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BOGUSŁAWA KONARZEWSKA, LUCYNA NYKA*

NEW SCOPES OF FACADES' DESIGN AS A RESULT OF THE APPLICATION OF OPTICAL FILTER TECHNOLOGIES

NOWE ZAKRESY KREOWANIA WIZERUNKU FASAD PRZY ZASTOSOWANIU TECHNOLOGII FILTRÓW OPTYCZNYCH

A b s t r a c t

Modern facades, whether made of glass or including transparent, translucent or reflective elements, let through a particular light spectrum or change its intensity in many different ways. "Filtering facades" may change the image seen through them or change the colour of passing light according to specific circumstances: the angle of observation or temperature. These indicated properties of facades acting as "filters" were made possible due to the great technological development observed in the last two to three decades, though the general characteristic of this phenomenon of *optical filters* had already been explored since the XVII century by Newton, and later on by Fresnel, Fraunhofer, Maxwell and Planck. Thanks to material engineering today it is possible to create unique glass facades with great functional properties, yet architects, engineers and artists do not stop at this point. The experiments undertaken in these fields explore transparency, reflection, refraction and diffusion and lead to fascinating effects that are worth examination.

Keywords: optical filters, glass facades, filtering façade

S t r e s z c z e n i e

Nawiązując do zasady działania filtru optycznego, współczesne fasady przeszklone oraz fasady zawierające elementy przezroczyste lub przeświecające przepuszczają określony wycinek widma optycznego ze światła o barwie złożonej lub zmieniają wartość natężenia przechodzącego przezeń światła na wiele różnych sposobów. Fasady „filtrujące" mogą przetwarzać obraz lub zmieniać barwę, na przykład zależnie od kąta patrzenia na nie czy zmiany temperatury. Wymienione właściwości fasad działających na zasadzie filtru optycznego osiągane są dzięki przyspieszonemu postępowi technologicznym ostatnich dekad, chociaż specyfika zjawisk optycznych badana była już od XVII wieku przez Newtona, a później Fresnela, Fraunhofera, Maxwella czy Plancka. Dziś chociaż dzięki inżynierii materiałowej możliwe stało się projektowanie wyjątkowych fasad przeszklonych o wyrafinowanych właściwościach funkcjonalnych, to architekci, technologowie i artyści nie zatrzymują się na tym. Eksperymenty podejmowane przy tworzeniu fasad filtrujących skierowane są na osiągnięcie zjawisk załamania, rozszczepienia, dyfrakcji, ugięcia czy interferencji światła, doprowadzając do niespotykanych, wartych przebadania efektów estetycznych.

Słowa kluczowe: filtr optyczny, fasady szklane, fasada filtrująca

* Ph.D. Arch. Bogusława Konarzewska, Assoc. Prof. D.Sc. Lucyna Nyka, Faculty of Architecture, Gdansk University of Technology.

1. Introduction

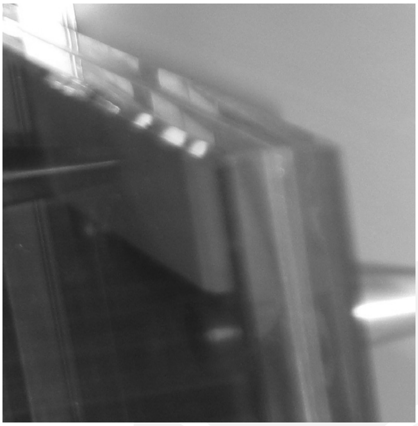
The spectacular evolution that glass and synthetic materials have undergone during recent decades has opened up new possibilities for the ~~creation~~ design of facades making use of filtering technologies. This is not the first time in history when architects are involved in developing such type of facades. The use of filtering building envelopes to let light into the building in a controllable manner, and "frame" the views thanks to different perforations or the semi-transparent materials, had already existed in the Middle Ages and was very popular in gothic and baroque as church stained-glass windows, translucent marble and alabaster. The numerous discoveries and inventions in material engineering together with advances in computer aided design and innovative prefabrication methods were all crucial phenomena that allowed for the creation of new types of filtering facades.

As a direct result of that historical development, the new generation of filtering facades can pass a particular section of the optical complex light spectrum or change the intensity of light in many different ways. Filtering facades may change the perceived image or colours according to the observation point or fluctuations in temperature. Contemporary experiments with these facades cover the design of singular or multi-layer flat surfaces, but additionally rely on the analysis of proportions, angles of particular glass elements or even non-linear structures in a way to create unique conditions for the refraction, reflection, diffraction, deflection or interference of light waves. All experiments that are undertaken today use the latest materials technology achievements.

The foundations for today's experiments on filtering surfaces in architecture have been established by researchers studying specific optical phenomena. These kind of studies have been carried on since the seventeenth century by Newton, and later on by Fresnel, Fraunhofer, Maxwell and Planck. These scientists tried to describe the phenomenon they observed with the corpuscular theory, then the electromagnetic wave theory of light and finally the quantum theory of radiation. Thus in the second half of the twentieth century, in which progress in materials technology has accelerated significantly, further studies on optical transmittance, heat transfer control problems, radiation or the ability to process the image seen through the façade have become even more intensive. As a result of these studies, filtering facades created today perform several functions simultaneously.

The primary objective of creating glass facades: perfectly smooth, big size, transparent glazing, which having improved thermal insulation that was clearly visible in the 80s and 90s, today has been extended to develop individual original glass features realized by using screen printing, an additional layer (double facade [2]), moving blinds or solar cells. The functional glass characteristics as for example energy transmission (g-value) were still improved, but in parallel, designers and engineers began to use translucent and filtering facade materials such as: milky and patterned glass, white and colored polycarbonate panels or acrylic glass that have undergone a variety of treatments to gain individual aesthetic features.

Today, due to the technological revolution in the field of materials science, filtering technologies such as printing or etching are used less, in favour of the technologies based on the internal design structure of materials. This is the way a new generation of filtering facades is being born. Precisely designed filtering facade properties can be achieved by applying polymer films onto the surface of the facade in a micro-or nano-scale, by making micro or nano grooves and by using diffraction gratings or materials with chemical composition. All these technologies change the visual aesthetics of facades by making them more dynamic and allow the creation of new aesthetic features that would have been impossible to achieve before.



Ill. 1. Optical and colouristic phenomenon when uniting a few glass layers and special polymer film (photo by B. Konarzewska)

Ill. 2. Radiant colour film (photo by B. Konarzewska)

2. A new generation of filtering facade

Nowadays, it is possible to precisely distinguish the methods that allow designers to create a “new generation” of filtering facades. Firstly, it is possible by forming specific, static micro or nano structures on the facade surface that creates dynamic patterns when seen from different points of view or depending on the angle of incidence of light. Another way to design the facade using the optical filter technologies is to design such a chemical composition of façade material that changes in response to external impulses, thus activating the specific filtering characteristics. Thanks to the achievements of materials science, the observer is unable to distinguish whether the dynamic changes that are actually observed are the result of active processes within the structure of the material, or whether these changes are supposable and only perceived visually, while the structure of the material remains static. Of these new types of filtering facades, it is possible to indicate two main groups: facades activated by environmental factors and facades activated as a result of energy supply.

The technology of polymer films, which dominates in the creation of filtering facades activated by environmental factors, relies on the application of one or more layers of thin films having different properties to glass or plastic surfaces. Polymer films can be divided into two groups: those that have a static structure, which remains unchanged under the influence of environmental factors, and films that have the ability to change the arrangements of micro scale particles under the influence of catalysis through environmental stimuli.

Radiant colour video, which is one of the most popular polymer films of static structure used now in architecture, consists of thin layers of films having different reflectivity characteristics while maintaining overall translucency (Ill. 2). The colour seen through this coating depends on the angle from which the observer looks at the facade and on the angle of the incident of light. Even a seemingly small change in the view angle can cause the surface colour that is perceived by the observer to appear totally different.

View directional film, also called light control film or privacy film, is another film that could potentially find many practical applications. When this film is applied onto the façade and depending on the change of position of the observer, the façade surface becomes more or less transparent so the observer can see through it. Thanks to micro-channels shaped in the polymeric material, the designer can determine visual accessibility to the interior by the proper formation of microscopic shutters, which are created in the process of photo polymerization usually through the use of ultraviolet light. Image redirection film (redirect the image film) is created in a similar manner: by extrusion of special grooves formed on a sheet of polymeric film. This film allows the viewer to "look" around the corner or "behind" the wall and see the object that is not visible when standing in front of the façade [3].

HDS holographic diffraction structures are among the popular "new generation" optical filters that have "entered" the field of architecture, but most of them are still prototypes. The phenomenon of refraction in various HDS structures results from a diffraction effect, similar to that created by mirrors, lenses, prisms and other optical devices. HDS is a three-dimensional pattern created by a laser light on high-resolution photographic film, which is later placed between two glass panes. Such structures can be used on the facade of the building to produce dynamically variable effects [4]. These designed surfaces reveal a variety of patterns, grids and lines in a wide range of colors depending on the angle of incidence and reflection of light, light intensity and the amount of artificial light sources. Although the creator of the facade may design some of these effects, parts of them are unpredictable as they depend on unforeseeable environmental influences. In this way, the use of filter technologies activated by environmental factors enables architects to introduce an "event" into architectural design, which has become an important factor in affecting the final impression gained by the observer when looking at the facade.

A noticeable group of experiments on filtering façades that is expanding impetuously today is the one based on materials that change thanks to chemical reactions inside their structure. Temperature change, as in the case of thermochromic and thermotropic glass or the amount of incident sunlight (photochromic glass), may have a decisive influence on the activation of filtering properties. The incident of sunlight on the façade activates filtering features that make use of phase changing materials – PCM. Façade insulating glass called GLASSXcrystal, already available on the market, is one such active filtering system, which comprises PCM that use solar energy for storage in the process of melting salt hydrate particles sandwiched between panels [5]. As the temperature decreases, the phase change material used for the façade as a result of the crystallization process releases heat.

The technologies presented above, which are used to stimulate the filtering properties of building surfaces, do not allow for the achievement of fully controllable results because the necessary stimulation dependent on environmental factors is unpredictable. However, with the provision of electricity, full control over precise reactions that take place on translucent façades becomes possible. By activating the facades electrically, parameters such as color, degree of transparency and graphics may be changed. These facades offer the possibility to comprehensively control light transmission through their surface or effect the process of colour reversibility. To achieve such effects, designers may use three general classes of materials: electrochromic, liquid crystals, and suspended particles.

Although electrochromic glass is still most commonly used for functional purposes especially in office spaces, its integration with architectural objects of irregular multi-dimensional surfaces has made it possible to achieve a new kind of effect that is broadening the idea of how this material may look as an active filtering facade. The electrochromic outer shell of *Chromogenic Dwelling*was formed in this way. Designed by Thom Faulders for the Octavia Boulevard Housing competition in San Francisco, the translucency of the individual elements of the façade are controlled by the user, depending also on the weather, sunlight or personal preferences. Similarly, liquid crystal technology can also be used to achieve unpredictable effects.

Liquid crystal technologies used on facades can take the form of computer controlled systems, thus making it possible to program the time and rate of translucency change for separate glass façade elements. In this way, the building envelope, like in the project of Michael Silvera`s, Liquid Crystal Glass House [6] that has a computer control system, may be a filter responsive to changes in environmental parameters. The polymer composite called SmartWrap, which was designed by Kieran Timerlake Associates LLP, is one of the most technologically advanced filtering façade materials.

SmartWrap is a very thin material formed on the basis of polymers whose structure comprises a substrate and layers that together form the composite film. It allows the climate to be controlled in the interior, is a source of light and electricity, has the ability to change colour and translucency, and may also be treated as an independent building envelope. It does not have to be provided with traditional window openings to let the sunlight in or to ensure a view to the outside. Instead, the architect can design printed and non-printed areas on the surface of the film to determine their rhythm [7].

3. Filter between interior and exterior

The potential for controlling the penetration of light and images into the building and creating non-traditional outside views are two very important attributes of facades acting as optical filters. A façade, which filters light optically, weakens the delineation of the natural border forming the outer barrier of the building with a specific, outwardly perceived and invariable aesthetic. It provokes and enhances the optical phenomena of reflection, refraction or image deformations and gives the impression of depth, such facades become indeterminable, but "inconspicuously" so. Because these various optical effects may overlap, we can receive the views of the external world from within the interior of the building as the original animation of light, shade or color, all of which are not fully predictable. On the other hand, images seen outside the building are framed and static, but present a heightened, more "essential" vision of what is outside through the effect of the optical filter facade.

These visual results may be gained through the realization of experiments that involve: nonlinear shaping of the facade surface: a nonstandard compilation of several filtering layers, integration within the façade structure of prisms or lenses, precision in the designing of fragments of glass surfaces with different angles and finally, the creation of moving filtering parts of various shapes and functional features.

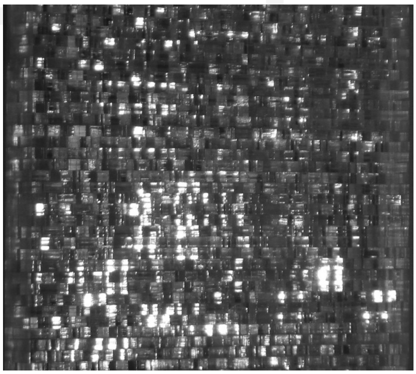
The Driving Test House by Paul van der Erve and Gerard Kruunenberga, which is a prototype house whose walls are entirely made of glass, is one of the most well-known, pioneering experiments based on a combination of translucent panes of glass or polycarbonate layers. [8].Thanks to various wall thicknesses and depending on the "depth" of the rooms, it was possible to achieve the effect of unreal depth, intensified by reflections and refraction of light inside the building. Different degrees of translucency and unique sea-green shades typical for these walls depend upon the angle of incident light and the place of observations (Ill. 1).

Glass or plastic plates are also specially "bent", molded or deformed to create the effect of a continuous transformation of the image being perceived through the filtering surface. Thanks to advanced manufacturing technology, it is even possible to produce single-layer crystal-like structures consisting of convex, concave or flat glass polygons. Herzog and de Meuron realized such a project for a Prada boutique in Tokyo. Glass facades of diamonds in varying curves "crop" and "convert" images of urban life seen through the openings, causing them to undergo constant distortion and dynamic deformation.

Thanks to facades filtering such attributes of urban life as traffic or dynamics, into which pulsating streetlights can "penetrate" , thus creating unpredictable light "projections". To use the dynamic character of the city, while creating an atmosphere of intimacy inside the building, the architects of the residential loft of Howard Street House in San Francisco [9], treated its facade as a multi-layer filter. Taking advantage of dynamic images of urban street life, the designers "let them through" a punched, layered barrier, behind which they placed a milky glass plate that became the focal plane. So depending on the traffic outside, blurry, dreamlike, almost abstract projections were created in the interior as a result of optical manipulation.

The fascination with the phenomena of fission and refraction of light, and ~~trials~~ attempting to design the geometry of patterns of light that penetrate the interior, perfectly illustrate the work of artist and architect James Carpenter, and in particular Sweeney Chapel and Periscope Window. In the Sweeney Chapel in Indianapolis, a glass "truss" of vertical and horizontal bands of dichroic glass formed in the shape of a box – like kind of vertical coffer, creates a rhomboid grid of light patterns in shades of green, blue, yellow and violet on the wall of the presbytery that light off, depending on the time of day and light intensity. It was designed almost with "laboratory" lighting patterns, which are being constantly "disordered" by a nearby tree that interferes with the light flow and light reflections created by the dichroic bands.

Ill. 3. Almere Business Center
(photo by L. Nyka)



Ill. 4. Sensi Tilesurface
(photo by B. Konarzewska)

The fascinating dynamic of the transient phenomena of light and the desire of designers to strengthen it may be revealed in other architectural projects. The result of this fascination appears in attempts at designing the interaction of light in connection with the filtering plane of the façade. Two good examples include the Periscope Window containing glass lenses by James Carpenter or the Rainbow church by Tokuin Yoshioka [10], which is a project consisting only of prisms.

4. Towards capturing environmental features

Materials as a type of optical filter are used in architecture to exploit the potential of natural light. The sun's rays interacting with the rain or clouds form short-term transitory but phenomenal results. Architects, in their attempts to imitate these effects, design material structures so that it becomes possible to experience these unique phenomena observed in nature, in an architectural or built environment. Patterns that designers intend to reflect are those characteristically found in the natural world: the smooth transition of colours, soft shades and unpredictable light reflections. Thanks to innovative technological solutions, diffraction and reflection of light or colour changes appearing on the filtering facades can be intensified and take an even more dynamic form than what is apparent in nature. Due to the nature and characteristic of the partial unpredictability, the designed graphical and textural effects are usually realized in the form of irregular organic compositions.

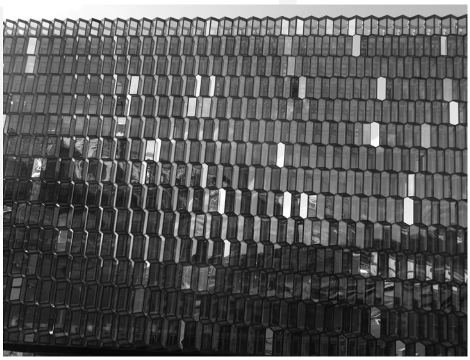
Advanced material engineering processes are responsible for the achievement of these imitative compositional solutions. Sensi Tiles [11] (Ill. 4) already existing on the market, which change under the influence of incident light, "spotting out" colours from the environment and reflecting or scattering them on the surface, is an example of one such architectural material solution. The process of melting fiber optics in a resin substrate and additionally treating the materials with the use of reflective or matte surfaces, etching or staining treatments for individual fragments of the base substrate, have created the impression that a living reaction to the surrounding surfaces is occurring. On these tiles, dynamic light, movement and touch induce hopping, colorful "sparks". Similar special effects have been achieved by architect and artist James Carpenter over many years of research and experiments with the use of dichroic glass, and by UN Studio with the use of the patented prototype multicoloured foil, as seen in The Gallery in Seoul, and Business Centre Almere in the Netherlands.

Architects may also include such unpredictable components as water within the façade structure to heighten the sense of depth, instability and prismatic reflections that would bring the created filtering facades closer to the natural world. An example of such a project using water, is the Africa Pavilion built for the exhibition EXPO 2008 in Zaragoza [12]. The main structure of the facades form square, semi-transparent plastic printed sheets, mounted only in the upper parts so they are movable by a breeze. These tiles are coated with a filtering membrane, which controls the degree of absorption and reflection of light. Additionally, the water "wall", whose fully reflective shining plane suggestively combines with the small moving tile of the proper façade, was created in front of the façade to become the unpredictable active filter, perceptible as an obvious reference to the natural landscape.

Harpa Concert Hall and Conference Centre [Photos 5 and 6], is one of the latest realizations of a filtering facade and actually of a whole complex filtering structure, for which, according to the artist, Olafur Eliasson, the inspirations were looked for in the "northern lights and the dramatic landscapes of Iceland" [13]. The main aim was to build the envelope of the building, which would create an unclear boundary between the interior and the exterior, by reflecting changing light and weather conditions. The envelope of Harpa Centre was actually created to be formed by light and its reflections reinforced by the delicate optical filters used in selected planes of the facade structure. It not only refers the building to, but also actually "blends" it, into the variable natural landscape. The prize of the Mies van der Rohe Award 2013, confirms the importance of values inherent in such projects [12].

5. Conclusions

The recent use of optical filter technologies has opened up new possibilities for creating an image of the building facade as an envelope that deepens the sense of light and its variability, and consequently broadens the use of natural phenomena to create new aesthetics in architecture. Thanks to the new generation of optical filters that were created as a result of progress in materials science, facades that initiate a new relationship between inside and outside are being created; building envelopes are sensational transitory compositions of light and colorful landscapes whose common feature is volatility and unpredictability. The unique levels of sophistication of these heterogeneous para-natural compositions found on the facades, bring the built environment closer to natural conditions. By the visualization of and interaction with such facades, the range of aesthetic stimulus offered by architecture, can be greatly extended.



Ill. 5, 6. Harpa Concert Hall and Conference Centre (photo by L. Nyka)

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