Timber-Glass Composite Structural Panels: Tectonics, Sustainability & Integrated Energetic System Solutions

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Keywords

1=Glass-Timber 2=Composite technology 3=Structural Panels
4=Energy Efficiency 5= Sustainability 6=Architectural solutions

Abstract

Prefabricated industrialised systems currently present an area of strong architectural and constructive development [1]. As a complement, the increasing option for composite solutions [2] [3] [4] diversifies the range of solutions, leading to results and performances that any material alone, with its limitations, could not achieve. The constructive system under analysis in this presentation was developed to fitting in contemporary architectural and tectonic concepts.

The present technology establishes an innovative timber-glass composite constructive system in which the combination of these materials simultaneously incorporates an energetic, functional and aesthetic character.

The system materialises in a multistructural modular panel which can be applied horizontally, as a slab, and vertically, as a resistant wall. It integrates passive solar systems and bioclimatic functions, which result in energetic efficiency, and constitutes a sheer innovation in the field of sustainable prefabricated structural elements.

This system becomes an architectural and structural skin, frontier between inner and outer spaces, reinforcing its importance in the energetic performance of the construction and the comfort of the inhabitable space, predominantly in terms of thermal transfers, air circulation and natural lighting levels – features that decisively contribute to the optimization of energetic efficiency and effectiveness of its management.

Introduction - motivation

The Et³ system was developed with the purpose of fitting in contemporary architectural and tectonic logics [5] [6], especially in the specific scope of the materials which compose it: glass [7] and timber [8]. This product, based on the logic of self-sustained panels, places part of its characteristics in the structural polyvalence of the panel – which can be applied either as slab or wall – and its dimensional metrics, adjustable to several foreseen project situations.

The business principles present in this research work bring out the need of a strategic marketing vision, without which it is not possible to achieve the concept of product [9]. In this case, obtaining an innovative and distinct product is a key factor. This necessarily implies the integration of productivity principles, mainly the appropriation of a semi-industrialized process. Prefabrication, control of costs and transportability are aspects that decisively influence a product which is intended to be modular and largely feasible, and fundamentally capable of offering quality.

Description of Et³ Energetic modular technology

The present technology establishes an innovative timber-glass composite constructive system in which the combination of these materials simultaneously assumes energetic, structural, functional and aesthetic character. This particular feature places the product of this investigation in the combined sphere of Engineering and Architecture, in the specific field of ground-breaking technologies in construction, both in new buildings and in the rehabilitation of existing ones.

The system materialises through a multipurpose modular panel, able to be applied horizontally or vertically. It integrates passive solar systems and bioclimatic functions. Besides prefabrication, this product assumes as strategic principles modularity, habitational evolutionability, industrial production and transportability. Such principles fit in the pursuit of productive optimization and implementation strategy.

While assume the role of architectonic and structural skin, Et³ system – Figure 1 – reinforces its importance in the energetic performance of the construction and the comfort of the inhabitable space, taking advantage of the solar energy. The central strategy is based on principles intended to be economically solid, culturally evolved, socially fair and ecologically responsible.

The panel comprises a timber substructure and two simple laminated structural panes of glass, one on each side of the substructure wherein the bonding is carried out by means of a single-component structural adhesive with semi-stiff behaviour after drying. The substructure consists of several timber boards arranged in parallel, interspersed by timber blocks and fixed with threaded steel rods.

Objective and basic problem solved by the present technology

The resolution of the question on the basis of the developments achieved with this project lies on sustainability criteria, and is, in a first stage, an answer to the latest challenges and global energetic conditions. Within this context, and based on the cooperation between the fields of research – University of Minho – and industry – dst, s.a. –, a sequence of products and innovative constructive technologies was developed, whose main purpose is also to strengthen

Figure 1

Architectural utilization prototype of Et³ Energetic modular technology – keeps, renews & reuses energy.

the competitiveness of the involved sectors. Timber is a renewable material. However, it does not ensure sufficient thermal inertia in order to be utilised in bioclimatic passive solar systems.

The Et³ Energetic modular technology goes beyond this concern by including energy accumulating stone elements inside the timber panels. Besides providing stiffness to the timber substructure, glass allows solar radiation to shine on its surface and prevents the subsequent dissipation of the gathered energy, thus complementing the system. The recourse to renewable energies can also be enhanced by applying solar glass, making possible the introduction of additional active solar systems – unprecedented feature in structural elements.

Besides the properties of the utilized materials – renewable and recyclable –, the constructive system is based on the presumption of reusing, via the solutions of evolutivity and connection / disconnection developed at the level of architectural detail. Hence, as a way of optimizing the production process and deeming the product replicable, modularity and prefabrication criteria were adopted according to the strategic scope of the developed solutions. Besides being economically central, these criteria make way to filling a market gap as far as energetic, sustainable and bioclimatic prefabricated structural products are concerned.

The Et³ lies on a scientific base of three years of undisclosed applied research, whose core was the timber-glass structural bonding. This technology – we named tglassbond, timber-glass structural bonding system – comprises an extraordinary potential of constructive and energetic development, yet internationally unexplored. Summing up, it is possible to state that, with this bonding technology – Figure 2 –, the mechanical capacity of the composite system is substantially higher than the sum of the individual behaviours of the composing materials, which confirms its structural capacity. With the purpose of achieving the ideal balance between strength and stiffness for each specific situation, an extensive set of experimental tests, which included several trades and adhesive types, was performed.

Innovative achievement compared to the actual state of the art

New tectonic concepts based on industrialised and prefabricated systems, extremely different from those presented by conventional solutions, are currently emerging in the field of timber – Lignatur, Ligu, Lignotrend, Homogen80, Wellsteg, Steko, Leno, Schuler, Bresta, Wenus, O'portune, KLH, among others. At he same time, the combination of timber with other constructive materials is also becoming a reality. Concrete, composite materials or steel are examples of what is becoming a brand new generation of extremely promising constructive and industrial procedures. In this particular case, timber-glass composite structural solutions present conditions to, in a near future, play a remarkable architectural role.

Figure 2

tglassbond technology – timber-glass structural adhesive bonding system. Laboratorial tests.

In general, the above-mentioned systems comprise resistant superficial elements, but there are differences among them. Objectively, it is possible to distinguish two groups: solid – composed of laminar surfaces – or optimized – composed of hollow surfaces. It is in the context of the latter that the present product fits in. However, none of these systems combines, nor foresees the possibility of combining, timber and glass. This is why the mentioned products do not solve the question of natural lighting and transparency, or the improvement of stiffness or resistance which glass can enhance in structural terms, when united to timber. The described products also do not include, at a functional level, the possibility of introducing passive solar systems which can increase the energetic effectiveness of the set. In general, these products do not even present such wide versatility nor aesthetic, functional and structural autonomy.

The combination of the potential of natural lighting with the expressive component, making use of the yet unexplored resistance capacity of glass – through the very first structural solar glass –, and integration of strategies of renewable energy, results in a prefabricated product, radically distinct from what is currently available in the construction market.

The Trombe ventilated wall is an important reference in this context. Nevertheless, its concept is usually not compatible with prefabricated constructions, even less when they applied as the entire structural component of the building, and certainly even less with features of lightness and luminosity in the vein of those accomplished by Et³.

Et³ holds a set of characteristics which, when combined, distinguish it in terms of innovation and marketing strategy:

- Multi-structurality. Autonomous triaxial element (slab, sustaining wall with vertical or with horizontal boards);
- Energy. Thermal, acoustic, lighting efficiency and consequent enhancement of energetic resources;
- Sustainability. Integration of passive and active solar systems, bioclimatic principles and natural lighting;
- Architecture and modulation. Metrics, modularity, habitability and urbanity;
- Self-restraint. Ribs integrated inside the element restraining perpendicular actions;
- Lighting and shadowing. Architectural expressiveness and effective solar protection in several orientations;
- Rehabilitation. Integration of technical infra-structures in the panel hollows;
- Prefabrication and applicability. User-friendly system, control of costs, quality control and transportability;
- Durability. Protection of the timber and the adhesive by means of glass skins.

Figure 3 depict the simplicity of production and assembly of panels, in different positions. They also illustrate the natural ventilation system at work, adaptable to the several seasons. The panel openings – located at the top and base, inside and outside –, allow the air circulation that ensures the cooling of the wall (in summer) and the heating of the inner space (in winter), thus minimizing the energetic costs and supporting comfort.

Plans concerning the practical implementation of this composite structural solution

The Et³ technology is at a stage of development in which, simultaneously, steps such as prototypes, replication

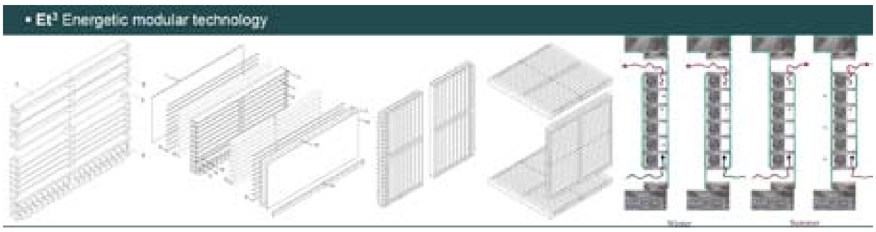

Figure 3

Assembly outline of the timber substructure, panels assembly and integrated natural ventilation system.

analysis and production potential, scientific validation, national and international patent registration, market research and implementation sectors survey, marketing project and business plan have already been fulfilled, and quite encouraging results were achieved.

As a starting point, several laboratorial prototypes were generated, then tested regarding their structural component – as will ahead be illustrated. The industrial production component was also analysed. The guarantee of quality control was proved, as well as the industrial productive profitability and cost decrease, thus leading to high replicability.

As far as the markets are concerned, the purpose is to follow ways that lead to export and implementation in all the European continent – particularly in countries that already have timber use policies (e.g. France, Germany, Switzerland, Austria, Finland) –, but also in Asia, North America and Australia, given the energetic advantages of the product.

The implementation sectors are broader than usual, due to the feature of panels being able to be traded as final product – for a regular use in rehabilitation projects or new construction –, or a sub-product of another product developed based on the Et³ system – the lighthouse, prefab modular houses & urban solutions, as show in the Figure 4 –, and in which commercially investment is intended. The utilization of the concept of multipurpose and structural autonomy of the Et³ panels leads to the conclusion that these comprise a considerable potential of market implementation.

Simultaneously the versatility presented by the product reinforces its possibilities of implementation and distribution. As an example, and in the case of rehabilitation, some of its advantages are highlighted: natural lighting integrated, time enhancement, integration of technical infrastructures and thermal efficiency, among others already mentioned.

Sustainability and strategic concepts

The present innovation comprises three components in the framework of the principles of sustainability: the economic viability of its implementation, based on a promising business plan; the environmental compromise with recourse to solar systems integrated in an innovative method; and the social and cultural support based on the constructive approach to nature and its renewable resources, which leads to the Forest Based Sector. Thus, the Et³ system reinterprets, reinvents and recreates new horizons in the application of sustainable solutions. That is the spirit of its impact.

Given the important role of the construction sector in the lives of populations, a high social impact regarding this project is expected, mainly in the perception of citizens on eco-efficient and environmental responsibilities.

Figure 4

lighthouse – prefab modular houses & urban solutions. Lightweight & natural lightening. Et³ architectural application.

Figure 5

Strategy and some principles associated with the implementation of the product of the investigation.

Stress Type Test	Bending		Compression		Shear Stress	
Referent. Position	Horizontal	Vertical	Vertical	Vertical	Vertical	Vertical
Struct.Elemt./Charct	Floor plate	Wall plate	Horiz.board	Vert.board	Horz.boad	Vert.board
Dimensions [mm]	3200x500	3200x500	1750x500	3200x500	1600x1600	1600x1600
Timber	**83,6 kN**	**24,7 kN**	**60,0 kN**	**280,0 kN**	**9,5 kN**	**10,0 kN**
Timber-Glass	**109,7 kN**	**102,5 kN**	**120,3 kN**	**> 500,0 kN**	**58,5 kN**	**110,2 kN**
Increasing capacity	**31 %**	**315 %**	**100 %**	**> 78 %**	**515 %**	**1000 %**

Table 1

Tests performed and failure load results (kN)

Experimental studies – laboratorial tests

In this set, twenty one panels were tested. Each composite panel was 224 mm thickness, and consisted of two 6.6.1 laminated glass bonded on both faces of the timber structure, made of four Pinus Sylvestris timber boards, with 200x30 mm² of cross section. The applied general variables were three, as outlined on Table 1:

- Panels composition: timber and timber-glass composite panel;
- Stress type test: bending; compression and shear stress;
- Relative position of the panels: vertical (wall plate) and horizontal(floor plate).

A general analysis to the behaviour of Et³ system, as slab – Figure 6 –, demonstrates that glass constitutes an increased value in the set. The element glass, though not resistant per se regarding the plan in which this test was performed, guarantees the effective reinforcement of the timber sub-structure. Hence, it works as a restraint element relative to timber. In doing so, glass works according to the plan that is favourable to it, allowing the load capacity achieved at the Ultimate Limit State (ULS) to increase an average of up to 30%. Also vertical displacement displays values much superior to those obtained in tests without glass, which is possible only due to deformation presented by glass at the plan in question. Moreover, because it worked in its axis of greater inertia, timber collapsed before glass itself.

However, both timber panels fail to present resistance after the Serviceability Limit State (SLS) was reached, which brings the question of safety. According to the tests performed, timber without glass is left excessively exposed to its own natural imperfections.

Figure 6

Laboratorial bending tests – horizontal position, system as slab

As structural wall system – Figures 7, 8, 9, 10 and 11 –, the glass contribute became even more evident. The carrying capacity of the panel with glass, when compared to those without it, become clear that there is an increase of stiffness and resistance, which makes possible to exceed very high value, still keeping a considerable safety margin, as well as a ductile failure at its post high peak. Besides, this piece exceeded, in a direct comparison, all the values obtained in test with composite beams [10], which verifies the idea, among others, that this panel can be safely utilized as structural wall.

Figure 7

Laboratorial bending tests – vertical position, system as wall

Figure 8

Compression-bending tests – load perpendicular to boards

Figure 9

Compression tests – load parallel to boards

Figure 10

Shear stress tests – horizontal boards

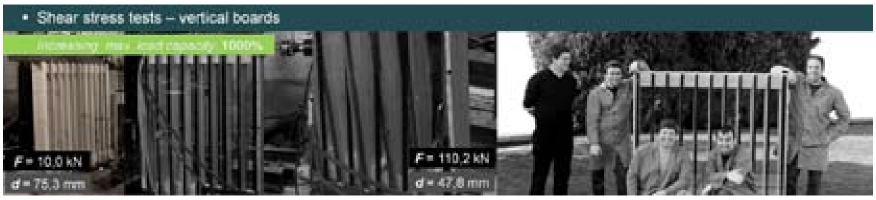

Figure 11

Shear stress tests – vertical boards

Conclusions

This system shall give rise to a product that constitutes an "open system", transmitting high loads both on its plane and perpendicularly to it, being combinable with other structural systems and, by means of the substructure, adaptable to the specific aspects and each project, with the advantage of always using the same standard parts. Part of the key to this question will lie in the accessible possibility of connection/disconnection of the system component parts. In terms of safety, the resulting panel prevents the brittle collapse of the system under all circumstances:

- Collapse of timber through tensile stress: prevented by glass and adhesive;
- Buckling of timber boards outwards: prevented by threaded steel rods;
- Buckling of timber boards inwards: prevented by massive wood cubes.

The main conclusion to withdraw of this work is that glass behaves as a structural reinforcement of the timber sub-structure. In particular, when used as slabs, the tests results show that the composite panel presented an excellent structural performance. Some central objectives were fulfilled when analyzing the use of glass in this system:

- Great mechanical resistance, increasing the maximum load obtained with the panel without glass;
- First crack through timber and only then through glass. This confirms the effectiveness of glass in this type of utilization;
- Ductile behaviour and collapsing – prevent brittle behaviour and assure safety;
- Contribution of glass to the effective strengthening of the structure. After its collapse, the loading decreased considerably and never rose again.

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