GEOMETRICAL ASPECTS FOR THE DESIGN OF PREFABRICATED LOAD-BEARING TIMBER-GLASS-FACADES

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ABSTRACT: The considerable increase in the architectural demands for highly transparent and load-bearing structures have recently resulted in the development of an innovative hybrid structure. This article provides a review of design parameters for Timber-Glass composite facades. The design/architectural question, which arose in the project, was how to define the interface of the prefabricated glass-timber-elements with the shell building. Through different design proposals different criteria as admittance of building tolerance and dilatation, load-bearing transfer capacity, maintenance requirements and architectural and design qualities were defined and verified through 3-d-models, prototypes and mock-ups.

KEYWORDS: facade system, building envelope, composite construction, timber, glass, envelope

The article consists of three major parts. Together with a brief introduction to LBTGC, its development, testing and load-bearing capacity in Chapter 2, reader will be introduced to a systemized analysis of design parameters and guidelines of different concepts of LBTGC in respect to their potential applications. And finally the set of design concepts will be presented in Chapter 3. These developed concepts aims to verify potential of this innovative structure as well as its aesthetic appearance and highlight the issues for further investigation.

1 INTRODUCTION

The European countries have to face profound changes in the demand for buildings, e.g. the quantity, the quality, the size, the functionality, the flexibility, the expected lifetime for new or for refurbished buildings have changed. The technical possibilities have multiplied, new materials and new construction methods appeared and finally a set of completely new requirements concerning environmental aspects and criteria of sustainability has to be translated into the built reality.

It is well known that the presence of natural sunlight improves the health of the persons living or working in buildings. Therefore, the possibility to increase the glass surface in buildings through load-bearing composite elements of wood and glass are of high interest. Beside this trend, modern housing and architecture is orientated towards high living quality and low energy consumption. In addition, the aim to reduce CO₂ emission and greenhouse gases means that buildings will have to be designed including solar design concepts and ecological approaches in terms of material. Glass as a facade component provides significant solar heat extraction by its selective transparency. Modern passive houses use this advantage and require solar energy by means of large glass areas and thereby are able to obtain the needed energy without conventional heating system. In respect of climate change great quantities of CO₂ are saved, something that is even more pronounced by the use of wood as a building material.

Facade are more and more becoming integrating structural elements, where such aspects as the regulation of inside-outside environmental conditions or the integration of building systems are major challenges and tendencies in contemporary façade development. As a consequence of energy concerns and efficiency issues, the façade as environmental building interface is becoming a complex organism of environmental and energetic systems and its dependencies.

Nowadays, timber-glass façades are presumed rather an “aesthetic” issue than a synergetic composite. As a consequence, a certain inner logic of combining timber and glass in a more sophisticated and feasible way could be announced, which allows to step much further ahead than just merging to materials independently in a conventional timber-glass construction. What therefore is lacking in recent developments in timber-glass construction is the integration of more structural, load-bearing or force-transmitting aspects of timber-glass facade, which probably could lead to a new concept of structural behaviour of buildings, where besides the stiffening core (escalator and stairway cages), shear wall

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functions and load-bearing capacity could also be transferred to the façade. The consequence on the seismic performance of the building will be a mayor point of interest in this regard.

Two typical horizontal load cases are wind and earthquake. More problematic of the two is definitely earthquake, which implies a rapid high intensity dynamic load onto the building, with the possibility of catastrophic consequences. One of the basic principles when properly designing a building to withstand horizontal loading is trying to avoid plan irregularity as much as possible. This means that a building’s stiffness should be uniform across the whole plan in order to avoid unfavourable torsion effects that otherwise will occur. The large glazed areas in e.g. the southern facades of a passive house would thus present a major problem for the engineers, since the glass areas do not provide practically any lateral stiffness. In those cases, a common practice in seismic engineering is to use steel frame systems, which often complicate the design, as these tend to cause thermal bridges and complicate both the design and the erection.

The contribution of glass areas to the stiffness of a building has traditionally been neglected in design. It has rightfully been so because normal designs used for e.g. windows provide relatively little strength and stability. In fact, the general assumption for such components has instead been that they should not be a part of the load-bearing structure.

With properly designed glass panes structurally bonded to the frame, with adequate material selections, proper design principles for the practicing engineer and sufficiently stiff but yet ductile connection between the glass and the timber-frame assuring a ductile failure in the connection instead of a brittle one of the glass, fixed “windows” could offer a considerable contribution to the resistance of a building during horizontal loading. Due to a ductile failure mode, a capacity design principle can be derived for a general setup of a timber frame in combination with a glass panel.

The research project Load Bearing Timber-Glass Composites (LBTGC), a multinational EU-wide research project in the institutional frame of the WoodWisdom-Net intended to develop a building system composed of timber and glass sections. It included design concepts, feasibility studies and performance assessments of the components in order to improve the overall performance.

2 LOAD-BEARING TIMBER-GLASS FACADES

2.1 Short introduction and basic principles of Load Bearing Timber-Glass Composite (LBTGC)

The load bearing glass joined to a metal sub-structure such as the “Structural Sealant Glazing” type, is already widely used and technologically recognized, as in automotive construction, for example, where its principal use is as part of the structural hull of the car body. In construction, its use is generally infrequent, due to the size of the elements, their long term performance and the compressive tensions produced between the metal and the glass when they expand from thermal difference, a much greater effect in construction than in automotive building due to the size of the elements.

It is for this reason that combining glass with wood has a series of advantages that run from a favourable structural performance for having very similar physical properties (especially a very similar thermal dilatation, [1]) to the possibility of mutual protection between the materials involved (protection for the wood from the elements using the glass on the exterior side and/or protection from the glass to avoid force increases in the contact, using the flexibility and adaptability of wood). Due to the fibre structure base, wood presents good resistance properties to traction while the glass resists compressive forces well, showing a tendency towards break danger when the forces pass certain limits [2, 3]. While with wood, the material acts inversely: under the demands of large loads, the wood tends to deform plastically until it fails completely, maintaining a certain load bearing capacity for a certain time, including in load situations above the calculation studies.

So, the combination of wood and glass results beneficial due to that favourable combination of two materials with very different structural aspects. Lately, composite elements that combine wood and glass have been analysed within several research projects [2, 3] and a number of final dissertations and thesis [1, 4, 5]. As a result, today it is possible to find some building prototypes that include this kind of composite elements [6].

2.2 The application of wood-glass composite elements

The Load Bearing Timber-Glass Composite (LBTGC) enables load transfer of horizontal forces through the glass pane so that the additional bracing elements for wind bracing or stiffening the building could be omitted. This innovative product provides new perspectives and application possibilities:

1. It can provide an improvement of resource and cost efficiency, as the facade as the envelope itself
performs as a structural unit: carries part of building loads and gives additional stiffening for the building;
2. Provides the possibility to substitute conventional facade joints like metal fitting and connector, as the low-tech character of glued connection simplifies the execution of the composite;
3. Allows more efficient and economically reliable integration of active energy strategies, like solar collectors and photovoltaic, into the structural building envelope due to multi-functionality of the element, great level of pre-fabrication and easy access for maintenance.

Possible applications of this load-bearing façade element could include prefabricated homes, greenhouses, as well as structural elements as part of a system that improves existing buildings. Finally the creation of roof coffers and structural facades with integrated thermal and hybrid solar panels can be achieved: these elements could take advantage of the facade attributes of impermeability, security and easy access for maintenance.

3 GEOMETRICAL ASPECTS FOR THE DESIGN OF PREFABRICATED LOAD-BEARING TIMBER-GLASS-FACADES

Many factors are involved when designing with structural glass within hybrid structures, such as issues of constructability, post-breakage behaviour, maintenance and cost associated with replacement of elements. Other criteria, such as functionality, architectural-aesthetic quality and design autonomy, thermal behaviour and environmental impacts are not less important.

A timber-glass composite consist of three structural components: a glass pane, a timber frame and load-bearing adhesive joints, that is holding both parts together.

The glass pane within the composite, used in bracing system, transfers both lateral and in-plane forces.

In the early concepts of structural composite for shear walls, developed by Hamm [7], a glass pane was glued directly on the timber frame construction.

Improving the system for façade application in respect to maintenance, ensuring removal and exchange of damaged elements as well as high degree of prefabrication, a wooden adapter frame was later to be introduced by Niedermaier [8]. This enables prefabrication of the shear wall element in shop conditions, where the adapter frame is glued on the glass pane under certified conditions and thus enables a simplified installation of the whole timber-glass frame on site by screwing the whole prefabricated frame onto the building substructure.

Various developments of the joint detail and the cross-section of the frame were developed and tested and are presented in the following Figure:

Figure 2. Joint system. In the frame angles are block settings that resist compression and thus allow the respective forces to the glass that can be transmitted in a diagonal direction along the glass pane. By restricting the introduction of forces at the angles, the introduction of moments and bending forces in the glass pane are limited. The silicone glue line transfers shear stress forces from dilatation up to a certain point. Source: Author’s image

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The developed assemblies can be classified into two basic concepts: symmetric and asymmetric assemblies. The assemblies where glass pane is positioned on neutral axis (Figure 3, No. 1 to 3) have an advantage of eccentricity free load transfer.

In the asymmetric assemblies where glass is glued onto the exterior of the timber frame (Figure 3, No. 5 to 7) the shear and compressive forces in the pane cause additional bending stresses in the glass, deform the glazing out of pane and increase the risk of buckling. Nevertheless, those systems are the most promising for building skin application since the glue line and the wood are better protected against direct weathering if used as a bracing element in the facade.

The symmetric composites would require further protective measures when exposed to weathering. As well as for composite with a bonding on the edge seal of the IGU (Figure 3, No. 8). A special case is the two-sided arrangement of the glazing analogous to timber-panel constructions (Figure 3, No. 4). Sealing the cavity and keeping it clean and dry is the crucial issue which remains unsolved.
The most straightforward joint design yields from a flat joint on the glass surface running continuously along the pane edges (Figure 3, No. 6). The racking deformation of a shear wall with just a continuous adhesive bond relates strongly to the joint rigidity. In the approach 7 (Figure 3, No. 7) additional blockings at the edges of the pane provide a direct load transfer and activate the compression diagonal in the glass. However, the undefined interaction of the bond line and the blocking – both with different material characteristics – complicates structural design. The cross-section shape becomes more complex. [9]

The technology applied for the transmission of forces between the glass and the wood is made through a specially formed frame that guarantees the mounting of elements of large dimensions given that it only needs to be assembled on site, and at the same time simplifies prefabrication which has been done in studio conditions with standards of cleanliness, temperature and clean environment. While permitting a rapid installation without the need for framing, this system maintains the position of the glass panel under loads in a way that allows for the movement caused by differential thermal expansion, induced load deflection and structure settling.

This element will form part of the building envelope, acting as a conventional load-bearing element that carries load but tends to be opaque.

Within the project 4 different types of connecting the prefabricated façade elements towards the building main construction were analysed.

![Figure 4](image.png)

**Figure 4.** The 4 different connection technologies revised in the study. Source: Author’s drawings.

The main problems the load-bearing timber-glass façade system has to deal with are basically the following:

1. **Tolerances:** How to deal with the dimensional tolerances between shell building and prefab timber-glass façade system, which easily in the case of the shell construction can lead to deformations in centimetres whereas the façade system counts on millimetres of tolerances in manufacturing?

2. **Load-transfer:** How to secure an effective and statically admissible load transference from the load-bearing timber-glass façade to the main building construction? As the composite façade construction is meant to carry vertical and horizontal loads from the building, a reliable and stable bolted connection between façade and shell has to be guaranteed.

3. **Maintenance:** How to enable the replacement of single façade elements in case of damage, end-of-lifetime or client demand independently from the rest of the building envelope? Overlapping profiled frames can prevent or at least render more difficult the easy replacement of single elements. Also a sufficient load-bearing capacity of the remaining elements has to be secured for the time lap of changing the element.

4. **Design:** Due to aesthetical reasons the facing width of the façade profile should be as slim as possible, in order to allow maximum percentage of transparency of the façade when required. On the other hand the aspects for secure load-transfer are demanding certain minimum contact area between shell and façade frame for secure load transmission. Sufficient edge distance between drill hole and outer edge of the timber profile also tends to enlarge the profile width and had to be taken into account.

Four basic solution were been developed. Each one do shows certain advantages and disadvantages in some of the above mentioned aspects.

### 3.1 The simple L-shaped bar

In order to allow the inclusion of a higher shear load in the bond line, it is obvious that the adhesive surface shall be increased and thus it gets lower tensions at the same load level. Therefore, it was considered to use an adapter frame with L-profile instead of a flat adapting frame which was one first solution and to implement a circular bonding.

This special L-profile was used to transfer the compression forces from the glass pane to the adapter frame through the blockings. Thus this turns out to be the simplest solution to connect the façade frames with the building shell. The wooden coupling frame consists of L-shaped plywood profiles which are bolted to the main building construction by clamping strips which holds and fix to frames which its corresponding main construction post. The tolerances on building site can be easily levelled out by increasing or decreasing the distance gap in the connection. The resulting gap has to be closed by a subsequent inserted sealing profile.
As simple as this typology of connecting the different timber-glass-elements might be, a series of weak points in its design has to be mentioned:

1. The load transfer between the elements in vertical as in horizontal direction is difficult to secure as load transfer will only be achieved through gripping force through the clamping strips, which is limited due to the missing direct surface contact and the reduced material properties of the plywood.

2. The open gap gives additional weakness for required weather tightness of the envelope and will be a constant chink in case of neglected maintenance of the façade.

3. Through creeping of the plywood in the contact area with the clamping strip deformation can take place which reduces the fixation of the construction, thus leads to reduced load transfer and load-bearing capacity of the timber-glass-façade.

3.2 The overlapping split bar

There are certain reasons to propose a profile with a flap that allows on the one hand to have only one line of union in the centre line of the post, so both sections can be screwed at the same time. On the other hand, because of the labyrinth seal, this construction provides better security to cap the groove between elements due to the displaced geometry.

Also the overall visible frame width can be reduced since the two parts of the profile can be fixed with the substructure with a single line of cantered fixing points. Anyway the minimum distances between the edge of the profile and angularity edges of the wooden profile must be respected.
Some drawbacks are to be stated:

1. Dealing with building tolerances is very limited due to the geometrical boundaries of this typology. In order to secure sufficient load transfer between the elements, the resulting gap edge to edge has to be partly infilled (in the area of the blockings) with a pressure-resistant material.

2. As a result of the winding geometry of the profiles there is a certain risk of material fracture in the grooves of the flanks which possibly can be reduced by a concave moulding in the covings of the profiles. Nevertheless there exist a danger that the profile crack in situation of high stress.

3. Replacement of single elements is difficult because of the overlapping geometry of the profile. Replacement of an element also requires to dismount adjacent vertical and horizontal element.

### 3.3 L-shaped couple bar with tooth profile

Another possibility to reduce the width of the frame-bar is the tooth-profile: the tooth profile allows centring the screw line and thus reduces the overall necessary width of two frame elements being connected to the post. Mayor advantage of this solution is the trouble-free solution to replace single elements of an existing façade, contrary to the case of the overlapping split bar solution we saw before. In relation to sealing quality of the joint, this solution provides an open fugue, which has to be sealed weather-proved.

This solution is in principle applied in the UNIGLAS | FACADE®, developed by our investigation partner Petschenig Glastec GmbH and Otto Chemie.

![Figure 8](image8.png)

**Figure 8.** Overlapping split bar solution. Drawing and 3d-study done in Department of Structural Design and Timber Engineering (ITI). Source: Author’s drawings.

![Figure 9](image9.png)

**Figure 9.** Couple bar with tooth profile used in UNIGLAS | FACADE® TGC façade. Source: Author’s image.

![Figure 10](image10.png)

**Figure 10.** Section of UNIGLAS | FACADE® TGC system. Generally, it consists of an L-shaped profile of birch plywood, which are peripherally mounted on all four glass edges and screwed evenly to the support structure. [10]

There are two mayor modifications proposed, basically related to the invention of blockings in the inner edges of the frame which increases load transfer capacity of the composite element:

1. The profile is L-shaped which allows to establish a direct contact zone of the timber profile with the glass edge, necessary to transfer the diagonally directed pressure forces into the glass pane. The L-shaped form also helps tighten and seal the fugue between
glass and plywood. In contrast to the UNIGLAS © FACADE© coupling frame which is a flat profile where the glass pane is glued with its edge surface to the plywood frame, the L-form enhances direct pressure force transmission in the composite element.

2. The UNIGLAS © FACADE© doesn’t use blockings to insert loads to the glass pane. In our proposal these continuous eight reinforcements in the four corners of the frame are directly milled in the plywood profile. In order to secure an equal and sufficient load transfer from façade to building shell, the part of the blocking area of the profile is kept straight, thus avoiding asymmetric design and in consequence an unequal distribution of plywood material in both sides of the frame.

![Figure 11. Proposed variant: The L-shaped profile provides a direct contact zone of the timber profile with the glass edge, necessary to transfer the pressure forces through the blockings, which are directly be milled in the plywood profile. The section of the blocking zone of the profile is kept straight, in order to reinforce the load transfer capacity in these highly stressed part of the frame. Source: Author’s drawings.](image)

Due to the tolerances in the float glass production, resulting from cutting, processing and workmanship, which for instance in the case of glass formats of 2000mm and nominal thickness of the glass till 12mm results in 2.5mm deviation from normal conditions [11], it is required that the blockings are able to compensate that deviation through adaption of geometry.

![Figure 12. The section of the blocking zone and the changing geometry of the profile in the corner edges of the frame shown in detail. Highlighted in yellow shows the inlays made out of hard-wood or high-strength plywood to compensate glass-pane tolerances. Source: Author’s drawings.](image)

Whereas in previous studies this was done by using a quick-setting-mortar which fill in the resulting blank between the edge of the glass pane and the coupling frame, here specific inlays made out of hard-wood or high-strength plywood are to be inserted in order to adapt to the actual size of the glass pane. In order to do so, the blocking inlays should differ in width at 1mm intervals equally, hence filling the gap and activate load transference through the glass pane. To make sure that no tensile forces can be transferred to the glass pane, no contact bonding between blocking and glass edge is provided.

3.4 L-shaped couple bar with tooth profile and coupling component “disk”

This solution is based on the previous one with the only modification of providing a further coupling element: a bending-resisting disk which improves the load-transfer of moments in the edges of the frame towards the shell construction.

![Figure 13. Connecting element: CNC-milled plywood disk which improves the load-transfer of moments in the edges. Source: Author’s drawings.](image)
In the disk connector are integrated the blockings which transfer the pressure load from one façade element to another. Due to its specific geometry this element provides a better flexural strength in the junction point than in the previous solutions. In addition the massive plywood disk of around 200mm diameter and 22mm thickness provides much higher stiffness against horizontal displacement.

Likewise these disk-like fixing devices facilitate the mounting of the façade elements as it has to be positioned and assembled first on the shell construction and thus serves as an alignment for the single façade modules.

Even though it wasn’t the main aim of the recently finished investigation project to account for product development, it would be a stimulating task in future to apply the studied results into a real-scale prototype and to transform the results in the long run into “real-world” market products, a new LBTGC-Façade System. The combination of wood with glass offers a new opportunity to build highly transparent buildings with lightweight, ecological, aesthetically attractive and even load-bearing façade systems.

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6 References


