

CoFoRD

Final Report

'Innovation in Irish Timber Usage (IITU)'

DAFM Project Reference No: 10 C 207

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End Date: 31/07/2016

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Collaborating Research Institutions and Researchers: Queen's University, Belfast; Dr. Daniel McPolin (PI)

Please place one "x" below in the appropriate area on the research continuum where you feel this project fits

Basic/Fundamental	—————→	Applied/Pre Commercial				
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Please specify priority area(s) of research this project relates to from the National Prioritisation Research Exercise* (NRPE) report;

Priority Area (s)	M Processing Technologies and Novel Materials
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Key words: (max 4) *Wood properties, engineered wood products; reinforced timber, cross-laminated timber*

1. Rationale for Undertaking the Research

Due to the increasing focus on the use of sustainable construction materials to meet environmental targets related to efficient energy use and emissions, a significant opportunity exists for the Irish wood products sector. In 2012, the Irish forestry and forest products sector generated €2.2 billion in annual output, representing 1.3% GDP, and employed approximately 12,000 people. Moreover, there exists a substantial potential to expand production. According to COFORD half of the forest estate is less than 25 years old and further expansion of forest cover is planned by policymakers. Forest products to a value of €303 million were exported: including €73 million worth of sawn softwood and €179 million worth of wood-based panels. In general, 89% of the wood-based panels were exported. The supply of round wood from Irish forests is projected to increase from 3903 million m³ in 2011 to 7110 million m³ in 2028. These figures show the potential of Irish forests to provide increased and sustainable supplies of wood products. Increased sales of existing products and the development of new markets at home and abroad for new added-value wood products will lead to job creation across the sector.

In order to increase the utilisation of Irish timber in construction, research was needed to establish the mechanical and physical properties of the current forest output. For timber construction products, the fundamental properties are the bending modulus of elasticity, the modulus of rupture, the density and the dimensional stability as these define the structural grade of the material.

To investigate the potential for new add-value timber construction products, novel engineered wood products for which Irish timber is suitable needed to be developed. Two key research areas were addressed: (i) Fibre-Reinforced Polymer reinforced timber and (ii) Cross-Laminated Timber (CLT).

- (i) Previous research at NUIG and QUB has shown that reinforcement with lightweight FRP rods will enhance the structural performance of Irish timber for building applications. The short-term behaviour of these systems is known. Investigation of the long-term behaviour of FRP reinforced beams in dry and moist environments was necessary to provide appropriate design factors and the development of efficient FRP reinforced joints to connect elements was required.
- (ii) Cross-laminated timber is a relatively new type of solid timber panel product with excellent load-carrying properties and is suitable for large scale commercial buildings. In order to tap into the growing global demand for CLT, it was necessary to investigate the potential use of Irish Sitka spruce in the production of CLT.

2. Research Approach

The research was organised in a number of Tasks, which were shared between the two partners. In Task 1, the physical and mechanical properties of Irish Sitka spruce were established by reviewing all available, relevant published work on this topic. A sample of the existing output from sawmills with a wide geographic spread across the island was procured. Testing was carried out using Irish and European standards followed by statistical analysis of the results. Some work was carried out jointly with Napier University. The use of a portable timber grading for determining the mechanical properties was assessed.

In Tasks 2, 3 and 4, potential engineered wood products were investigated using a combination of experimental, analytical and numerical methods. A novel creep testing rig was developed at NUIG to investigate the long-term performance of reinforced timber beams. A total of 40 beams underwent extensive characterisation and non-destructive flexural testing in their unreinforced state before 20 of them were reinforced with novel basalt fibre reinforced polymer (BFRP) rods. They were then tested under a constant load for a period of 75 weeks in controlled climates during which the moisture content, deformation and strains in the beams were continuously monitored. Numerical models were developed to predict the moisture diffusion and deformation response of the beams and calibrated against the experimental results. These models enable the prediction of the response of beams of different sizes with different reinforcement ratios. At QUB, factors influencing the performance of glued-in BFRP connections were investigated on small specimens using a novel pull-bending test adapted from a similar test used in concrete technology. Based on the test results, a connection design tool was developed, which predicts the theoretical connection strength. Using this design tool, moment connections in a box-section portal frame were designed and tested at full scale.

The development of Irish Sitka spruce CLT panels was carried out in NUIG. The first phase of the research involved the selection of a suitable adhesive and associated processing parameters. Small scale specimens were manufactured using two different adhesives and four different clamping pressures. A total of 900 specimens were tested to find the shear strength and the bond durability. Having determined the optimum adhesive and pressure combination, large-scale three- and five-layer specimens were manufactured using different layer thicknesses to

determine the modulus of elasticity in bending and shear. Finally, a commercialisation study was performed to determine the viability of CLT manufacturing in Ireland considering both supply aspects and market potential.

3. Research Achievements/Results

Outline main results achieved

Task 1

- The mechanical (Modulus of Elasticity and bending strength) and physical properties of the Irish Sitka spruce were established. A database has been created in Excel containing all of the test results together with historical data from the IIRS database.
- The mechanical and physical properties of Irish Sitka spruce have not changed significantly over that last 25 years. MOE was found to be the limiting factor for strength classification.
- The MOE, strength and failure behaviour of Irish Sitka spruce in compression have been established.

Task 2

- The use of glued-in BFRP rod reinforcement has been shown to reduce the long-term moisture-induced creep deformations in timber elements loaded, which together with the strength and stiffness enhancement shows the significant potential of these wood products.
- A validated numerical model for structural design of reinforced glulam has been developed.
- Values for viscoelastic, mechano-sorptive and swelling/shrinkage strains have been established for Irish Sitka spruce that can be used by other researchers.

Task 3

- The viability of using glued-in BFRP rods as connections in Irish timber elements has been established.
- Optimum connection length and edge distance as a function of glueline thickness and rod diameter were established through experimental testing.
- A design tool was developed for the pull-out strength of rods with varying parameters.
- Moment connections using optimal parameters were tested both for durability and for their suitability in an in-service application.
- Based on the findings of these experimental tests a guideline design procedure was reported with a theoretical prediction of strength of a connection using glued-in rods.

Task 4

- Two adhesives (PUR and PRF) have been found to be suitable in terms of strength for the manufacture of CLT panels using Irish Sitka spruce.
- PRF-bonded panels display higher durability than PUR-panels.
- A pressure of 0.4 N/mm² is sufficient for manufacture.
- MOE and strength values in bending and shear have been determined for 3-layer and 5-layer panels.
- The thicker the CLT panel, the lower its bending strength
- The viability of using Irish Sitka spruce for CLT manufacture has been established. This presents new opportunities for Irish timber in the home and export markets. A niche product for commercialisation, a CLT modular floor system, was identified. The main benefit over other floor systems is the significant reduction in installation time, a reduced labour requirement, consequently financial saving.
- CLT production of below 10,000 m³ annually would be initially more favourable, significantly reducing costs of establishing a CLT plant.

Task 5

- Dissemination of the project outcomes has been achieved through a variety of approaches including conference presentations, workshops, learned journals, and face-to-face meetings with industry.

4. Impact of the Research

4(a) Summary of Research Outcomes

(i) Collaborative and Industry links developed during this research

Links have been established with the main sawmills and with researchers at Edinburgh Napier University in relation to the establishment of the properties of Sitka spruce. In addition, links have been established between NUI Galway and forestry researchers in UCD and in Teagasc. This has led to two joint research projects investigating the links between forestry management practices and the properties of Irish timber (Sitka spruce, Norway spruce and Douglas fir). NUI Galway has developed links with the main European producers of CLT panels, connections for CLT, and CLT manufacturing equipment and continues to work with some of these companies. These links will be important in the move to commercialisation of Irish CLT. Links with Balcas sawmill in Fermanagh have been established with QUB for supply of Irish timber.

(ii) Outcomes where new products, technologies and processes were developed and/or adopted

Suitable processing parameters for the production of CLT from Irish Sitka spruce have been established. The mechanical performance of the panels in bending have been demonstrated. On the basis of a desk study, the commercial viability of a niche CLT flooring panels has been demonstrated. These are valuable first steps towards the commercialisation of Irish CLT. In the next steps, further validation of the mechanical properties will be needed and connection systems for these panels will need to be tested and design values established. During the course of the project, links with 10 timber suppliers (8 in NI and 2 in RoI) were established to investigate the potential deployment of a timber-FRP composite flooring system. An investigation was carried on the design and testing of 14 structural units. Additionally, design work was carried out for SME in NI which produces small scale timber box beam portal frames, however glued-in rods were not included in this design.

(iii) Outcomes with economic potential

Suitable parameters for manufacturing CLT panels using Irish Sitka spruce have been established. A niche CLT modular floor system has been identified as most suitable to the Irish context and a route to commercialisation has been established. During the latter stages of the project, QUB have been approached by two companies, **Keystone Group and Quinn Building Supplies**, to assist with the development of timber composite systems which they wish to bring to market. These discussions are at an early stage but it is hoped that a partnership will be established for design and testing of a commercial element solution or a larger research project with broader goals of timber modular solutions.

(iii) Outcomes with national/ policy/social/environmental potential

The mechanical properties of the current Sitka spruce resource have been established and this will feed into future forestry policy
Data to support revisions to European timber design standards in relation to the reinforcement of timber has been generated. This will also have implications for National standards. The potential to use native timber in a high-performance building product will have significant environmental benefits if brought to full production and utilised widely in the construction sector.

4 (b) Summary of Research Outputs

- (i) Peer-reviewed publications, International Journal/Book chapters.

International journal publications

1. Sikora, KO, McPolin, DO, Harte, AM (2016). *Effects of the thickness of cross-laminated timber (CLT) panels made from Sitka Spruce on mechanical performance in bending.* *Construction and Building Materials* 116:141-150.
2. Sikora, KO, McPolin, DO, Harte, AM (2016). *Shear strength and durability testing of adhesive bonds in cross-laminated timber (CLT).* *Journal of Adhesion* 92(7-9):758-777.
3. O'Neill, McPolin, Harte (2016). *Box section frames with Glued-in basalt FRP rods as moment connections.* *Construction and Building Materials*, submitted for re-review 4 Nov 2016
4. Steiger, R, Serrano, E, Stepinac, M, Rajčić, V, O'Neill, C, McPolin, D, Widmann R (2015) *Strengthening of timber structures with glued-in rods.* *Construction and Building Materials* 97:90-105.

Published peer-reviewed conference papers

5. O'Ceallaigh, C., Harte, A., Sikora, K., McPolin, D. (2014) *Enhancing Low Grade Sitka Spruce Glulam Beams with Bonded-in BFRP Rods.* In *Proc. of COST Action FP1004 Conference, Experimental Research with Timber, Prague, Czech Republic.*
6. Sikora, K., Harte, A., McPolin, D., (2014) *Durability of adhesive bonds in cross-laminated timber (CLT) panels manufactured using Irish Sitka spruce.* In *Proc. of 7th Wood Structure and Properties Conference, Zvolen, Slovakia.*
7. O'Ceallaigh, C., Harte, A., Sikora, K., McPolin, D., (2014) *Mechano-sorptive Creep in Reinforced Sitka Spruce.* In *Proc. of 7th Wood Structure and Properties Conference, Zvolen, Slovakia.*
8. Sikora, K., Harte, A., McPolin, D. (2014) *Irish Timber - Bond quality of cross-laminated timber (CLT) from Irish Sitka spruce.* In *Proc. of Civil Engineering Research in Ireland, Belfast*
9. Harte, A., Sikora, K., O'Ceallaigh, C. (2014) *Irish Timber - Characterisation, Potential and Innovation,* In *Proc. of Civil Engineering Research in Ireland, Belfast.*
10. O'Neill, C., McPolin, D., Taylor, S., Harte, A, (2014) *Influence of embedded length on strength of BFRP rods bonded parallel to the grain in low grade timber by pullout-bending tests,* In *Proc. of Civil Engineering Research in Ireland, Belfast.*
11. Sikora, K., Harte, A., McPolin, D. (2015) *Bonding strength and durability of adhesive bonds in Sitka spruce cross-laminated timber.* In *Proc. of 3rd International Conference on Structural Adhesive Bonding, University of Porto, Portugal.*
12. O'Neill, CM, McPolin, D, Taylor, SE, Harte, AM, (2016) *Glued-in basalt FRP rods as moment connections in box section frames,* In *Proc. of World Conference on Timber Engineering WCTE 2016, Vienna.*
13. O'Ceallaigh, C, Sikora, KS, McPolin, D, Harte, AM (2016) *Viscoelastic creep in reinforced glulam,* In *Proc. of World Conference on Timber Engineering WCTE 2016, Vienna.*
14. O'Neill, C., McPolin, D., Taylor, S., Harte, AM (2016) *Distribution of stresses along the length of BFRP rods glued-in to Irish Sitka spruce.* In *Proc. of Civil Engineering Research in Ireland, Galway.*
15. O'Ceallaigh, C, Sikora, K, McPolin, D, Harte, AM (2016) *Viscoelastic creep of FRP reinforced glulam,* In *Proc. of Civil Engineering Research in Ireland, Galway. **Award for Best Timber Paper in Conference.***
16. Harte, AM (2016) *Mass timber - the emergence of a modern construction material.* In *Proc. of Civil Engineering Research in Ireland, Galway.*

- (ii) Popular non-scientific publications and abstracts including those presented at conferences

Institution of Structural Engineers, Young Researchers Conference , London, 2016
O'Neill, CM, *Glued-in BFRP Rods as Moment Connections in Indigenous Low-Grade Timber*
O'Ceallaigh, C, *Long-term deformation in unreinforced and reinforced Sitka Spruce glulam*
Awarded Second Place Overall
Society of Chemical Industry (SCI) Construction Materials, Young Researchers Forum,
London, 2016
O'Neill, CM, *Behaviour of Glued-in BFRP Rods under combined Axial Force and Bending Moment*

(iii) National Report
None

(iv) Workshops/seminars at which results were presented

1. *COST Action FP 1101 WG 2 Workshop in Telc, Czech Rep. 21/6/2013*
2. *COST Action FP 1101 WG 2 Workshop in Trento, Italy 1/9/2013*
3. *Ryan Institute Research Day, NUI Galway, 24/9/2013*
4. *COST Action FP 1101 Training School in Athens, Greece 7-10/10/2013*
5. *COST Action FP 1101 Training School in Mons, Belgium 7-10/12/2013*
6. *COST Action FP 1004 Training School in Trento, Italy 15-17/4/2014*
7. *COST Action FP1004 Conference, Experimental Research with Timber, Prague, Czech Republic 21-23/5/2014*
8. *UL-NUIG Research Day, University of Limerick, 20/5/2014*
9. *National Forestry Conference, Enfield, 6/6/2014*
10. *The 57th Society of Wood Science and Technology International Convention, Zvolen, Slovakia, 23-27/6/2014*
11. *Civil Engineering Research in Ireland Conference, Belfast, N. Irl. 28-29/8/2014*
12. *COST Action FP 1101 Training School Galway 8-11/12/2014*
13. *Annual Augustine Henry Forestry Lecture, Society of Irish Foresters, Dublin, 5/3/2015*
14. *17th Institution of Structural Engineers Young Researchers' Conference, London 4/4/2015*
15. *Forest Service Conference, Wexford, 25/5/2015*
16. *3rd International Conference on Structural Adhesive Bonding, University of Porto, Portugal, 2-3/7/2015*
17. *IITU Industry Seminar, Innovations in Timber Construction, 16/10/2015*
18. *Institution of Structural Engineers Young Researchers Conference, London, 6/4/2016*
19. *Young Researchers' Forum III: Innovation in Construction Materials, 12/4/2016*
20. *World Conference on Timber Engineering, Vienna, 22-25/8/2016*
21. *Civil Engineering Research in Ireland Conference, Galway 28-29/8/2016*

(v) Intellectual Property applications/licences/patents
None

(vi) Other

5. Scientists trained by Project

Total Number of PhD theses: _____2_____

Please include authors, institutions and titles of theses and submission dates. If not submitted please give the anticipated submission date

1. Conan O'Ceallaigh NUI Galway PhD Thesis: *An Investigation of the Viscoelastic and Mechano-sorptive Creep Behaviour of Reinforced Timber Elements* Proposed Submission date: 6 December 2016.
2. Caoimhe O'Neill QUB PhD Thesis: *Glued-in Rod Moment Connections in Low-Grade Timber*, Submission date: 31 January 2017 (thesis fully drafted, researcher on maternity leave until March 2017).

Total Number of Masters theses: _____0_____

Please include authors, institutions and titles of theses and submission dates. If not submitted please give the anticipated submission date
N/A

6. Permanent Researchers

Institution Name	Number of Permanent staff contributing to project	Total Time contribution (person years)
NUI Galway	4	1.33
QUB	1	1
Total		

7. Researchers Funded by DAFM

Type of Researcher	Number	Total Time contribution (person years)
Post Doctorates/Contract Researchers	2	2.916
PhD students	2	6
Masters students		
Temporary researchers		
Other		
Total		

8. Involvement in Agri Food Graduate Development Programme

Name of Postgraduate / contract researcher	Names and Dates of modules attended
N/A	

9. Project Expenditure

Total expenditure of the project: €433,304.34 (excl BIK)

Total Award by DAFM: €484,663.00

Other sources of funding including benefit in kind and/or cash contribution(specify): €46,000 (BIK)

SIP Energy - €30,000 BIK (Exploitation advice, Access to industrial facilities and personnel)

ECC Teo - €10,000 BIK (Supply sawn timber)

Murray Timber Group - €6,000 BIK (Supply sawn timber)

Breakdown of Total Expenditure

Category	Name Institution 1	Name Institution 2	Name Institution 3	Name Institution 4	Total
Contract staff	-	-			-
Temporary staff	-	-			-
Post doctorates	149200.61	-			149200.61
Post graduates	61586.88	68064.11			129650.99
Consumables	36657.75	14498.73			51156.48
Travel and subsistence	11228.67	3984.05			15212.72
Sub total	258673.91	86546.87			345220.80
Durable equipment	1728.97	1043.23			2772.20
Other	7709.17	-			7709.17
Overheads	77602.17	-			77602.17
Total	345714.22	87590.12			433,304.34

10. Leveraging

Summarise any additional resources'/funding leveraged by this award from other sources i.e. Additional Staff, National/EU funding secured, EI Commercialisation Fund

- **NUI Galway Teagasc Walsh Fellowship**
Links have been established with Teagasc through the project. This has resulted in a joint application for a Walsh Fellowship, which was successful and the project is currently underway. (Award to NUI Galway: €88,000)
- **EU Woodwisdom ERANET Fastforests project**
Links with UCD Department of Forestry, FCBA (FR), Ecole du Bois (FR) and FVA (DE) have been established resulting in successful application under the EU Woodwisdom ERANET. The project is now underway and a PhD student at NUI Galway is working on this project. (Award to NUI Galway: €102,700)
- **InterTrade Ireland FUSION Award**
The project has established links between the two universities and industry. Both universities have been approached to work with a company wishing to develop skills in timber engineering. NUI Galway has engaged in a KT Fusion project with Taylor and Boyd to help them develop expertise in the design of CLT buildings. (Award to NUI Galway: €30,800). QUB have partnered with Newell Roofing to help them develop façade and roofing support system. (Award to QUB: £23,250)
- **EU Interreg NWE Adhesive Free Timber Buildings (TAFTB) project**
NUI Galway together with Project partners from UK, France, Germany, Luxembourg, Belgium were recently successful in securing €4.8 m in EU funding to develop adhesive free construction products using European timber including Irish Sitka spruce. (Award to NUI Galway: €317,670)
- **Invest NI / InterTrade Ireland**
QUB were successful in securing 10 Innovation Vouchers for the development and testing composite flooring systems. This work has also supported and facilitated UG research projects. (Award to QUB £40,000).

11. Future Strategies

Outline development plans for the results of the research.

Suitable parameters for manufacturing CLT panels using Irish Sitka spruce have been established. A niche CLT modular floor system has been identified as most suitable to the Irish context and a route to commercialisation has been established. The outcomes from the project IITU have confirmed that there is potential in using Irish Sitka spruce for CLT manufacture and this presents new opportunities for Irish timber in the home and export markets. In order to develop the product that will be launched to the market, further verification of mechanical performance needs to be carried out. In particular stiffness, bending and shear strengths of CLT floors loaded out-of-plane need to be established. In addition, connections systems for these floor panels need to be tested and optimised. NUI Galway has been awarded funding for 12 months from DAFM under the 2015 Competitive Call for research proposals Research Plus strand to undertake this further development work.

During the latter stages of the project, QUB have been approached by two companies, **Keystone Group and Quinn Building Supplies**, to assist with the development of timber composite systems which they wish to bring to market. These discussions are at an early stage but it is hoped that a partnership will be established for design and testing of a commercial element solution or a larger research project with broader goals of timber modular solutions.