THE 'XR BEAM' - A TRUSSED HARDWOOD BEAM FOR VALUE-ADDED USE OF ROUNDWOOD THINNINGS IN THE SOUTH-EAST OF ENGLAND

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SUMMARY

This paper outlines early experiments made with a novel structural beam that may offer value-added uses for small diameter coppiced roundwood, a common material extracted from woodland management, in the south east of England. The intention of the research is to stimulate and expand new market potential for this under-utilized resource within the domestic construction industry. The beam is designed to be produced with as few manufacturing processes as possible to reduce cost and waste and to retain the natural strength of the timber as the tree has grown it. The beam is designed in keeping with existing production capability of wood-mills in the region and to make use of industrial offcuts of plywood as a ubiquitous engineered material for components. The XR beam is designed as a vehicle to encourage more wide-spread use of regional hardwood coppice that benefits the local rural economy, promotes woodland management, and offers sustainable local alternatives to the imported timber that dominates the UK construction sector.

KEYWORDS: Roundwood, Beam, Coppicing, Sustainability, Sweet Chestnut.

INTRODUCTION

Despite structural potential, few standardised timber building products make use of roundwood (Woolfe 2000, Burton 1998), and fewer still, from hardwood species that are locally grown close to the point of use (Ramage 2017, Smith 2013, Chiles 2009). In the context of the global climate crisis, we need to use local timber where possible instead of imported, higher embodied energy alternatives. One way we might achieve this is by finding viable new, value-added uses for local roundwood thinnings and coppice. The XR (cross-web reinforced) beam was developed from woodland coppicing operations as a provocation to the architectural, engineering and construction sectors to recognise the sustainable building potential of underutilised hardwood species grown in the UK.

Coppicing and continuous-cover silvicultural management of species like sweet chestnut can yield relatively straight-growth trees whose timber exhibit good strength properties (van de Kuilen 2016) and durability, without the need for wood treatment or modification. Yet this natural form of timber is rarely used structurally (Frese 2014). Traditionally coppiced roundwood is sold at low-value for biomass, domestic firewood, charcoal burning or fencing applications. The remaining 59% of woodlands in England are not under active management, squandering this natural resource of locally grown timber (RFS 2019). To address this, a regional collaboration was established to research and develop new markets in domestic structural timber applications. The XR beam was the first novel building product to be developed from this partnership. The beam is constructed from longitudinal wedges cut from locally grown hardwood logs processed from roundwood coppice thinnings of sweet chestnut, with good characteristic mechanical properties (Vega 2019).

MATERIALS AND METHODS

Segmented coppiced roundwood

To source materials for the beam, regional procurement of hardwood was conducted in the south east of England from trees felled through woodland management operations at the Woodland Enterprise Centre, Flimwell (Figure 1). Initial trials were carried out with Ash, *Fraxinus Excelsior*, and subsequent prototypes were made using coppiced Sweet Chestnut, *Castanea Sativa*. The roundwood logs were cut radially into eight segments down the length of the log on a mobile sawmill (Figure 2a/b). Radial cutting and careful selection of the cutting path in this way not only resulted in reduced wood wastage, (by virtue of fewer cuts compared to rectangular section timber), but also retained roundwood fibre strength around defects such as knots which also tend to radiate from the centre of the tree.

Figure 1. Coppicing operations at the Woodland Enterprise Centre, Flimwell.

Figure 2a/b. Radial cutting of roundwood log on a mobile saw mill.

Plywood gussets

Once roundwood cutting was complete, two of the opposing radial segments produced from one tree were re-assembled along a linear neutral axis to form the top and bottom flanges of a beam (Figure 3b, 5). The beam was designed in this way to maximise stiffness by placing a high proportion of the cross-sectional area of wood as far from the neutral axis as possible, in accordance with fundamental beam theory (DoITPoMS, 2020). This spatial arrangement was achieved by connecting the top and bottom members with a cross-web reinforcement of interlocking birch-ply gussets (Figure 3a/b). 6mm thick Birch-ply was specified for the gussets as a common sheet material used in CNC fabrication in the UK. The notched shape of the gussets were designed to tessellate efficiently into scrap off-cuts of birch plywood and to interlock along the beam's length with the intention of improving bending stiffness and shear strength. 'Upcycling' of industrial off-cuts in this way diverted prime engineered hardwood material into a value-added building product in combination with sustainably sourced, UK grown hardwood. Once dry assembled with screw fixings perpendicular to the beam, the composite specimen was load-tested in the field mimicking proportions defined in BS EN 408:2010+A1:2012. The gussets measured 275mm (L) x 175mm (W).

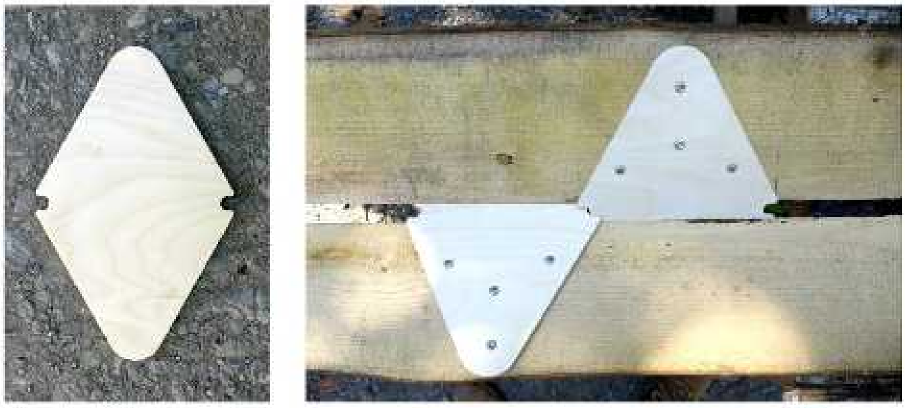

Figure 3a/b. Birch plywood gussets (6mm) mechanically fixed and interlocking at the neutral axis of the beam.

Accounting for tree taper in beam design

Coppicing encourages straight growth of sweet chestnut (Figure 1) but the natural tapering of the trunk from tree base to crown had to be accounted for in the beam design. This natural taper of the roundwood was accommodated by rotating one of the radially cut segments through 180° such that the thick end of one beam segment corresponded with the thin end of the opposing segment (Figure 4). This arrangement also appeared to even out natural variation in tension and compression wood down the length of the beam to give a more homogenous mechanical behaviour in bending.

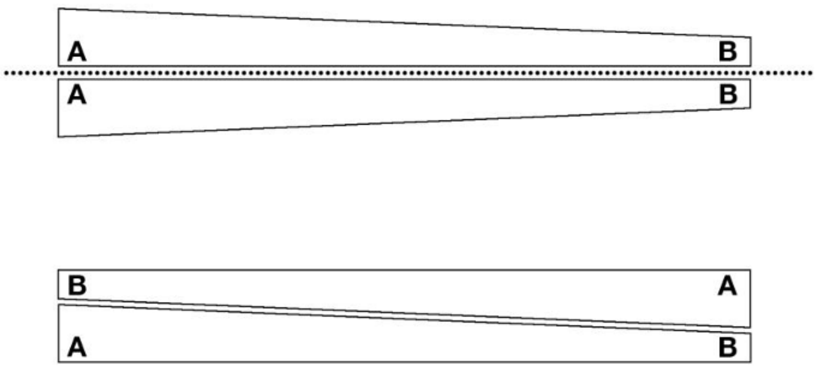

Figure 4 – Top: Long sectional illustration showing natural taper (exaggerated) of the roundwood log down its length from base (A) to apex (B) and dotted linear cut-line for producing the segments.
Bottom: Long sectional illustration showing flipped taper orientation of top chord resulting a parallel beam configuration (also exaggerated for illustrative purposes).

Experiment 1 – Ash thinnings

The XR Beam was conceived for a conical low-pitched roof for a workshop building at the Woodland Enterprise Centre in Flimwell but the first physical prototype was assembled as part of an undergraduate making workshop with 2nd year Architecture students at London Metropolitan University (Figure 5). This early prototype connected top and bottom flanges of the Ash 'wedges' 3000mm in length with a web of flexible triple layered ash plywood measuring 3mm thick and 70mm wide. These were mechanically fixed with screws on opposing upper and lower faces of the timber wedges, allowing them to weave flexibly between the members and interconnect them whilst resisting shear once loaded. The prototype was tested by loading the beam simply supported at each end with body-weight. This crude testing was used to provide initial proof of concept and informed the next design iterations of the beam.

Figure 5. 1^{st} prototype made from Ash (Fraxinus Excelsior) radially cut in $1/8^{th}$ segments and connected with 3-ply 3mm x 70mm Ash plywood.

Experiment 2 – Sweet Chestnut coppice

The 2^{nd} prototype of the XR Beam explored the use of straight growth coppiced sweet chestnut (Figure 6) as an abundant, low cost and underutilized resource that grows extensively in the south of England. Unseasoned harvested roundwood coppice from woodland management operations provide an abundance of straight sample roundwood for sawing. Each 'log' was cut into eighths by making four equally-spaced radial cuts down the length of the trunk. Two of the eight segments produced were then inter-connected across a neutral axis using CNC 6mm birch-ply gussets as a more rigid alternative to the 3m ply used in the first prototype. These gussets were designed with recessed notches on either side to receive and interlock with the next gusset in series down the length of the beam (Figure 3a/b,6).

Figure 6. The 2^{nd} prototype made from Sweet Chestnut (Castanea Sativa) with birch plywood gussets

Load Test Method
A simple field-test based on proportions stipulated in the BS EN 408:2010+A1:2012 standard was designed. The beam was made level and simply supported at either end on pivot points such that the distance between the external support and the nearest loading point was six times the height of the specimen (Figure 7).
Dimensions of the beam comprised of a span of 6000mm which was eighteen times the cross-section height of the beam (333mm). The beam was divided into three equal sections of 2000mm along the 6000mm specimen length which defined the two equally spaced loading points.

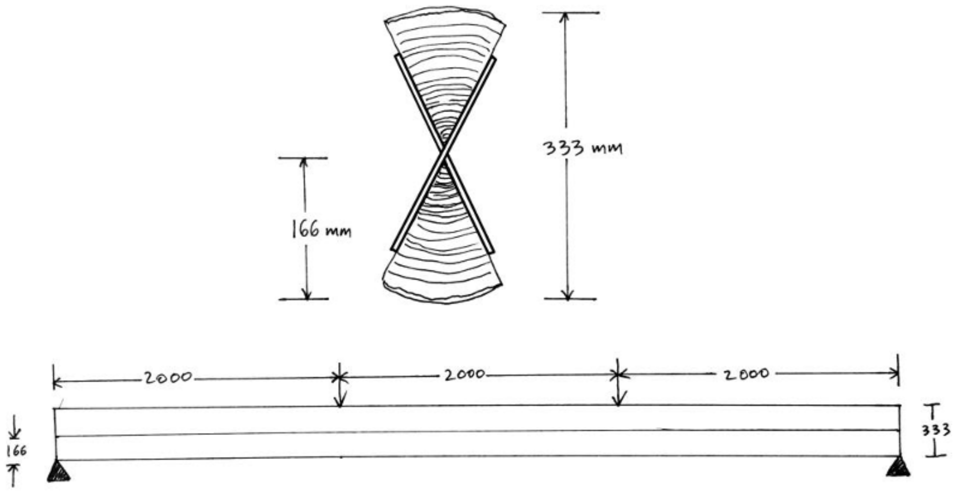

Figure 7. Top - Cross-sectional drawing of the XR-beam showing end-grain and interlocking gussets (not to scale). Bottom - Loading diagram based on proportions defined in BS EN 408:2010+A1:2012.

Load was applied simultaneously at the two loading points using loads of 30 kg increments (60 kg in total across the two load points). The individual loads comprised 30 litre water-filled containers that were pre-weighed using a digital scale accounting for self-weight of the container.

A datum was set and marked at ground level with a broad flat steel fixing. The location of this datum was determined by a plumb-line from the centre-point of the beam to ground and provided the fixed point from which deflection measurements were taken. As a field-test, a measurement tolerance +/-1mm was applied to all results.

Measurements were recorded from the ground datum and a fixed centre-point whilst the beam was unloaded and after settlement of all subsequent loading increments. Deflection measurements began at a start-load of 120 kg comprising two 30 kg loads applied to each of the two load points (Figure 8), increasing to a final load of 240 kg. As a non-destructive test, no maximum load was reached and no modulus of rupture (MOR) was determined.

Figure 8. Load test in progress with 240kg of load distributed between x2 load points along the 6000mm XR Beam.

RESULTS AND DISCUSSION

Unconventional, water-load testing and form-finding have been applied to roundwood building structures in the past, most-notably at Hooke Park on the Westminster Lodge (Cullinan, 2020) to provide proof of structural concept. The authors feel this represents a cost-effective and rapid means of informing conceptual design that is valuable to the design process for approximated comparison to other materials and beam typologies.

Experiment 1 – Ash

The first XR beam prototype helped define the optimum thickness of the plywood gussets defined as a balance between flexibility and stiffness of the gusset itself. As the beam displayed some torsional behaviour on simple loading, the second prototype made use of stiffer and more widely available 6mm birch-ply to both improve the structural performance of the beam and fit existing CNC production capacity in the south east England region.

Experiment 2 - Sweet chestnut

The second sweet chestnut-based XR beam supported the maximum test load of 240kg with a deflection of 16mm at it's centre along it's 6000mm length (Table 1). Although not as accurate as a calibrated test in laboratory conditions, the rudimentary water load test applied in the field, did provide some error-factored data for informing the next iteration of beam design that will determine used to the MOE.

Table 1. Deflection and incremental load measurements.

Load (N)	**Deflection (m)**	**Load (kg)**	**Deflection (mm)**
0	0	0	0
1176	0.003	120	3
1765	0.01	180	10
2353	0.016	240	16

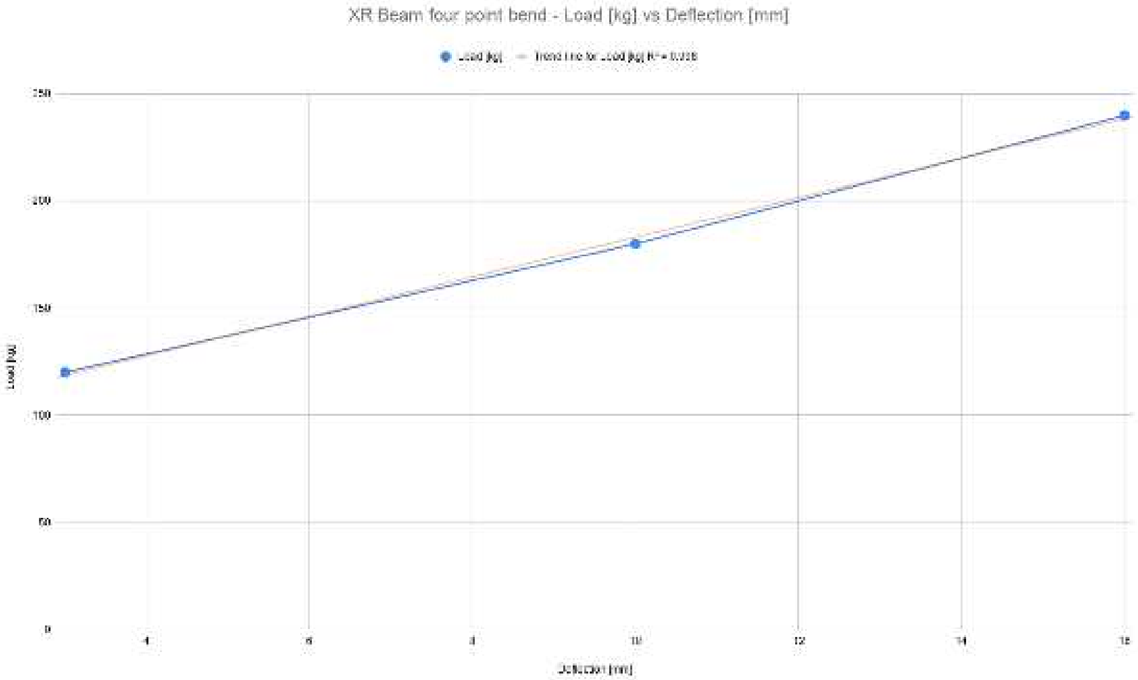

Figure 9: Load vs Deflection at centre of beam under incremental loads during a four-point bending test. Note: Field-measurement tolerances of +/- 1mm in the measurement of deflection. The test was non-destructive; no modulus of rupture (MOR) was defined.

CONCLUSIONS

By designing the XR beam to exploit the natural strength and stiffness inherent in the growth of a tree, the resulting coefficient of determination on the load-deflection plot (Figure 9) indicates a uniform bending behaviour in the beam with little deviation in the deflection measurements. This suggests the beam functioned as a uniform composite structure in bending as intended. Use of radial cutting down the length of the roundwood also proved successful as a processing technique for reducing waste compared to traditional rectangular cross-section timber.

Due to use of unseasoned timber with a high moisture content and the unique geometry of the beam in cross-section (Figure 7), further bending tests are needed to determine bending stiffness and modulus of elasticity (MOE) in a seasoned iteration of the beam. An assessment of the moment of inertia for the segmented sector cross-section of the specimen accounting for the thickness and stiffness of the plywood gussets is needed to help provide an accurate bending stiffness for the composite beam and define its modulus of elasticity. With the MOE quantified, comparisons to other structural beams and wood species should be made to help assess the stiffness of this design compared to conventional rectangular or I-joist profiles for which beam modulus data exists.

The gussets provided a natural spacing between the beam flanges that defined the neutral axis. This natural spacing might also offer other benefits if used in construction such as perpendicular service runs between structural elements, as voids for insulation, or as cavities for inclusion of membranes. Gluing of the gussets in addition to mechanical fixings should also be tested in another beam iteration to determine any additional shear and/or beam stiffness benefits this may provide. The results would then be assessed against the benefits of a 'dry' construction, which facilitates greater end of service-life timber re-use.

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