Load Bearing Timber-Glass Composites: New Opportunities for Turkey

HALET ALMILA ARDA BUYUKTASKIN*, GUZIDE ASLANKAYA AND MORVARID DILMAGHANI
Department of Architecture, Istanbul Technical University, Taskisla Campus, 34437 Istanbul, Turkey
**Corresponding author: almila@itu.edu.tr, +90 212 2931300 / 2284*

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Abstract

Nowadays, timber with its natural appearance and glass with its transparent characteristics provide new opportunities for architects and engineers in construction as load-bearing systems. The main aim of presented research is to introduce timber-glass composite structural elements as new products to the Turkish market. A questionnaire method has been evaluated with the timber industries with the aim to gather market insight into the production of timber-glass components in order to query the knowledge of the timber industries about the suitability of timber-glass composite as a structural element. In line with this research, potential architectural design applications called pilot projects are presented by using timber-glass composites as load bearing elements. The pilot projects throughout will provide insights into the practicality and applicability of the developed composite systems in creating different design and application solutions. According to the respondents of the questionnaire, the timber industries in Turkey indicated that load-bearing capacity of timber-glass composite structural elements can be advantageous and the new structural element will be probably able to compete with other alternative structural elements in Turkey.

Keywords: Composite systems, timber-glass composite systems, questionnaire, pilot project, timber industries

Introduction

Nowadays, besides the architecture, the building must also consider ecological characteristics alongside the construction forms and the engineering criteria of materials. In the light of this consideration, the future role of timber in buildings needs to be re-examined. Additionally, it is known that the modern architecture demands even more transparency in building elements as interior elements like shear walls, beams or ceilings. Since glass has an utmost advantage in transparency, it can be utilized in buildings not only as a window element but also as a load-bearing structural material.

Timber-glass composite building elements may be a good alternative giving architects and engineers new opportunities for novel load bearing systems.By using load bearing timber-glass composite elements, it is possible to use timber and glass together and thus adding transparency as a quality to a natural, ecological material. The composite elements combine the best of the characteristics of two different materials for a common purpose. In structural terms, the timber assumes good bending behaviour, being ductile to compression, whereas the glass presents a very positive result in terms of the compression force (Pequeno and Cruz 2009). The main characteristic of this composite system is that timber provides ductility and glass offers resistance and stiffness. The bonding system is also very important for the strength of the composite system (Cruz and Pequeno 2008). The adhesive provides strength and flexibility. That is the path to its structural utilization necessarily when subjected to transmission of heavy loading (Cruz et al. 2007). Furthermore, by the research project of the Pontifical Catholic University of Chile, industrialized products based on timber-glass composite elements are developed responding to the structural requirements, climate demands, fire protection and humidity. Its position within the building can vary; it can be integrated into the facade, the roof, in the interior as a partition wall and even as a floor element (Saleh Pascha 2014). Recently, composite elements that combine timber and glass have been analysed within several research projects (Winter et al. 2010, Eriksson et al. 2013) and a number of final dissertations are presented (Blyberg 2011, Neijbert 2013).

Moreover, a prototype of a load-bearing timber-glass composite facade has been developed and a simple demonstration object has been constructed. The main idea of the prototype is to produce a showroom as an outlook on how a facade made with such building components could be carried out, and what it could look like in a real building. The interfaces between load-bearing timber-glass composite elements to the roof and to the floor has been designed.

Since the main design idea was to demonstrate the load bearing capacity of the timber-glass composite elements, the design was created to make this property evident to any visitor. Therefore the facade elements were installed in a tilted manner, forcing them to take horizontal loads of the building (Nicklisch 2015), (Figure 1). Another example for which current trends in modern architecture are focused on minimizing the boundaries between the external environment and interior of the building is given in Figure 2. This requires a continuous increase of the amount of translucent surfaces allowing natural sunlight to enter the building not only in facades but also as interior elements (Kozlowski 2014).

Figure 1. Completed demonstration project: timber innovation showroom in Germany

Figure 2. Pilot project with hybrid timber-glass load bearing components

Apart from these works, an international research project was also carried out as a part of European Project, EU WOODWISDOM-NET research programme with participants from Austria, Brazil, Chile, Germany, Slovenia, Sweden and Turkey (Istanbul Technical University, Asst. Prof. Dr. H. Almila Arda Buyuktaskin as Turkey Project Coordinator). The WoodWisdom-Net International Research Programme is focused on timber material science and engineering in forest-based value chains. Scientific and the Research Council of Turkey (TUBITAK) was the national funding organisation of Turkey. Project title is "Urban Wood, timber based construction for multi-storey buildings concerning the potential of adhesives bounded timber-glass composites as load bearing beams, columns, stiffening panels" with the project acronym "Load Bearing Timber-Glass Composite Structures (LBTGC)". The three-year project that ended in March 2015 comprised investigations relating to the mechanical behaviour as well as architectural aspects on timber-glass composites in load-bearing structures.

This paper specifies the possibility of using timber-glass composites as load-bearing elements including a questionnaire to introduce this new product to Turkish market with the aim of its further commercialising. Issues affecting the perception of prefabricated timber elements were identified through interviews with small, medium and large-sized timber companies in Turkey, including residential builders. The research has given a focus for understanding the attitudes of the largest manufacturers to use timber-glass composite elements. The study also presents some pilot projects designed by the use of this new product. It is believed that the initiation of pilot projects will provide valuable insights into understanding the practicality and applicability of timber-glass composite system, and help create different design and application solutions.

Materials and Methods

In the following sections, firstly timber-glass composite material is introduced; secondly, the methods including questionnaires and pilot projects are investigated.

Materials

The timber-glass composite element, which is considered in this study, consists of birch plywood, tempered soda-lime glass and a two-component silicone adhesive. The cross-section which is planned to be used in pilot projects is given in Figure 3.

Plywood being a glued assembly of thin sheets of timber called veneer has also many of the advantages and properties of solid timber such as light weight, ease

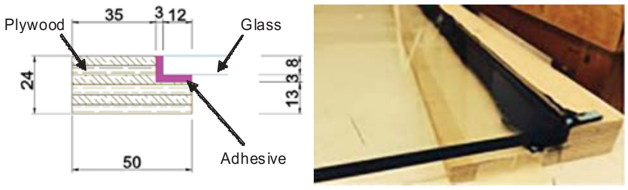

Figure 3. Cross-section of the timber-glass element (units are in mm)

of working, high strength-to-weight ratio, and ease in fastening (Faherty and Williamson 1988). 24-mm thick birch plywood manufactured according to BS EN 636-2 is planned to be used. This type of plywood is appropriate for use in protected external applications as defined in hazard class 2 (BS EN 335-3) e.g. behind cladding or under roof coverings and for interior situations where moisture conditions raised above the hazard class 1 level. It is also capable of resisting weather exposure for short periods of time. Plywood panels, made of cross-bonded 1.4-mm thick veneers, were sanded on both sides and their surfaces were smooth, hard and durable. According to EN 314-2, each glue lines are to satisfy two criteria that are the mean shear strength and the mean apparent cohesive wood failure for all bonding classes. Furthermore, plywood is split-resistant and has excellent shock absorbancy characteristics. Like timber, plywood is an insulator and has low thermal conductivity when it is dry. The transverse arrangement layers of plywood, prevents the timber from moving and gives the panel the necessary strength and stability in every direction. Therefore, it is particularly suitable for reinforcing timber structures and load bearing walls (Steiger 2007). It is known that when applying pressure on the timber fiber direction, the hollow cells compact in a permanent way, this is called plastic behaviour. Tension causes elastic deformation, it strains, but returns to its original shape when stress is released. Timber is the weakest when loaded perpendicular to the fiber orientation – either in tension or compression– independent on the timber species, this is a significant factor. For example, yield compression strength for birch, is 56.3 MPa in parallel to the grain (longitudinal) and 6.7 MPa in perpendicular (tangential or radial) to the grain direction. Shear strength in plane of the fiber direction is relatively low due to the phenomenon that fibers will roll over each other. In comparison to steel (210 GPa) and concrete (30 GPa), timber is a soft material. Birch timber has an elasticity modulus of 13.9 GPa (Forest Products Laboratory 2010). The elastic behaviour of birch plywood is extremely linear in both tensile and compression modes, until a certain stress level is reached (Vischer 2015). As mentioned previously, the type of plywood, which is considered for this research, is birch. Birch plywood is characterised by its strength, stiffness and resistance to creep. It has a high planar shear strength and impact resistance, which makes it especially suitable for heavy-duty floor and wall structures. It has good surface hardness, damage and wear resistance. Properly surfaced and edge sealed birch plywood also offers excellent weather and moisture resistance (FFIF 2002). The birch plywood board is classified as one of the most popular types of plywood due to its superior mechanical properties and beautiful appearance. Birch plywood is composed of thin veneers of birch cross-banded and used in areas where a balance of cross grain strength is desired, or where the use of plywood can save installation time with adequate performance (Lieblein et al. 1982).

For this research, tempered glass, which is four to five times stronger than float glass is used. One of the reasons of this choice is that when glass panels are loaded, the pre-compressed surface of tempered glass leading to the surface retains compression and significantly reduces its brittleness (Bength 2005). Furthermore, the large amount of energy stored in glass causes a tempered pane to break into many small glass dices. The fractured pieces may remain together and if they fall out could not lead to injury (Wurm 2007). Tempered glass having safer breakage performance was chosen under the consensus of the project partners. And also, as the tempering process of glass does not change the surface characteristics of the glass, material is ready for the adhesive application.

The two-component silicone adhesive used in the research is sealant Ottocoll S660. It is specifically developed for timber-glass composites. The main characteristics of this adhesive can be enumerated as follows: high stability bonding, very good temperature and moisture resistance (Otto Chemie 2017). Silicone type adhesives allow greater indexes of flexibility, thus assuring the needed structural mechanical resistance and load distribution ability. This adhesive is chosen not only for its functional and structural reasons but also for aesthetic reasons (Cruz, Pequeno 2008). Furthermore, as silicones are elastic even at low temperatures and adhere very well to glass and common frame materials, they are extremely suitable for structural glazing systems (Wurm 2007).

Methods

In this study, the aim is to discover the attitudes and expectations of timber industry in using timber-glass composite elements in building constructions. For this purpose, surveys as a data gathering method is chosen to collect, analyse and interpret the views from target audiences. A questionnaire comprising twelve multiple-choice questions, as given in Table 1, was used to elicit ideas and behaviours, preferences and attitudes. The survey was conducted with involving thirty timber companies in

Table 1. The timber questionnaire

Question number	Questions to answer
1	What is your first impression about the usage of timber-glass composite as load bearing system?
2	What is the actual use of the timber material?
3	Which kind of tree can be more resistant as load bearing element?
4	How would be the resistance of timber-glass composite considering its chemical and physical characteristics?
5	If the timber is used in load-bearing system, will it be necessary to preserved or not?
6	How will be the strength of plywood as a load-bearing element?
7	Will the timber-glass composite as a structural element be suitable for the construction of residential buildings?
8	For which types of buildings timber-glass composites can be considered as a good choice?
9	In your opinion, will the new material be able to compete with other materials?
10	Which plywood standards are used by your company?
11	What are the sources for supplying plywood in Turkey?
12	What is the willingness of the potential customers to use the new product?

Turkey through different media such as: e-mail, telephone, personal interview (face-to-face talk). There are a great number of timber companies in Turkey, around half of those specialized in the field of manufacture of timber and timber-glass products. At the moment the start-up of new companies is more intense in the furniture manufacturing sector. There are other companies such as producers of hard wood, soft wood, timber for wood work and construction, timber-based panels, plywood and also producers/suppliers specializing in timber treatment and protection. The people interviewed in the mentioned companies were in general graduates from the forestry programmes of the universities. They have a good knowledge of different technological processes, new products and their development procedures. In addition, interviewed companies staff has a considerable level of experience related to the product construction and design processes, the manufacture of pilot samples and testing them. To help with the survey, some pilot projects using timber-glass composite elements in the assembly of their structural system, were also investigated.

Results

The answers given to each question of the timber questionnaire are summarized below, referring also to the figures.

The first question to the timber industry was about determining the first impressions about the usage of timber-glass composite as load bearing system. As it can be read from Figure 4, 59% indicated that load-bearing capacity of timber-glass composite structural elements can be advantageous, 13% of them specified that the system can be adequate. 21% of the respondents mentioned that the load-bearing capacity of the system can be weak since it can be affected by the behaviour of glass and ductile property of the timber material (Figure 4).

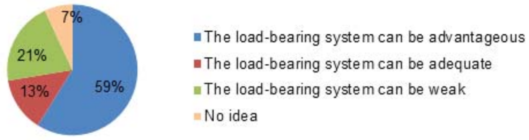

Figure 4. Distribution of answers on the first impression on timber glass composites

Second question was to query about the actual use of the timber material. Figure 5 illustrates that 57% of timber material in construction is used as covering elements, such as; floors, roofs, ceilings and as the interior and exterior wall cladding. The percentage response for the use of timber as load-bearing element (like column, beam) and as joinery element (like window, door and decorative items) were equal. 11% of the respondents specified that timber material can be used for all options (Figure 5).

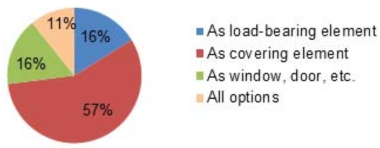

Figure 5. Distribution of answers on the actual usage of timber material in Turkey

Third question focussed on finding out the kind of tree which can be more resistant as load-bearing element. 40% of the respondents chose pine (a type of coniferous species) as a load-bearing material as being more resistant than other types of trees. 29% of answers showed that spruce, as another type of softwood, is also resistant. Also, 17% of the respondents replied that plywood that is obtained from birch tree (a type of hardwood) has very high resistance. They also emphasized that the advantage of the birch tree was its fast of growth compared to other timber species. 14% of the respondents selected other options such as oak, iroko and teak trees (Figure 6).

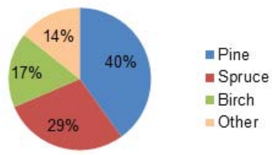

Figure 6. Distribution of answers on the question related to the more resistant type of trees

The fourth question queried the knowledge of the timber industries about the resistance of timber-glass composite considering its chemical and physical characteristics. Figure 7 illustrates that 53% of the respondents specified that timber-glass composite element as a structural element has high strength. Some of the timber companies mentioned that the element can have high strength as long as the torsion and buckling of the glass are controlled.

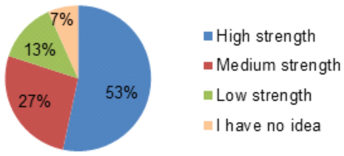

Figure 7. Distribution of answers on the strength timber-glass composite

The goal of the fifth question was to determine whether the timber used in load-bearing system has to be preserved or not. Unlike the mineral materials like masonry and concrete, timber as an organic material is subject to damage from fungi and insect. 26% of the respondents specified that all preservation methods to prolong the life of timber can be used together and almost 21% of them specified that the methods, as specified in the Figure 8, can be used separately. 9% of companies mentioned that impregnating would not be necessary in very high-quality products (Figure 8).

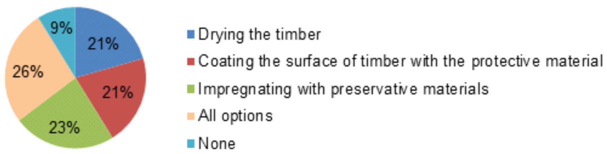

Figure 8. Distribution of answers on the methods for preservation of timber

The sixth question was to query the strength of plywood as a load-bearing element. According to the survey, 59% of the respondents indicated that plywood, which is used as a structural element in load bearing timber-glass composites can have a higher shear strengt compared to even solid wood. 24% of them specified tha the strength can be medium (Figure 9).

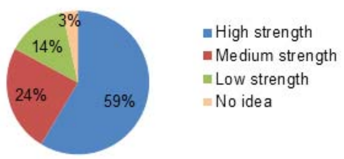

Figure 9. Distribution of answers on the plywood strength as a load-bearing building material

The seventh question tried to determine the suitability of timber-glass composite as a structural element for the construction of residential buildings. 62% of respondents stated that usage of timber-glass composite structural element can be an appropriate solution for residential buildings but 14% of them found it unsuitable and stated that it should be subject to testing before use (Figure 10).

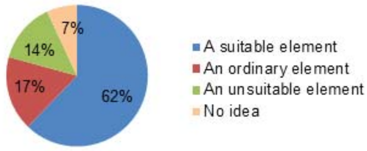

Figure 10. Distribution of answers on the using timber-glass composite elements for residential buildings

The eighth question explored the building types for which timber-glass composites can be considered as a good choice. 40% of the respondents marked museums among other proposed options. 26% of them specified that timber as an ecological material combined with glass can be used in all types of construction. Additionally, to the proposed options, respondents mentioned that timber-glass composite material can be also advantageous for schools, villas, sport halls, office buildings and places like dormitories (Figure 11).

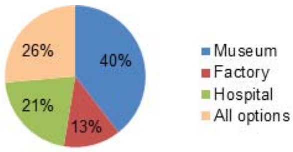

Figure 11. Distribution of answers on using timber-glass composite element for buildings

The ninth question queried the competition ability of the new material with other materials. 39% of the respondents stated that this new structural element will be able to compete with other alternative structural elements in Turkey. 29% of them specified that potential customers would require time and experience with the product. On the other hand, 21% of them mentioned that as timber needs preservation and maintenance, it would be difficult to compete with other products in use for similar purposes (Figure 12).

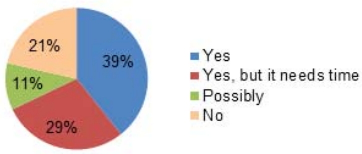

Figure 12. Distribution of answers on the competition of timber-glass composite with other materials

The tenth question explored the plywood standards used by the timber manufacturers. It was seen that 47% of respondents used almost all of the specified standards. Furthermore, 35% use other standards such as EN 1995-1: 2004 ‘Design of Timber Structures’, ASTM D1037 ‘Standard of Test Method for Evaluating Properties of Wood-Base Fiber and Particle Panel Materials’, DIN 1052 ‘Design of Timber Structures -General rules and rules for buildings’, TS 446 ‘Coniferous Sawlogs’, and E1 ‘Certificate of conformity’ (Figure 13).

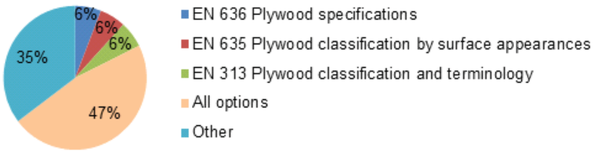

Figure 13. Distribution of answers on the plywood standards in use

The eleventh question queried the sources for supplying plywood in Turkey. 16% of the timber industries in Turkey stated that they provide plywood with in house production, whilst 40% imported the material. It was also found that 32% of the respondents bought raw materials from local companies and improved the product quality prior to selling. 12% of them have no resources for plywood production (Figure 14).

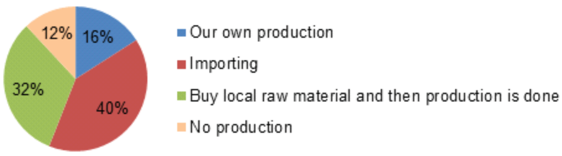

Figure 14. Distribution of answers on the plywood supply in Turkey

The last question determined the willingness of the potential customers to use the new product, 52% of the respondents stated that they support the use of this new structural element upon the availability of the product as a reliable construction element. However, 38% of them stressed the critical importance of testing. 10% of the respondents expressed that they do not support this product due to the brittle behaviour of glass (Figure 15).

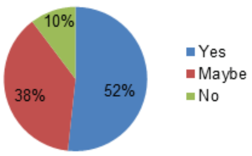

Figure 15. Distribution of answers on the question related to supporting the new product

To highlight the advantages of timber-glass composite structural elements, pilot projects designed by two M.Sc. architect students, being also the co-authors of this paper, are developed. These pilot projects are some architectural designs to attract attention to the timber and glass industries, letting them imagine the possible joining of two materials and visualize the possibility of practical applicability for the new developed composite systems. Possible applications of this innovative product could be in the specific areas of small public spaces such as bus stops, resting places and bagel kiosks.

First pilot project is a bus stop, which is a good example to show the benefits of using timber-glass composite as load bearing element (Figure 16). It is designed for passengers and bicycle parking. Its total area is approximately 10 m^2. It can be used for every district in the city. The bus stop has four glass facades, which provide transparency and an aesthetic appearance. Timber slats are used in faēades for visual effects. Timber-glass roof is extended to protect passengers waiting outside. In addition, a bicycle parking area and flowerpots made of timber are designed to complement the design.

Figure 16. The design for a bus stop

The other design project is a resting place for academic members, located on a hexagonal-shape platform in the campus of Faculty of Architecture, Istanbul Technical University, with nearly of 65 m^2 of area (Figure 17). The design, for this purpose, consists of different timber sections. The architectural design expands and shrinks as an accordion.

The third design is a kiosk to sell bagels (Figure 18). Some finished products like timber table compatible to the design are also used. This ecological and transparent design can be used at city squares.

Discussion and Conclusions

Among the different timber systems, the load-bearing timber-glass composite system, which is discussed

Figure 17. The design for a resting place

Figure 18. The design for a bagel kiosk

in this paper, can be considered as a suitable option for Turkish market, where the consumer is looking for something different in terms of appearance and performance. It is seen that timber-glass composite structural elements combine the advantages of both materials. Combining glass with such ductile material as timber improves the structural performance and expands the scope of applications beyond the initial limits.

It is seen that the use of timber-glass composite in the pilot projects provides some advantages like aesthetic value, environmental friendliness, lightweight structure, architectural expressiveness, lighting and effective shadowing in several directions, prefabricated and easy assembled systems. An important advantage of glass-timber composites is that the manufacturing of these structural elements does not demand heavy industrial facilities. On the contrary, these composite elements are produced by fast and low power consuming techniques. The suitability of glass-timber composites to ecological structures also empowers the value of these systems. Furthermore, those composite elements enable a more efficient functionality of structural glass elements allowing the use of approved timber joining techniques.

The results provide a marketable component system for buildings that optimally uses timber and glass. They show clearly the potential of timber-glass composites but at the same time, they emphasize the lack and the trust for new load-bearing materials. The industrial sector can be convinced to use these elements by their key benefits such as fixed price cost estimation, material standardisation, fast production, reduced work onsite, less coordination of multiple trades, minimum construction waste, improved building quality, high speed of construction and sustainability. In addition, independence from weather conditions is as an advantage of factory based work.

It can be concluded that timber-glass composite as an environmentally friendly and sustainable building material may have a lot of advantages, which are deserved to be discovered.

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