TECHNICAL TRANSACTIONS 5/2019
ARCHITECTURE AND URBAN PLANNING

DOI: 10.4467/2353737XCT.19.050.10574
SUBMISSION OF THE FINAL VERSION: 21/05/2019

Marcin Brzezicki orcid.org/0000-0002-3901-144X
marcin.brzezicki@pwr.edu.pl
Wroclaw University of Science and Technology

Glass protected timber façades – new sustainable façade typology

Fasady drewniane chronione przez szkło – nowa ekologiczna typologia fasad

Abstract

It is increasingly common in the architecture/building industry that glass is placed in the front of the proper façade and serves as a protective layer for the wall behind. This type of external glazing is also used as an envelope for timber façades. External protection by glass slows down timber decomposition and weathering as it screens out potentially dangerous climatic factors like rain, moisture, and frost. Timber-behind-glass is becoming one of the most promising typologies in façade design from a sustainability perspective. The presented paper discusses this new emerging architectural trend. The combination of timber and glass is expected to produce both very durable (long service-life) and simultaneously environmentally friendly façade as timber locks CO_2 into its substance.

Keywords: timber façade, building glass, double leaf façade

Streszczenie

Coraz częściej w architekturze szkło jest umieszczane przed właściwą fasadą i służy jako jej zewnętrzna osłona. Ten rodzaj szklenia jest również stosowany jako zewnętrzna obudowa fasad drewnianych. Szklana tafla spowalnia starzenie drewna i jego degradację, ponieważ eliminuje potencjalnie niebezpieczne czynniki klimatyczne, takie jak deszcz, wilgoć i mróz. Drewno-za-szkłem staje się jedną z najbardziej obiecujących typologii w projektowaniu elewacji z perspektywy zrównoważonego rozwoju. Przedstawiony artykuł omawia pojawiający się w architekturze nowy nurt. Można się spodziewać, że połączenie drewna i szkła będzie skutkowało zarówno bardzo trwałą, jak również bardzo przyjazną dla środowiska fasadą, ponieważ drewno wiąże na trwałe CO_2 w swojej masie.

Słowa kluczowe: fasada drewniana, szkło budowlane, fasady podwójne

1. Introduction

Timber is becoming popular as it is recognized as an environmentally friendly alternative to several high-carbon-footprint building solutions [21]. The reason for this is the fact that biomaterials can efficiently sequester carbon during biomass growth (one tonne of CO_2 per cubic meter of wood [10]) and – after their service life period is finished – can decompose into the environment without any waste. Nowadays timber is also a subject of cutting-edge technological inventions like large-scale lamination (dating back to 1950. in the 20th century but has been constantly improving ever since), different surface treatments (acetylation, furfurylation) [20] and a new range of innovative bio-based façade materials [19].

Nowadays, timber is gradually becoming an increasingly important building material, especially in the context of a CO_2 neutral economy. It is frequently said – also in popular culture – that "timber is the new concrete" [7]. Currently, timber-based building technologies are gradually replacing cement-based technologies, especially in selected structural applications. After a period of tragic fires in 19th century cities, new building regulations were imposed that are now seen as outdated and "inhibiting the construction of taller wooden structures in many countries" [10]. With the advent of new timber treatment technologies – basically glulam and cross-lamination – timber gradually became "economically attractive again and introduced a new dynamic" after strict regulations were dropped [21]. Fire requirements are usually met by (i) the over-dimensioning of timber members, (ii) additional gypsum-board cladding, or (iii) the use of sprinklers.

It is common in architecture for glass to be located in the front of the proper façade serving as a protective layer for the wall behind. This type of external glazed envelope does not necessarily contribute to the building's illumination – glass also faces so-called "blind wall" sections – therefore this façade typology is called *redundant* [4]. This layered type of façade originated as a tool of microclimate regulation in double skin façades – the space between glass and façade is utilized as a thermal buffer that slows down heat exchange – but gradually developed as an independent aesthetical trend in contemporary architecture.

The presented paper discusses a rare combination of the two aforementioned technologies, where glazing is used as **an external envelope for the timber-clad façade**. In this arrangement, glass gains a new function. It slows down timber decomposition and weathering as it screens out potentially dangerous climatic factors like rain, moisture, and frost. This emerging architectural trend for the purpose of the presented paper is tentatively named *timber-behind-glass. Timber-behind-glass* façade morphology originated in façade design. It was the innovative approach to façade design that led to the creation of multi-layered systems dating back to the beginning of the 21st century [16] which then gradually evolved into redundant typologies where glass is used mainly as an external envelope but sometimes clearly as an aesthetical tool [4]. *Timber-behind-glass* façade morphology has not been identified directly in scientific research yet. Therefore no straightforward references can be made so far.

2. State of the art

The use of an external layer of glass is considered to be a tool of formal expression in architecture, as it provides additional depth to the façade. In this context, the issue has been analyzed by numerous theoreticians of architecture. The discussion was initiated by the paper *Transparency: literal and phenomenal* published in 1963 defining so-called "shallow space" as a by-product of façade layer stratification [18]. The most exhaustive review of glass façades is given in the book Engineering Transparency [1] that features papers by architecture theoreticians including Keneth Frampton and Beatriz Colomina. In 2014 one author published an article defining a new type of transparency in architecture named "redundant transparency" [4]. The paper described the emerging creative trend of using light-permeable materials in the spandrel portion of the façade, allowing the materials to "simultaneously maintain their essential property of light transmission and enrich the spatial depth of the façade" [4]. This study of the light-transmitting building envelope in conjunction with raising environmental awareness became a direct inspiration for the presented paper.

An exhaustive study of both glass and timber façades is available and easily accessible. The comprehensive study of glass façades titled *Facade construction manual* is given by Herzog, Krippner, & Lang [8] but the façades are addressed in a general manner, with some remarks on the timber technologies. The same author published a comprehensive guide to timber structure design in architecture, including timber façades and cladding, titled *Timber construction manual* [9]. Both books were published more than 10 years ago.

Knaack et al. published the book *Façades: principles of construction* [12] which become one of the most valuable resource books on the subject of façade design. The book also features intelligent and adaptive double-skin façades. In building performance and engineering, much attention has been addressed to the consideration of timber façade elements like windows and doors especially in the context of the timber service life (Surmeli-Anac, 2013) but no extensive study on timber protected by glass has been done yet.

3. Research methodology

The term "morphology" for the description of the way that the façade is built was introduced by Moloney [15] in the book titled *Designing Kinetics for Architectural Facades: State Change*. The term originated from the field of biology, where word "morphology" is used to describe the spatial relations of the elements of a living organism, while "physiology" describes the way it works. Morphological analysis was a default research method adopted in the presented paper. This method of analysis separates the elements of the analyzed façade system into individual components and classifies them according to the function fulfilled, assigning it a "physiological" purpose – a function. In the presented study, initial morphological studies of timber and glass façades have been based on the photographs, on-site measurements, and inspections performed during field trips and on iconographic materials. All façades featured in the presented photographs were visited by the author. After being distinguished, the morphological features of the façades served as a formulation of an initial typology of *timber--behind-glass* façade systems. In the following chapters, the typology is presented first, while the case studies are described afterward.

4. Typology

It must be stated, that *timber-behind-glass* façade typology is not yet clearly defined in literature and – despite the presented trials – still requires extensive desk-study research to determine all the cases of application. However some typological regularities might be distinguished based on the analyzed case-studies. This façade typology is becoming more and more common and was used – in different settings – by many architects. Timber-behind-glass façade typology is constantly developing, delivering new solutions.

The general spatial organization of *timber-behind-glass* façade typology features, quite obviously, **a pane of glass positioned at the front of a timber façade**, usually – but not exclusively – parallel to each other. Therefore glass forms the external layer and timber cladding – internal. From a "morphological" perspective different possible distances between the timber cladding and glass are possible, so a **cavity of a different** depth and volume is created (Fig. 1). This constitutes a basic typological factor for *timber-behind-glass* façades, that is also closely connected to the air circulation described in detail below. Also, single, or double glazing might be used, as well as different types and geometries of glass. This geometrical diversity is typical for the works of architecture.

From the "physiological" point of view, the typological approach is more complex as featured case-studies might be divided according to many factors/parameters. The most influential one from a functional perspective is **air circulation**. Therefore *timber-behind-glass* façades might be divided into (i) sealed- and (ii) ventilated envelopes.

- In sealed envelopes, the timber façade is separated from the external environment and works in constant microclimatic conditions, usually the same as the building's internal ones. Glazing forms a continuous sealed envelope covering the entire façade or even the whole building. The distance between the sealed glass envelope and the timber cladding might be different, spanning from a few centimeters to over a dozen meters in case of glazed winter gardens and atria (see the previous paragraph addressing different cavity size).
- In ventilated solutions, the timber façade is usually protected only from rain, while air circulation remains possible, therefore the timber is exposed to external temperature, frost and humidity fluctuations. The location of ventilation openings might be different – similarly – as in double leaf façades. The apertures might be located at the bottom and at the top of the façade, or the openings might be regularly scattered over the whole surface. The air flow can be determined by the size of the openings: narrow slits would allow only for limited air exchange while wide gaps would facilitate extensive drafts.

The other factor influencing the functional performance of the façade is the **interior illumination**. Usually, glass covers the entire façade, regardless of the windows located in the internal timber layer. In certain sections, glass is juxtaposed with the so-called "blind wall". This allows the division of sections of the façade into (i) daylight active – permitting daylight deep into the room or (ii) redundant – glazed, but not contributing to the building's illumination. Therefore possible solutions range from daylight active façades, where light penetrates the building through numerous layers of glass, and redundant, where only a relatively shallow space is illuminated, the space between the external glazed envelope and the solid timber-clad wall.

The possible variation of the timber-behind-glass typology is presented in Fig. 1.

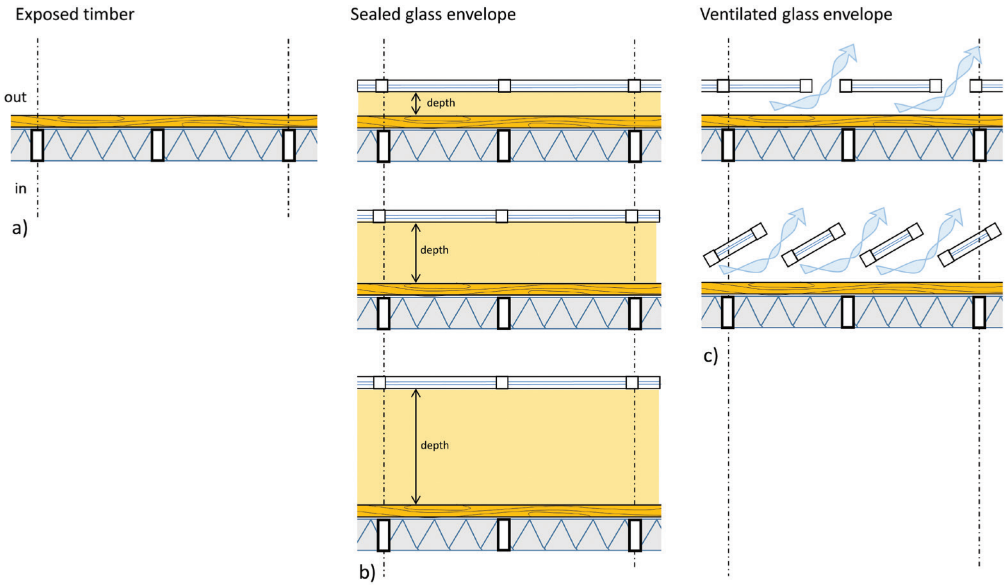


Fig. 1. Schematic diagram of the typology of timber-behind-glass façades; a) shows unprotected timber cladding, b) shows a sealed glass envelope and timber cladding behind. The different depths of the cavity are illustrated by a yellow hue, c) pictures different variations of ventilation strategy: shown in plan and section views. Diagram by author

5. Case studies

Air circulation was assumed to be a basic functional or "physiological" factor defining different types of timber-behind-glass façades. Façade depth and interior illumination are important but seem to be a secondary factor.

5.1. Sealed envelopes

With the increasing amount of timber used for structural purposes, cases of the sealed *timber-behind-glass* façades are becoming more common. Recently, in selected countries, timber gained positive fire ratings allowing for the use of massive exposed laminated elements for structural purposes (e.g. in Switzerland). This relatively novel application of traditional material is considered an advantage in many buildings, therefore architects are eager to expose the natural texture and quality of the timber.

The glazed curtain wall is regarded as a standard material in office buildings. Those two – timber and a sealed glazed curtain wall – are matched to create new formal appeal. These cases of façades start with a relatively small depth of façade cavity – a few centimeters – that is usually defined by standard façade-to-structure solutions. In this typology, one of the most prominent recent case studies is the Tamedia building in Zurich (arch. Shigeru Ban, 2013, Fig. 2) where the timber structure is vaguely seen through the glazed envelope or the FrameWork building in Portland (arch. Works Partnership Architecture, 2015). Another – even more interesting but dating back to the year 2000 – is the GC Osaka Building, also by Shigeru Ban (arch. Shigeru Ban, 2000, Fig. 3) where 50 mm thick timber is used as a "flammable barrier" cladding for steel structural elements [6]. The whole structure is enveloped in a glazed curtain wall from the bottom to the top of the building, clearly showing timber elements through the glass, as glass panes are also used in the spandrel areas of the façade.

Fig. 2. Tamedia building in Zurich (arch. Shigeru Ban, 2013). Photo by author

Fig. 3. GC Osaka Building (arch. Shigeru Ban, 2000). Photo by author

Increasing cavity depth allows for more elaborate chiaroscuro effects. In the well-known case study of Bibliothèque nationale de France (arch. Dominique Perrault, 1989, Fig. 4) timber shutters located directly behind the glass create an impressive sculptural effect of what is basically boring planar glass façade. A similar effect, but not as elaborate, is visible in the case of the Oskar von Miller Forum in Munich (arch. Herzog + Partner, 2000, Fig. 5), where veneer laminated shutters are used to regulate daylight penetrating into the building. Because of the serrated geometry of the glazed envelope itself, the visibility of the timber depends on the observer's viewpoint.

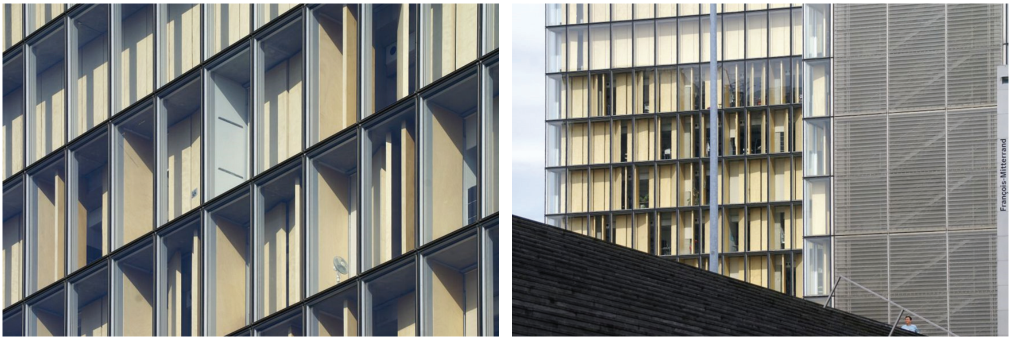


Fig. 4. Bibliothèque nationale de France (arch. Dominique Perrault, 1989). Close up of the tower façade. Photo by author

A large atria allows the observation of the timber façade from a wider perspective. In those cases the enlarged cavity – the distance between glazed envelope and timber cladding – is frequently used as a circulation space, so the users can interact with the timber cladding and enjoy the space. Academy Mont-Cenis in Herne (arch. HHS Planer, 1999), CDU party HQ in Berlin (arch. Petzinka, Pink and Partners, 2000, Fig. 6a) and Oslo Opera (arch. Snohetta, 2007, Fig. 6b) are the most prominent examples of large glazed envelopes that encompass the entire building. They are also called *cloches* (*cloche* – meaning the bell jar in French). *Cloches* are basically used for climatic purposes, but the timber protection comes as an additional advantage. One of the most recent examples in San Sebastian's academic library "Carlos Santamaría Centre" (arch. JAAM, 2011, Fig. 7), where the entry atrium "which opens up like a large mouth, pointing the vertex towards the sky" [5] is clad in timber and externally glazed forming a very high quality of circulation space.

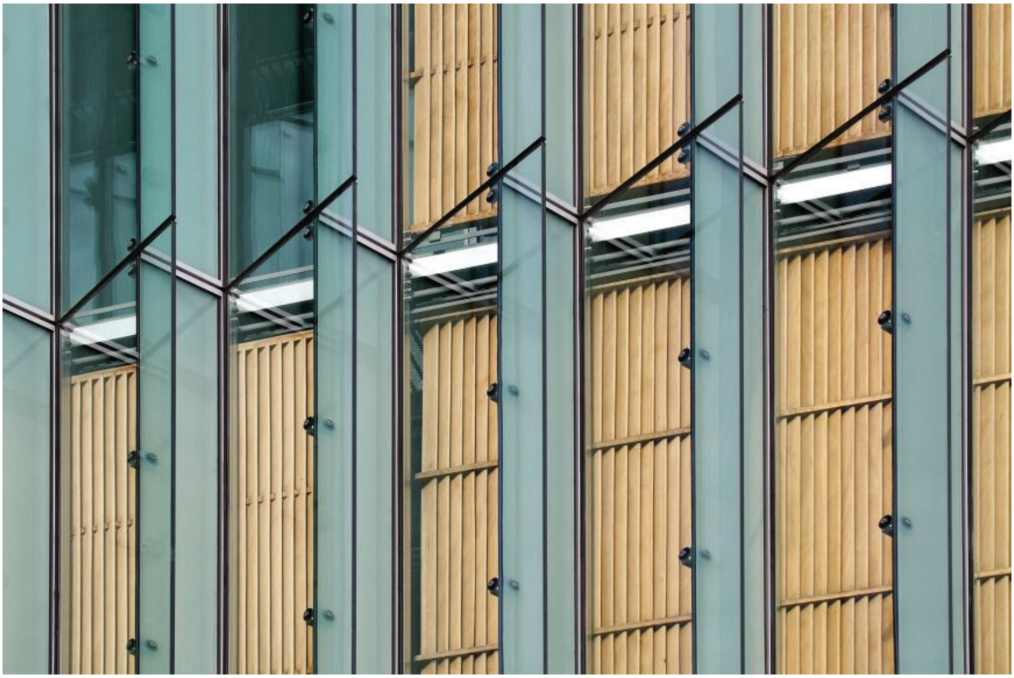
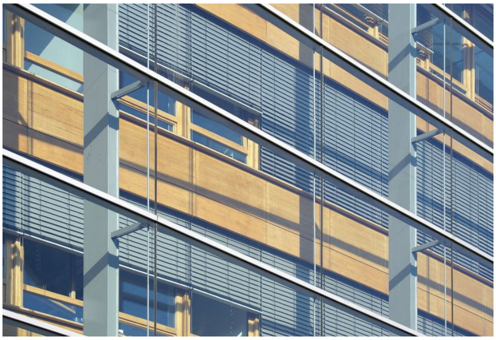


Fig. 5. Oskar von Miller Forum in Munich (arch. Herzog + Partner, 2000). Photo by author



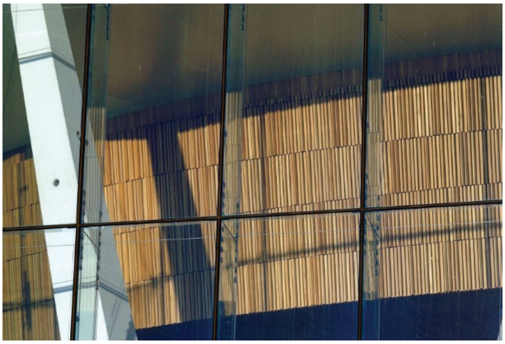


Fig. 6. a) CDU party HQ in Berlin (arch. Petzinka, Pink and Partners, 2000) and b) Oslo Opera (arch. Snohetta, 2007). Photo by author

Fig. 7. San Sebastian's academic library Carlos Santamaría Centre (arch. JAAM, 2011). Photo by author

5.2. Ventilated envelopes

The examples of *timber-behind-glass* applications in ventilated envelopes range from the classic double-skin-façades to complicated bespoke design ventilated envelopes.

The application of timber in double façades usually involves timber-framed internal glazing or the cladding of ventilation openings. This morphology was quite frequently used over the last two decades, with examples in Munich in the Mercedes-Benz Centre (arch. Lai Architekten, 2002, Fig. 8) or in Frankfurt am Mein in the façade of the H1 building of the University of Applied Sciences (arch. Heribert Gies Architekten, MainzVoigt & Herzig Architekten & Ingenieure, 2007, Fig. 9). The timber in the last case-study was clearly chosen as "pleasant material", rather than as an environmentally considered solution [3]. Beyond the aesthetic impression, the double façade was of course used for building microclimate regulation. A similar solution, but with a serrated glass arrangement for a more dynamic air exchange, was designed in an office building located at Hammerstrasse 19 in Düsseldorf (arch. Petzinka Pink Architekten, 2000, Fig. 10) and in the refurbishment of Bayerische Vereinsbank in Stuttgart (arch. Behnisch & Sabatke, 1969 i 1997, Fig. 11). Especially in the latter case, "a double-leafed façade was (...) proposed (...) as part of the building's new climatic strategy. The result is a completely different aesthetic and a building which operates in a more environmentally responsible manner" [1]. Apart from this, the proper façade of the building has been clad with wooden planks.

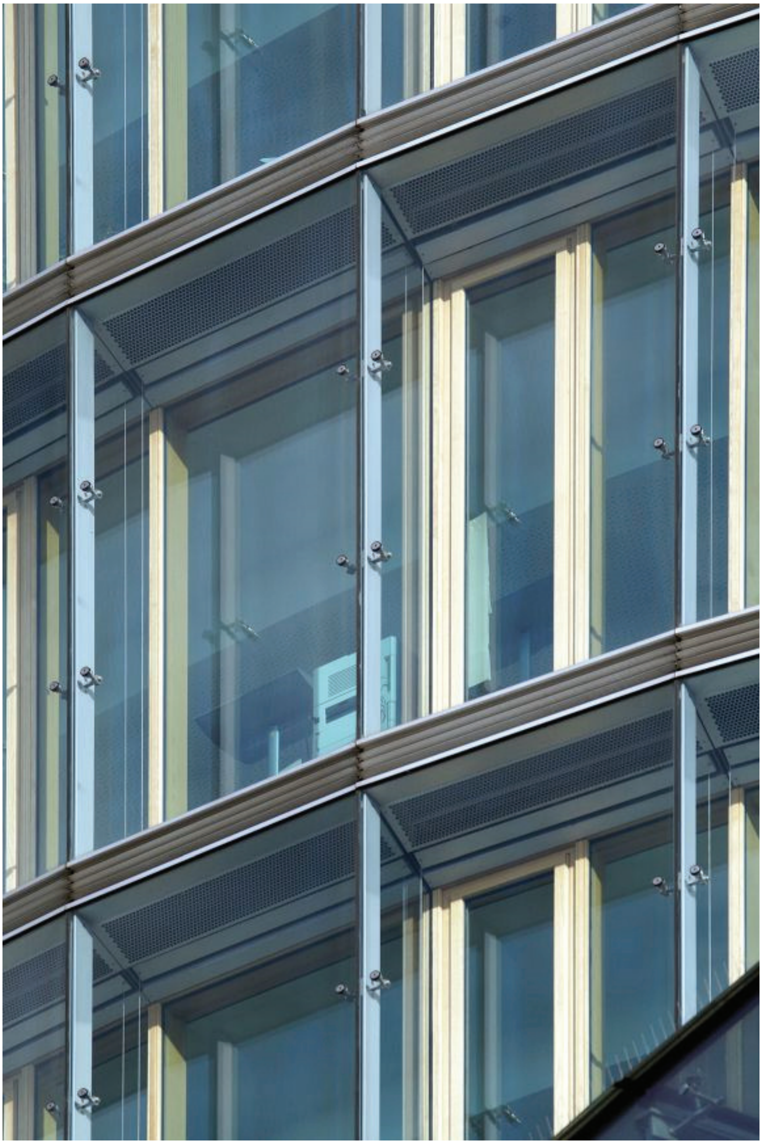


Fig. 8. Mercedes-Benz Centre in Munich (arch. Lai Architekten, 2002). Photo by author

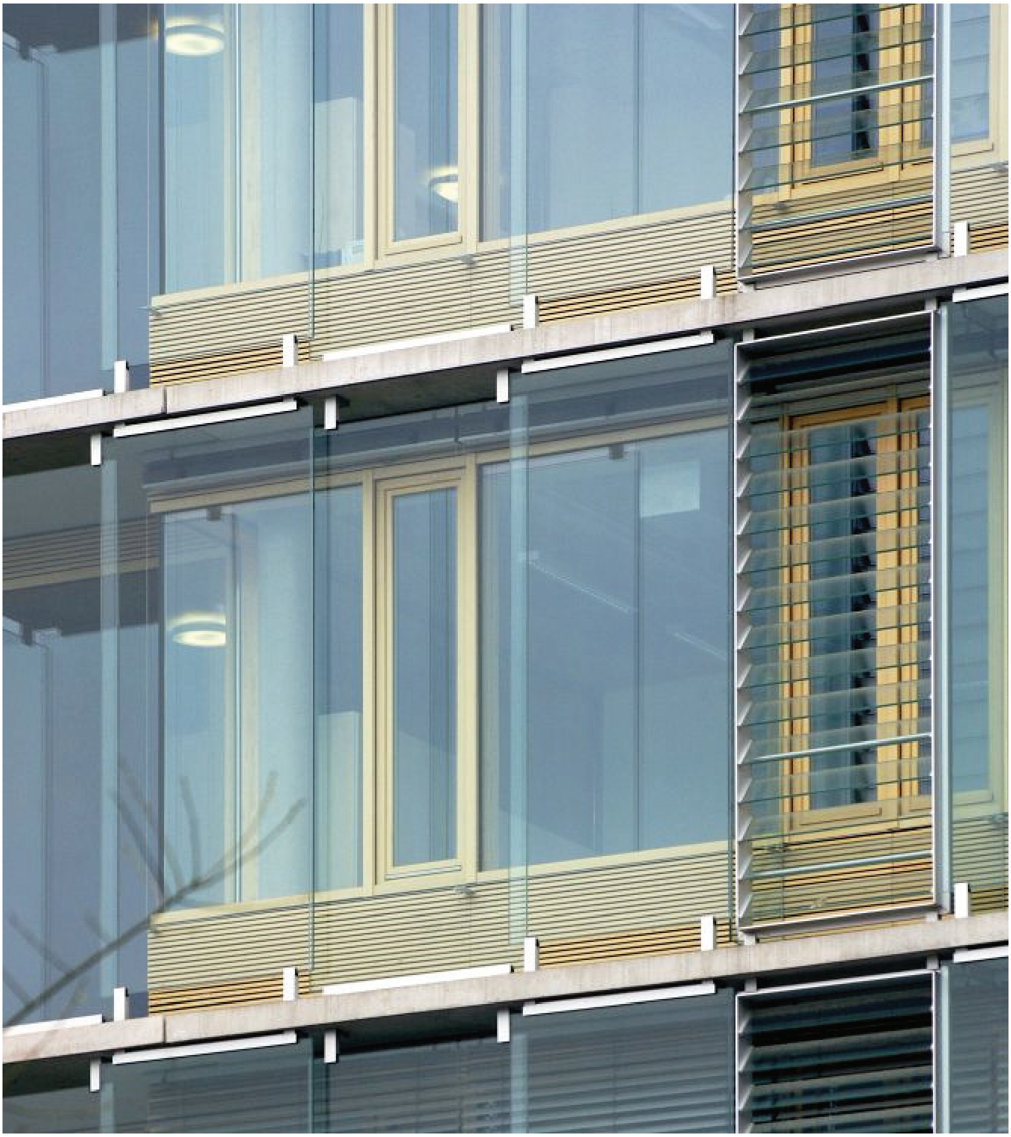


Fig. 9. H1 building of the University of Applied Sciences in Frankfurt am Mein (arch. Heribert Gies Architekten, MainzVoigt & Herzig Architekten & Ingenieure, 2007). Photo by author

Beyond the standard double-leaf façade, some custom designed solutions are present. The most striking is the use of the external glazed envelope in Rheinisches Landesmuseum in Bonn (arch. Knut Lohrer, 2003, Fig. 12). The existing building extension was clad in massive timber elements, that is externally protected by a large ventilated pane façade that is cable hung from above. Thin vertical slits between the panes of glass allow for air exchange between the external and intermediate spaces surrounding the building. Another striking contemporary example of this typology is the research institute in Cerdanyola del Vallès (arch. Harquitectes

Dataae, 2017). The building is designed to function in the hot and humid climate of Catalonia, therefore "architects grouped insulated wooden cubes around four atriums that serve as buffer zones. An economical industrial greenhouse system encloses the entire block in polycarbonate panels that can be opened" [17]. Despite glass not being used, the whole system works as in a classic *timber-behind-glass* arrangement, but additionally, the external layer of the façade is adaptive, as it opens and closes depending on the weather and the season of the year. The internal cubes are clad in 16 mm plywood, which is a relatively fragile material when exposed to external conditions. The application of the external ventilated envelope allows the use of bio-based veneer elements as external cladding.

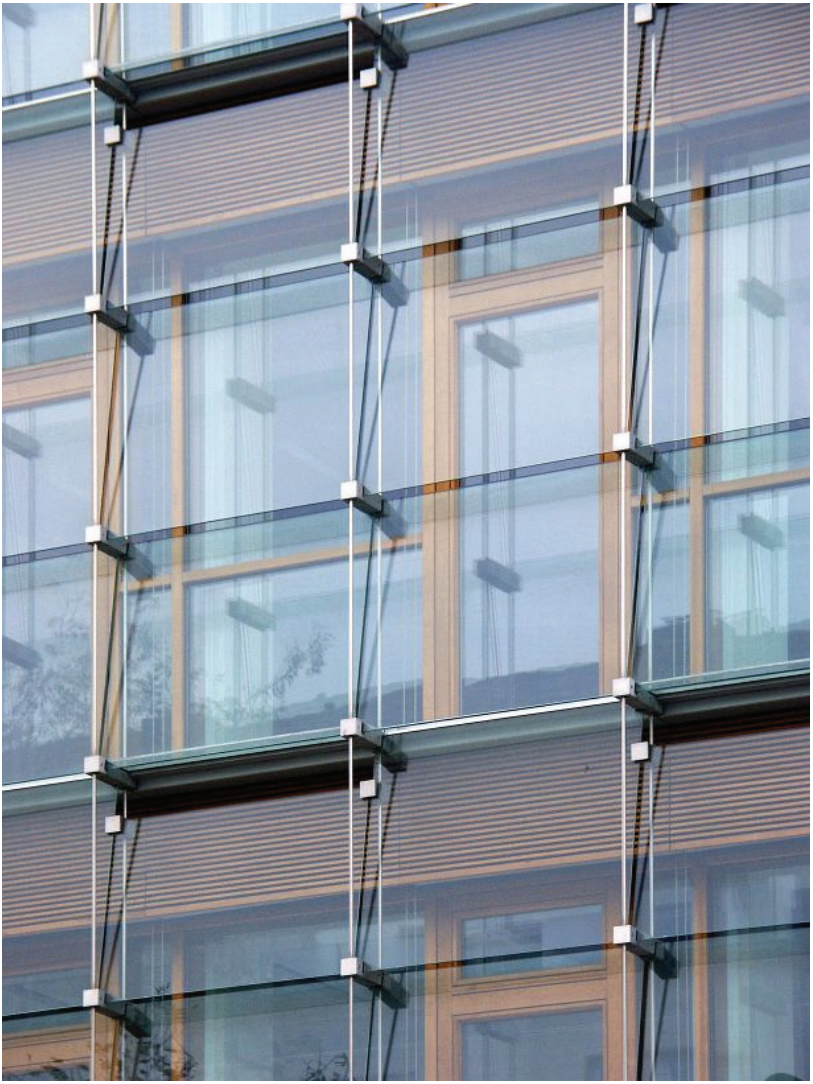


Fig. 10. Office building in Hammer strasse 19, Düsseldorf (arch. Petzinka Pink Architekten, 2000). Photo by author

Fig. 11. Bayerische Vereinsbank in Stuttgart (arch. Behnisch & Sabatke, 1969 and 1997). Photo by author

Fig. 12. Rheinisches Landesmuseum in Bonn (arch. Knut Lohrer, 2003). Photo by author

Another striking and fairly recent example of the ventilated *timber-behind-glass* morphology is a Market Hall in Ghent (arch. Robbrecht en Daem Architecten & Mjose Van Hee Architecten, 2012, Fig. 13). This is a newly constructed roof covering a rectangular event space in the center of the medieval city. The new building replaced the parking lot, that previously existed on the site. A steel roof that is "5-times folded" looks like a capital letter "M" in section view. The load-bearing steel structure is clad with timber. The external timber cladding is covered by the glass tiles from the outside – "a glass envelope protects the wood and provides a soft shine, with the sky reflected, integrated" [14]. *Timber-behind--glass* morphology is used all over the building – in the sloping sections of the roof and on the vertical sections of the wall. Tiny translucent rectangular windows are embedded in the timber cladding allowing light to penetrate inside the building.

Fig. 13. Market Hall in Ghent (arch. Robbrecht en Daem Architecten & Mjose Van Hee Architecten, 2012). Photo by author

6. Discussion

The case-studies presented above feature glass envelope and timber cladding in different spatial arrangements. It has to be clearly stated, that in many of them the external glazed envelope was not deliberately planned as a weather screen for timber. It merely fulfills this function as a by-product of the façade morphology, usually aesthetically or climatically motivated. This spontaneous *timber-behind-glass* architecture trend does not seem to be organized in any considered way, rather it occurred in many places simultaneously over the course of the past 20 years.

Currently, with rising environmental awareness, we can benefit from the already existing trend by examining the cases of application and discovering the new potential of this façade morphology. This new potential lies in the reduction of the building's carbon footprint, both by reducing its energy use (the climatic competent) and by extending the service life of the timber. External glazing serves a protective layer for the timber, but it also decreases the number of chemicals used for timber conservation and reduces the environmental load. Both issues open wide possibilities for future applications.

Based on the given case-studies, it is also clearly visible, that ventilated *timber-behind-glass* systems were used in buildings with ventilated façades, mainly at the beginning of the first decade of the 20th century. Currently, increasing energy performance requirements demand air-tight envelopes to be developed and designed and central air-exchange systems with heat exchangers to be used as postulated by German Passivhaus standard. New requirements do not necessarily mean that ventilated timber-behind glass morphology cannot be used. It still presents a wide range of possible applications if located externally in relation to the air-tight membrane. Glass located as an external protective layer for vulnerable bio-based materials will provide protection and extend the service life of timber cladding.

7. Further research – sustainability perspective

Further research into the subject of *timber-behind-glass* façade morphologies opens a new perspective of both sustainable (timber or bio-based cladding) and durable (glass) composites. Timber and glass used in proper combination will allow substantial improvement of the durability of a bio-based façade structure or cladding, simultaneously defining new features as a result of synergy and compensating their potential drawbacks. An architectural *timber--behind-glass* façade will substantially reduce the timber maintenance effort as the glass will constitute the protective layer for timber [11]. It is also expected that – at the "disposal" stage of the façade's life cycle – the timber will be in a condition to either allow for cascade use (use of timber for other applications, e.g. for particle boards) or for recycling (bio-decomposition of timber). The combination of glass and timber – two materials of very different LCA – might also have a compensatory effect (timber, the lower LCA material will compensate glass, the environmentally higher LCA material). As two materials of very different carbon footprints are combined in one solution, the optimal environmental outcome is hoped to be achieved [13].

The main degradation factors for timber are both abiotic: moisture, UV radiation, as well as biotic factors: fungus and molds. Improved moisture management and air circulation give a solid ground for the assumption that the service life of timber cladding will be comparable to the timber elements used in interiors. Blocking UV radiation might also substantially improve the service life of the timber. Use of selective glazing – UV-selective glass – might slow down the destructive process of timber photolysis [22].

It is also hypothesized that *timber-behind-glass* typology has an insulation potential as the thermal buffer created between timber and glass slows down the heat exchange and facilitates the passive heat capture. A similar mechanism to double-skin-façades is expected, although it has to be taken into consideration that the air exchange rate might influence both the moisture management and the buffer's insulation potential.

8. Summary

Timber-behind-glass morphology emerged mainly as an aesthetic trend, originating from double-leaf-façades at the beginning of the 21st century. It developed independently without any theoretical grounds and was applied by different architects in buildings of different function and formal appeal. Only the recent shift towards low-carbon economy allowed us to realise the sustainability potential of the discussed façade morphology. The generally described trend above still requires research and more detailed analysis. The presented paper is just a first approach to organize and systematize the features of the trend by outlining basic typologies that are observed in the relatively rare cases of application. The potential of the new façade morphology lies in the combination of both glass and timber in a layered arrangement. It brings new capacity for the façade industry and for the sustainability of the built environment while opening up a wealth of new architectural formal experiments.

The field study was performed with the following equipment used for photographic documentation of the buildings: Sigma EX 10-20 mm / 4-5.6 DC HSM lens and telephoto zoom lens Sony 70-300 mm f / 4.5-5.6 G SSM.

References

[1] Bayerische Vereinsbank. Office Building Renovation, https://behnisch.com/work/projects/0029 (accessed 18.04.2019).
[2] Bell M., Kim J., *Engineered transparency: the technical, visual, and spatial effects of glass*, Princeton Architectural Press, Princeton 2009.
[3] Bodenbach Ch., *Doppelte Schale, roter Kern*, Bauwelt, 33/2007, 30–35.
[4] Brzezicki M., Redundant transparency: *The building's light-permeable disguise*, Journal of Architectural and Planning Research, 31(4)/2014, 299–321.
[5] Cultural Infrastructure, https://wearelibrarypeople.com/project/spain/san-sebastian/san-sebastian-academic-library-spain/pr/15696 (access: 18.04.2019).
[6] GC Osaka Building, http://www.shigerubanarchitects.com/works/2000_gc-osaka-building/index.html (access: 18.04.2019).
[7] Golenda G., *Timber Is the New Concrete: 8 Architects Pioneering Laminated Wood. This is the beginning of the timber age*, https://architizer.com/blog/inspiration/collections/nice-curves-sinuous-laminated-wood-framework/ (access: 18.04.2019).
[8] Herzog T., Krippner R., Lang W., *Facade construction manual*, 1st ed., Birkhauser-Publishers for Architecture, Basel–Boston 2004.
[9] Herzog T., *Timber construction manual*, Birkhäuser, Basel–Boston 2014.
[10] Horx-Strathern O., Varga C., Guntschnig G., *The future of Timber Construction, CLT – Cross Laminated Timber*, Zukunftsinstitut GmbH, Frankfurt am Main 2017.
[11] Jirouš-Rajković V., Turkulin H., Dolušić Ž., Štivičić Š., *Light resistance of wood indoors*, paper presented at the 5th International Conference On Wood Technology, construction industry and wood protection under motto "Current trends", 2003.
[12] Knaack U., Auer T., Klein T., Bilow M., *Façades: Principles of Construction, Second and Revised Edition*, TU Delft 2014.
[13] Lippke B., Oneil E., Harrison R., Skog K., Gustavsson L., Sathre R., *Life cycle impacts of forest management and wood utilization on carbon mitigation: knowns and unknowns*, Carbon Management, 2(3)/2011, 303–333, doi:10.4155/cmt.11.24.

[14] Market Hall, https://miesarch.com/work/2782 (access: 18.04.2019).

[15] Moloney J., *Designing Kinetics for Architectural Facades: State Change*, Taylor & Francis Group, Florence 2011.

[16] Pottgiesser U., *Fassadenschichtungen – Glas: mehrschalige Glaskonstruktionen; Typologie, Energie, Konstruktionen, Projektbeispiele; mit Auswahlkriterien und Entscheidungshilfen*, Bauwerk, Berlin 2004.

[17] *Research Institute in Cerdanyola del Vallès*, Detail, 5/2017, 50–57.

[18] Rowe C., Slutzky R., Hoesli B., *Transparency*, Birkhäuser Verlag, Basel–Boston 1998.

[19] Sandak A., Sandak J., Brzezicki M., Kutnar A., *Bio-based building skin (series Environmental footprints and eco-design of products and processes)*, Springer Open, Singapore 2019, doi:10.1007/978-981-13-3747-5.

[20] Sandak J., Sandak A., Riggio M., *Characterization and Monitoring of Surface Weathering on Exposed Timber Structures With a Multi-Sensor Approach*, International Journal of Architectural Heritage, 9(6)/2015, 674–688, doi:10.1080/15583058.2015.1041190.

[21] Schoof J., *Timber Construction Returns to the City*, Detail, 1–2/2018, 10–18.

[22] Timar M.C., Varodi A.M., Gurău L., *Comparative study of photodegradation of six wood species after short-time UV exposure*, Wood Science and Technology: Journal of the International Academy of Wood Science, 50(1)/2016, 135–163.

If you want to quote this article, its proper bibliographic entry is as follow: Brzezicki M., *Glass protected timber façades – new sustainable façade typology*, Technical Transactions, Vol. 5/2019, pp. 5–22.