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DEVELOPING THE SCOTS PINE RESOURCE

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NORBUILD EDTC







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METLA
SKOGSSTYRELSEN
NORTH KARELIA POLYTECHNIC
Forest Research
An agency of the Forestry Commission

Contents

The English text was revised by Elspeth Macdonald and Ben Davis.

1 - Introduction

Glue laminated timber, commonly referred to as GluLam, (strength graded timber lamellas bonded together to form a sizeable structural component) has a wide range of structural applications, ranging from beams to columns to truss members. Norbuild Timber Fabrication and Fine Carpentry Ltd produces bespoke GluLam from Douglas Fir (Pseudotsuga) however the Douglas Fir resource is diminishing impacting upon security of supply. The purpose of this research project is to determine the feasibility of producing GluLam from other locally sourced Scottish Home Grown Timber including Sitka Spruce (Picea sitchensis) and Scots Pine (Pinus sylvestris) as well as determining a suitable method of ensuring product quality given the increasing variability of timber supplied.

As a result this study is important to ensure the continued growth and success of NorBuild TFFC ltd. Further to this there are also opportunities for NorBuild to increase their business activity supplying local builders and timber frame manufacturers. Having the flexibility to supply a range of GluLam products will present them with further market opportunities such that the business can grow and support employment in the local community.

2 - Lamella preselection and quality assurance processes

2.1 - Introduction

A rigorous quality assurance (QA) process was undertaken as part of the study in order to:

1. Determine the feasibility of using other locally sourced timber
2. Provide a method for optimising the resource available (normally of lower quality)
3. Provide all necessary information required for academic rigour

The QA process is as presented in Figure 2.0 and includes visual, acoustic and structural grading at varying stages of the GluLam fabrication process (Figure 2.0).

a) Visual Grading *b) Acoustic Grading* *c) Structural Grading*

Figure 2.0: *Grading Process*

It is worth noting that included within this process was the benchmarking of the currently produced Douglas Fir GluLam product (low grade Douglas Fir was used for this which is not necessarily representative of the standard material used) in order to provide data for relative comparison with the proposed Sitka Spruce (Picea sitchensis) and Scots Pine (Pinus sylvestris) GluLam.

Standard lamella dimensions for GluLam beams are dependent on the resource available and are normally standardised to meet the specifics of the market supplied (rim-board, ridge beams, long span beams etc). With respect to this the lamella dimension for the test beams were agreed with the input of NorBuild to be 42x100x4800mm and in order to adhere to the British Standard Code of Practise load span conditions the lamellas for structural grading were cut to 2400mm lengths.

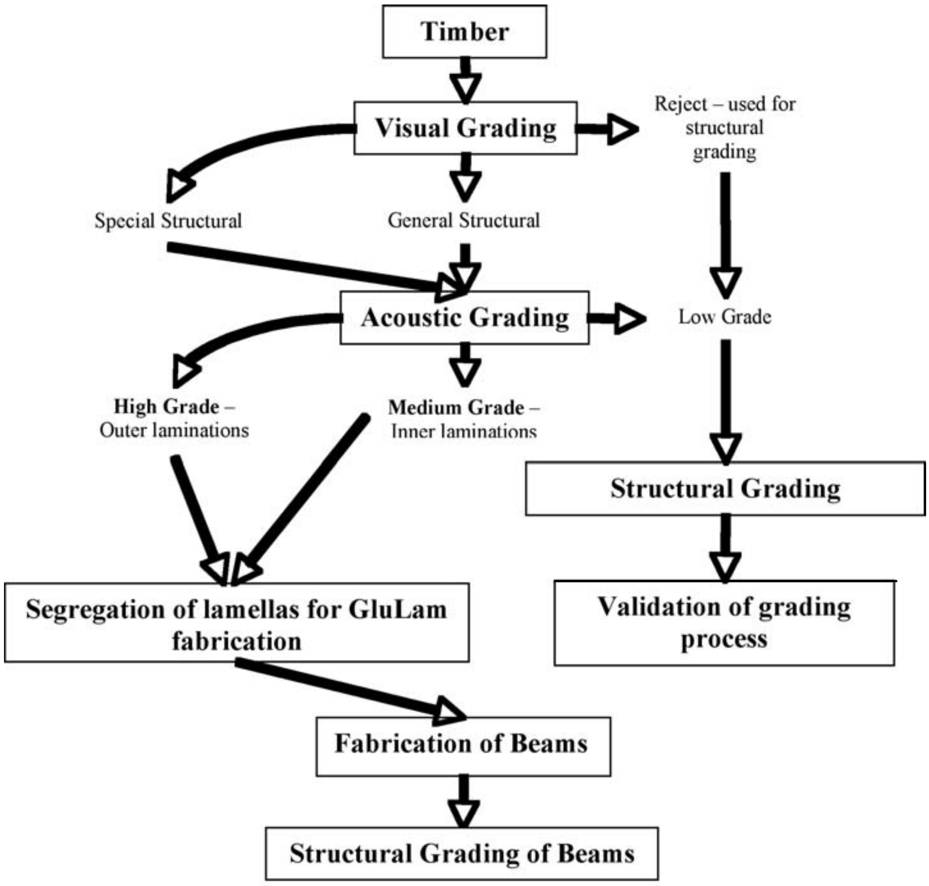


Figure 2.0: *GluLam Test Beam Structural Grading Process*

2.2 - Visual Grading

Each piece of timber was visually assessed and correspondingly graded for structural purposes in accordance with BS EN 4978:2007 (1). The standard specifies the permissible limits for two visual strength grades, general structural grade (GS) and special structural grade (SS), timber which did not meet the specification for (GS) was rejected and not used in fabrication of the GluLam beams. However, in order to make full use of the resource available the rejected timber was used to QA the acoustic grading process. By using the low quality rejected material for this QA procedure the accuracy limitations of the acoustic grading process for lower grade timber was also tested.

2.3 - Acoustic Grading

Acoustic technology is widely acknowledged as an accurate and efficient non-destructive method to determine wood quality (2) (3). Acoustic grading was carried out using a Hitman HM200 which is a handheld tool capable of quantifying Modulus of Elasticity (MoE) in bending a key mechanical wood property, quickly and accurately without causing damage to the sample.

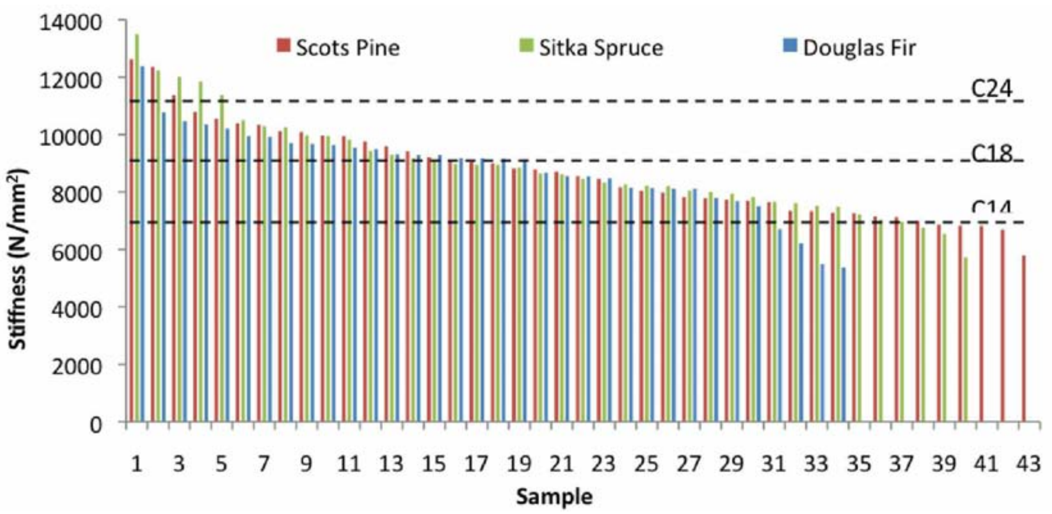
In order to determine the MoE of a piece of timber using the Hitman HM200 the length, density and sonic velocity of the piece must be determined and Equation 1 applied. Therefore, each piece of timber was weighed using platform scales capable of measuring lengths of timber accurate to 3 decimal places and the sonic velocity (V), when excited using a standard hammer, was measured by the acoustic grading kit.

$$MoE = \rho_k * (V)^2$$

Where;
ρ_k is the density of the piece in (kg/m^3).
V is the sonic velocity in (km/s).
MoE is the stiffness in (N/mm^2).

Equation 1 - Acoustic Grade MoE Calculation

The information from this process is as contained in Figure 2.1 and it is demonstrated from the MoE values obtained that there is a relatively large degree of variability for all species.



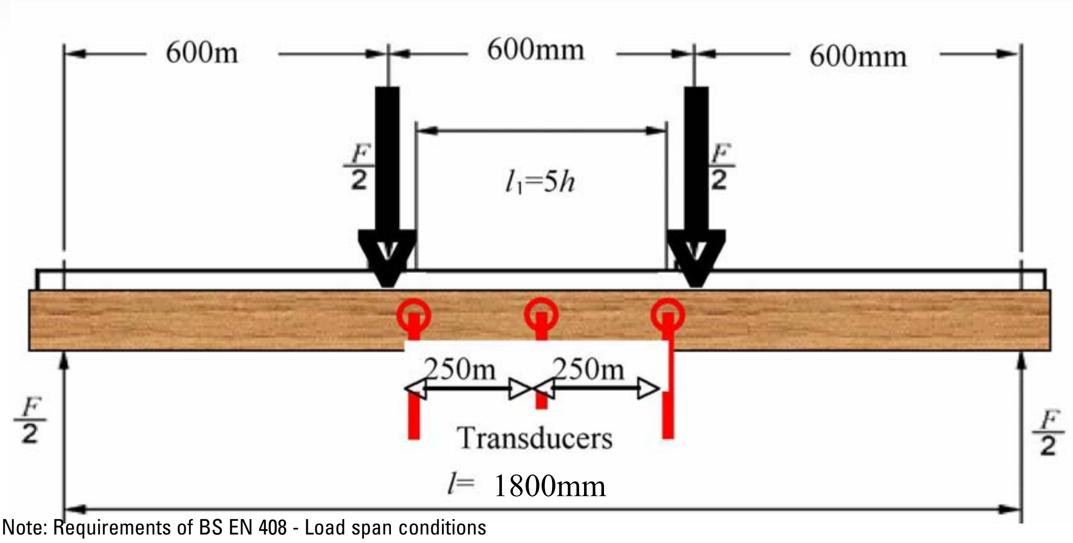
Note: Due to availability only 34 pieces of Douglas Fir were acoustically graded.

Figure 2.1 - *Acoustic MoE Comparison*

Each piece of timber was then classified in accordance with BS EN 338 - "Structural Timber Strength Classes" (4). This allowed timber with higher strength class to be specified for the outer lamellas of each beam and lower strength class for the inner lamellas optimising the available resource.

2.4 - Structural Lamella Acoustic Grading Validation

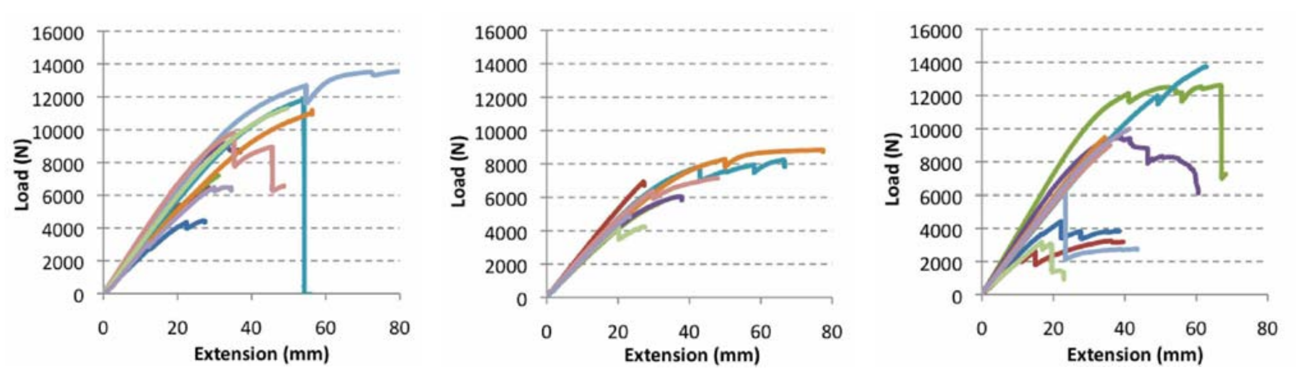
In order to validate the acoustic grading process, particularly when being utilised on low grade material, the lowest grade material was segregated and structurally graded in accordance with BS EN 408 (5). In total 30 pieces of timber were tested, 10 from each type of species. Figure 2.2 shows the test arrangement for the 4pt bending test in accordance with the code.



Note: Requirements of BS EN 408 - Load span conditions

Figure 2.2: *Test arrangement for measuring MoE in bending*

Each piece of timber was loaded to failure and contained in Figure 2.3 are the load displacement plots of the varying samples. Early failures of the lamella samples, especially the Douglas Fir, were as a result of the low timber quality and corresponding level of defects resulting in early fracture of the timber components. However, it is worth noting that through re-engineering in the form of GLuLam low quality timber can be utilised in a manner that enhances its ability to be used in structural components. Low quality timber would be used in GluLam at positions where bending stresses are limited and as GluLam can be a combination of low and relatively high grade material stresses under bending conditions will be distributed to the stronger timber sections as a result of the effect of combination. Adequate QA selection processes would therefore ensure lower grade material would be used as the central lamellas of GluLam beams fabricated as these lamellas undergo less bending stress under applied loading conditions. Specification of the higher grade material in the outer lamellas therefore improves both the strength and stiffness criteria of the beams, with stiffness often the governing criteria in beam design where load span conditions dictate.

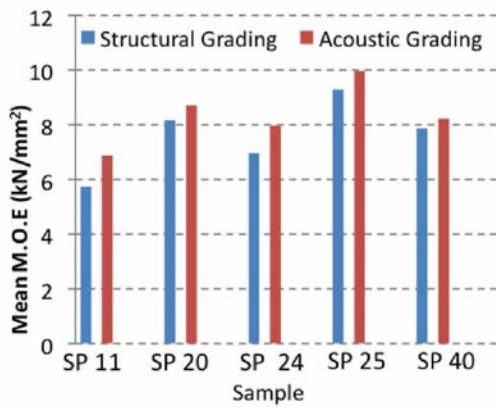


a) Scots Pine *b) Sitka Spruce* *c) Douglas Fir*

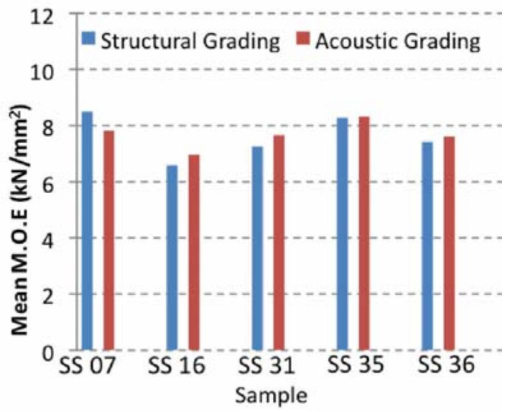
Figure 2.3: *Load Slip curves from Structural tests on lamellas*

The acoustic MoE results are compared relative to those from the strength grading process carried out in accordance with BS EN 408 (5) in Figure 2.4 (see APPENDIX A for full information) and Figure 2.7. From the results shown in Figure 2.4 a high degree of correlation in results is apparent even for low grade material and Figure 2.7 provides further evidence of this when considering the correlation of determination (R2) of the acoustic MoE vs. Structural MoE for each timber species, 0.96, 0.74 and 0.79 for Scots Pine, Sitka Spruce and Douglas Fir respectively.

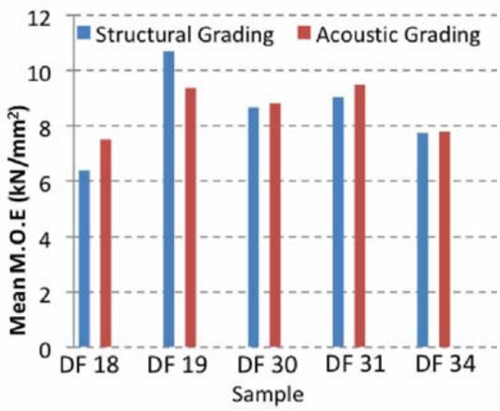
NOTE: *The relative comparison is limited due to sample range and approach (comparing acoustic grading of a 4.8m length to that of the average of the two cut sections of 2.4m structurally tested). However, based on the evidence of previous studies and degree of positive correlation the process is to an extent validated given the confines of the study.*



a) Scots Pine



b) Sitka Spruce



c) Douglas Fir

Note: the red line represents the MoE of each sample when it was acoustically graded at 4.8m in length. In order to meet the load span conditions of the structural test standard (BS EN 408) each of these 4.8m lengths were cut in half. Each half was marked A or B (Appendix A) and the blue line represents the average MoE of sample A and B in each case.

Figure 2.4*: Acoustic vs. Structural Grading*

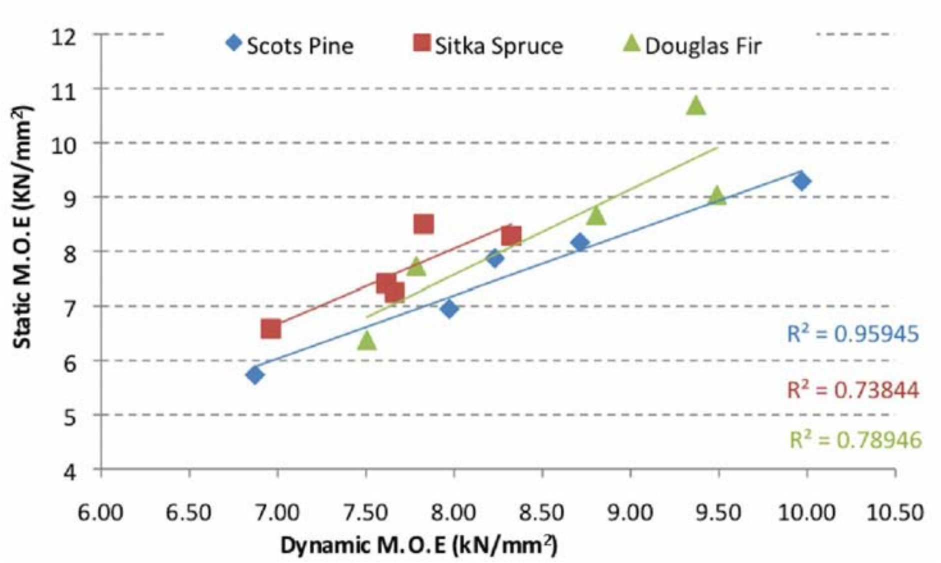


Figure 2.5: *Relationship between Static and Dynamic M.O.E (R^2 Values)*

2.5 - Structural Lamella Failure Mode Classification

Of the individual lamellas tested it was noted from the visual grading process that the Scots Pine and the Douglas Fir contained larger knots whereas the Sitka Spruce contained smaller more frequent knots. The positioning and size of knots within the timber sections would have an impact upon the failure mode. Knots tend to cause grain variation with larger knots exaggerating this further. Timber with large knots in the bottom chord subject to bending will therefore tend to fail quicker and in a more brittle fashion due to tension perpendicular to the grain taking place, in particular this is evident in the Douglas Fir samples (Figure 2.3). To quantify this affect the failure modes of the individual lamellas tested were classified through visual inspection on completion of the tests according to failure types as presented by Bodig and Jayne (6) (Figure 2.5). As a result of this it was identified that the majority of samples failed in a diagonal failure mode evidence of which is shown in Figure 2.5.

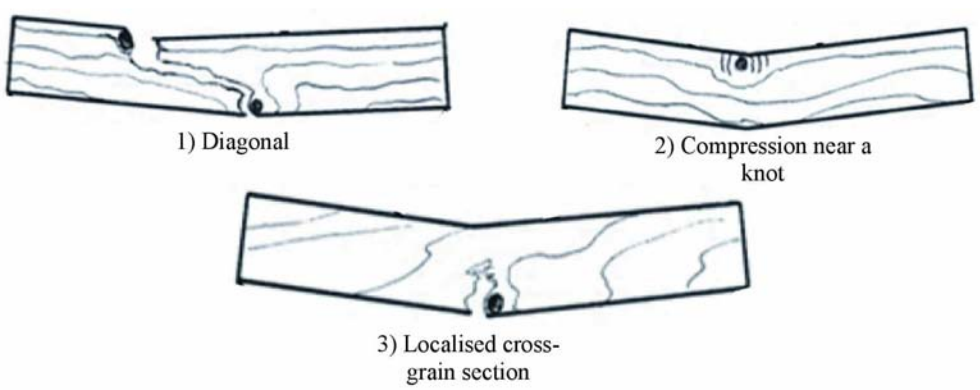


Figure 2.5: *Structural testing of lamellas - failure modes*

a) Scots Pine (1) *b) Sitka Spruce (1)* *c) Douglas Fir (1)*

***Figure 2.5**: Structural testing of lamella - failure modes*

GluLam offers the opportunity to reduce the impact of knots on the structural performance through re-engineering the product. In order to take advantage of this the flaws within the timber must be situated away from areas of high bending stress, primarily the top and bottom chords of the beam at mid-span positions. A further re-engineering technique which would enhance this is the utilisation of finger jointing of shorter sections containing minimum flaws. Re-engineering therefore offers the opportunity to enhance the structural performance and optimise the use of resource if applied correctly and with adequate QA.

2.6 - Summary

Acoustic grading in combination with visual grading would provide an enhanced level of QA of the timber resource available for use in GluLam fabrication. The visual and acoustic grading process would allow timber with defects and relatively low MoE to be pre-selected and used in areas where bending stress is less critical i.e. the middle of the beam. Further re-engineering through the use of finger joints would also help to further optimise the use of resource available.

3 - GluLam Structural Test Programme

3.1 - Introduction

An objective of the research programme is to test and asses a standard GluLam size which would generally be specified for rim board and ridge beam construction. Contained in Table 3.1are standard GluLam sizes and taking this into consideration a 250_90x4800mm GluLam beam with 6 laminations at 42mm thickness was chosen (Figure 3.0).

Width (mm)	Depth (mm)										
	225	270	315	360	405	450	495	540	585	630	675
65	■	■	■	■							
90	■	■	■	■	■	■					
115	■	■	■	■	■	■	■	▒		■	
140	■	■	■	■	■	■	■	▒	▒	■	▒
165							▒	▒	▒	▒	▒
190								▒	▒	▒	▒
Key:	■	typical sizes available off the shelf									
	▒	typical sizes									
Squarer sections are also available for columns.											

***Table 3.1**: Common GluLam sizes (5)*

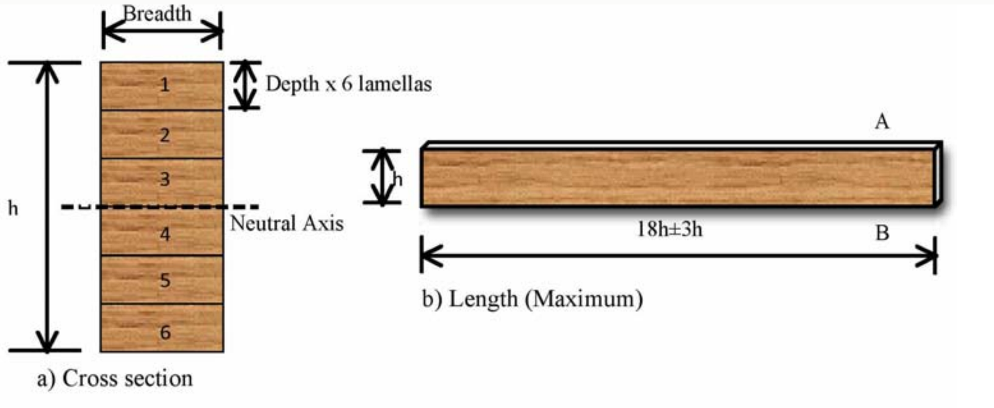


Figure 3.0: *Proposed GluLam beam dimensions*

Fabrication of the Douglas Fir (Pseudotsuga), Sitka Spruce (Picea sitchensis) and Scots Pine (Pinus sylvestris) GluLam beams was carried out at Norbuild in controlled conditions (Figure 3.0) and the adhesive used was Purbond HB S309 (6) (for further information on the adhesive used see APPENDIX C). A total of five 250x86x4800mm beams for each species type were fabricated, four of which were tested to destruction. See Table 3.2 for specifics of dimensioning and Table 3.3 for the make-up of the beams themselves optimising the use of material available.

a) Lamella segregation

b) GluLam pressing

Figure 3.0: *Fabrication of GluLam Beams*

Timber Species	Lamellas			Finished Beam			
	Depth (mm)	Breadth (mm)	Length (mm)	N° Laminations	Depth h (mm)	Breadth (mm)	Length (mm)
Douglas Fir	42	100	4800	6	252	86	4800
Sitka Spruce	42	100	4800	6	252	86	4800
Scots Pine	42	100	4800	6	252	86	4800
Note: Although each lamella was 100mm wide they were not completely straight and hence when they were glued together then did not produce a flush finish. In order to produce a flush finish each beam was run through the planning machine and the finished breadth reduced to 86mm.							

Table 3.2: *Lamella and GluLam Beam Dimensional Information*

Lamella as per Figure 3.0	Scots Pine				Sitka Spruce				Douglas Fir			
	Beam 1	Beam 2	Beam 3	Beam 4	Beam 1	Beam 2	Beam 3	Beam 4	Beam 1	Beam 2	Beam 3	Beam 4
1	C27	C22	C22	C22	C24	C22	C22	C22	C20	C20	C22	C22
2	C22	C20	C20	C20	C16	C18	C18	C18	C18	C20	C20	C18
3	C14	C14	C14	C16	C16	C16	C16	C16	C16	C16	C16	C16
4	C16	C16	C16	C16	C16	C16	C16	C16	C18	C16	C16	C18
5	C18	C18	C18	C18	C20	C18	C20	C20	C20	C18	C18	C20
6	C30	C22	C24	C22	C27	C35	C30	C30	C20	C22	C35	C20
Note: Strength classes based on results from Acoustic and Visual Grading												

Table 3.3: *GluLam lamella make-up*

3.2 - Structural performance testing of GluLam Beams

In order to determine the strength and stiffness properties of each of the 3 beam types a series of structural tests were carried out in accordance with BS EN 408 (5) as detailed in APPENDIX B. Four point bending tests were carried out as shown in Figure 3.0 which allowed the critical structural parameters for beam design to be determined, global (Equation B.1) and local (Equation B.2) MoE in bending, Bending Strength (Equation B.4) and Shear Modulus (Equation C.1).

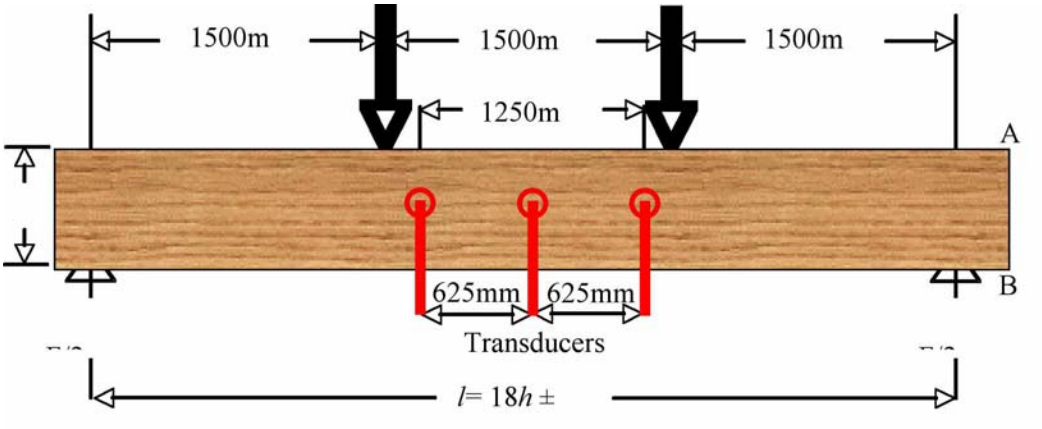
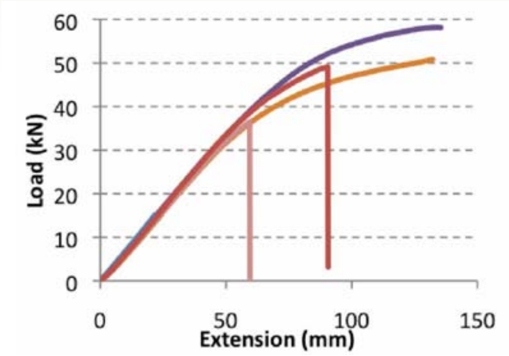
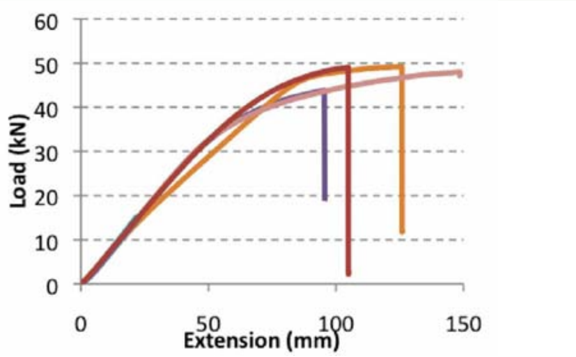


Figure 3.0: *Test arrangement for measuring MoE in bending*

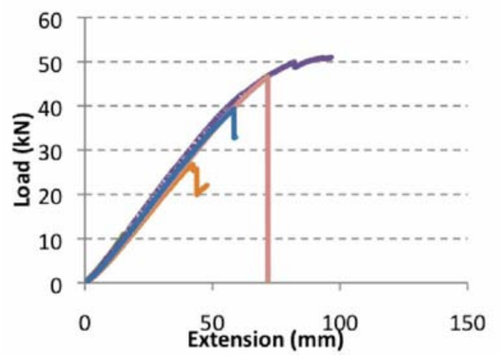
Each beam was loaded edgewise in orientations A and B as shown in Figure 3.0. Loading was applied at a constant rate to 0.4fmax,est and the load was then removed and the sample rotated 180 degrees, loading was then re-applied at a constant rate until failure occurred. This process allowed two values (both orientations) for MoE to be determined for each test piece and averaged for a more precise value. Contained in Figure 3.1 are the load displacement curves for each of the test samples and the results from the testing are contained in Table 3.4.



a) Scots Pine



b) Sitka Spruce



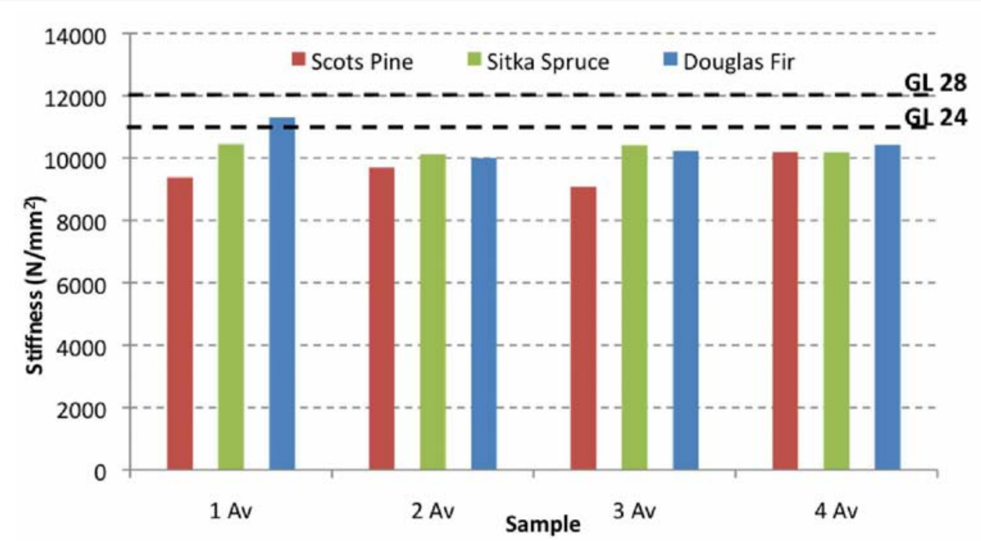
c) Douglas Fir

Figure 3.1*: Load vs. Extension - GluLam Beams*

In accordance with BS EN 408 (5) the 'Single span method' has been applied in order to determine Shear Modulus (G), this was carried out edgewise as defined in Error! Reference source not found., the results of which are also contained in Table 3.4. Shear Modulus (G) by this method is calculated by considering the apparent MoE (Equation B.3) calculated from deflections measured over the gauge length l1 (Figure 3.0). The average MoE results for each of the 4 beams (1- 4Av) contained in Table 3.4 are compared relative to the minimum MoE requirements for GL grades according to BS EN 14080 (10) in Figure 3.2.

Sample No	Fmax (kN)	Local MoE (N/mm²)	Global MoE (N/mm²)	M.C %	Bending Strength f_m (N/mm²)	Shear Modulus G (N/mm²) - Single span method
Scots Pine						
SP1A	-	9377.79	9211.92	-	-	415.51
SP1B	58.19	9679.97	9231.95	8.66	48.72	428.9
SP2A	-	10285.77	9445.7	-	-	455.74
SP2B	50.77	9699.46	9349.69	8.92	42.51	429.76
SP3A	-	8422.46	9268.68	-	-	373.18
SP3B	36.49	9415.47	9223.69	8.96	30.55	417.18
SP4A	-	10773.44	9775.61	-	-	477.35
SP4B	49.17	10564.27	9643.11	7.44	41.17	468.08
SP Mean	**48.66**	**9777.33**	**9393.79**	**8.49**	**40.73**	**435.98**
Sitka Spruce						
SS1A	-	11157.91	9556.96	-	-	494.38
SS1B	43.83	11345.36	9729.51	8.39	36.69	502.69
SS2A	-	11266.88	10142.93	-	-	499.21
SS2B	49.23	10601.16	8483.56	9.33	41.22	469.71
SS3A	-	11266.88	9720.34	-	-	499.21
SS3B	47.98	10890.39	9776.27	8.13	40.17	482.53
SS4A	-	11266.88	9650.2	-	-	499.21
SS4B	49.07	10578.53	9227.23	9.07	41.08	468.71
SS Mean	**47.53**	**11046.75**	**9535.87**	**8.73**	**39.79**	**480.91**
Douglas Fir						
DF1A	-	11736.1	11504.38	-	-	520
DF1B	50.97	11374.4	10622.64	9.75	42.67	503.97
DF2A	-	11398.34	9429.66	-	-	505.03
DF2B	26.82	9650.8	9519.79	8.83	22.45	427.6
DF3A	-	10583.76	9659.88	-	-	468.94
DF3B	46.36	11042.14	9641.82	9.38	38.81	489.25
DF4A	-	10870.12	10110.97	-	-	481.63
DF4B	39.3	10676.51	10051.86	9.3	32.9	473.05
DF Mean	**40.86**	**10916.52**	**10067.62**	**9.31**	**34.21**	**473.47**
Note: Sample A was loaded to 0.4Fmax,est and sample B taken to failure in each case.						

Table 3.4: *GluLam test Results*



Note: Samples 1-4 Av represent the average of the local and global MoE as detailed in Table 3.4.

Figure 3.2: *Individual Beam Average GluLam MoE Comparison to GL Requirements*

BS EN 14080 (8) gives characteristic material properties for homogenous and combined GluLam members (Table 3.5) and it is stated in BS EN 14080:2009 that in order to meet the requirements of a GL24 (combined) beam the central lamella should be strength class C18 or above and the outer lamellas of minimum C24. The beams fabricated did not conform to the requirements of BS EN 14080 (10) (Table 3.3) and as such this has impacted upon the structural performance, primarily that of stiffness, resulting in the beams not complying with the GL24 requirements.

For example considering the mean local MoE results from Table 3.4, Scots Pine (9777.33N/mm2), Sitka Spruce (11046.75N/mm2) and Douglas Fir (10916.52N/mm2) this is below the GL24 minimum requirements in accordance with BS EN 14080 (8) 11,500 N/mm2, only the Douglas Fir GluLam 1 AV has a MoE values comparable with that of the BS EN 14080 requirements (Figure 3.2). In terms of strength all beams demonstrate, Scots Pine (40.73N/mm2), Sitka Spruce (39.79N/mm2) and Douglas Fir (34.21N/mm2), that the re-engineering processes has resulted in compliance with GL24 (24 N/mm2) for GluLam types.

Therefore, although optimising the use of material available has limited the stiffness level of the beams relative to the minimum requirements it is worth noting the structural requirements of graded timber according to BS EN 338:2003 (4) (Table 3.6). Given that bending stiffness is normally the most critical factor in beam design low grade timber could feasibly be re-engineered to provide a GluLam alternative to C16, C22 and possibly also C24.

GluLam strength classes	GL24	GL28	GL32	GL36
Bending Strength (N/mm^2)	24	28	32	36
Bending MoE (N/mm^2)	11500	12500	13500	14500
Shear Modulus (N/mm^2)	650	650	650	650
Density (kg/m^3) *	380 (350)	410 (380)	430 (410)	450 (430)
* The density values are indicative properties with the combined GluLam values in (brackets)_				

Table 3.5*: BS EN 14080:2009 - Relevant characteristic properties for Homogenous and Combined GluLam*

GluLam strength classes	C16	C22	C24	C27
Homogeneous GluLam				
Bending Strength (N/mm^2)	16	22	24	27
Bending MoE (N/mm^2)	8000	10000	11000	11500
Shear Modulus (N/mm^2)	500	630	690	720
Density (kg/m^3) *	370	410	420	450
* The density values are indicative properties				

Table 3.6: *BS EN 338:2003 - Structural timber strength classes*

3.3 - Glue Line Bond Strength Tests

Visual inspection of the beams after testing revealed that in the majority of cases failure was caused by tension in one of the bottom laminations or by the presence of a knot in a crucial location. This type of failure can be seen in Figure 3.3 where it is clear that the knot in one of the bottom chords has caused the failure. The positioning and size of knot would have an impact upon the failure modes. There were no signs in any of the beams of failure occurring due to delamination in the glue line. However, as part of the QA process it was deemed necessary to carry out a further program of tests to assess the glue line bond strength for the varying types of timber by means of bond strength tests. Essentially this is to provide evidence that failure of the timber will occur before failure of the actual bond which is essential to ensure the GluLam beams perform as intended.

a) Scots Pine

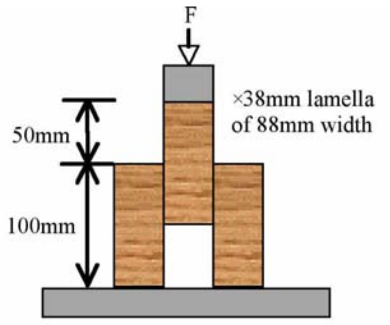
b) Sitka Spruce Failure

c) Douglas Fir

Figure 3.3: *GluLam Failure modes*

The current standard EN 14080:2009 (8) is a draft, therefore the test method prescribed is not current beyond 30th of April 2009 and an up-to-date version of the code was unavailable at the time of writing. It is understood that the current method within the code is not without problems and given that it induces eccentric loading of the joint would prove a conservative estimation. Therefore, for the purposes of this exercise a "bespoke" test set up as shown in Figure 3.3 was employed.

The "bespoke" method requires the fabrication of small scale samples in a manner representative of actual full beam fabrication. Acceptability under the anticipated revised standard is at this stage unknown however for the purposes of this feasibility study it will allow a relative comparison to take place and ensure the proposed alternative timber types have equivalent bond strength to that of Douglas Fir.



a) Bespoke set up

b) Actual test set up

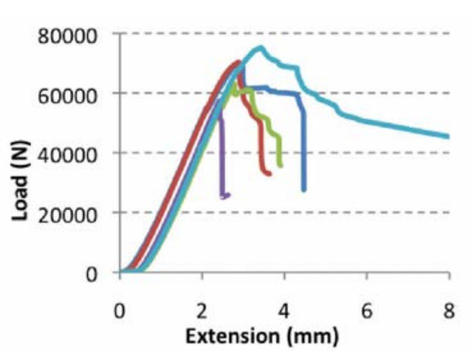
Figure 3.3: *Glue line bond shear strength*

In order to determine the glue line bond strength five samples for each species type were tested as described previously. Each sample was loaded to failure, contained in Figure 3.4 are the load vs. displacement curves, and after testing each sample was visually assessed (Figure 3.5) and an estimated percentage wood failure to the nearest 5% recorded.

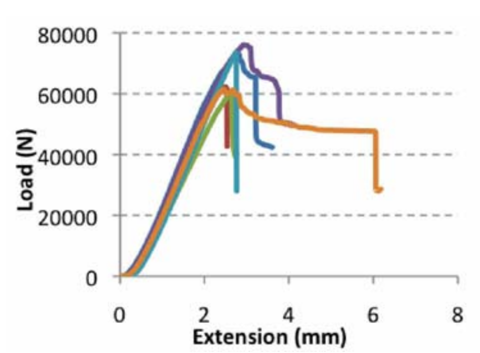
Contained within Table 3.7 and Figure 3.6 are the results of the test schedule and it is demonstrated that all samples were relatively consistent in the load they sustained before failure occurred although the percentage wood failure for the Douglas Fir was significantly less for a number of the tests pieces. Scots Pine and Sitka Spruce return an average wood failure of 79% and 87% respectively, the Douglas Fir only returned a value of 46%. Therefore, for the small sample range considered the Sitka Spruce and Scots Pine gluebond is comparatively better.

BS EN 386:2001(9) gives guidance for the minimum wood failure relating to the shear strength and this is as defined in Table 3.8. It is evident from the information provided in Table 3.8 that as the shear strength increases the wood percentage failure is seen to decrease. Further it is demonstrated that the use of the Purbond HB S309 with Scots Pine and Sitka Spruce is feasible.

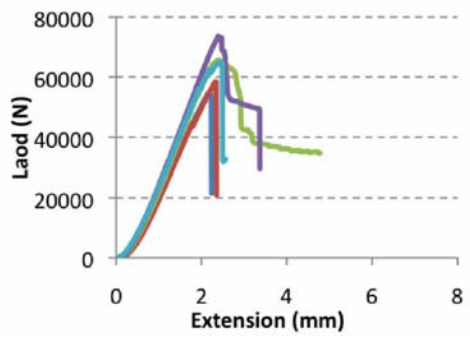
Finally Figure 3.6 shows the relationship between the glue line shear strength and the percentage wood failure and this demonstrates that the majority of samples that produce high shear strength also produce a high percentage of wood failure as would be expected.



a) Scots Pine



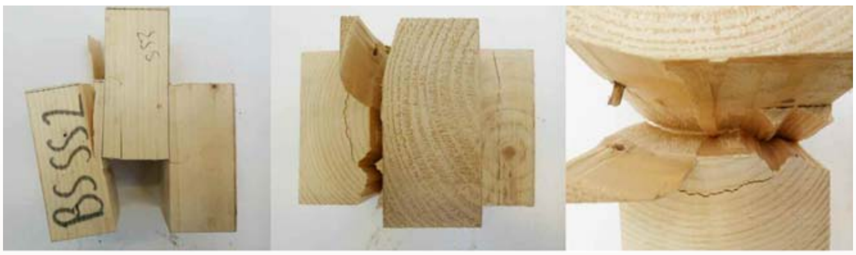
b) Sitka Spruce



c) Douglas Fir

Figure 3.4: *Load vs. Extension - GluLam Beams*

a) Scots Pine



b) Sitka Spruce Failure

c) Douglas Fir

Figure 3.5: *Bond strength failure modes*

Sample Nº	Height (mm)	Width (mm)	Surface area (mm^2)	Max Load (N)	Shear Strength (N/mm^2)	% Wood Failure
Scots Pine						
SP1	50	88.6	8860	69828.12	7.88	95
SP2	50	89.06	8906	70303.89	7.89	100
SP3	50	88.21	8821	63036.42	7.15	70
SP4	50	88.79	8879	57355.96	6.46	30
SP5	50	88.6	8860	75244.89	8.49	100
Average SP	**50**	**88.65**	**8865.2**	**67153.86**	**7.57**	**79**
Sitka Spruce						
SS1	50	88	8800	62258.01	7.07	100
SS2	50	88	8800	72797.04	8.27	100
SS3	50	88	8800	59759.31	6.79	90
SS4	50	88.63	8863	76019.09	8.58	80
SS5	50	88.57	8857	73460.55	8.29	60
SS6	50	88.72	8872	61424.73	6.92	95
Average SS	**50**	**88.32**	**8832**	**67619.79**	**7.66**	**87.5**
Douglas Fir						
DF1	50	88.73	8873	54606.1	6.15	10
DF2	50	88.72	8872	58529.32	6.6	25
DF3	50	88.73	8873	65708.99	7.41	90
DF4	50	88.93	8893	73686.45	8.29	80
DF5	50	88.93	8893	64998.85	7.31	25
Average DF	**50**	**88.81**	**8880.8**	**63505.94**	**7.15**	**46**
Note: Purbond HB S309 was the adhesive used in the fabrication of all beams						

Table 3.7: *Glue line bond strength results*

Minimum wood failure percentages relating to the shear strength (EN 386:2001)						
	Average Values			Individual Values		
Shear Strength $f_{v,a}$ (N/mm^2)	6	8	$f_{v,a} \geq 11$	$4 \leq f_{v,a} < 6$	6	$f_{v,a} \geq 10$
Minimum wood failure (%)[1)]	90%	72%	45%	100%	74%	20%

For values in between, linear interpolation shall be used.

[1)] For average values the minimum wood failure percentage is: 144 - 9*$f_{v,a}$

For the individual values the minimum wood failure percentage for shear strengths $f_{v,a} \geq 6$ N/mm^2 is: 153.3 - 13.3*$f_{v,a}$

Calculation of mean results from glue line bond strength tests

Sample	Shear Strength $f_{v,a}$ (N/mm^2)	Calculation Method	Minimum wood failure (%)
Scots Pine	7.57	144-9*$f_{v,a}$	75.83
Sitka Spruce	7.66	144-9*$f_{v,a}$	75.1
Douglas Fir	7.15	144-9*$f_{v,a}$	79.65

Note: Test results are based on 'bespoke' test method as described in above.

Table 3.8: *BS EN 386:2001 - Minimum wood failure relating to the shear strength*

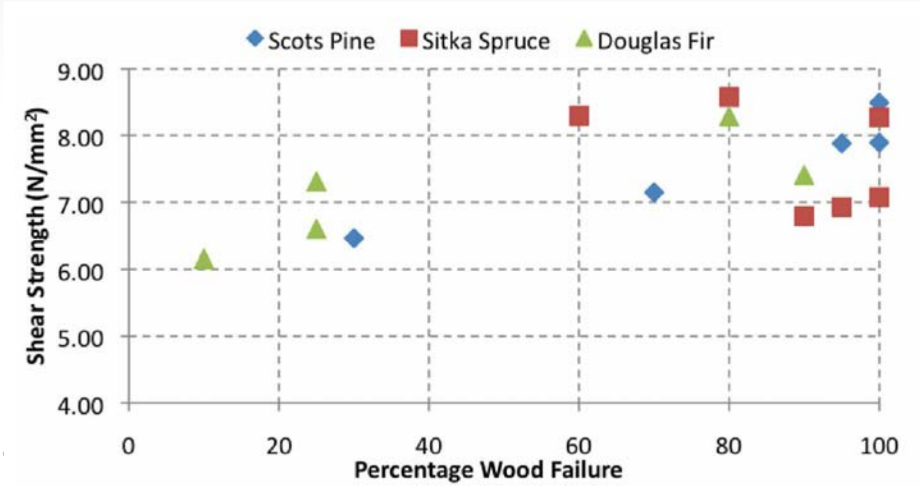


Figure 3.6: *Glue line shear strength vs. Percentage wood failure - GluLam beams*

3.4 - Summary

The range of GluLam beams tested did not meet the required strength and stiffness properties required to be classified as GL24, the lowest GluLam classification in accordance with BS EN 14080. However, this was primarily due to the low grade of timber used in the fabrication process in order to determine the potential for using such material in re-engineered applications particularly when increased levels of QA and material optimisation are applied. To this extent the study has been successful as it demonstrates that by applying the necessary processes low grade home grown timber can be re-engineered to enhance performance. Therefore although not meeting the minimum GL standards there is capacity to ascertain equivalent properties to those of C16 to C24 and above if the material is properly utilised. It is also noted that the re-engineering process could be further enhanced if finger jointing techniques were employed to remove defects.

4 - Conclusion

Based on the findings of this feasibility study GLuLam fabricated from locally sourced Sitka Spruce and Scots Pine is a viable alternative to that fabricated from Douglas Fir when considering the key structural performance criteria tested. The sample range for this study was limited but it demonstrates that through appropriate acoustic and visual grading Home Grown resource can be optimised to produce viable structural components with added value.

The results of this study can be used as evidence to qualify the grading approach for the optimisation and specification of short span GluLam beams primarily for domestic construction. There is also the consideration that although the beams in this instance, due to the low grade material used within the study do not conform with the minimum requirements of BS EN 14080:2009 for GL24, there is evidence that a lower grade GluLam product of equivalent properties to C16 and C24 could be produced. The production of a GluLam product from low grade material could therefore be feasibly accredited and used in higher end value products, for example floor rim beams, lintels and short span joists. Further, GluLam is not restricted by depth of section which can be increased to improve stiffness performance and further increase use (stiffness in bending is normally the limiting criteria in beam design).

If the relatively higher grade material can be selected, segregated and optimally specified during the GluLam fabrication process applying appropriate grading techniques then the available resource can be better utilised adding value. Although this study used primarily low grade material, higher grade home grown resource is available including the necessary minimum C18 for central lamellas and C24 for outer lamellas. Pre-selection and optimal specification would therefore allow the production of at least GL24 and perhaps GL28. This would reduce load span restrictions and increase available market possibilities.

Critical to the volume production of Home Grown GluLam is the implementation of robust grading and pre-selection processes in order to ensure the resource is optimally utilised as detailed in Figure 4.0. With respect to this, and based on the available resource to be used and target market, a range of standardised GluLam sections require to be determined. Following on from this a more extensive programme of work should be implemented to determine the optimal GluLam sections that can be produced and through an extensive test programme create the necessary information required for full accreditation and European Technical Approval of the standardised Home Grown GluLam product.

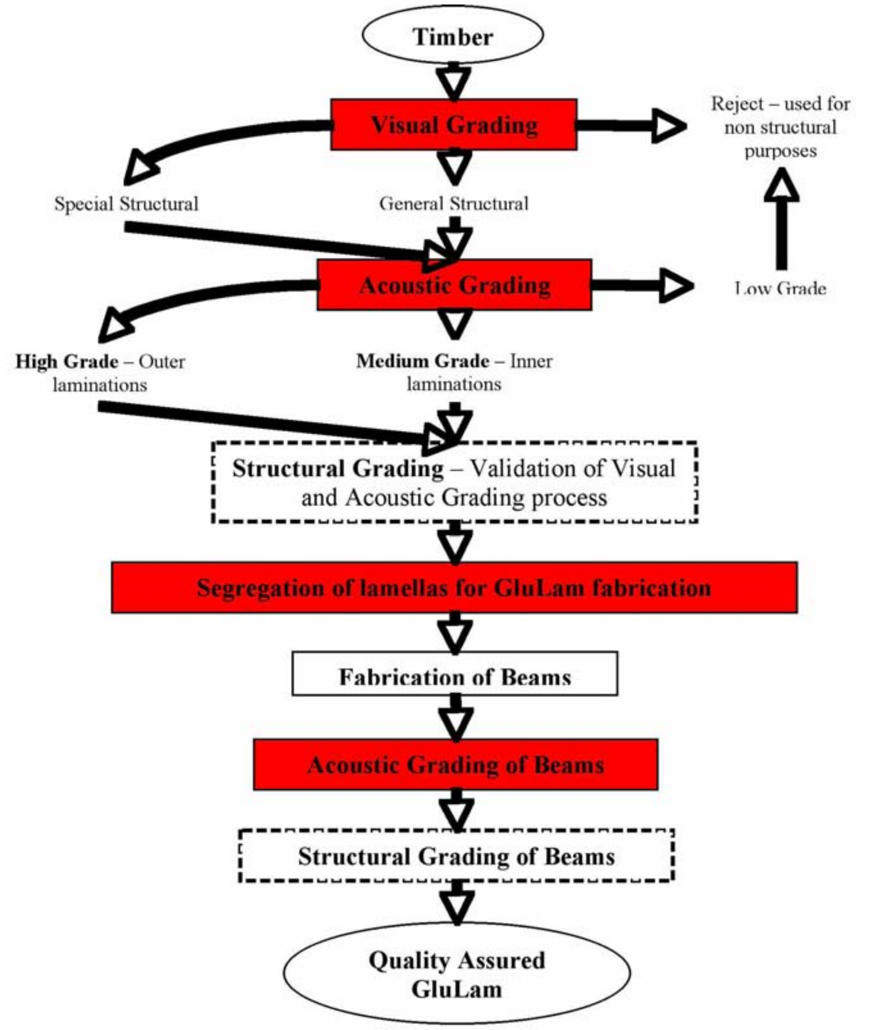


Figure 4.0: *Quality Assured GluLam Fabrication Process*

Note: Highlighted red tasks indicate those which if carried out by GluLam manufacturer will insure a quality product.

5 - Bibliography

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Appendix A.

Modulus of Elasticity of Lamellas from Structural and Acoustic Testing

Acoustic Grading Results			Structural Test Results				MoE Difference
Lamella Ref	Hitman MoE kN/mm^2	Strength Grade	Batten ID	MoE KN/mm^2	Average MoE KN/mm^7	Strength Grade	%
Scots Pine							
S.P 11	6.87	-	SP11A	5.45	5.74	-	16.52
			SP11B	6.02		-	
S.P 20	8.71	C16	SP20A	8.02	8.16	C16	6.31
			SP20B	8.31		C16	
S.P 24	7.97	C14	SP24A	7.38	6.95	C14	12.82
			SP24B	6.522		-	
S.P 25	9.97	C20	SP25A	8.57	9.29	C16	6.81
			SP25B	10.02		C22	
S.P 40	8.23	C16	SP40A	7.75	7.87	C14	4.37
			SP40B	7.99		C14	
Sitka Spruce							
S.S 7	7.83	C14	SS07A	7.96	8.5	C14	-8.61
			SS07B	9.04		C18	
S.S 16	6.96	-	SS16A	6.2	6.59	-	5.4
			SS16B	6.97		-	
S.S 31	7.66	C14	SS31A	7.65	7.25	C14	5.38
			SS31B	6.85		-	
S.S 35	8.32	C16	SS35A	8.16	8.28	C16	0.49
			SS35B	8.41		C16	
S.S 36	7.61	C14	SS36A	7.99	7.42	C14	2.62
			SS36B	6.84		-	
Douglas Fir							
D.F 18	7.5	C14	DF18A	7.96	6.38	C14	15.05
			DF18B	4.79		-	
D.F 19	9.37	C18	DF19A	12.12	10.69	C30	-14.11
			DF19B	9.27		C18	
D.F 30	8.81	C16	DF30A	8.75	8.67	C16	1.56
			DF30B	8.59		C16	
D.F 31	9.49	C18	DF31A	8.72	9.04	C16	4.78
			DF31B	9.35		C18	
D.F 34	7.78	C14	DF34A	6.5	7.73	-	0.7
			DF34B	8.96		C16	

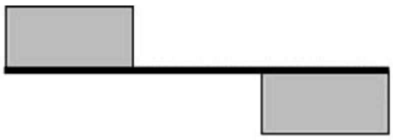
Note: Acoustic grading was carried out on 42x100x4800mm sections of timber, these sections were then cut to 2.4m lengths and structurally graded hence there are two samples (A and B) which correspond to each acoustically graded sample. Average MoE represents the average of sample A and B for each acoustically graded sample.

Appendix B.

Determination of mechanical properties - 4 Point Bending

To determine the MoE in accordance with BS EN 408, a test piece with a length not less than 19 times its depth should be simply supported over a span equal to 18 times its own depth. The load should be applied symmetrically between points with a distance between them equal to 6 times the depth of the test piece. The rate in mm/s at which the load is applied should not exceed 0.003 times the depth of the section. In addition, the load applied must not exceed 40% of the ultimate load required to cause failure. This ensures that the test does not push the specimen into its plastic region which would cause permanent change in its behaviour and therefore make the results from any further tests inaccurate. Lateral restraint may be applied as necessary to prevent buckling but should allow the specimen to deflect without significant frictional resistance. The beam is taken to failure and the bending strength is calculated applying: Error! Reference source not found..

The MoE of timber indicates the materials stiffness or its resistance to deformation. There are two forms of MoE which can be calculated; global (Error! Reference source not found.) and local (Error! Reference source not found.). Global MoE considers the whole specimen in testing whereas Local considers the section of the specimen between the points of loading (Figure 3.0). The localized version has the advantage of eliminating the effect of shear forces and only taking into account bending stresses. The local bending moment therefore provides a better indication of the stiffness performance of the beam under pure bending and will be used for relative comparison.



a) Shear force diagram

b) Bending moment diagram

Figure A.1: *Shear force and bending moment diagrams - 4 point bending*

uare millimetre.

Equation C.1 Shear Modulus

Appendix C.

Purbond HB S309 - Data sheet