The “Fassadenladen” (Facade Shutter)—A New Interpretation of the Window Shutter, with Biogenic Materials

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Abstract: As part of a collaborative project, we took the window shutter—a widely used traditional facade element—and reinterpreted it for “adaptive” solutions using new, sustainable technologies. The aim was to design a modular construction kit that varies radiant energy, light and air flow to weather conditions and occupant requirements in new and existing residential and office buildings.

Key words: Facades, sun protection, use of daylight, biogenic materials, residential and office buildings.

1. Introduction

We introduced the term “Fassadenladen” (facade shutter) to describe the versatile use in the building skin. The device “Fassadenladen” with many variations has much in common with a traditional shutter, which is mounted on a building’s exterior, movable and resistant to the elements. But to control light a very different concept is used in comparison to common louvers. The shape and arrangement of the elements/slats to cover the window/facade follow other principles of operation with an advanced performance and quite different appearance. These include protection from the sun, daylight transmission, visual contact with the outside environment and ventilation. To meet the varying demands from the floor to the ceiling the device provides adapted zones in addition.

The most characteristic element and feature of the “Fassadenladen” is an optimized fin made from an extruded renewable biopolymer. Unlike wood-based materials, plastic material can be industrially manufactured for more complex shaping and sophisticated translucency. The latter enhances a regulated transmission of daylight that common wooden or aluminium shutters lack. The thermal bioplastics used for our facade shutters contain a high proportion of renewable raw materials, selected for properties such as transmission, reflection, absorption and emission.

The design of these sophisticated slats follows the archetype of a natural leaf transformed into a long plastic fin with a significant core and thin blades on both sides. These kinds of translucent leaves assembled in the “Fassadenladen” can provide shading familiar to the shade of a tree in bright sunlight, for many people a delightful atmospheric experience.

2. The Collaborative Project

Facades represent a crucial interface between exteriors and interiors. They are responsible for a building’s energy balance and comfort and do much to determine its appearance. Adaptive structures on
facades are important for creating sustainable and efficient houses [1]. For years now, the construction sector has been looking for sustainable and more recyclable alternatives to conventional materials that reduce the consumption of materials and energy.

“FabioW” is a collaborative project that, in addition to developing novel biopolymer materials, has reinterpreted the traditional window shutter. Mounted on a building’s exterior, the “Fassadenladen” (facade shutter) provides the efficient delivery of various functions, especially those in a building’s vertical zone. These include protection from the sun, daylight transmission, visual contact with the outside environment and ventilation.

For its contribution to the project, the Nuremberg Institute of Technology, besides providing scientific supervision and general coordination, developed principles for the design and configuration of the shutter’s slats and for the construction and testing of working assemblies. The principles are meant to enable functional flexibility in new and existing residential and office buildings. The team at the Nuremberg Institute of Technology relied on computer simulations and a test bench to assess the shutter designs [2].

3. Developing the Design

For the development of the new facade shutter, we took inspiration from shōji (Japanese sliding panels made of rice paper) and semi-sheer drapes (Fig. 1) as well as from nature such as leaf canopies (Fig. 2). In all the examples, multi-layered structures provide varying degrees of transparency, producing a play of light and shadow. Such effects can also be produced using semi-transparent biopolymers, as the overlapping sheets in Fig. 3 show. Some biopolymer samples between 0.5 and 2 mm thick appear

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1 Fassadenladen—Hochtechnologie mit biogenen Werkstoffen—Ein universeller Baukasten als Neuinterpretation des Fensterladens (FabioW). Project duration: 02/2016 to 07/2018. Partners: Nuremberg Institute of Technology, Faculty of Architecture (project direction), Faculty of Civil Engineering, Faculty of Business Administration and the Institute for Energy and Buildings (IEG), University of Erlangen-Nuremberg, Institute of Polymer Technology (LKT), Fraunhofer Institute for Building Physics IBP (Holzkirchen), TECNARO GmbH, Joma-Polytec GmbH, and ROMA KG. Funding: BMEL—Federal Ministry of Food and Agriculture, Berlin, via FNR (Fachagentur Nachwachsende Rohstoffe e. V., Gülzow-Prüzen).
translucent in backlight but opaque under normal lighting conditions. The semi-transparency of the material, allowing the transmission of daylight, was a key feature of the “Fassadenladen” design. The other main criterion of the material was formability in extrusion.

In stark contrast to conventional, purely functional products providing shade, our “Fassadenladen” has been modelled on antecedents in nature. Our design uses multi-layered structures and alternating degrees of translucency that lets in daylight while casting pleasing shadows and improving the quality of interior space.

The transparency of biogenic polymers can be controlled via the thickness of the material. This allows our “Fassadenladen” to deliver privacy and glare protection without darkening the room and requiring artificial light, as is the case with roller shutters, Venetian blinds and other conventional systems. In addition, the “Fassadenladen” ensures a constant relationship to the outside environment so that occupants can always surmise the time and weather. The qualities of the translucency of the material are particularly evident when daylight is important. The “Fassadenladen’s” properties open up enormous creative potential and produce beautiful atmospheric effects.

Because the quantity of materials, extrusion dies and time available to us in the development phase was limited, we worked to identify a general design that could later be trimmed and varied over the course of further experimentation. As per the product’s design concept, the effect in different light conditions had to be distinguishable from existing materials such as extruded plastic and cold-forged metal.

3.1 Geometry

While trying out many different variants in determining the geometry, we arrived at a slat design with a static core consisting of a hollow, rhombic section (Figs. 4 and 5). The fins attached to the rhombus are kept as thin as possible so that some of the incident sunlight can pass through the semi-translucent material and make better use of daylight. The thinner the biopolymer is, the greater its translucency is. The thickness of the fins was designed so that the overall transmittance reduces thermal energy while allowing a pleasant amount of daylight to enter the building’s interior.

The surface of the fins is interrupted by a small variation in the material thickness (Fig. 6). This creates different degrees of translucency, while the slightly elevated section serves as an edge, which helps reduce width. The slats can be arranged horizontally and

Fig. 4 Sketches of the “Fassadenladen” design.

Fig. 5 Prototype studies.

Sources: Peter Bonfig.
Fig. 6 Backlit 3D-printed slat pattern R 1.2.3 in a two-layer configuration. Source: THN-AR.

vertically. But horizontal configurations, in which the surface of the fins are vertical, can better serve functions in a building’s vertical zone through different spacings and overlaps (Fig. 7).

The slat geometry takes into account functional requirements (weather resistance and the avoidance of standing water) and engineering requirements (x-axis resilience to horizontal stress). Each main axis possesses different response properties that compensate for deformations due to weight and creep.

We sought to create a lively nuanced appearance through highlights and shadows. We also used thin materials (between 0.5 mm and 3 mm) that can transmit daylight [3]. We initially planned to construct the frame, ribs and bars as well, but during our experiments we decided to concentrate on the extrusion of the slats and the regulation of their translucency. The remaining parts will be manufactured using other materials, preferably those with a high share of renewables. Metals are useful for elements exposed to high levels of stress and strain.

The slat shape we selected (R 1.2.3, 100 × 32 mm; Fig. 6) has a hollow diamond-shaped core (32 × 24 mm) with a slight longitudinal extension in the x-axis. The front sides of the core have a concave groove that modulates the surface while offering a possible attachment location for, say, countersunk screws. The two fins (each 37 mm long) are asymmetrical. One side has a two-step taper from 3 mm to 0.5 mm; the other side is smooth and at a right angle to the transverse axis of the slat. This enables different options for attaching the slat via the fin.

| vertical functional zones | radiation | ventilation (by thermal effects) |
|--------------------------|-----------|---------------------------------|
| top zone                 | transmission and redirection of daylight | exhaust air |
| field of vision          | transmission of daylight, glare protection, sun shading views, privacy provisions | neutral zone |
| parapet                  | sun shading, privacy provisions | air intake |

Fig. 7 Facade zones. Source: Peter Bonfig.
4. Slat Configuration

We took into account numerous factors when deciding how to arrange the slats along the surface of a building: facade zones, occupants’ field of vision, angles of light when the sun is the highest, and other aspects. Depending on its dimensions, the facade opening can be divided into multiple functional zones (Fig. 7), whose proportions can vary. Some are equally distributed; others place greater emphasis on the field of vision.

For windows up to approximately 1 meter in height, the parapet area (lower zone) may require privacy. In this zone, glare protection and the supply of daylight are of secondary importance. This is followed by the occupants’ field of vision (middle zone). The main focus here is on view, glare protection and privacy. The top zone represents the skylight. Its main requirements are the transmission of daylight and glare avoidance; privacy is secondary.

In a series of preliminary studies [4], we examined the well-known properties and possible uses of rigid and movable slats (in horizontal and vertical positions) (Fig. 8). The mechanism we used was completely

![Fig. 8 Studies on the horizontal configuration and superimposition of opaque and translucent slats. Source: Peter Bonfig.](image)

![Fig. 9 Design for a sliding, ceiling-to-floor “Fassadenladen” (no scale). Source: Peter Bonfig.](image)
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The “Fassadenladen” (Facade Shutter) is a new interpretation of the window shutter with biogenic materials. It is different from those of conventional products providing protection from the sun. The slats, which combine to form surface elements, have similarities with translucent leaves and gathered curtains. Like traditional shutters, the “Fassadenladen” is mounted on the building exterior for maximum sun protection, views and ventilation. But unlike latticed shutters or exterior curtains, our shutter can also withstand high wind speeds.

Using working models on a scale of 1:1, we optimized the performance and appearance of the design. In the process, we observed that overlapping slats arranged horizontally provide good weather protection and sun protection when the sun is high in the sky. When the sun is low, however, horizontal lats must remain mostly closed if they are to keep out glare, which greatly limits visibility and daylight. Translucent materials can mitigate or eliminate the last problem. This speaks for our use of a thin material that transmits light.

We tested 3 versions of the “Fassadenladen” for performance characteristics (Figs. 9 and 10). Preliminary studies showed that the slats are best placed in two layers (one in front of the other) to exploit the full potential of the horizontal configuration (Figs. 11 and 12). We also experimented with a single-layer arrangement. The working models were designed to fulfill a variety of needs: from energy reduction to design to privacy.

4.1 Sun Protection

Because the primary function of the facade shutter is sun protection, it competes with conventional products such as Venetian blinds. To stand out, the
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Facade shutter must place a premium on thermal insulation in the summers. The arrangement of the slats with respect to one another is based on the positions of the sun, depending on whether the “Fassadenladen” is on the building’s south, east or west side. The primary goal is to provide shade when the sun is the highest during the spring (March 21-June 21). On the south facade, the elevation angle ranges from 42 to 63 degrees, while on the east and west sides the shutters must contend with far lower positions of the sun. At these angles, sunlight cannot reach the interior of the building because of the wall jamb and the frame of the “Fassadenladen”. Accordingly, we created a design that can provide 80 degrees of sun protection on east- and west-facing facades.

4.2 Privacy and Glare Protection

The need for privacy and short-term glare protection led us to use a two-layer configuration of the slats (Fig. 6) that completely covers the opening. For these requirements, the inside slats must be positioned between the gaps separating those in the outer layer, eliminating visual relationship between interior and exterior, though unlike conventional products the translucency of the biogenic material allows daylight to pass through (Fig. 13). This configuration provides particularly effective glare protection when the sun is low (i.e. in the mornings for east-facing facades and in the afternoons for west-facing facades).

4.3 Outlook

Our project features an externally mounted facade system that provides complex and also balanced performance for protection from the sun, use of daylight, outside viewing and natural ventilation. The advantages and possibilities of shutters are combined with an innovative approach using other principles and materials with a different appearance opposite to widely used blinds. There is not only a huge market volume for such advanced shading products but the “Fassadenladen” gives occupants a new sensual experience.

5. Building Interfaces

The “Fassadenladen” can be used like traditional shutters or similar products consisting of flat, window- or facade-covering elements that slide, flap or fold in various directions and attach/integrate in different ways. With externally mounted sun protection systems, the movements often combine different principles. In determining the building interfaces and the construction of working models, we took a closer look at a horizontally sliding “Fassadenladen” (Fig. 9).

The position of the shutter vis-à-vis the opening depends on the type and direction of its movement. Typically, the “Fassadenladen” is placed to the left or right of the opening and comes in one or more parts.
Alternatively, configurations with a vertical sliding shutter or a folding shutter rotating around the horizontal axis can be mounted above or below the opening. The “Fassadenladen” can be controlled manually or mechanically with an automatic drive, depending on the needs of the occupants. On account of the shutter’s low weight, it is possible to adjust multiple sets of shutters at once.

Following the principle that the “Fassadenladen” should be deployable in various scenarios, we designed a universal construction kit that is more open to the outside than other systems. It also has two sets of shutters, each with a single layer of slats, which together can overlap and perform other complex tasks. Placing a second layer of vertically sliding slats in the field of vision enables fine adjustments to light transmission, i.e. the incidence of light, the visual relationship with the exterior world and what people see from the outside looking in. The sliding movement allows occupants to regulate the gaps between the slats linearly and create effective ventilation behind the shutter (Figs. 11 and 12).

The possibility of resizing the shutters shapes the appearance of the installation. The horizontally movable facade shutter is a single component whose dimensions correspond to those of the opening it covers. Hence, sufficient areas for resizing must be taken into account to the left or right of the openings. To reduce these areas, creating a one-piece rotary shutter (around the vertical axis) is conceivable, as is a multi-piece folding sliding shutter in which the dimensions can be reduced by a factor of 2 to 4. Several arrangements are conceivable for placing the shutter at the boundary between the buildings’ conditioned and unconditioned environment. For effective sun protection, the “Fassadenladen” can generally be mounted on the exterior of building at a distance from the opening or as a boundary for the facade gap in the case of, say, maintenance walkways and pergolas. However, there is also the possibility of integrating the shutter with the window or at the facade level for building envelopes with two or more skins. Such integration provides an additional layer of weather resistance.

Studies of installation scenarios with Nuremberg facades made of different materials (brick, stone, wood and metal) showed our shutter’s high adaptability and structural compatibility. Given its largely neutral appearance in light, the “Fassadenladen” can be combined with different exterior colours, either harmonizing or contrasting with the surfaces. Moreover, supplemental renderings have produced very positive atmospheric effects on interiors. In the case of exterior openings at corners, different surface configurations are possible that accommodate the building’s orientation and the associated position of the sun. Vertical (Fig. 14) and horizontal (Fig. 13) arrangements of the slats are particularly useful on the east and west sides and on the south side respectively.

The configuration, arrangement and kinematics of the “Fassadenladen”—with its opaque, translucent and transparent areas—must be continually developed for different building facades. The “Fassadenladen” offers many more solutions and configurations than, say, Venetian blinds or roller shutters.

### 6. Summary of Our Work So Far

The “Fassadenladen” is a new component made from renewable materials and designed to be mounted on building exteriors. The central parts of the shutter are extruded biopolymer slats whose shape has been optimized for surface coverage. To increase the amount of renewable materials in shutter, we tested frame structures consisting of biopolymers. The project’s work shows that bio-based sun protection systems represent a sustainable alternative to standard aluminium or PVC products. The project partners undertook a comprehensive battery of studies on performance (both of PLA and bio-PA-based materials) and the extrusion shapes that form the basis of the shutter design. The project employed two types of materials that produce a stable composite.
Nevertheless, the materials will have to be adapted to meet the properties required in other projects [3].

Through extensive variant studies we developed an innovative slat [5]. Using two different designs we created a refined form both regard to geometry and to the graduated thickness of the fins. We then evaluated its functional performance and aesthetic distinctiveness by constructing samples and working models on a scale of 1:1. Visual representations of various installation scenarios show that the shutter can easily adapt to different facades in terms of construction, material-specific parameters and atmospheric effects on interiors.

We carried out static preliminary measurements and studies on load assumptions, requirements and span widths. From them, we obtained good values for load transfer from external influences, especially wind. We also discovered that design modifications can limit deformations from temperature stresses to a tolerable level consistent with intended use. The tests resulted in viable cross-sections and dimensions for the parts in the working models (Figs. 15-17).

Through simulations, we could demonstrate that the “Fassadenladen” provides effective thermal insulation during summer while allowing in an abundant amount of daylight. These effects apply to adjoining rooms as well [6]. The shutter can also selectively utilise solar energy for heating and the amount of daylight it lets through reduces energy use for artificial lighting. When examining possible occupant impairment due to sunlight glare, we found that the translucency of the
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slats and the gaps between them can lead to disruptive glare. But an intelligent arrangement of the slats can avoid this problem. The results of the simulations were evaluated and verified using the test benches of the Fraunhofer Institute for Building Physics IBP (Holzkirchen) (in the laboratory and onsite). The measurements calculated from the simulation and the test bench results were in good agreement. The slight deviations that occurred are attributable to different and hard-to-ascertain external conditions.

We also carried out concept tests to measure the “Fassadenladen’s” market acceptance. Although the surveys consisted entirely of drawings and photographs, the findings indicate that consumers see the advantages of the facade shutter over conventional hardware store products, especially when it comes to sun protection and daylight use. However, further tests taking into account service life and costs will be needed to develop the working prototypes into a marketable product.

The “Fassadenladen” represents a new type of component for energy-efficient and sustainable building envelopes. In designing and building this product, the collaborative project also made an important contribution to the optimization of biogenic materials use. The partners intend to apply for funding to carry out a follow-up project.

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