of the fibers (basalt and glass) has been laid out to enhance the metaphorical level of the design. In the fixed panel both materials are laid together by engaging the i-Mesh fiber placement technology: the basalt fibers are concentrated in the bottom part and generate a metaphorical and optical link to the ground and the earth, given their volcanic origin. Meanwhile, glass fibers placed primarily at the top of the panel transmit considerably more light and are used to create a link to the sky. In the moving panel, the two material constituents are made visible in a different way since the two panels overlap in the closed position: the front panel is made entirely out of glass fibers and the back panel is made entirely out of basalt fibers.

### 3.3 Kinetic concept and mechanical implementation

The task for the kinetic concept was to arrange a semitransparent facade with a weather protection function, to be flexible enough to allow the interior to be fully opened for events. To meet these requirements, various methods were applied in an interdisciplinary manner between architects and mechanical engineers to find a variety of innovative solutions. With the help of brainwriting and the gallery method [19], more than 20 different opening concepts were developed within a very short period of time, which on the one hand were reminiscent of familiar openings such as theater curtains, but on the other hand also exhibited quite complex and organic movement patterns.

The concepts generated were then evaluated and selected based on various factors such as visual appearance and ease of implementation. The result was a concept in which two layers of textile move in front of each other, and the irregular distribution of fibers creates a superimposed interference effect. This also plays with the visibility of the building's interior technology, as some sections are more transparent than others, as well as with the incident light.

To implement the mechanical structure, some reference applications were studied at the beginning. For example, sailboats, garage doors, or conveyor systems in mechanical engineering have similar properties to those required for this facade. In order to gain an insight into the design and construction as well as the special features, manufacturers of each of these products were contacted and expert opinions on the transferability of this facade system were obtained. In the course of this exchange, industrial partners were also acquired to support the implementation of the adaptive facade with knowledge and technical components.

In the end, the mechanical system was inspired by the side sectional garage doors from Hörmann KG. These move in a similar way on the horizontal plane and their guide system was therefore a good reference. In addition, the thematic proximity to the construction industry was another advantage. The CAD model for the substructure of FiberSKIN is depicted in **Figure 10**. One major challenge in designing the facade was the transition from tolerances between the structure of the building (some cm) to the facade (a few mm). In order to achieve this, two specially designed support structures were integrated into the design. The first one is shown in **Figure 10** in the right upper corner. The sheet-metal design was selected as it meets the requirements for lightweight design and a high degree of design freedom. Here, another industry partner (TRUMPF Werkzeugmaschinen SE + Co. KG) was supporting to proper design of the brackets.

On the lower side of the facade, a classic L-profile was used, in which sufficient adjustment possibilities were provided by means of elongated holes in order to meet the small tolerances of the adaptive facade. As a measure to compensate for further tolerances and, in particular, to pre-tension the textile, a variety of roller carriers with corresponding compression springs were installed (see **Figure 10**, middle detail picture). These springs allow continuous adjustment of the pre-tensioning of the facade and are at the same time reliable even under high wind loads on the textile since they cannot overstretch in contrast to tension springs.

These combined measures jointly made it possible to meet a tolerance of approx. 2 mm over the entire width of 6 meters. Corresponding laboratory tests confirmed the design through endurance tests in which the facade underwent over 20,000 cycles.

The kinetic movement of the adaptive facade can be seen in the **Video 1**, https://bit.ly/46n1DgX.

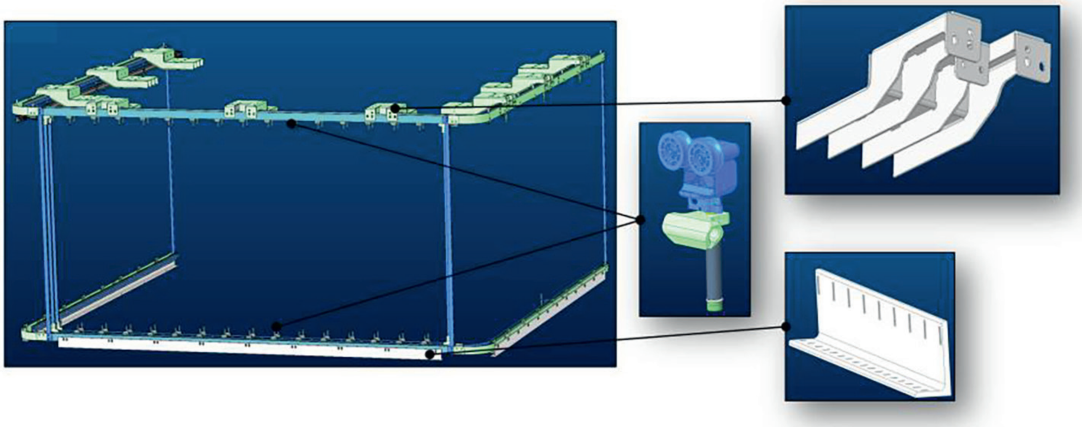

**Figure 10.**
*CAD model of the mechanical substructure of FiberSKIN © M. Voigt/IKTD.*

### 3.4 Details embedded in manufacture

In order to keep the engineering effort and the costs for the prototype as low as possible, while maintaining a high degree of design freedom, suitable reference applications were selected. The advantage here is that a large number of components have already been designed for similar use cases, which can only be slightly adapted and transferred for our prototype. A high degree of design freedom was otherwise allowed by the customized pattern design or by bespoke detailing. The focus was set on the clamps and on the large brackets that hold the facade. The clamps, which were placed regularly along the facade, served as an interface between the mechanical and architectural components. These are an integral part of the kinetic mechanism and fix the textile through special keder connections (see nodes blue marked in **Figure 9**).

The interdisciplinary and integrated design process of the clamps can be visualized based on their development. As these form the interface between the architectural part and the mechanical engineering part, they were subject to the most iterations. **Figure 11** visualizes the different development stages. It can be seen, that the design process started with a very rudimentary functional oriented CAD model of the assembly (**Figure 11**, Gen. (1). After the first discussions the improvements in the clamp design were mostly linked to lightweight design but also included some first shape finding aspects. Afterward, the shape was significantly improved in the third generation. Further improvements integrating new functionalities (Gen. 4 and 5, further connection possibilities were added) led finally to the stage where the clamps were integrated in the whole assembly back again. Generation 6 shows the detailed and final manufacturing version of the assembly including the clamps. This assembly was then used to frame and pre-tension the mesh. Therefore, on each of the blue-marked connection points in **Figure 9**, one of the clamp assemblies was mounted. Together with the mesh, this forms the two movable panels of the adaptive FiberSKIN facade.

## 4. MagneticSKIN

A user-centric approach in facade design involves placing the needs, preferences, and experiences of building occupants and users at the forefront of the design process. It emphasizes creating facades that not only fulfill functional requirements

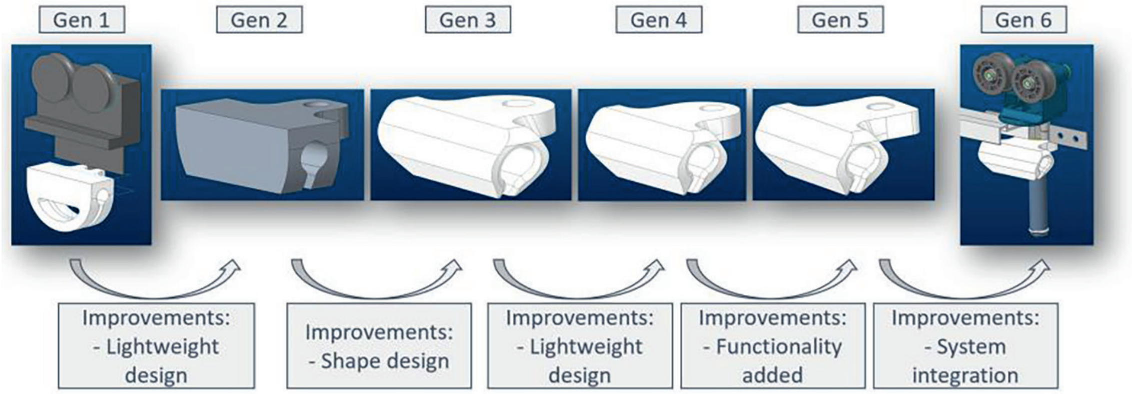

**Figure 11.**
*Design process of the keder clamp–optimizing shape, weight, and functionality © M. Voigt/IKTD.*

but also enhance the well-being, comfort, and overall satisfaction of the people who interact with the building skin.

### 4.1 Concept

*MagneticSKIN* is a pioneering interactive facade system designed to respond dynamically to human touch (see **Figure 12**). By exploring non-verbal ways of communication through haptic interaction, this approach aims to create a harmonious interplay between architectural esthetics and human experience. The ground level of D1244 is ideal for this purpose since it offers direct and convenient accessibility for individuals to engage with both the external and internal layers of the system.

In contemporary architectural practices, there is a growing emphasis on the ability to tailor specific properties of building envelopes to enhance comfort and overall space usability [20]. This focus primarily revolves around meeting physiological needs and individual preferences. However, the exploration of psychological needs and the broader activation of human senses remains largely uncharted territory. The proposed system delves into the significance of bridging this gap and investigates the potential benefits of integrating sensory stimuli to create more engaging and immersive built environments.

“Touch is the sensory mode that integrates our experience of the world with that of ourselves” according to Juhani Pallasmaa [21]. By considering touch and other sensory experiences during the design process, architects can enhance the emotional connection people have with their surroundings, leading to more memorable and enjoyable spaces [22]. The overall aim is to create a system that places the user at the core of the design process and to start understanding how haptic experiences influence perception, emotions, and behavior.

The interaction system follows the principles of system dynamics comprising of a set of sensors and actuators interconnected through a microcontroller and a specific

**Figure 12.**
*Live interaction with the MagneticSKIN facade during the CRC 1244 symposium in May 2023 © U. Regenscheit.*

set of rules or code. This design allows the system's behavior to be dynamically shaped by continuous interaction with users.

### 4.2 Pattern design

The arrangement of the round permanent magnets on the membrane surface follows a deliberate pattern inspired by the key trigger points found in an average-sized human hand. The abstract representation of these points results in a group of eight magnets. There is a total of five variations of this group, out of which the overall semi-regular clustered pattern is created by organically arranging them across the canvas (see **Figure 13**).

Each group of eight magnets corresponds to an electromagnet and sensor, working together to form what is referred to as an "active module." In addition to the active modules, there are "passive modules" composed of either individual permanent magnets or groups of magnets, to which no actuator is assigned. The role of these passive modules is to harmoniously integrate the pattern, especially in areas not easily reachable by hand for users interacting with the facade.

### 4.3 Detailing

The structural system consists of a wooden frame placed on adjustable steel posts for water protection and supported at the top by steel brackets (see **Figure 10**). By employing exclusively bolt/screw connections, the entire system can be easily disassembled, making it highly reusable and recyclable. The same principle applies to both inner and outer lightweight textile layers, which cover up the substructure, as well as to all components of the interaction system.

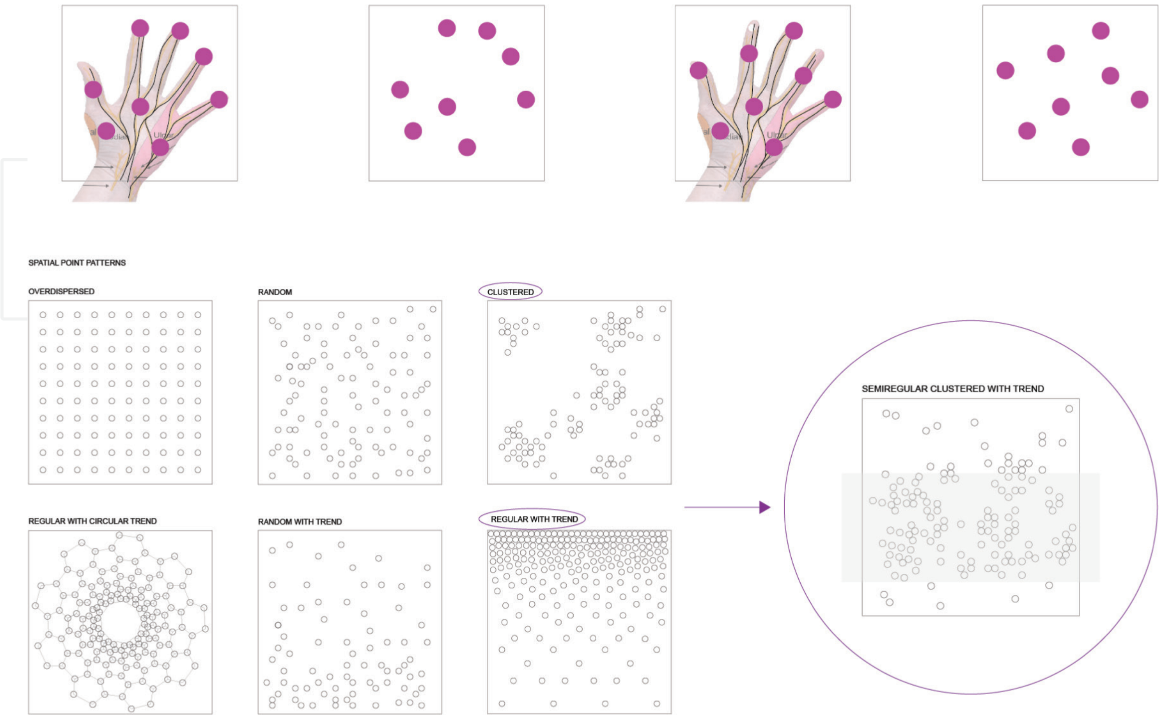

**Figure 13.**
*Pattern creation based on trigger points inside a human hand combined with spatial point arrangements © A. Cazan/ILEK.*

To achieve a sleek, canvas-like appearance, an aluminum tendering frame from Roho is utilized to secure and prestress the outer membrane also around the corners. This frame is raised 8 cm above the ground, creating a hovering effect that gives the illusion of the facade smoothly floating above the concrete platform.

The outer membrane protects the inside space and the electrical components. It consists of a silver PVC-coated PES membrane onto which round permanent neodymium magnets are positioned: these measure 15 mm in diameter and 2–3 mm in thickness. By placing one magnet on the inside and one on the outside of the membrane, the connection is made solely by the electromagnetic field, making a later dismantling, reuse, and even repositioning of magnets extremely simple.

On the inside of the facade system, there is an additional layer made of highly flexible elastane with iridescent visual properties, onto which round permanent magnets with the same 15 mm diameter but only half the thickness (1, 5 mm) are placed (see **Figure 14**).

This configuration allows for a dynamic interaction between the inner and outer layers, enhancing the overall sensory experience and interaction. While the outer membrane was completed in May 2023, a mock-up of the inner layer has been temporarily installed. It offers visitors a chance to experience the different haptic qualities and to test interaction scenarios between inside and outside space.

### 4.4 System dynamics

By touching the inner or outer side of the facade, users push that specific area of the textile back toward the core of the system, thus triggering an interaction. This inward movement is continuously monitored by ultrasonic sensors, which measure the distance to the default state of the membrane. The sensors then transmit this information to the Arduino microcontroller, which processes the data and sends corresponding commands to the appropriate actuators (**Figure 15**). For each sensor in the system, there is an associated actuator, which is turned on only when the predefined conditions stipulated in the Arduino code are being met. Distance and time are the defining parameters in reaching the desired effect. By experimenting with the time intervals between activations, changes in polarity, and the natural vibration frequency of the membrane, different pulsation rhythms can be achieved.

**Figure 14.**
*Prototype of the inner layer of MagneticSKIN © U. Regenscheit.*

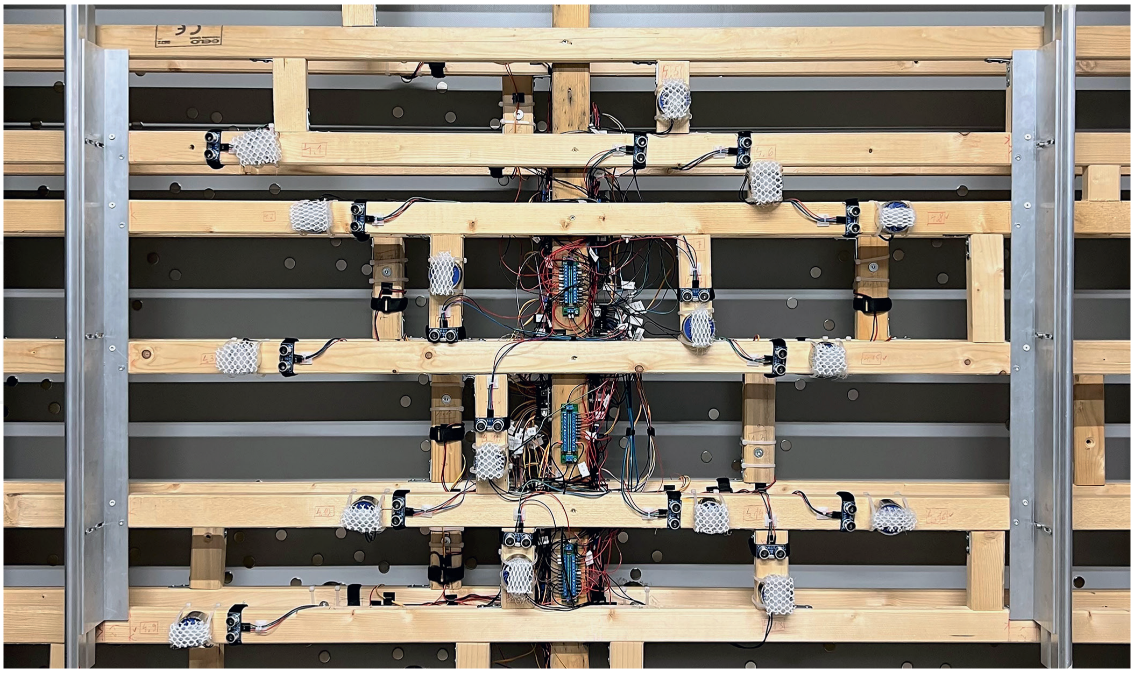

**Figure 15.**
*Part of the interaction system seen from the inside © A. Cazan/ILEK.*

The name *MagneticSKIN* derives from the use of electromagnetic properties to activate the double-layer textile skin. 24 V powered electromagnets, each capable of generating an attraction force of 800 N, are being used as actuators. By placing permanent magnets on the membrane, the electromagnets behind the membrane are able to attract and repel the latter at predefined time intervals, thereby creating a puls-like sensation on the surface. The intensity of the effect directly correlates with the number of activation points perceived by the ultrasonic sensors and the depth of the inward movement. The greater the number of active points, the more intense the overall effect, which can be seen and (more importantly) also be felt by the users interacting with it. Thus, a new form of non-verbal haptic communication is made possible, connecting users with the outer layer of the built environment and fostering interaction and communication among the users themselves.

### 4.5 Output and future perspectives

The feedback from the users who have interacted with the system since May 2023 has been overwhelmingly positive, with many describing a puls-like sensation similar to a heartbeat and expressing a willingness to engage with it, thus confirming the relevance of the interaction with building skins and the perception of the built environment. By having had the opportunity to observe the system in use, it can be stated that incorporating interactive elements in the facade design encourages user engagement and instills a sense of ownership over the building.

Embracing interactive technologies and haptic qualities of materials could give architects the opportunity to create immersive experiences, where architecture transcends its traditional role and becomes a dynamic medium for human interaction and sensory perception. Moreover, the research on *MagneticSKIN* and its successful implementation serves as a significant step forward in understanding the potential of haptic communication in architecture, paving the way for the creation of more immersive and user-oriented built environments in the future.

## 5. Outlook

The three facade systems described in the present article show the high range of functionalities that can be achieved by using textile skin systems in new ways. Due to their lightweight and flexibility, it is easy to move and deform such panels. Thus, they can easily be adapted to different architectural purposes. Moreover, extended production ranges (as shown e.g. at the multi-layered 3D-textile for *HydroSKIN* or the customized non-woven planar mesh for *FiberSKIN*) allow for new fields of application to be explored. This fits very well in the attempt to design innovative adaptive systems, that react to different conditions in a dynamic and effective way. Modern textile skins can be also designed and built in such a way that each component has a low carbon footprint and is fully recyclable. Moreover, the experimental interdisciplinary setup of the CRC 1244 allows not only to explore the potential of new systems, geometries, and functions but also to validate experimentally the developed solutions in a real-world condition and showcase the quality of the application in full scale. Currently, the first applications clad two floors of D1244 (out of 12). Additional cladding systems are to be built in the coming months. One of the next textile facade systems is called *KineticSKIN* and will be installed on the second level of the building (see **Figure 16**).

In general, adaptive kinetic facades are designed to respond in real-time to changing environmental conditions and indoor comfort requirements by means of kinetic mechanisms that allow them to dynamically adjust their form, position, or transparency. Such facade systems can allow for proper shading and enhance occupant comfort while improving energy efficiency [23, 24].

The objective of this research is the optimization of indoor daylighting conditions and the reduction of solar heat gain as well as unwanted solar radiation in the urban canyon [25]. Excess solar radiation is reflected into the atmosphere, reducing the urban heat island effect. This is performed by reorienting the wings (facade modules) in response to changing weather conditions. The upper wing tracks the sun and reflects solar radiation to its source, thereby reducing undesired solar heat gain

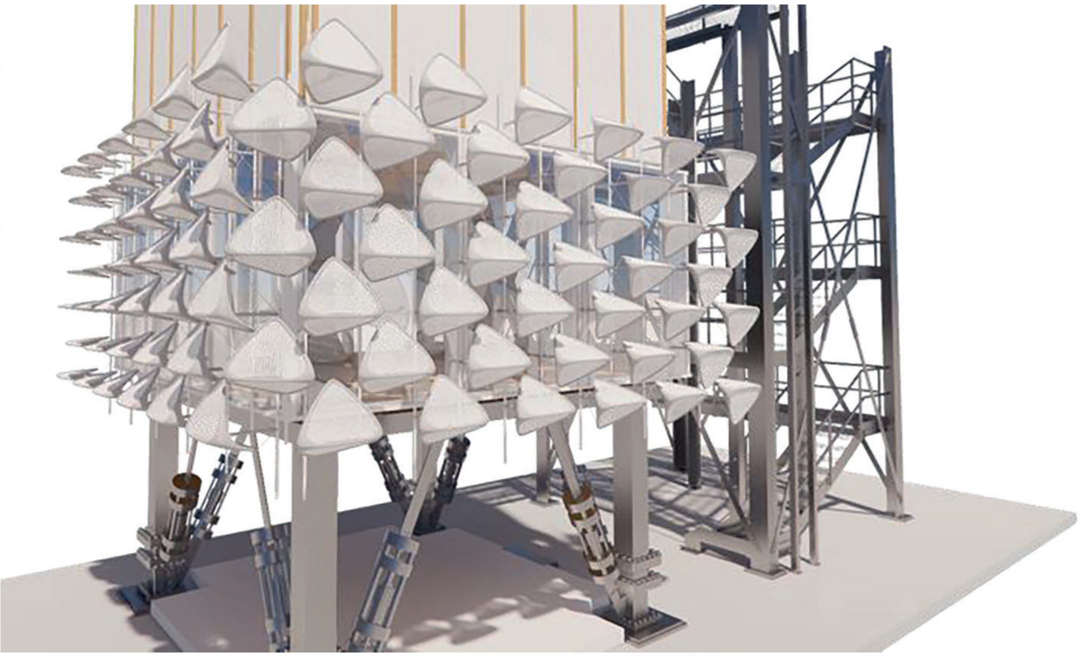

**Figure 16.**
*Rendering of KineticSKIN to be installed at the D1244. © M. Jeong/ILEK.*

and reducing building energy consumption. At the same time, the lower wing serves users' visual comfort (illuminance and view).

A small number of actuators were employed to prevent adding weight to the facade and to keep energy usage low. During the hot summer months, the facade can minimize solar heat gain by shading the windows, thus reducing the demand for air-conditioning. In winter, it can allow sunlight to naturally warm up the interior, minimizing the need for heating. The system is designed to optimize natural daylight penetration into a building's interior so that artificial lighting needs are reduced. Moreover, it enhances comfort by regulating indoor temperatures and reducing glare.

PAOSS represents another approach of a targeted, kinetic sun and glare protection system using a simple, resilient, and low-energy actuation mechanism. The pneumatically operated origami sun shading system-abbreviated "PAOSS"—is used for the targeted control of light transmission. It combines the esthetic and material-immanent qualities of textile materials with the functional aspects of integrated active pneumatic actuators to initiate the change of shape e.g. to open the elements (**Figure 17**). Textile folding structures are particularly suitable for changing their shape from a large shading area to a minimal folded state and vice versa by reversible folding. They are therefore highly interesting as selective sun and glare protection elements for improving user comfort and reducing energy consumption. The National Aeronautics and Space Administration (NASA) has developed an origami folding geometry for astrophysical purposes called "Starshade" [26], which is characterized by a particularly large difference in area between the opened and folded closed state. An adaptive, pneumatically actuated sun and glare protection system inspired by "Starshade" was designed and developed to be embedded as an interlayer in ETFE cushion facades. Through the use of active components, it is possible to achieve a targeted, partial, or full-surface regulation of light and radiation transmission, as well as the back-reflection properties of the facade [27]. The ETFE facade is planned to be installed on the eleventh floor of D1244.

Within three to four years all 12 floors of D1244 will be clad with different adaptive facade systems. One of the focuses will be set on insulated glass units, integrating further functions such as cooling, energy harvesting and storage, etc. As soon as all the facades are installed, the next cycle will start, thus establishing for the D1244 the experimental character of a laboratory at a real scale.

**Figure 17.**
*Visualization of PAOSS in un-activated closed state (right), targeted partial glare protection state (middle), and full-surface shading state (left) © C. Eisenbarth/ILEK.*

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## Video materials

Video materials referenced in this chapter can be downloaded at: https://bit.ly/46n1DgX

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