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TIMBER CURTAIN WALL – INNOVATIVE STRUCTURALLY GLAZED UNITISED SYSTEM FOR BUILDING ENVELOPES

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Abstract: This paper presents the results of research conducted within R&D project. The primary goal was to apply the current state of the art technology in aluminium to a timber-based frames, but also to improve the energy performance of the building envelope and create environmentally friendly product, which physical, structural and aesthetic performances are equal to or even better than equivalent aluminium systems. The developed TimberCW is an innovative structurally glazed curtain wall system entirely comprised of laminated timber profiles incorporated in a fully prefabricated unitised curtain wall design, where glass panes are bonded by the structural silicone to timber frames. While most current timber curtain wall systems are stick designs, combined with aluminium elements, this new concept introduces timber split mullions and entirely eliminates aluminium structural members, whilst maintaining high weathertightness performance. In order to retain thin cross sections, as they are common for aluminium design, specialised corner connections in timber frame and stainless-steel bracketry has been developed and laboratory tested. Comparative energy efficiency analysis and condensation risk assessment of the TimberCW vs fully unitised aluminium systems of identical overall geometry and structural performance are presented. Full scale laboratory testing has been undertaken and certification obtained, proving the TimberCW concept suitable for project application.

Keywords: TimberCW, laminated timber frame, unitised system, structurally glazed curtain wall, thermal performance.

1. Introduction. Presently, the technology of exterior building envelopes is dominated by the curtain wall based on the aluminium framing, which can be divided in two families: unitised systems and stick systems. Unitised systems are completely prefabricated (frames and infill) and more technologically advanced, providing the better overall quality and performance than stick systems, which are assembled on site, offering the economic advantage, in particular for low-rise buildings. Unitised systems are often structurally glazed, and this technology provides aesthetically pleasing flush appearance, but also some performance advantages (bomb blast resistance, e.g.). Since awareness of energy efficiency and sustainability have been growing rapidly in recent decades, the introduction of timber as a suitable framing material for building envelopes is imposed as a reasonable option.

The above listed logically leads toward to investigate possible alternative structural solutions of wood-based curtain walls. Therefore, the scope of this research conducted under R&D project is to prove that the technologically advanced concept of the curtain wall system can also be applied using innovative wooden frames:

- Unitised wooden frames in lieu of the stick system.
- Glass units structurally sealed directly to the wooden substrate.

By achieving the scope, the additional advantages will be brought to the unitised technology:

- Improved energy performance – TimberCW system effectively increases the energy efficiency during the lifetime of the building due to the difference in the thermal transmittance between aluminium and wood systems.
- Zero (0%) aluminium content – aluminium is a material with the large carbon footprint, having C02 net emissions in the production and processing of 26 t/m^3, whereas wood sequesters only 1 t/m^3 [1].
- Hygrotechnical (rot) and mechanical (thermal dilatation) interaction problems between aluminium and the wood are eliminated.

2. Current State of the Art and Goals of R&D Project TimberCW

2.1 About current curtain wall systems incorporating timber. Due to the nature of wood, most current curtain wall systems incorporating timber are based upon conventional stick system designs whereby timber sections are combined with aluminium ones that in effect provide weathertightness and glass retention. Stick systems are assembled on site from individual frame elements which form a lightweight grid that supports the infill (glass, cladding panels and insulation). While stick systems are simple and efficient, they are not well suited for high-rise buildings, due to so far known limitations of stick systems, among which are:

- They are installed from the outside, so the scaffolding or an external platform are required, which is impractical and costly for high-rise construction.
- Assembly on site is detrimental to the quality, in particular for the structural silicone, which is not recommended to be applied on site.
- Limited capacity for the accommodation of differential vertical movements between floors – these are caused by live loads, but also by long term effects as the creep and settlement (high rise buildings usually feature thin metal deck slabs, whose low stiffness will highlight this problem).

Further, there are interaction problems between aluminium and the wood itself:

- Differential temperature elongation between aluminium and timber, which may lead to the defect in aluminium-to-timber fixing.

To prevent this differential deformation, countersunk head screws are usually used to fix the aluminium (or inox) profile to the wood, and the range of thermal elongation of the aluminium profile (depending on the type of the glass and of the construction of the frame), can be illustrated by an example of typical 3600 mm high unit:

– on the yearly basis the temperature of the aluminium profile will vary between approximately 0°C and 40-50°C, resulting in 3,3-4,1 mm differential aluminium-to-wood dilatation, or 1,6-2,0 mm at screws located near profile's ends;

– on the daily basis in the summer the temperature of the aluminium profile will vary between approximately 20°C and 40-50°C, resulting in 1,6-2,5 mm differential aluminium-to-wood dilatation, or 0,8-1,2 mm at screws located near profile's ends.

Since the movement capacity at screws is limited or prevented, this elongation will cause the searing load in screws and over time this will lead to the deterioration of the connection and eventually to the failure of the metal-wood assembly, which has been observed in the practice. If stainless steel is used instead of the aluminium, the differential movement will be reduced to 40% of those of the aluminium, but still, over a number of cycles, detrimental effects may be observed.

Figure 1. Countersunk head screws fixing the inox profile with limited movement capacity

- Screws that fix the aluminium have the same temperature as the aluminium section, so the possible difference in the temperature between aluminium and timber sections may lead to the local condensation around screws, leading to the rot localized at screw holes and subsequent failure of the connection.

2.2 Goals of the Research Conducted under R&D Project TimberCW. The scope of this research was to develop a functional, fully unitised curtain wall system that would:

- feature split timber mullions and stack joints;
- have zero (0%) aluminium content;
- have the same sight lines (width of the frame), structural stiffness and loadbearing capacity as the equivalent aluminium system;
- have the same or better weathertightness performance as the equivalent aluminium system;
- have better energy performance than the equivalent aluminium system.

2.2.1 Unitised Construction. Unitised systems are fully preassembled in the shop, and shipped to the site for the installation already complete with the frame, infill and gasketry. Although more complex than stick systems, there are significant advantages of timber unitised systems:

- unitised systems are installed form the inside, without the requirement for the scaffolding or external platforms;
- shop production and assembly maximise the quality of the workmanship;
- appropriate for the structural silicone;
- stack joints enable the accommodation of large differential vertical movements between floors.

2.2.2 Zero Aluminium Content. Aluminium is a material with the large carbon footprint, due to its poor thermal properties (conductivity 160 W/mK) and to high energy requirements for the production, processing and recycling. Exclusion of the aluminium from the TimberCW system effectively increases the energy efficiency. Interaction problems between aluminium and the wood are thus eliminated as well.

3. Design Concept. TimberCW is a system entirely comprised of glued laminated wood profiles, using spatial lamination – longitudinal, lateral and layered gluing of wood lamellae [2], incorporated in a fully unitised curtain wall design. Glass units are fixed to the frame by the structural sealing, which avoids the direct exposure of wood elements to the weather. Unitised systems feature split mullions; conveniently slim in typical aluminium framing design, that provide aesthetic narrow sight lines.

3.1 Equivalent Aluminium System. In typical curtain wall applications, spanning between floors, the main limiting structural property of frame members is stiffness, rather than resistance. The allowed lateral deflection d under the design load is, according to EN 13830 [3].

- $d \leq L/200$, if $L \leq 3000$ mm;
- $d \leq 5$ mm $+ L/300$, if 3000 mm $< L <$ 7500 mm;
- $d \leq L/250$, if $L \geq 7500$ mm.

Frame elements of TimberCW have the same stiffness of the equivalent aluminium system. The chosen comparable aluminium system is series 180 by Permasteelisa. The width of the frame is maintained the same for both systems, 90 mm. TimberCW system features are the following:

- split wood mullions and stack joints;
- zero (0%) aluminium content;
- same sight lines (width of the frame) as the equivalent aluminium system;
- structural properties and loadbearing capacity not lower than the equivalent aluminium system;
- same or better weathertightness performance as the equivalent aluminium system;
- better energy performance than the equivalent aluminium system and adequate durability.

The Young's module of elasticity in bending of the wood is 4-7 times lower than that of the aluminium. Also, the limiting bending stress is much lower, depending on the used wood species and grade. The system depth has to be increased approximately 30% in order to match the structural performance of the aluminium frame. The depth of the wood profile is 180 mm and of the aluminium profile 140 mm, i.e. 28,6% more for the nearly equal lateral stiffness.

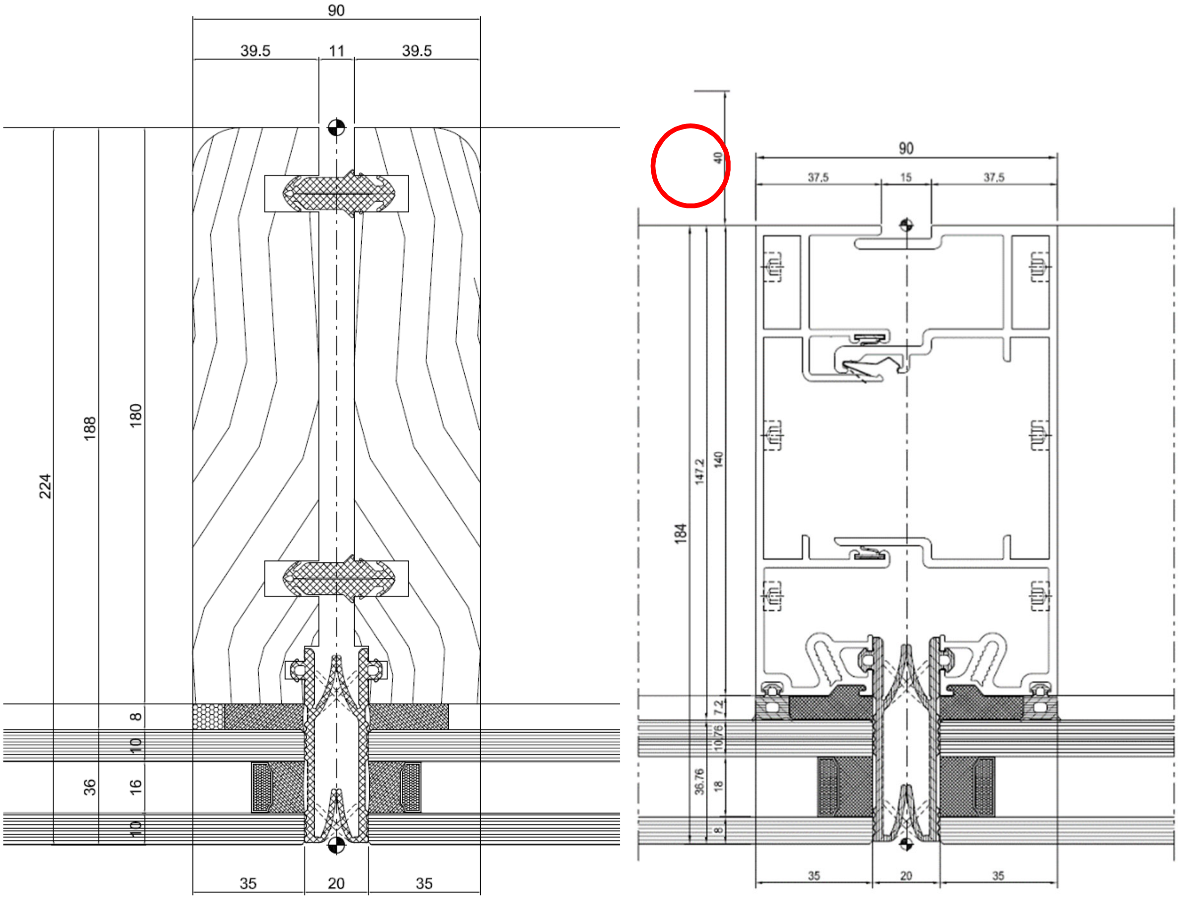


Figure 2. Wood frame and equivalent 180 series aluminium frame

3.2 TimberCW Profiles. The profiles used are from glued laminated timber (glulam), using spatial lamination – longitudinal, lateral and layered gluing of lamellas. Grain orientation in different lamellas reduces the risk of warping and a single thin lamella is on the side face for the improved aesthetic quality.

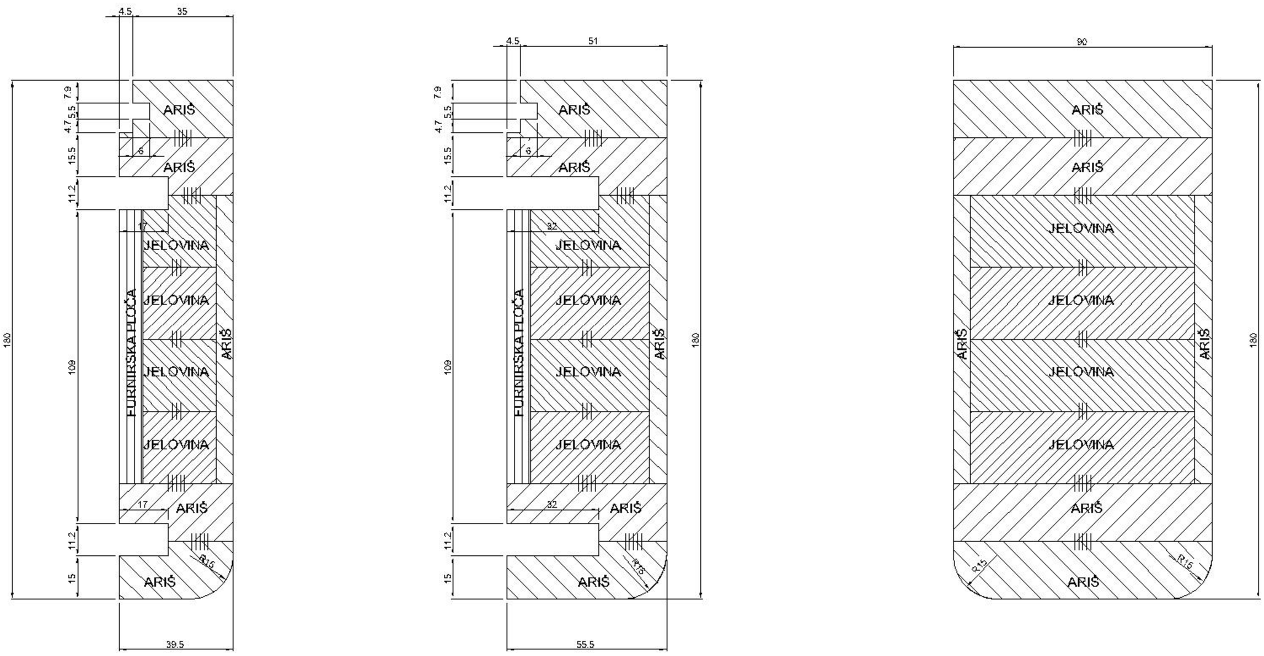


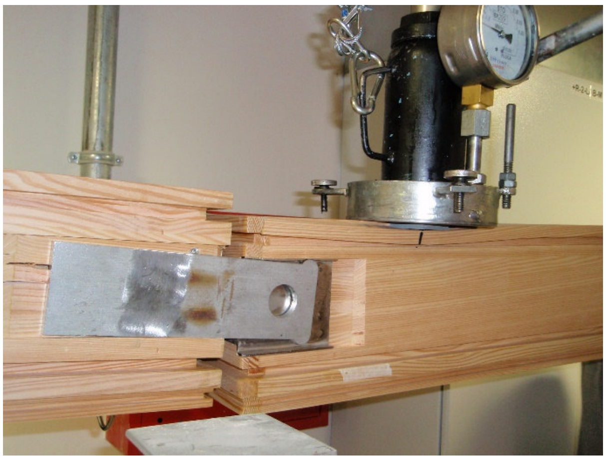
Figure 3. Wood profiles: mullion and upper transom (left), lower transom, intermediate transom

The section has been developed in the collaboration with University of Zagreb, Faculty of Forestry. The material used for the sample was fir wood for the core and Siberian larch for the ridges, Marine grade plywood stiffened the internal lateral face. The choice of the wood material was based on its availability, moderate cost and adequate structural properties. Final choice can be project driven, and a number of other species, including hardwood, may be used.

3.3 Corner Connection. A vertical row of curtain wall units structurally forms a Gerber beam. The horizontal reaction from the upper unit is transferred to the lower unit through the stack joint using bespoke spigots at the corners of the unit. Mullion sections in unitised system are very narrow, for 90 mm of the frame width, the mullion width is only 39,5 mm and specialised bespoke corner connections are required to form the corners of the frame and enable the load transfer the load in limited space. Connection corners and brackets in stainless steel 1.4404 have been developed for this [4, 5].

The transfer of the shear load through the corner connection (joint of the Gerber beam) until the failure has been successfully tested (on three corner samples) at Faculty of Civil Engineering of University in Rijeka. The observed range of results was homogeneous. The increase of the deformation was approximately linear and it did not show any significant plastic deformation after the load release at 5 kN. The breakage pattern was through the splitting of the wood at fixings of the stainless steel connection joint. The resulting loadbearing capacity (~15 kN) is superior to the loadbearing requirements of the joint (2,5-4,0 kN).

Figure 4. Appearance of TimberCW profile



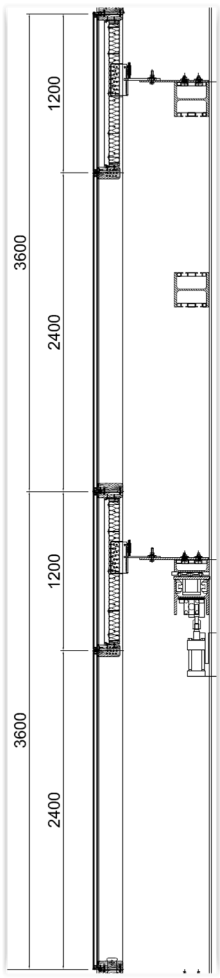


Figure 5. Structural test of the corner connection (left) and Gerber beam system (right)

3.4 Structural Glazing. Since the aim of the development was to eliminate aluminium parts from the design, the mechanical glazing with external retaining clips was not preferred, as it would expose timber elements to the external weather. Glass units are fixed directly to the timber frame by structural sealing. The structural silicone used is two component Sikasil SG500. The silicone joint and the process of the application have been developed with the collaboration of the company Sika and tested for adhesion in their laboratory [6, 7], while tensile strength was tested by Permasteelisa [8].

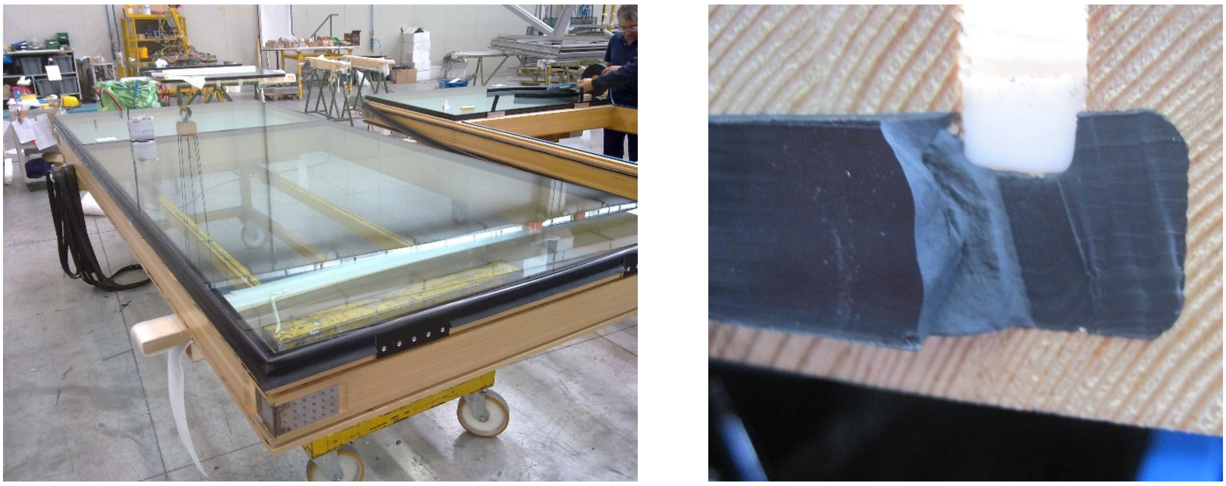


Figure 6. Glazed unit (left) and peel test – pure cohesive failure (right)

3.4.1 Peel test. The adhesion of 3 silicones were tested (peel test according to EN 13022-2: A.3.2 and C.3.1): Sikasil SG-500 (two component structural silicone sealant), Sikasil SG-20 (one component silicone sealant for structural glazing) and Sikasil WS-605 (one component silicone weather sealant). The silicone was applied to the:

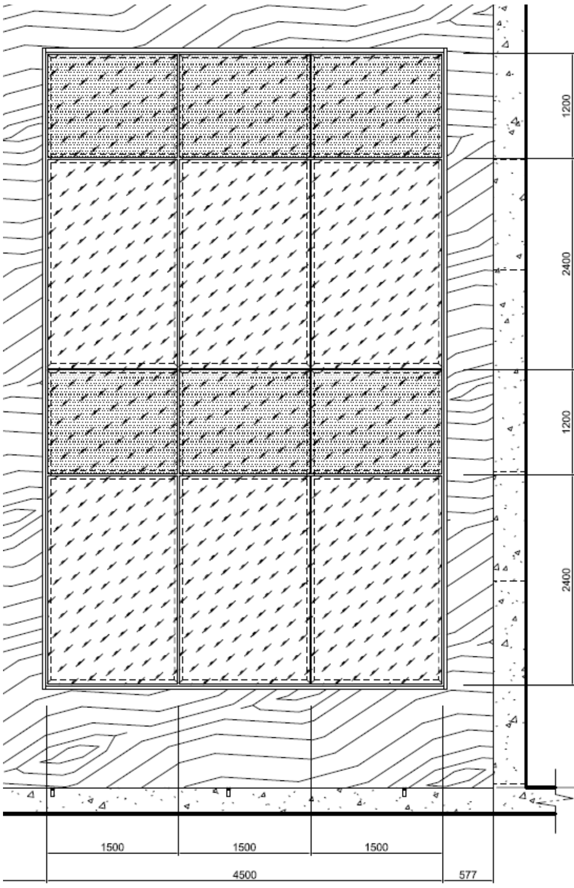
- non-treated surface;
- surface of the sample that was painted with water based transparent finish (the surface in contact with the silicone was protected by adhesive tape);
- and to the surface of samples impregnated with fire retardants.

Surfaces in all combinations both treated and not with the primer. Samples were conditioned up to 21 days in the water saturated atmosphere (90% RH) and high temperature (55°C).

The results of the adhesion test were positive, meaning that the silicone peels through the cohesive failure, proving that the adhesion to the substrate is higher than the cohesive strength (denominated by “1”). Only samples of Sikasil SG-20 (not used for the project) on non-primed surface showed partial adhesive failure (“2” through “5”) and separation of edges (“RA”).

3.4.2 Tensile Strength Test. Tensile strength test [8] of silicone (EN 13022-2: A.3.1 and C.5 and EN 15434) on 10 “H” samples. The results of the adhesion test were positive. No adhesion failure was observed. All samples broke through cohesive failure in the silicone within known material strength limits. At 4 samples the breakage of the wooden substrate was observed, caused by the small thickness of the wooden lamella used (between 5,6 and 5,8 mm), but this did not invalidate the test results.

4. Performance Mock-up Testing. Full scale laboratory testing of a two-storey high by three units (4500mm x 7200mm) sample was carried out in Permasteelisa laboratory (Vittorio Veneto, Italy). The sample were successfully tested according to EN 13830 and certification obtained for constructability, air permeability, water tightness, serviceability, thermal cycling, accommodation of building movements, impact and structural resistance, proving this concept suitable for project application [9].



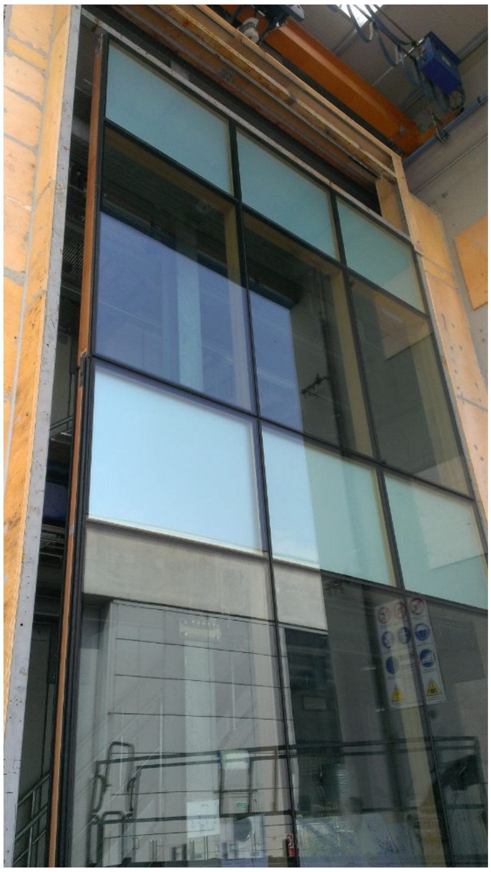


Figure 7. Sample geometry (left) and external view on installed sample (right)

Test sequence and performance:
1 – Air permeability ±600 Pa
2 – Static watertightness 600 Pa
3 – Wind resistance ±2 kPa
4 - Air permeability ±600 Pa
5 - Static watertightness 600 Pa
6 - 3 temperature cycles -20 ºC / +50ºC
7 - Air permeability 600 Pa (chamber only)
8 - Air permeability ±600 Pa
9 - Static watertightness 600 Pa
10 - Vertical movements ±10 mm* -1 cycle
11 – Horizontal racking ±7 mm - 2 cycles
12 - Air permeability ±600 Pa
13 - Static watertightness 600 Pa
14 – Dynamic watertightness 600 Pa (airplane engine)
15 - Water hose test
16 - Safety test ±3 kPa
17 – Impact load, external in 3 points, 45 kg falling from 950 mm
18 - Impact load, internal in 3 points, 45 kg falling from 950 mm

Figure 8. List of test sequence and performances (left) and internal view on installed sample (right)

5. Energy Performance. In order to evaluate the thermal performance of the Timber CW, a comparative analysis of 4 different systems is made for a typical unit, characteristic for unitised curtain wall projects [10] The modular width of a unit is 1500 mm and the height 3600 mm, of which 2400 mm is the visual area and 1200 mm is the insulated shadowbox. It has been assessed the thermal transmittance characteristic for winter conditions, using 2 different glass configurations: a double-glazed unit (DGU, $U_g = 1{,}1$ W/m²K) and a triple glazed unit (TGU, $U_g = 0{,}6$ W/m²K).

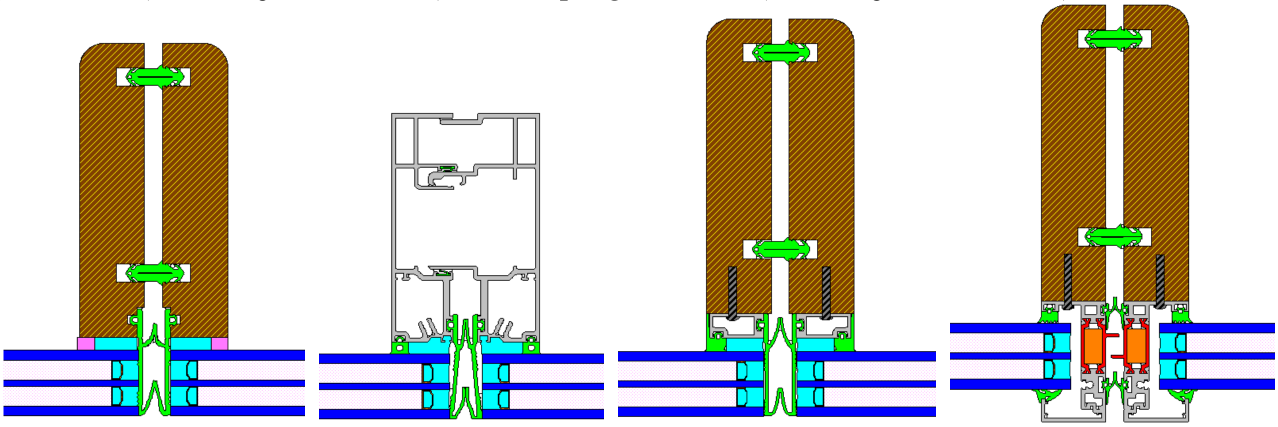


Figure 9. Four framing systems subjected to the thermal transmittance assessment

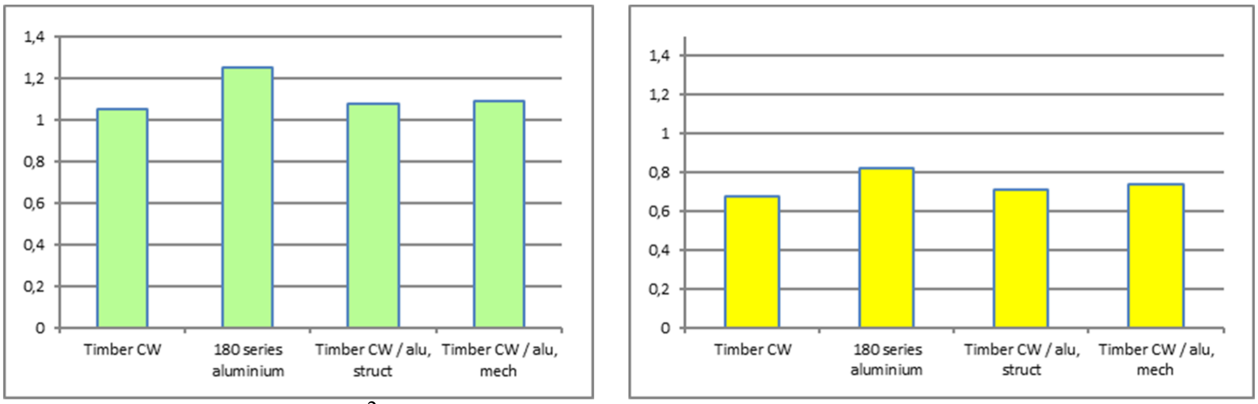


Figure 10. Overall Ug [W/m²K] for double glazed, DGU (left) and triple glazed unit, TGU (right)

TimberCW has 84% of the overall thermal transmittance of the aluminium system for the option with DGU (Ug = 1,05 vs 1,25 W/m²K) and 83% for the option with TGU (Ug = 0,68 vs 0,82 W/m²K). Composite systems fall in between.

6. Conclusions. The development of the TimberCW system has proven to be a successful innovative technical solution in meeting the proposed targets:

- Spatially laminated wood frames with specifically developed fittings proved applicable for a fully unitised prefabricated façade system, featuring advantages over wood stick façade systems and aluminium constructions.
- The structural glazing directly to the wooden frame proved to be feasible and functional after the extensive testing.
- Energy performance of the wood-based framing system is better than of the equivalent aluminium curtain walling, resulting in ca 35-41% better thermal transmittance of the frame alone (for the warm glass edge technology) and up to 20 % better overall thermal transmittance of the building envelope. The carbon footprint and heating costs are demonstrated to fall below the standard aluminium prefabricated façade elements. 0% aluminium content contributes to the reduction of the embedded energy in the system.
- The structural properties, weathertightness and transparency of the TimberCW building envelope are equal or better than the aluminium solutions. Standard testing of the TimberCW system proved that all the high end requirements according to EN 13830 are fulfilled, rendering the system suitable for high-rise buildings and adverse climatic conditions.

TimberCW demonstrates that the structurally glazed unitised systems using innovative wooden frames is the feasible technology that provides better energy performance than aluminium based systems. At the same time, it is advantageous to composite alu-wood stick systems, being suitable for high-rise buildings and avoiding some stick related constraints (poor movement accommodations and aluminium-to-wood fixing problems).

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ДЕРЕВ’ЯНА НАВІСНА СТІНА – ІНОВАЦІЙНА СИСТЕМА ЗІ СТУКТУРНИМ СКЛІННЯМ ЯК ЄДИНА УНІФІКОВНА ОГОРОДЖУЮЧА КОНСТРУКЦІЯ

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Анотація. У цій роботі представлені результати досліджень, проведених в рамках R&D проекту. Основна мета полягала в тому, щоб застосувати сучасну технологію поєднання алюмінію та дерев’яних каркасів, а також покращити енергоефективнчсть конструкції та створити екологічно чистий продукт, фізичні, конструктивні та естетичні характеристики якого рівні або навіть вище елементів аналогічних алюмінієвих систем. TimberCW це інноваційна система зі структурним склінням дерев’яної навісної стіни, яка повністю складається з ламінованих дерев’яних профілів, включених у повністю збірну об’єднану конструкцію огороджуючої стіни, де скляні панелі приклеєні структурним силіконом до дерев'яних рам. Ця нова концепція повністю виключає алюмінієві елементи конструкції та забезпечує високу атмосферонепроникність. Для збереження тонких поперечних перерізів, які є звичайними для алюмінієвих конструкцій, були розроблені та проведені лабораторні випробування спеціалізованих кутових з'єднань в дерев'яному каркасі на кронштейнах з нержавіючої сталі. Представлено порівняльний аналіз енергоефективності та оцінку ризику конденсації TimberCW та повністю уніфікованих алюмінієвих систем ідентичної загальної геометрії та конструктивних характеристик. Були проведені повномасштабні лабораторні випробування та отримана сертифікація, що підтверджує, що концепція TimberCW підходить для проектного застосування.

Ключові слова: TimberCW, ламінований дерев'яний каркас, уніфікована система, навісна стіна зі структурним склінням, теплові характеристики.

ДЕРЕВЯННАЯ НАВЕСНАЯ СТЕНА – ИННОВАЦИОННАЯ СИСТЕМА СО СТУКТУРНЫМ ОСТЕКЛЕНИЕМ КАК ЕДИНАЯ УНИФИЦИРОВАННАЯ ОГРАЖДАЮЩАЯ КОНСТРУКЦИЯ

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Аннотация. В данной работе представлены результаты исследований, проведенных в рамках R&D проекта. Основная цель заключалась в том, чтобы применить современную технологию сочетания алюминия и деревянных каркасов, а также улучшить энергоэффективность конструкции и создать экологически чистый продукт, физические, конструктивные и эстетические характеристики которого равны или даже выше элементов аналогичных алюминиевых систем. TimberCW это инновационная система со структурным остеклением деревянной навесной стены, полностью состоящая из ламинированных деревянных профилей, включенных в полностью сборную объединенную конструкцию ограждающей стены, где стеклянные панели приклеены структурным силиконом к деревянным рамам. Эта концепция полностью исключает алюминиевые элементы конструкции и обеспечивает высокую атмосферонепроницаемость. Для сохранения тонких поперечных сечений, обычных для алюминиевых конструкций, были разработаны и проведены лабораторные испытания специализированных угловых соединений в деревянном каркасе на кронштейнах из нержавеющей стали. Представлен сравнительный анализ энергоэффективности и оценка риска конденсации TimberCW и полностью унифицированных алюминиевых систем идентичной общей геометрии и конструктивных характеристик. Были проведены полномасштабные лабораторные испытания и получена сертификация, что подтверждает, что концепция TimberCW подходит для проектного применения.

Ключевые слова: TimberCW, ламинированный деревянный каркас, унифицированная система, навесная стена со структурным остеклением, тепловые характеристики.