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THE ARCHITECTURAL DESIGN OF LIGHT-PERMEABLE FACADES –  
A SUMMARY OF RECENT TRENDS AND OBSERVATIONS

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PROJEKTOWANIE ARCHITEKTONICZNE FASAD PRZEZROCZYSTYCH –  
PODSUMOWANIE NAJNOWSZYCH NURTÓW I OBSERWACJI

**Abstract**

Contemporary architectural transparency, understood as the optical property of the construction material, is constantly being redefined and, over the last two decades, new design trends have developed. These trends are the result of: (i) dynamic technological progress; (ii) advancement in the field of materials science; (iii) changes in the attitude of clients and users. Transparency is no longer limited to specific functions (e.g. illumination of the interior) but has become a tool of formal expression itself. This paper defines most recent trends, which are divided into two main types: (i) optical-perceptual – relying on phenomenal effects, (ii) geometrical – that differentiate the large group of spatial transformations developed from what was initially flat planar façade.

**Keywords:** transparency, architecture theory, façade glazing, glass printing, glass coating

**Abstract**

Współczesna przezroczystość w architekturze, rozumiana jako właściwość optyczna materiału budowlanego, jest stale redefiniowana. W ciągu ostatnich dwóch dekad pojawiły się nowe nurty w projektowaniu przezroczystych elewacji w architekturze. Nurty te są wynikiem: (i) dynamicznego postępu technologicznego; (ii) osiągnięć w dziedzinie materiałoznawstwa oraz (iii) zmiany w nastawieniu klientów i użytkowników. Przezroczystość nie ogranicza się już do pełnienia konkretnych funkcji (np. doświetlenie wnętrza), ale sama w sobie stała się narzędziem formalnej ekspresji. Niniejszy artykuł definiuje najnowsze nurty, które dzielą się na dwa główne typy: (i) optyczno-wrażliwe – oparte na zjawiskach optycznych, (ii) geometryczne – wyróżniające dużą grupę przekształceń przestrzennych początkowo płaskiej fasady.

**Słowa kluczowe:** przezroczystość, teoria architektury, przeszklenie fasady, nadruki na szkle, powłoki na szkle

*Glück ohne Glas, wie dumm ist das,  
Backstein vergeht, Glasfarbe besteht...  
Sprüche für das Glashaus  
Paul Scheerbart (1914)*

*Happiness without glass, how stupid is that,  
the brick will perish, while glass will continue to exist  
Sayings for the glasshouse  
Paul Scheerbart (1914)*

## **1. Introduction**

Contemporary architectural transparency (understood as the optical property of the material) is constantly being redefined and, over the last two decades, new design trends have developed in relation to transparent façades in architecture. These trends are the result of dynamic technological progress and advancements in the field of materials science.

Contemporary trends in architecture are generally rooted in philosophy and reflect the prevailing social moods and transparency is no exception. It must be stressed, however, that the term transparency has been repeatedly redefined and is often metaphorically used as a tool of political discourse by various authors. Some authors also find general relationships with the current human condition, as “transparency expresses the dichotomy between the visual interconnection and the isolation of the individuals in modern society” [21]. These authors assume that certain optical characteristics of transparent envelopes can be permanent. This is not true because the visual experience connected with viewing architectural glass greatly depends on the light. Glass walls are “both reflective and transparent depending on the time of day, the angle of the sun, and the weather” [4]. Therefore, when some lighting conditions change, so do the relationships between the visual experience and architectural glass. In an attempt to bring some objectivity to the issue of trends in architectural transparency, the author of this paper presents a different point of view that is based on systematic morphological analysis. This analysis, however, might be somewhat subject to the author’s personal aesthetic preference.

## **2. Methodology**

The objective of the presented research project was to investigate and identify new trends in the architectural design of transparent façades, identify their scope and devise models that illustrate sets of typical features in each trend. The identification of new trends is crucial not only for architectural theory but also for the planning of glass production strategies and the manufacturing of glass processing equipment, which can serve as practical tools in implementing certain visual solutions. This paper is a presentation of the results of a large study of over five hundred facades located in Europe, USA, and Japan and built between 2001 and 2018.

The objective of the presented research program was to investigate and isolate new trends, identify their range and formulate models of the trends – “a group of all the features typical of the trend” [32]. The analysis of the visual performance of the building facades was performed in conjunction with the analysis of the innovative technologies used to build the façade. It was assumed that the “trend is a set of architectural objects, while the model is a group of the features typical of the trend” [31]. In order to create models of the trends, it is necessary to analyse the architectural form and the visual appeal of buildings. During this stage of the analysis, special attention was paid to the fact that the specific piece of architecture “shows usually only some of the features which are recognised as representative for the trend” [32]. The distinction of these features helped to create models of the trends and assign the selected buildings to the trends. This problem is also addressed in Section 5 and in Table 1.

Methodology is based on in-situ research of case studies, specifically, the photographic documentation of existing buildings, the conducting of measurements and field observations. Field observations are an essential component of the proposed scientific method and plays an important role in collecting data and formulating scientific insights. Originally, the analysis of individual facades as case studies was intended. After the collection of data and the photographic inventory began, it became evident that the study of each case was unfeasible. J. Gerring in *Case Study Research* states that the study should “include 5–10 cases” [16]. At the time this paper was written, the database had 524 entries and was growing. Because of the large number of database records, it was decided to change the methodology from a case-study analysis to a large sample analysis. As a result, it also proved to be more effective in creating models of trends of transparency in contemporary architecture. However, it has to be stated that particular façades are presented in this paper for illustrative purposes, not as case studies. This is based on the assumption that only the most representative case-studies are suited the best to present the trends in the most visible way. The presented facades have the most profound features that are characteristic of the illustrated sub-groups of trends.

All façades presented in the paper were visited and photographed by the author. Although this kind of aesthetic assessment is usually rather emotionally-driven than science-based, one must realise that a scientific method for the objective appraisal of beauty has yet to be invented. The author’s emotional assessment is counterbalanced by his analytical approach focused on identifying the technique, the materials that were used, and the optical results. For each sub-trend, the morphological analysis was performed while taking into the account the following factors: (i) geometry (ii) the number of transparent layers, (iii) the depth of penetration of the eye and (iv) homogeneous or heterogeneous light transmission through the façade.

### **3. Background**

Architects approach transparency differently depending on their own attitude and that of the client. Some solutions are well thought out and serve as architectural manifestos, others are by-products of the chosen design technologies, e.g. double façades were initially introduced

to regulate climate and handle acoustics. Furthermore, transparency in architecture remains an important tool of political discourse when used by those authorities that associate optical transparency with institutional transparency. Paradoxically, the term transparency – rarely seen in reality in the form of bonafide visual manifestation – has gained an additional meaning associated with “legitimacy, policy efficiency, and good governance, as well as a universal remedy against corruption” [15]. This politically-driven discourse is still present in architecture and – despite the fact that transparency has gained an identity of its own – is commonly used to justify the excessive use of glass in public buildings.

#### **4. Aesthetic trends in transparency**

Despite the fact, that transparency in architecture is deeply rooted in technological advancement, aesthetic qualities are of profound importance in the decision that is made by both the client and the architect on the use of glass in façade. Glass, as addressed below, carries immense symbolic meaning that seems crucial for the decision making process. The advancement of glass technology has always been pushed by human imagination and aspirations. First, people dreamt of larger glass panes, than glass walls, then whole glazed buildings. And technology has provided adequate means of fulfilling these aesthetic ideas and aspirations. As a result of the analysis described in Section 2, two main types of trends have been distinguished: (i) optical/perceptual and (ii) geometrical. These are addressed below. It is important to note that in final table of optical and geometrical trends do not sum up to 100% but frequently go above this value because the analysis on the quantitative level have been performed separately for optical and geometrical types.

##### **4.1. Optical/perceptual trends**

Perceptual and optical experiments are a new, distinctive and booming trend leading to the creation of the new styles of transparent facades that offer new experiences to building users and visitors. Many innovative techniques are used to enrich the spatial depth of the facade, multiply the observed plans and achieve the picturesque effects of blur, stratification or movement. However, as it has also been observed, many pre-existing techniques (meaning existing before the year 2000) are still used, therefore – for the sake of accuracy – they are also included in the provided analysis. A brief description of the trend’s models and representative case-studies are given below.

###### **4.1.1. Classic/clear transparency**

Classic transparency is basically the use of transparent or partially coated glass. This trend was regarded as the basis for the definition and the reference of the other trends. The classic/clear transparency model is defined as the unmodified transparency of the light-transmitting material (with some possible partial use of coating on the glass). This trend is present in a total of 23.2% of optical type cases. It was a surprise to find out that only about a quarter of



the studied facades preserved the original optical properties of the light-transmitting material. However, the above-mentioned “excessive use of glass” (see Section 3) could still be found and is frequently used to emphasise the prestige of the building, for example, in the Supreme Court in the Hague (arch. by KAAAN Architecten, 2015), which has recently been reviewed as “more crystalline than transparent” [24] or the well-known CDU headquarters in Berlin (arch. Petzinka and Partners, 2001). Although the former building is extensively glazed at the street level, it only enables a shallow penetration of its doubled-glazed envelope on the top floors (see Fig. 1, Fig. 2). Such glazing manifestos have repeatedly been built around Europe since the 1960s, with Stuttgart’s Landtag von Baden-Württemberg (arch. Horst Linde, 1961) as the originator of this trend. The most recent trends in architectural transparency seem to have shaken off this political “transparency” burden by allowing visual and material experiments to take a leading role in the creation of architectural space and the user’s impressions.

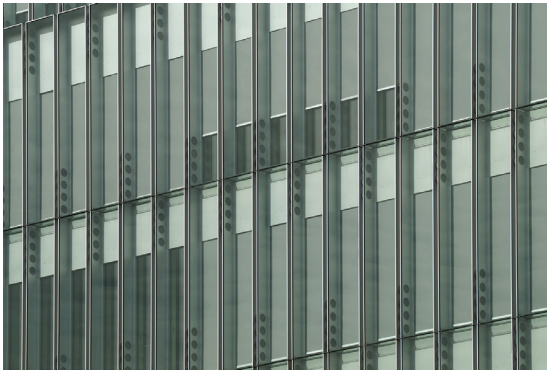


Fig. 1. Supreme Court in the Hague  
(arch. KAAAN Architecten, 2015)



Fig. 2. CDU headquarters in Berlin  
(arch. Petzinka and Partners, 2001)

#### 4.1.2. Obstruction of transparency

Obstruction of transparency is defined as an intentional significant change of optical parameters of light-transmitting materials used in the façade, and its model is defined as the local or gradual loss of the light-transmitting properties of the façade. The obstruction trend is the most numerous trend type, totalling 40.6% of optically analysed facades. Within this type, a few sub-groups (or sub-trends) were defined including (i) homogeneous obstruction (e.g. frosted glass – 7%); (ii) heterogeneous obstruction (e.g. silk printed glass or frit printed glass 11.5%). The models might be formulated as follows: heterogeneous obstruction takes place when “light transmission is blocked by elements that are randomly or evenly scattered in front of, or on the pane’s surface” [12] or homogenous when a homogenous decrease in light intensity is experienced. This group of obstruction trends also includes the shading systems of different types as external/internal blinds, shutters, rollers that affect the visibility and light transmission, which in total account for 22.1% of facades.

Research has shown that obstruction is the dominant trend, denoting the enthusiastic use of prints, rasters, blinds, shutters and other systems in order to achieve other, previously unavailable visual effects (veiled transparency, visual occlusion). In many situations, the

transparent panes of glass only serve as a *scaffolding* for the creation of a specific visual *veil*. The obstruction of transparency has recently gained in importance with the emergence of innovative technologies and materials that offer new formal solutions. Heterogeneous obstruction can be achieved by printing, laminating or depositing a thin layer on the surface of the glass. Examples of such solutions include the screen-printed glass in Hôpital Jean Mermoz (arch. F.-H. Jourda, 2008), Clinique du Parc (arch. Xanadu, 2007) and small patches of reflective surface which create a pattern on the glazed façade of the Uni Carl Vogt in Geneve (arch. 3BM3, 2015) – see Fig. 3, Fig. 4, Fig. 5.



Fig. 3. Hôpital Jean Mermoz (arch. F.-H. Jourda, 2008)

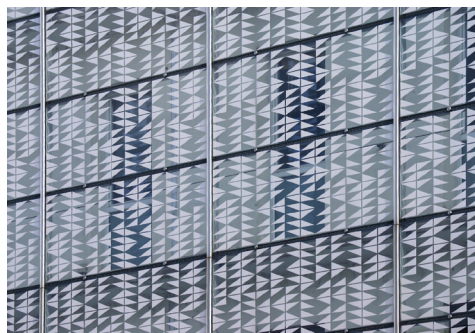


Fig. 4. Clinique du Parc (arch. Xanadu, 2007)



Fig. 5. Uni Carl Vogt in Geneve (arch. 3BM3, 2015)

Examples of *veiling* include the use of evenly translucent or foggy/ornamental glass that is embossed with a small-scale graphic or geometric pattern. This type of material distorts the image transmitted through the glass and causes the elements behind it to appear hazy and foggy. Some architectural theoreticians notice the connection between this type of transparency and postmodernism and trace the beginning of this trend back to the writings of the French philosopher Jean Starobinski, who derives a foggy translucence from the ancient and archetypical “Poppea’s veil” [33]. Herbert Muschamp even says that “the skin of a building is not used to reveal but to hide” [22].

On the optical level light-scattering materials behave differently than fully transparent. The entire translucent pane emits scattered light and successfully blocks the image but lets the light pass through. This is a feature of translucent light-permeable materials that changes the quality of

light and thus gives a soft and hazy quality to the illumination. From an architectural perspective, translucency offers the unique possibility to dematerialise the building, to blur its boundaries and achieve visually different results in different daylighting scenarios. The Silesian Museum in Katowice (arch. Pysal Ruge Architekten, 2013) is a good example of the use of ornamental glazing embossed with a so-called frost-flower pattern, while the headquarters Sotax AG (arch. Itten+Brechbühl, 2013) could serve as an example of the use of a uniformly translucent façade. The new Credit Suisse Backoffice (arch. Burckhardt+Partners, 2012) offers an even more exciting visual experience as the building is equipped with “recessed ribbon windows with translucent glass balustrade elements” [23] which make the areas where translucent panes are mounted seem out of focus, see Fig. 6, Fig. 7, Fig. 8.



Fig. 6. Silesian Museum in Katowice  
(arch. Pysal Ruge Architekten, 2013)



Fig. 7. New Credit Suisse Backoffice  
(arch. Burckhardt+Partners, 2012)

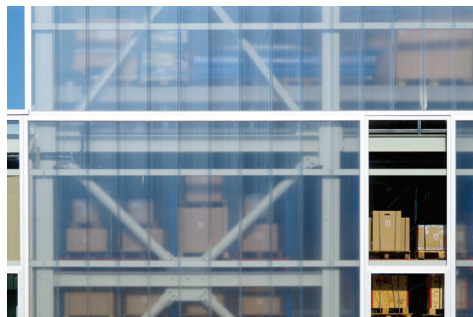
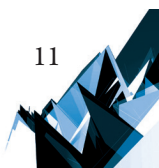


Fig. 8. Headquarter Sotax AG  
(arch. Itten+Brechbühl, 2013)





#### 4.1.3. Reflexive coating/mirrored glass

Significant progress has also been made in the field of applying different coatings to glass. Use of reflexive coatings still remains a notable trend in the application of light-transmitting façade materials (7%). This sub-trend model is defined as both a significant reduction of transparency together with the specular reflection of a large portion of incoming light to the extent that enables a virtual image to be created that dominates the pane. Originally, silver was used for this purpose, but for the sake of cost, aluminium is now widely applied. This type of coating reduces the energy gain through the façade to facilitate the regulation of the microclimate but simultaneously disturbs the transmission of the image, usually from the inside to the outside. Reflective coatings visually turn the glass into a two-way mirror (although of course, some daylight is introduced into the building) [8].

The reflexive coating has significant disadvantages, both functional and aesthetical. It always reflects the same percentage of incident light so in the winter, the desirable greenhouse effect will not work. In architecture – after the original fascination – the reflective coatings have faced a wave of harsh criticism as e.g. “(...) the glass skin repels the city outside” [34] and were commonly associated with corporate architecture. Reflective coating impacts not only the appearance of the buildings “thereby changing the buildings into impermeable mirrored solids” [11].

#### 4.1.4. Multiplication

The multiplication of optical phenomena in façades was initially a side-effect of the deliberate use of an extra layer of glass in order to improve the thermal performance of windows. This *doubling* trend peaked in the mid-1990s with the development of technology and methods of calculating airflow (computational fluid dynamics) and assessing the climatic performance of double facades, which in turn provided evidence supporting the choice of a given technology.

Distinctive features of this trend – those characteristics of the model – include the multiplication of optical phenomena, e.g. higher absorption (if a ray of light penetrates through more layers), the multiplication of reflections or even the loss of the contrast such as in the Lightcube Office in Zurich (Fischer Architekten, 2006, see Fig. 9) where “material transparency of the walls” is converted “into perceptual opacity” [4]. The aesthetic effect is also created by intentionally moving apart the layers of glass in the façade to achieve a chiaroscuro effect on what is basically a flat glass facade. Additionally, there can be the impression of the apparent duplication of the elements of the structural frame, as the light is zigzagging between panels, e.g. the façade of Bern Train Station (arch. Atelier 5, 2003).

This trend has been clearly visible since 2000 (10.5%) within the studied group of facades and in the architecture of transparent facades, it has been present since the 1990s. The research shows the decreasing popularity of doubling solutions in the second decade of the 21<sup>st</sup> century. This may be due to the tendency to seal the building envelope to recover heat and thus to limit natural ventilation schemes of which the double façade was a part of. Double façades also provide additional space for solar gain regulation devices (rollers or blinds) thus eliminating the need to use mirrored glass to regulate insolation. This important change in technology enabled new optical characteristics to appear. Due to daylight playing a key

role in the perception of the transparency of a building, the elusive appearance of its façade depends very much on the viewing conditions. This phenomenon has become the most interesting feature of new multiplied transparent walls. In their designs, architects have started incorporating the effects of multiplied optical phenomena, such as decreased transmission and overlaid reflections, in order to achieve rhythm, proportion, and balance.

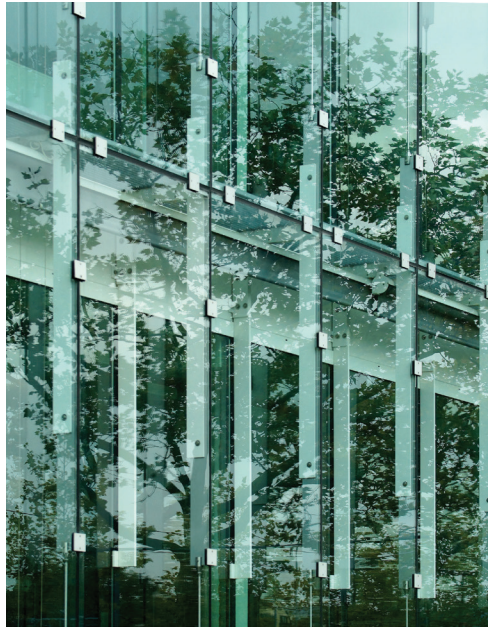


Fig. 9. Lightcube Office in Zurich (Fischer Architekten, 2006)

Notable buildings and concepts that are usually quoted by architecture critics, such as the Tres Grande Bibliotheque proposal (OMA, 1997), the Institute for Hospital Pharmaceuticals (Herzog de Meuron, 1995), and Kunstmuseum Winterthur (arch. Gigon & Guyer, 1995), represent the multiplication trend which, at some point, gave birth to the – redundancy trend discussed below.

#### 4.1.5. Redundant transparency

Redundant transparency is probably one of the most interesting trends, although it is not very popular (2.1% of recorded cases). It was identified and described by the author in 2014 in his paper entitled *Redundant transparency: the building's light-permeable disguise*. The sub-trend model is defined as follows: redundant transparency occurs when light-transmitting materials are used to “enrich the spatial depth of the spandrel region of a building's facade without affecting its main important function of bringing light into the building” [10]. The use of light-transmitting materials does not affect the illumination of a building but visually activates large areas of the façade that were previously relatively inert. The shallow space behind this redundant glazing adds the impression of depth to the previously flat part of the building. Originally, redundant transparency took the form of

(i) the shadow-box, and (ii) the cloche. The shadow-box consisted of a relatively shallow space behind glass, such as in the case of the Deutsche Krankenversicherung headquarters in Cologne, Germany (arch. Störmer Murphy and Partners, 2005) – see Fig. 10. This form later developed into much more complex solutions with entire buildings covered by a cloche, which describes bell-shaped glass. The cloche, defined as an additional transparent layer of the outer envelope, originated in buildings in the early 20<sup>th</sup> century e.g., the Steiff Factory (arch. Richard Steiff, 1903). However, it became very popular as it proved to be surprisingly effective in shaping the microclimate in a building by mitigating seasonal temperature differences. This was achieved by exploiting air circulation in the summer period and solar gain in the winter period. An excellent but not widely known example of this cloche solution is the glazed enclosure build over the go-cart racing track in Delft in the Netherlands (arch. Cepezed, 2001) – see Fig. 11.



Fig. 10. Deutsche Krankenversicherung (arch. Störmer Murphy and Partners, 2005)



Fig. 11. Go-cart racing track in Delft (arch. Cepezed, 2001)

#### 4.1.6. Perceptual transparency

Small-sized meshes or perforated surfaces (although typically heterogeneous) are optically perceived as producing a homogenous decrease in transparency. This phenomenon of perceptual transparency occurs when the openings in such meshes or perforations are so small as to be beyond the limits of the spatial acuity of the human eye. This sub-trend model is therefore defined by the phenomenon of the perforated surface/mesh becoming evenly transparent. This perceptual phenomenon is eagerly used by architects as it produces the effect of transparency without the use of materials which transmit visible light. There are many solutions that take advantage of this technology ranging from a glittering mesh, such as the one on the façade of the De Baljurk in Hague (arch. Eric Vreedenburgh, 2005) to perforated

metal sheets which not only create the effect of transparency but simultaneously produce moiré fringes. This sometimes unwanted consequence is especially visible in the expanded metal cladding of the recently refurbished Toni-Areal development in Zurich (arch. EM2N Mathias Müller und Daniel Niggli, 2014), see Fig. 12, Fig. 13.

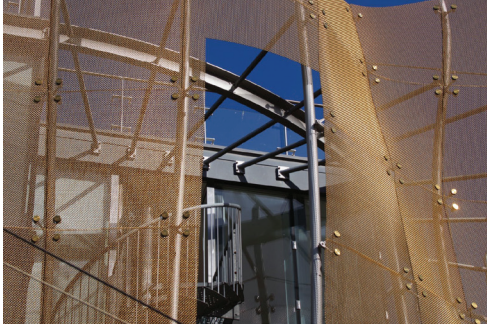


Fig. 12. De Baljurk in Hague (arch. Eric Vreedenburgh, 2005)



Fig. 13. Toni-Areal development in Zurich (arch. EM2N Mathias Müller und Daniel Niggli, 2014)

#### 4.1.7. Underlit facades

In the course of the research, it was also necessary to introduce new parameters that have not been defined before. One of these is the definition of the directionality of the light transmission through the facade. This parameter describes the predominant direction of light transmission from the perspective of the aesthetic outcome significant for the viewer and especially applies to the night viewing conditions. After dusk, the usual direction of light transmission is reversed as artificial lights are lit inside the building [8]. This artificial light radiates out of the building reversing the usual direction of light transmission from the inside to the outside – this defines this sub-trend model. It became evident during the research, that there is a growing trend for façades that are deliberately designed to look better in night conditions, than in the daylight. This new trend was tentatively named underlit façades and was found to be especially present in Japan (1.8% of cases in total, of which 7.3% in Japan) – see Fig. 14. The rationale behind this is the fact that predominant exposition of the façade to the client usually happens after dusk (e.g. in Tokyo in summer, twilight falls at 19:00 and in winter, at 17:00). Therefore, designers and clients focus on the attractive appearance of buildings at these times of the day when customers leave their jobs and stroll through the city.

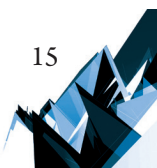






Fig. 14. Left: Ginza Six Store Dior, Tokyo, Japan (arch. Yoshio Taniguchi, 2016);  
Right: Louis Vuitton Hilton Umeda in Osaka, Japan (arch. Office of Kumiko Inui, 2009)

## 4.2. Geometrical trends

Geometrical deformation is deeply rooted in the sculptural qualities of the building's volume. Many methods of shaping the building's volume are used. Architects tend to choose the method that best suits the functional program, reflects the relationship with the surroundings and corresponds with individual aesthetic sensitivity (the unique architectural style). Briefly speaking, transformations that vary in scale are generally made to: (i) the entire volume of a building (in 3D), (ii) in the depth of the façade (in 2.5D – relief, analogous to the double façade design) and (iii) on the flat surface of the façade – pattern in 2D – also called façade decoration. Those two sub-groups (2.5D and 3D) are described in the detail in the paper entitled *Studies on glass facades morphologies* recently published by the author [11].

The presented typology is based on façade geometry and divides facades into two groups of *spatially deformed* facades with surface continuity (and their variations), which produce various types of curves (single or double-curved), and *segmented iterations*, which consist of single facets that form a folded/serrated/protruded surface of the façade [3]. The general typology is explained in the diagrams in Fig. 15.

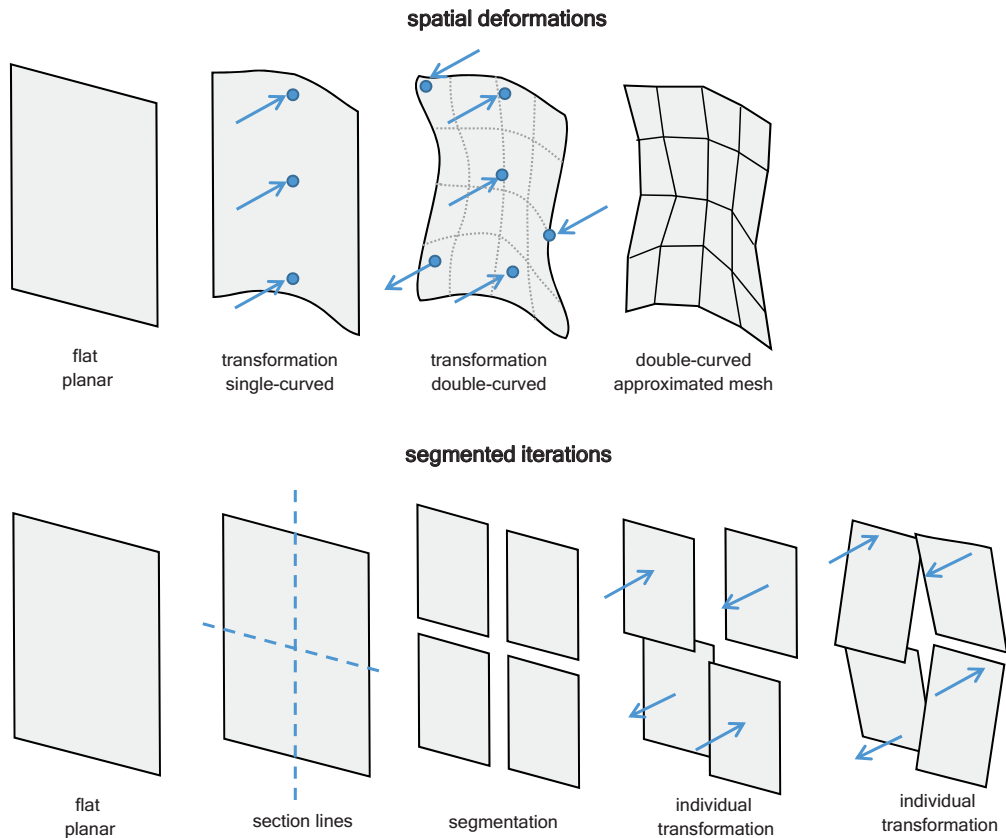


Fig. 15. Surface transformation phases (schematic diagram by author)

#### 4.2.1. Planar curtain wall

Use of a flat glass curtain wall is the most widespread technical solution and is observed in 45.5% of geometrical cases. As with the clear transparency trend, it is used here as a reference for other geometrical deformation trends. The definition of this sub-trend model can be simply formulated as a flat, planar surface of the glass, regardless of whether it is constructed using mullions and transoms, or is, for example, frameless.

The first curtain walls were flat. This facilitated the production of mullion and transom elements and the assembly of flat glass sheets. With the application of this technology, the façade of the building has no load-bearing function and is only a thermal and functional barrier. This trend is characterised by a system of mullions and transoms, which are usually aluminium, constituting a framework for glass panels. This technology is deeply rooted in the achievements of the modernism movement, with the first cases of application in Bauhaus, Dessau (arch. W. Gropius, 1926). Curtain walls are used globally and are present in all observed locations, possibly due to the evident spread of curtain-wall technology as a part of the so-called international style. The most visible invention in curtain-wall technology is the use of timber as a more sustainable solution than aluminium. Because timber rots when exposed to the outdoor environment, profiles with aluminium on the outside and timber on the inside seem to be the most suitable solution.

#### 4.2.2. Double leaf facades

These are thoroughly described in Section 4.1.4, which considers multiplication. From a geometrical perspective, this sub-group accounts for 12.1% of recorded façades and is described as a “system consisting of two glass skins placed in such a way that air flows in the intermediate cavity” [28]. This geometrical sub-group features intakes and exhaust for air-circulation. These are usually located on the surface of the façade. Recently, more cases of non-planar double-leaf facades have been recorded as planar façades, but curvilinear facades are also built.

#### 4.2.3. Spatial deformations

Spatial deformations preserve the continuity of the surface. Such surfaces are characterised by smooth transitions and the absence of acute angles (mild/soft angles are more common). Spatial deformations produce both regular and irregular shapes. The former sub-group includes single-curved surfaces (cylindrical, conical, elliptical and rotational geometry) and double-curved surfaces (synclastic and anticlastic shapes, e.g. hyperbolic paraboloid) while the latter covers all free-form transformations (including twisting, bending, tapering, free-forming). The model of this trend could be characterised by the unbroken continuity of the surface.

At the technical/manufacturing level, double-curved or free-form geometry is usually achieved by using flat or curved glass. The use of flat glass requires the approximation of curved surfaces by using flat faces/panels (triangles or planar quads). Thus, a mesh is created which represents the curvature or free-form geometry of the facade. The rare example of this can be found in the case of the Headquarters of the Department of Health of the Basque Government in Bilbao, Spain (arch. Coll-Barreu Arquitectos, 2004), where “folded element produces multiple views of the city, and changing its appearance depending on the point of view, the hour and the season” [3] – see Fig. 16. The issue of mesh geometry and the definition/optimisation of mesh nodes has recently evolved and currently constitutes a separate discipline of science, both in mathematics, geometry and façade engineering. The most comprehensive lecture on the topic is provided in the book *Architectural geometry* [25].



Fig. 16. Headquarters of the Department of Health of the Basque Government in Bilbao, Spain (arch. Coll-Barreu Arquitectos-Juan Coll Barreu & Daniel Gutiérrez Zarza, 2004)



The use of curved glass in single- and double-curved facades is rare because its production costs are very high. Glass can be hot or cold bent. Hot bent glass can be bent at smaller radii, while cold-bent glass only allows much smaller curvatures and thus requires large radii – the minimum cold-bending radius is approximately 1500 times the thickness of the glass. Cold bent glass requires a rigid sub-frame to maintain its shape as this is visible in the case of the Van Gogh Museum’s New Entrance (arch. Hans van Heeswijk Architects, 2015) where large panes of glass are cold bent on a lattice of vertical glass fins and rigid steel horizontal curved girders – see Fig. 17.



Fig. 17. Van Gogh Museum’s New Entrance (arch. Hans van Heeswijk Architects, 2015)

The above spatial deformation might be also visible in a smaller scale, not at the scale of the whole volume, but on the scale of the façade’s depth (as addressed above in 2.5D resulting in the bas-relief). These rare cases include the hot-bent glass façade elements that are later assembled to form basically planar facades but undulated on the scale of the façade’s relief. These cases include the sinusoidal glazing of Casa da Música – Sala de concertos, in Porto (arch. OMA, 2004 – see Fig. 18) and a similar system was used in the MAAS museum in Antwerp (arch. Neutelings Riedijk, 2011 – see Fig. 19). The example of the Swiss Re Ltd Headquarters

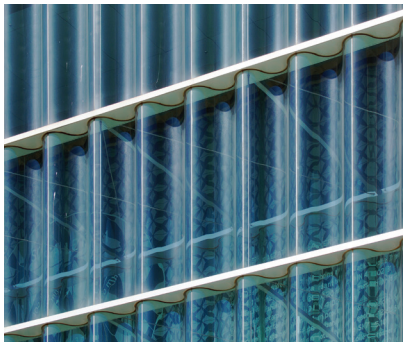


Fig. 18. Casa da Música – Sala de concertos, in Porto (arch. OMA, 2004)

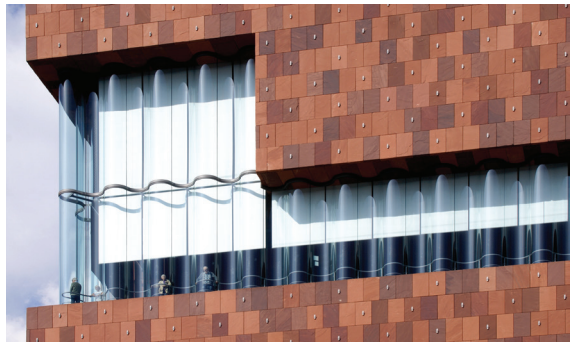
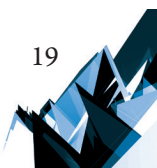


Fig. 19. MAAS museum in Antwerp (arch. Neutelings Riedijk, 2011)



in Zurich (Diener & Diener Architekten, 2017) presents an obvious transition case between the spatial deformation and surface iteration, as its glass cladding – in the form of undulating planes – is also a shingle-like arrangement along the façade – see Fig. 20.



Fig. 20. Swiss Re Ltd Headquarters in Zurich (Diener & Diener Architekten, 2017)

#### 4.2.4. Surface iterations

Iteration breaks the continuity of the façade surface and divides it into individual facets which can be oriented in different directions (the above-mentioned approximation also divides façades into individual facets by creating a mesh, but these facets are used as smooth transitions that represent a curve). The model of this trend could be characterised by – in the opposition to the previously described trend – the broken continuity of the surface and the creation of a segmented facade. The general geometrical rule for surface iteration (general scenario) requires two consecutive spatial operations. Firstly, the fragmentation/division of the façade's surface into segments (either regular or irregular), and secondly, the geometrical transformation of the segments obtained in the previous operation (e.g. translation, rotation, scaling, skewing) – see the diagram in Fig. 15.

Among the most popular iterated solutions are facades with:

- ▶ **Protruding and retracting segments**

Parts of the façade form oriels that project forwards and backward, e.g. Bürogebäude Haus 1 in Munich (arch. Ganzer-Hajek-Unterholzner/Louvieux, 2010) – see Fig. 21.

- ▶ **Serrated/folded segments**

These are basically characterised by the zigzagged geometry in the vertical or horizontal section (horizontal section serration being much more frequent) and parallel fold lines. This produces rectangular façade facets/panels. Serrated facades are also characterised by the *angle of serration* which describes the angle between the panel and the overall surface of the facade. In repetitive/rhythmic solutions, the angles are usually of the same measure, e.g. the Oskar von Miller Forum in Munich (arch. Herzog+Partner, 2009) – see Fig. 22; when arbitrary geometry is applied, the angles are random e.g. the Osaka Fukoku Seimei Building (arch. Dominique Perrault Architecture, 2010). Arbitrary serration requires much more labour-intensive detailing, as all the junctions at unique angles have to be solved/designed separately. Serration can also be applied



Fig. 21. Protruding and retracting segments.  
Bürogebäude Haus 1 in Munch (arch. Ganzer-  
Hajek-Unterholzner/Louvieaux, 2010)



Fig. 22. Regular serrated segments:  
Oskar von Miller Forum in Munich  
(arch. Herzog+Partner, 2009)

to the entire façade or it can be limited to a single storey. Very interesting visual effects can be achieved when the serration on the upper and lower stories is different e.g. the Conservatorium of Amsterdam (arch. van Dongen – Koschuch, 2005) – Fig. 23. The issues of serrated facades – including serrated double facades – were addressed in depth in the paper entitled “Morphology of serrated glass facades: repetitive and non-repetitive serration: single and double serrated facades” [13].

► **Pleated segments**

These are similar to those mentioned above but with arbitrary fold lines, e.g. Tokyu Plaza Ginza (arch. Nikken Sekkei, 2016), which produce arbitrary polygonal facets/panels on the façade – see Fig. 24.

► **Shingled segments**

Panes of glass are positioned in a similar arrangement to fish scales or shingles. Glass shingles are frequently used to introduce air into the space of the façade because the manner in which panes are arranged rarely provides a tight connection between the panes (as in the case of roof tiles). Such examples of the use of shingle segments are the H 19 Office Building in Duesselfor (arch. Petzinka Pink und Partner, 2002) – see Fig. 25 – and Steiermärkische Sparkasse in Graz (arch. Szyszkowitz-Kowalski, 2006) – see Fig. 26. In Ghent’s market hall (arch. Robbrecht en Daem and Marie-José van Hee, 2013) glass plates mimic ceramic roof tiles, providing improved quality of light transmission through the glazed envelope of the roof – this recent case study was analysed in detail in the paper entitled *Glass protected timber façades – new sustainable façade typology* published by Technical Transactions no 2/2019 [7].

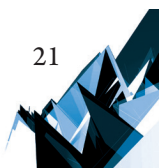






Fig. 23. Serrated segments in different directions Conservatorium of Amsterdam (arch. van Dongen-Koschuch, 2005)

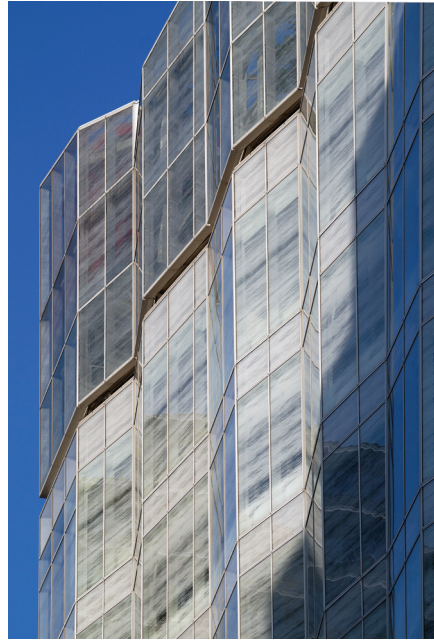


Fig. 24. Tokyu Plaza Ginza (arch. Nikken Sekkei, 2016)



Fig. 25. H 19 Office Building in Duesselfor (arch. Petzinka Pink und Partner, 2002)



Fig. 26. Steiermärkische Sparkasse in Graz (arch. Szyszkowitz-Kowalski, 2006)

► **Finned segments**

These are not a pure example of a segmented iteration, but, once the fins are added, they are visually divided into separate parts and alter the surface of what is basically a flat façade. The issues of glass fins were addressed in depth in the paper entitled *Glass fins – a structural and aesthetical application in glass facades* [6] which distinguished between fins that are used as (i) decorative (aesthetic enrichment of the facade), (ii) functional



(e.g. as sunshade) and (iii) structural (stiffening and load-bearing) elements of the façade. From the structural point of view, glass fins replace the opaque vertical mullions in classic curtain-wall façade systems. The first successful application of this system in buildings (e.g. Willis Faber & Dumas Headquarters by Foster and Partners, in which the façade is partially hung from above using glass fins) facilitated the spread of the system and pushed the technology for the creation of new developments. Glass fins are connected with the façade glazing by the means of patch fittings, corner connections or point mount fittings; there are numerous available systems offering fin heights of up to 12–15 meters, reaching 18 m in some conceptual proposals.

## 5. Quantitative results

As a result of the analysis described in Section 2, two main types of trends have been distinguished: (i) optical/perceptual, (ii) geometrical. From a methodological point of view, modern trends cannot be categorised because the analysed façades – records in the database – represent distinctive features that fall into many types and sub-groups simultaneously e.g. a façade could present both the features of geometrical serration and obstructed transparency, as is the case with the Historical Archive of the Basque Country (arch. ACXT, 2013) – see Fig. 27.



Fig. 27. The example of the façade falling into multiplied types and sub-trends: irregularly serrated and obstructed transparency – Historical Archive of the Basque Country (arch. ACXT, 2013)

Therefore, the presented approach is more “many-valued logic” [18], rather than strict categorisation. Trend developments over time was presented in the diagram of the glass trends. This diagram (see Fig. 28) is based on a similar methodology to diagrams initially created by Charles Jenks. Despite the fact, that – as Jencks claims – “architects dislike being pigeon-holed as much as do politicians and writers” [19], assigning the case-studies to trend types, and sub-trends was a necessary operation. However, finding an “evolutionary” connection between trends, as was the original aim, requires a detailed case-study of each façade. These connections certainly exist, but, taking into account the number of analysed facades, this study requires more time and effort than a simple morphological analysis, model building and a mere graphical representation.

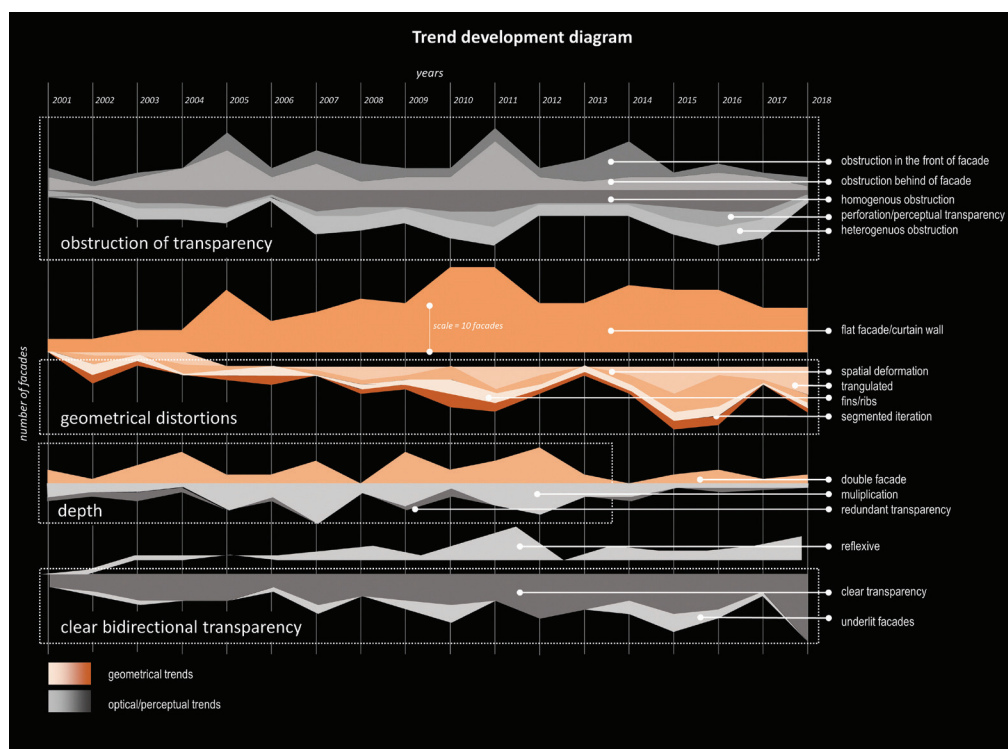


Fig. 28. Trend graph representing the development of the most important trend types (optical and geometrical) and sub-groups over time for the years 2000-2018

The interpretation of the presented diagram should be considered carefully, with respect to the fact that it represents the trend distribution of facades from the collected data pool and does not include all facades. As it was initially said, only the most representative examples are chosen that present the characteristics of the trend in the most visible way. However, some buildings still have inclusion in the database pending and therefore might not contribute to the overall image of recent trends. The presented research program is intended to be a long-range task, and the more facades that are collected, the more precise the available results will be. Analysis of the database remains ongoing and it seems that in

the future, a matrix approach would probably be used to describe the trends with greater precision, than is currently presented. Nevertheless, some results may be provided and conclusions generalised drawn on the basis of 524 cases that were collected. These results include the following:

- ▶ The algorithm for the establishment of the trend model was presented (identifying the most important characteristic features of the trend). Trend models – the characteristic features of trends are summarised in Table 1.
- ▶ The existence of the trends originating in the twentieth century was confirmed (e.g. clear transparency, reflexive glazing, curtain wall). The number of façades peaked around 2010–2011, but this might be the result of the largest amount of cases being recorded for this period.
- ▶ Previously unknown trends were described (as redundant transparency, underlit transparency, perceptual transparency).
- ▶ Geometrical study of the façades shows the visible growth of the number of geometrically complex façades (triangulated, serrated and ribbed/finned). It seems that Bilbao’s building might be a starting point of the independent sub-group development, see Fig. 16.
- ▶ The optical sub-trend of multiplication and the geometrical trend of doubling the façade layers almost coincide because the optical effect of multiplication is almost always enforced with the technical operation of layer “doubling”;
- ▶ A relatively constant proportion of façades with the obstruction of transparency is observed, even taking into account the significant fact that more façades completed in the years 2010-2011 were recorded.
- ▶ The chronology of façades was studied and constituted the basis for the study of the trend’s development over time. Façade’s form depends upon climate, prevailing local technology, and construction tradition was also confirmed.

Table 1. Trend model definitions – the most important characteristic features of the trends

Trend sub-group	Model definition
1	2
Optical/perceptual trends	
Classic/clear transparency	<ul style="list-style-type: none"> <li>▶ unmodified transparency of light-transmitting material</li> <li>▶ some possible slight use of coating on glass is possible</li> </ul>
Obstruction of transparency	<ul style="list-style-type: none"> <li>▶ local or gradual loss of the light-transmitting properties of the façade</li> <li>▶ intentional significant change of optical parameters of light-transmitting material</li> </ul>
Reflexive coating/mirrored glass	<ul style="list-style-type: none"> <li>▶ significant reduction of transparency together with specular reflection</li> <li>▶ virtual image created that dominates the pane</li> </ul>
Multiplication	<ul style="list-style-type: none"> <li>▶ multiplication of optical phenomena</li> <li>▶ multiplication of reflections</li> <li>▶ higher multi-pane absorption</li> </ul>

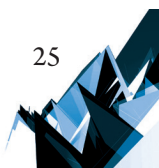


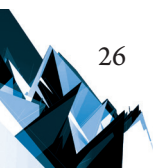
Table 1 (continued from the previous page)

1	2
Redundant transparency	▶ light-transmitting materials used to “enrich the spatial depth of the spandrel region of a building’s facade without affecting its main important function of bringing light into the building” [10]
Perceptual transparency	▶ perforated surface/mesh becoming evenly transparent
Underlit facades	▶ change of the predominant direction of light transmission from inside to the outside ▶ artificial light radiation out of the building after dusk
Geometrical trends	
Flat curtain wall	▶ flat, planar surface of the glass, regardless of whether it is constructed using mullions and transoms, or is, for example, frameless
Double leaf facades	▶ system consisting two glass skins placed in such a way that air flows in the intermediate cavity ▶ intakes and exhaust for air-circulation
Spatial deformations	▶ smooth transitions and the absence of acute angles (mild/soft angles are more common) ▶ triangulation possible if straight line approximation is applied
Surface iterations	▶ broken continuity of the façade surface ▶ division into individual facets which might be oriented in different directions and at a different angles

## 6. Discussion

Although, as stated above, aesthetic considerations have priority over technical solutions in many situations, in fact, many purely formal trends evidently find their origin in technology and design decisions that are governed by rational issues (e.g. the impression of depth that was created as a by-product of double façades). The implementation of certain rational technical solutions simultaneously creates many opportunities for visual expression. This also applies to other aspects of façade technology, which can be a source of other creative inspiration. **Drawing visual and formal inspirations from the achievements of façade technology** is a general feature of recent trends in the design of light-transmitting facades. Another notable trend in façade technology is characterised by the **increasing complexity of the facade**, not only from the technological perspective (e.g. the increasing amount of components) but also in terms of façade geometry; this trend is the high variety of the forms that are used.

The façade becomes more than a passively perceived interface, envelope, and enclosure of the building’s volume. **The relationship between the interior and exterior seems be much more complicated.** Façade represents order, hierarchy, power and prestige. Symbolically it frequently encodes the transparency of the institution itself. The facades thus become



an integral part of the brand and a recognisable feature. As clients' expectations differ, the designer's attention is attracted to the other aspects of the design of transparent facades. The question arises of whether the designers' motivations are more superficial than before (e.g. in the modernist period). The answer is no. The way that facades are designed today simply demonstrates **the change in the sensitivity of both designers and users of architecture**.

Apart from the strict, countable results (as in Section 5) a conclusion requires a wider discussion on the character of the trends and their development. When trends are viewed from a broad perspective, several observations can be formulated and discussed. They apply to both optical/perceptual and geometrical trends.

### 6.1. The desire for depth

Elements of artificial and authentic space stratification are present in almost every analysed optical/perceptual and geometrical trend. In general, the superposition/juxtaposition of transparent layers seems to be the most prominent tendency. Surface iteration – even if not intended by the designer – undoubtedly results in a relief of the façade (2.5D transformation). As Christian Schittich notes: “superimposing layers of various kinds – printing, louvers, etc. – over a glass skin can produce further variations within the transitional zone” [29]. These new elements which constitute the transitional zone could also be recognised as a case of “additive configuration of planes” as it is addressed by A.C. Schultz in her extensive research on architectural overlaying [30]. This observation has been confirmed by many other researchers [26].

The presented research clearly indicates that the *depth of the façade* is what stimulates architects to search for new ways of utilising light-transmitting materials. Pane superposition could be one of the ways to achieve this. “The plastic effect of the facade within its immediate surroundings is essentially created by the offsetting of the individual surfaces within the facade and the resulting shadows” [17]. Nina Rappaport also observes that the “wake of postmodern discourse (...) has created a need for a visual surface simulation and depth” [26]. Paradoxically, many architects – following Mies van der Rohe's statements that glass itself provides sufficient variability to the façade – simultaneously seek additional measures to spatially activate what is commonly seen as a boring flat glazed wall. This is probably deeply rooted in the human appreciation of beauty. For the vast majority of non-expert observers, only the sculptural aspects are recognised as aesthetically pleasing – see the discussion in [36].

The optical/perceptual or geometrical 2.5D transformations enable the stratification of space and the differentiation of planes. Furthermore, the following are examples of effects that were previously absent and are now applied:

- ▶ the connection of spaces visually without providing a bonafide spatial connection thus avoiding the exchange of air that occurs with double-leaf facades,
- ▶ the establishment of space between the multiplied panes,
- ▶ the visual hanging of the element of the façade “in the air” while in technical terms fixing them firmly but enabling them to apparently float while viewed in certain lighting conditions,



- ▶ sculpting with light by creating space which is much more daylight dependent and creates the evident chiaroscuro effect; glass layering seen as a way of building up architectural space, or, as Yoshinobu Ashihara labels it, “space that is created centrifugally” [2].

Another reason for the desire for depth might be the recent change in the function of the façade. In his influential book *Complexity and Contradiction in Architecture* from the early 1960s, Robert Venturi devised a new division of a building into its “volume” and its “façade” [35]. Terence Riley described a very similar mechanism of “shifting the objects meaning from its form to its surface” [27]. This “transformed the building from the monolithic form into the act of communication – a symbol, a message bearer” [20]. thus strengthening the role of the façade itself. The other possible reason indicated by K. Kuma in the interview is that “(...) architects today are more sensitive to the fact that glass is always caught up between the various phenomena that take place on its two sides, and are eager to experiment with a new type of transparency while developing increasingly ambiguous definitions of enclosure” [5]. Kuma also says that as a result “boundaries are blurred not only between inside and outside but also between what is perceived as real and virtual” [5].

## 6.2. Conclusion

The façade has always been seen as more than mere protection against the weather. It has symbolised prestige and power, first with the use of stone, now through glass and technology, which perform a similar function but offers easier and more direct communication. It is no longer necessary to be an expert in Greek mythology – as it was before – to understand the message of the architect. This information can now be communicated more directly and understood by the observer. Media facades present the most recent type of information-infused transparency and, most probably, are paving the path to the future of the façade industry. New technologies also facilitate the communication of new architectural ideas to the audience, thus creating new social values and stronger relationships among people.

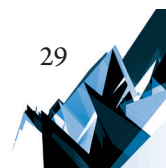
In the brief study of transparency provided above, the main identified trends open the way for a much more extensive study in the future. Judging from the given analysis, the increase in spatial depth of the façade is no longer an emerging trend but has become a well-established practice. However odd it may seem, this trend coincides with an equally strong tendency of both image blurring and transmission interruption. Moreover, in many cases, these trends reinforce each other or blend together. Glazed façade designs have now become more of an art than ever before. The demand for new technologies will stimulate innovation in the field, with a possible focus on smart solutions in the near future.

*The presented paper was funded by the Polish National Science Centre grant entitled: “New trends in architecture of transparent façades – formal experiments, technological innovations”, ref. no. 2014/15/B/ST8/00191.*

*The presented paper contains excerpts (less than 50%) from two conference papers entitled Recent trends in architectural design of light-permeable facades, that was presented on GDP 2017 Conference in Tampere, Finland [9] and Studies on glass facades morphologies presented in the Engineering Transparency conference in Düsseldorf in 2018 [11].*

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