MODCONS

Project Summary – Mar 2022

The MODCONS Project is focused on examining the use of Irish grown timber in the manufacture of engineered wood products for modular construction to address the need for increased supply of housing and to develop a sustainable building solution as we transition to a net-zero carbon economy.

The main objectives of the MODCONS Project are

- To design, prototype and test modular building components manufactured from engineered wood products, including cross-laminated timber (CLT).
- To examine the fire performance of modular timber building components
- To examine and optimise the acoustic performance of modular timber buildings.
- To examine the life cycle performance to reduce the impact of construction on the environment and improve the circularity of the construction industry

DESIGN	TESTING	OPTIMISATION
Design of a multistorey modular timber building with Irish grown wood products	**Structural, fire and acoustic testing of engineered wood products**	**Optimised design based on physical test data**

Department of Agriculture, Food and the Marine
An Roinn Talmhaíochta, Bia agus Mara

NUI Galway
OÉ Gaillimh

MTU
Ollscoil Teicneolaíochta na Mumhan
Munster Technological University

cpac Modular

ÉIRECOMPOSITES

MURRAY TIMBER GROUP

PUNCH consulting engineers

rothoblaas

Project Objectives

The MODCONS Project is a joint project between the Timber Engineering Research Group at the National University of Ireland Galway and Munster Technological University focused on increasing the knowledge and use of timber in modular construction. The project flow chart and the associated tasks of the project are presented in Figure 1. The main items discussed in this project summary are Task 2, 3 and 4.

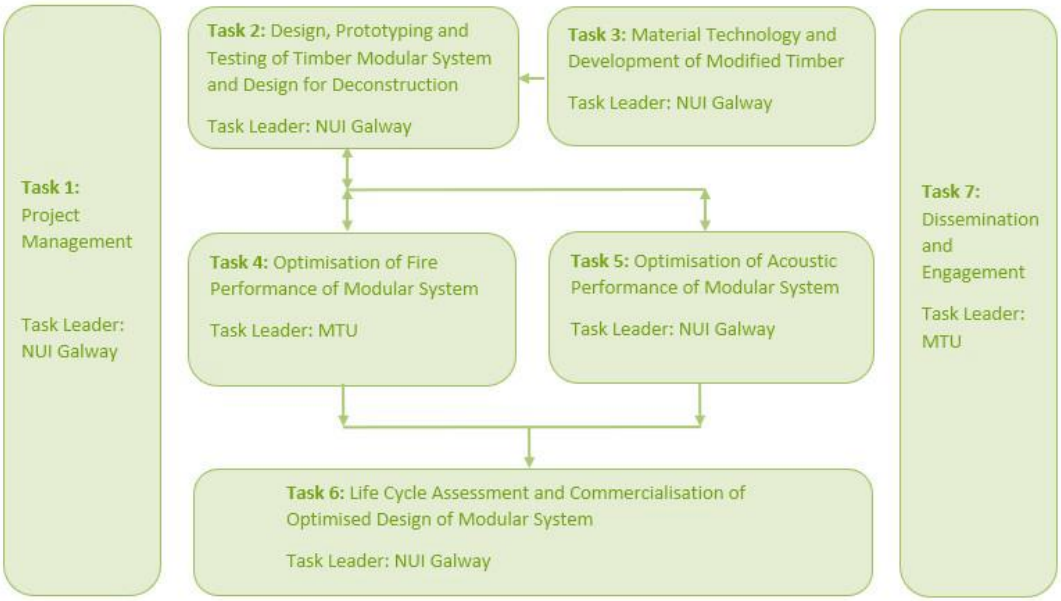


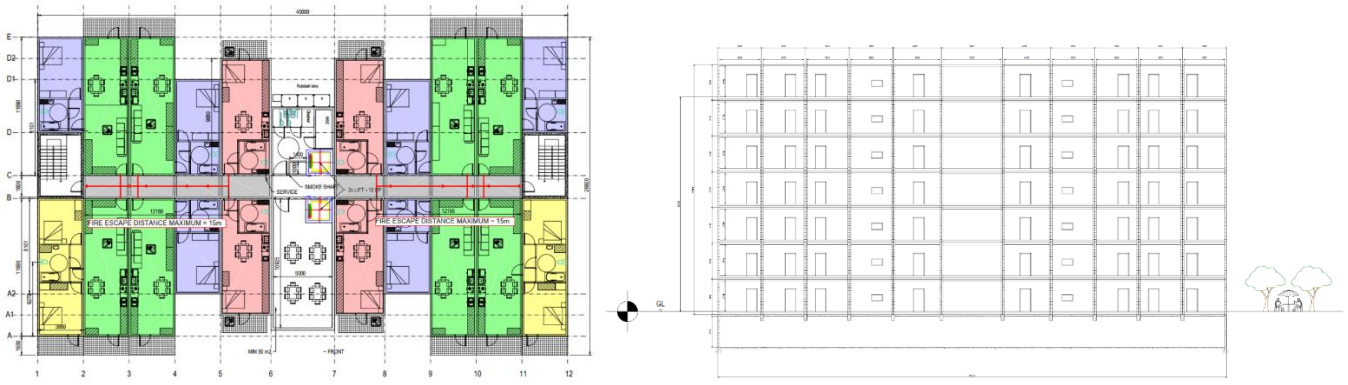
Figure 1. MODCONS Project Flow Chart

Design, Prototyping and Testing of Timber Modular System

The design, prototyping and testing of a timber modular system is one of the most important aspects of the MODCONS Project. To date, a seven-storey building has been designed following a volumetric construction approach to optimise offsite construction prefabrication and minimising time on site. See Figure 2a which presents the layout of the building. The structural material of the volumetric units is Cross Laminated Timber (CLT). The CLT walls in the units act as load transferring elements from factory to site designed to withstand the structural demands of lifting, transportation, and long-term stability of the building. The CLT panels are designed based on the properties of local Irish Sitka Spruce timber of strength class C16.

The plan layout of each storey is similar, as presented in Figure 2a, consisting of access stairways and 22 volumetric units made from CLT panels. Reinforced concrete is used for the stair cores which act as fire escape routes. It is proposed that the apartment units (with bedrooms, living rooms, kitchens, and WCs) be built and internally fitted-out off-site. This means the construction of a building can be split between onsite erection and assembly, and offsite prefabrication to speed up the overall construction time.

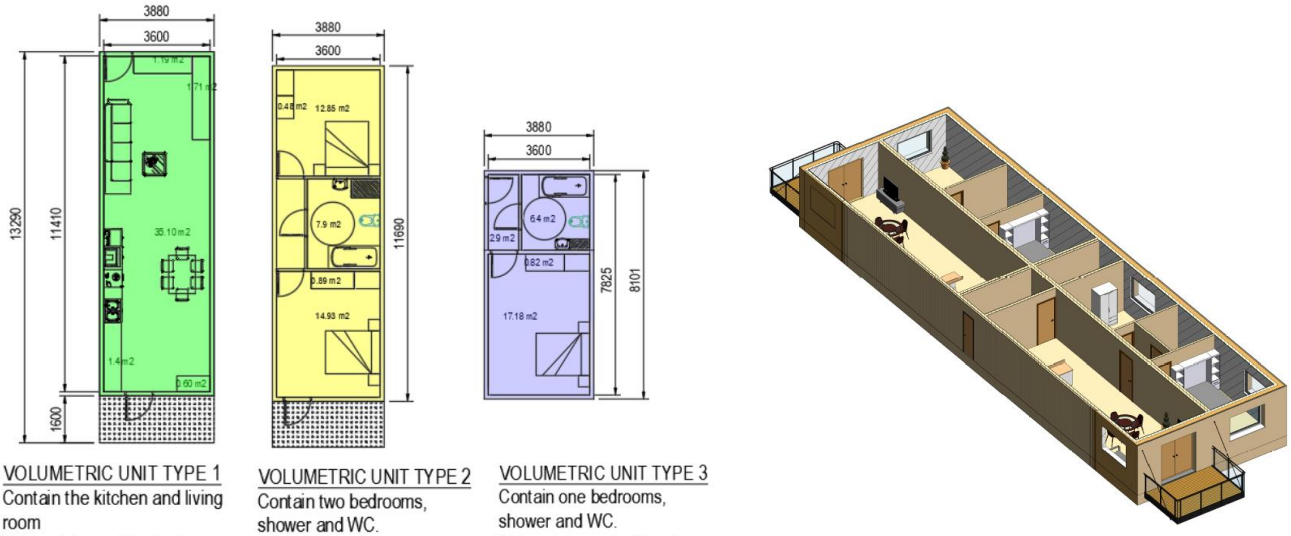
All unit dimensions on plan are less than 4.3 m wide x 16 m long, meeting the regulated transportation limits with a permit from An Garda Síochana (EISB, RSA, Road Safety Authority, 2015).



a) b)

Figure 2: MODCONS Modular building design comprising 7 storeys, a) typical floor plan and b) elevation

A selection of the volumetric units and the unit-unit combination to form whole apartments are presented in Figure 3. There is also 4th type of unit which is a fully contained studio unit that can be used as a standalone unit in any location. The various unit-unit combinations mean the bedroom, kitchen and bathroom are all included in each unit and mixing the unit types, one, two or even three-bed units can be made. The robust design of the units allows for a customisable layout that is both scalable and stackable allowing for a range of different building designs.



a) b)

Figure 3: Volumetric units, a) a selection of volumetric unit types, b) unit-unit combination

CLT Manufacturer and Testing

The CLT designed in this project using Irish timber is based on previous experimental testing performed by the Timber Engineering Research Group at the National University of Ireland Galway. Further testing is planned as part of the MODCONS project which is currently scheduled for 2022.
Based on the design of the 7-storey modular CLT building using Irish-grown C16 timber, the CLT panel lay-ups (No. of layers and layer thickness) are designed as follows:

- Walls: 3 layers; 40-40-40 mm
- Ceilings: 3 layers; 40-30-40 mm
- Floors: 5 layers; 40-20-20-20-40 mm

These panel lay-up designs have been determined by calculation in accordance with Eurocode 5 design standards to carry the structural demands of the 7-storey building. These panel designs are currently being manufactured using Irish timber provided by Murray Timber Group Ltd. Tests will be performed to examine the racking resistance of such panels and further testing is planned to examine the connection behaviour between the modular CLT units and also unit-unit connections will be examined.

a) b)

Figure 4: CLT panel manufacture, a) panel adhesive application and lay-up, b) the CLT panel is subjected to a specific pressure while the adhesive cures

The manufacture of the CLT panels is presented in Figure 4 where the individual layers are adhesively bonded together and subjected to a specific pressure until the adhesive cures. The panels are also laterally constrained during the clamping process to ensure there is no excessive movement between the layers. The adhesive type and clamping pressure have been specifically chosen based on previous tests that have been shown to be compatible with Irish Sitka spruce.

Material Technology and Development of Modified Timber

The development of a modified Sitka spruce product has been experimentally characterised as part of the MODCONS Project. Modified or densified timber through a process of thermo-mechanical compression has been carried out on Irish Sitka spruce to improve its structural performance. The process of thermo-mechanical compression involved subjecting timber to simultaneous heat and pressure to reduce the void

space of the timber, increasing its density and enhancing many structural properties. In Figure 5 an example of an uncompressed specimen is compared to a specimen that has been densified to form compressed wood.

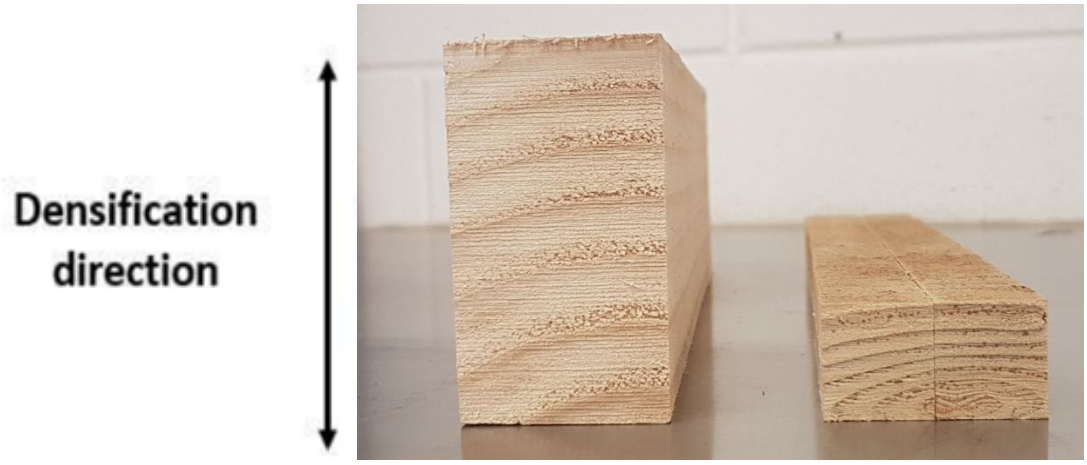
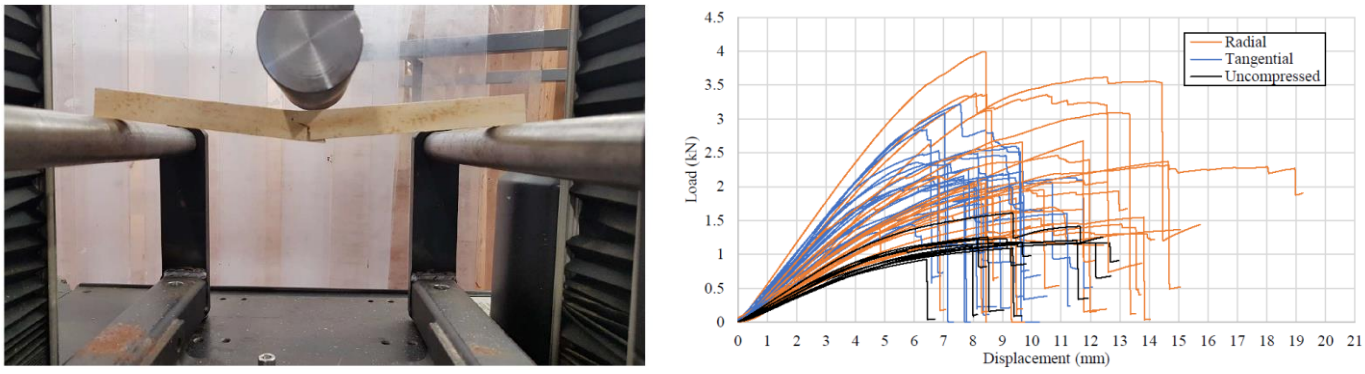


Figure 5. Densification of Irish Sitka spruce to form compressed wood

The density of Irish Sitka spruce makes this timber particularly suitable for the manufacture of compressed wood and the success of this technology relies on establishing the correct processing parameters. The processing parameters examined in this study is the pressing time and the compression ratio (CR). The pressing time is examined to establish the duration of time required to reliably produce compressed wood. The compression ratio (or densification ratio) refers to the difference between the initial and final thickness of the timber as a percentage of the initial thickness.

There have been bending tests performed on long clear specimens of compressed timber with dimensions of 20 x 20 x 300 mm^3 to determine its bending strength and stiffness. An example of a tested specimen subjected to bending failure is presented in Figure 6a and the load-displacement behaviour of all specimens tested is presented in Figure 6b.

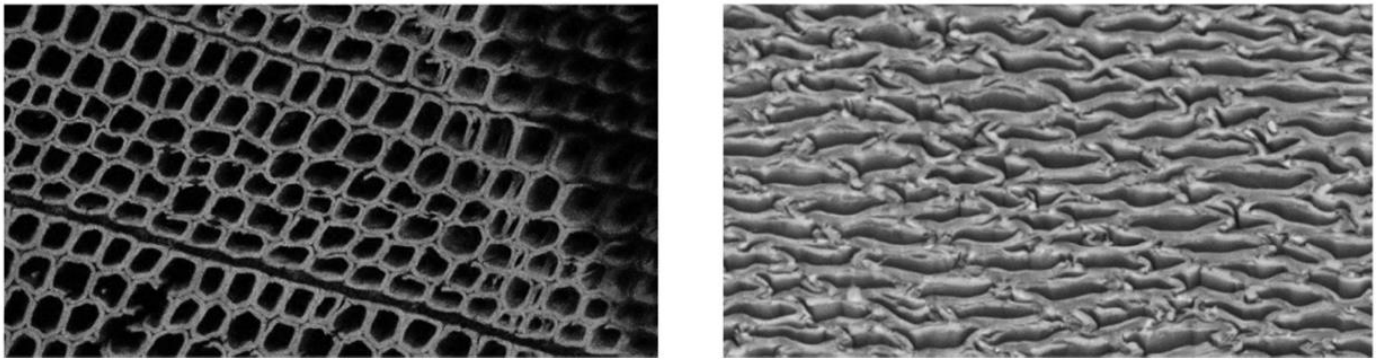


a) b)

Figure 6: Structural tests, a) bending test set-up and specimen subjected to bending failure and b) Load-displacement behaviour of all specimens: Uncompressed specimens are presented in black, specimens loaded in the radial direction are presented in orange and specimens loaded in the tangential direction are presented in blue.

It can be seen visually in Figure 6b that the majority of compressed wood specimens demonstrate greater strength and stiffness when compared to the un-compressed specimens (Black lines) regardless of the loading direction (radial or tangential direction). The results of the structural examination indicate that the strength and stiffness of compressed Irish Sitka spruce generally increase with increasing CR. The optimised parameters for further production have now been established and will contribute to the development of dowel laminated timber elements.

To further examine the influence of the processing parameters on the manufacture of compressed wood, a microscopic study was carried out. Specimens with a thickness of 20-40 μm were taken from specimens subjected to compression along the radial direction in accordance with the test programme. The specimens were cut using a rotary microtome to view the cell structure under a microscope. As seen in Figure 7b, the cells or lumen of the specimen have been compressed considerably due to the thermo-mechanical process. The voids have been reduced and the density of the material has significantly increased. The test has also demonstrated the maximum CR that can be exerted on the timber before excessive damage is caused to the timber.



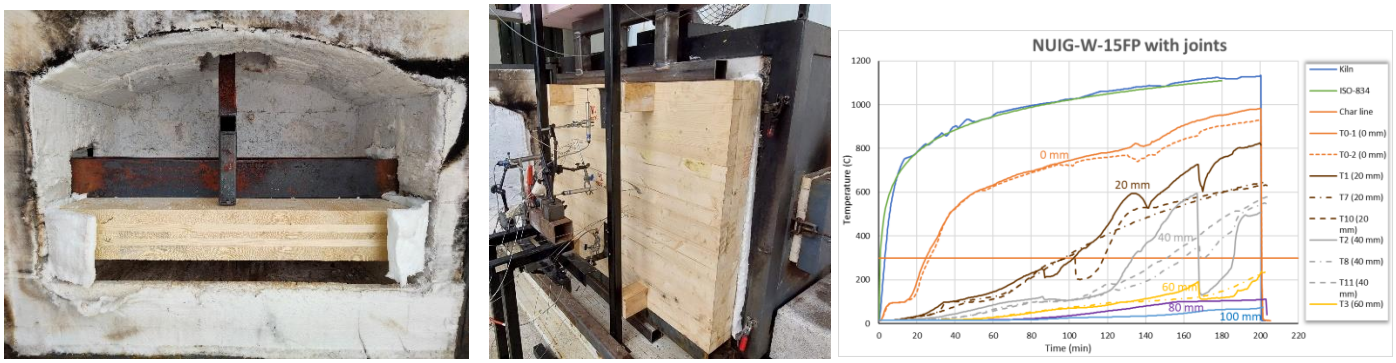
a) b)

Figure 7: Microscopy study, a) Microscopic image of the uncompressed Specimen (Scale 50 μm) and b) Microscopic image of a compressed wood specimen (CR of 68.4%)(Scale 50 μm)

When examined in low-, medium and high-density groups, timber compressed to a density above 1000 kg/m^3 result in an increased likelihood of damage and it is recommended to utilise the low- or medium-density groups for the manufacture of compressed timber.

Fire Testing of CLT manufactured from Irish Timber

The development of fire tests in accordance with EN 1363 and EN 1365 Part 1 and Part 2 has begun in Munster Technological University (MTU) on floor and wall panels. A series of test specimens that utilise C16 and C24 grade material will be tested to allow for comparisons in performance to be observed. The C16 grade timber was provided by Murray Timber Group Ltd. and commercial CLT panels using C24 Grade material was provided by a European manufacturer. In Figure 8, the fire test setup and a sample of experimental data have been presented. In Figure 8a, a 5-layer floor panel is positioned within the kiln and subjected to a structural load under three-point bending. In Figure 8b, a 3-layer wall panel is orientated in the vertical direction and subjected to the kiln temperature on one face only. The wall specimen is also subjected to a vertical load equal to that of the equivalent 7-storey building designed as part of the MODCONS project.



a) b) c)

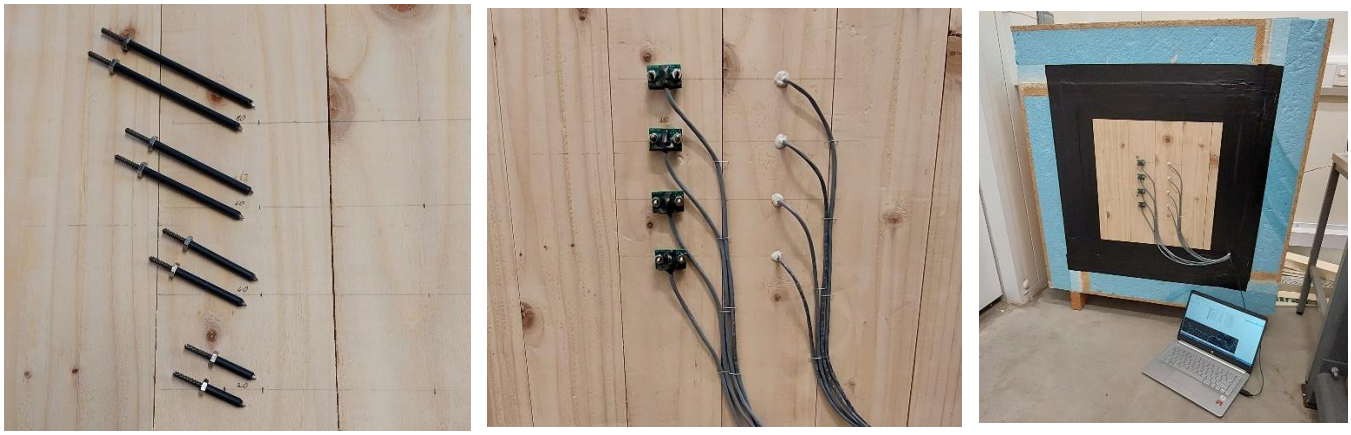
Figure 8: Fire performance tests, a) Floor panel, b) wall panel and c) temperature results at various depths through the CLT panel

All panels subjected to fire testing have also been instrumented with thermocouples at various depths in order to determine the transfer of heat through the panel and determine when and to what depth the panel has charred. As shown in Figure 8c, the temperature of the kiln which follows the standard fire curve in ISO-834 is presented as well as the temperature of the panel at different depths. A horizontal line is also presented at 300°C which is referred to as the charred line. This line indicates the temperature at which timber converts to char after undergoing the process of pyrolysis.

The temperature and time are then plotted and the average charring rate may then be calculated for CLT floor, ceiling and wall panels. Furthermore, tests are not only performed on exposed timber panels but tests have also been carried out with typical fire protection measures such as Type-A and Type F plasterboard which are commonly used for all types of construction. To date, the results have been quite successful with the CLT panels remaining structurally sound for significant durations beyond the typical ratings of 60, 90 and 120 REI.

Structural Monitoring

The structural monitoring of the CLT structure is an important aspect of the MODCONS project and will serve as a useful tool to understand and learn more about the use of such structures in Ireland. It is envisaged to instrument a CLT panel within a building to better understand how the panel is behaving under in-service conditions. Currently, a structural monitoring system is being calibrated for use on Irish grown timber. This system is capable of monitoring moisture content, temperature, internal and external relative humidity and CO_2 concentrations within the proximity of the panel. Furthermore, the system is capable of monitoring moisture content at different depths within the CLT panel and accurate calibration will allow this to be used for CLT manufactured from Irish Sitka spruce. The instruments and set-up of the validation of the structural monitoring system can be seen in Figure 9. The insulated moisture content pin pairs of varying depth are shown in Figure 9a. In Figure 9b, the moisture content pin pairs have been inserted into the CLT panel alongside temperature probes at similar depths to apply temperature corrections and accurately determine the moisture content in the CLT panel.



a) b) c)

Figure 9: Structural monitoring, a) insulated moisture pin pairs, Moisture pins and temperature probs installed within Irish C16 CLT panel and c) CLT panel housed within the insulated box to ensure a moisture content gradient exists between the internal and external face of the CLT.

In Figure 9c, the instrumented CLT panel is secured within an insulated box that has internal sensors to measure the internal relative humidity and temperature. Externally, the relative humidity and temperature will be controlled by a state-of-the-art conditioning chamber that will be used to simulate different environmental conditions to examine the behaviour of the CLT and validate the monitoring system prior to its installation within a structure in Ireland. As the use of CLT will typically be used within internal conditions, it is expected that this experimental programme will go beyond the expected operational environment that a CLT panel will be exposed to in-service.

Project Publications

The MODCONS Project Brochure highlights the main objectives of the MODCONS Project and can be downloaded via this Link

There are several publications submitted for review at national and international conferences which will be made available when published. The list of current publications from the MODCONS project are presented below;

- O'Ceallaigh C., McGetrick P., Harte A.M., (2021) **The Structural Behaviour of Compressed Wood Manufactured using Fast-grown Sitka Spruce.** *In Proceedings of the World Conference on Timber Engineering (WCTE) 2021, Santiago, Chile 9-12 August.*

Project Acknowledgements

The MODCONS Project team are very grateful for the support and guidance of the industry partners involved in the MODCONS Project. To date, our industry partners have had a significant influence on the outcomes of the project from providing the structurally graded C16 Sitka Spruce by Murray Timber Group Ltd. from which all the CLT panels have been manufactured, to the structural design guidance from PUNCH Consulting Engineers, CPAC Modular and Rothoblaas related to the design of CLT, Irish Building regulations, logistics and connection design and for the use of specialised test machines with ÉireComposites. We look forward to continued success as the project proceeds and our future collaboration.

Project Team

The MODCONS Project is a joint project between the Timber Engineering Research Group at the National University of Ireland Galway and Munster Technological University focused on increasing the knowledge and use of timber in modular construction.

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- **Mr. Kieran Ruane,** Academic Researcher
- **Mr. Yasir Khan,** Masters Researcher

Stakeholder Engagement

Knowledge engagement with the industry, regulators and other interested parties related to innovation in engineered wood products and modular construction methods is a key priority of the MODCONS Project. To keep up to date with project progress and recent developments, please visit our website and join our mailing list. If you would like to engage with the project team, please contact us via the email addresses listed above.

Project Website: *www.nuigalway.ie/terg/modcons*

Project Twitter: *To keep up to date on project progress and recent developments, follow us on Twitter. #MODCONS_Project*

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