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Coppiced sweet chestnut in UK construction – challenges and opportunities for design development of hardwood building products

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ABSTRACT
This study comprised two focus groups exploring technical challenges and opportunities for small diameter sweet chestnut hardwood in construction. Five structural building products were designed and fabricated informed by the findings from the focus groups. Simple mobile sawmill and manual cleaving processes were used to align with regional skills and wood processing infrastructure. The building products developed were designed to provide a regenerative alternative to imported softwood timber that dominates the UK construction sector. Radially-sawn beams were found to provide high yield from small diameter roundwood and cleaving of short lengths of coppice was an effective way of producing building products from the highest proportion of short-rotation, coppiced sweet chestnut trees.

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Introduction

Despite broadleaves accounting for half of all trees in the UK and 74% of all trees in England (Forest Research 2022a), very little UK grown hardwood is used in the built environment. Instead, imported softwood is the main source of timber used in the UK construction sector (Ramage et al. 2017), accounting for 90% of consumption of wood in new homes (Timber Trade Federation 2021). Of the 0.8 million green tonnes of hardwood harvested in the UK in 2021, 85% was burnt as wood fuel or biomass, whilst importation of hardwood increased 30% to 162,000m^3 (Forest Research 2022a). Timber frame construction accounted for over a quarter of new houses in 2022, up 10% from 2016 levels (Environmental Audit Committee 2022). Timber stores approximately 0.9 tonnes of carbon per m^3 (Structural Timber Association 2021) and constructing a home from timber has been shown to save between 20% and 60% of the carbon emissions of masonry and reinforced concrete buildings, respectively (Spear et al. 2019).

Global demand for wood is forecast to increase by 170% over the next 30 years fuelled by decarbonisation legislation and housing demand from increased urbanisation (van Romunde 2020). If the UK is to meet domestic demand for timber and adhere to carbon abatement legislation, use of domestically grown hardwoods in buildings will need to increase.

Over the next 50 years, sweet chestnut is forecast to have the highest mean yield class of any broadleaf tree in the UK (Forest Research 2014). There are 19,000 hectares of sweet chestnut woodland in the UK, with approximately 60% located in the southern counties of Kent, and East and West Sussex (Braden and Russell 2001; Unrau et al. 2018). Sweet chestnut is increasingly used in exterior cladding thanks to its natural durability, which makes it a good alternative to imported larch or cedar, but very little of this timber is used in other building applications.

Coppice forestry yields fast growth hardwood with a high proportion of durable heartwood and coppice management is a naturally regenerative form of forestry. Coppice harvesting trees on a periodic basis, every 15–30 years, encourages natural regrowth of juvenile trees and increases biodiversity by opening up the woodland floor to sunlight (Mason and MacDonald 2002; Mattioli et al. 2016; Fuller and Moreton 1987).

Coppiced sweet chestnut is a significant timber resource in Europe (Unrau et al. 2018; Marini et al. 2021; Romagnoli and Spina 2012), with approximately 500,000 ha of sweet chestnut forest in Italy and 920,000 ha in France (Manetti et al. 2022). Despite widespread use in central European architecture and a small number of innovative sweet chestnut timber buildings in Britain (Homerton Dining Hall, Woodland Enterprise Centre, Shorne Visitor Centre), there is a dearth of research into the construction potential of coppiced sweet chestnut in UK buildings.

Due to the short growth cycle, coppicing yields relatively small diameter trees, and the UK hardwood

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sawmill industry focuses almost exclusively on large diameter logs that yield a greater proportion of sawn boards. The UK also lacks significant finger-jointing and glue-lamination capacity to convert hardwoods like sweet chestnut into building products on a competitive scale. Despite these barriers to more widespread use in buildings, previous studies have highlighted that UK grown chestnut coppice is an important, naturally durable hardwood species suitable for use in construction, but that its future 'economic viability is dependent on new products being developed ' (Braden and Russell 2001). Our study addresses this gap in knowledge, with a view to better understanding the barriers to building with coppiced sweet chestnut in the UK, and how they can be overcome.

Aim

Our aim was to (i) to explore challenges and opportunities for sourcing, designing and manufacturing wood products with coppiced sweet chestnut, and (ii) to design and fabricate experimental building component prototypes made from coppiced sweet chestnut.

Method

Focus groups

We conducted two focus groups:

1. Exploring opportunities and barriers to sweet chestnut supply into the UK construction sector.
2. Exploring technical challenges and opportunities for design, processing and fabrication with coppiced sweet chestnut timber in the UK construction sector.

Each focus group was held online and video recorded so that the discussion could be transcribed. Participants for the focus groups were selected using snowball sampling. Recommendations from the collective network of the research collaborators were approached as well as third-party suggestions via those invited to participate. The focus groups were assessed for diversity in order to represent a broad cross-section of the timber supply chain and construction sector, including: woodland owners, foresters, sawmillers, wood product manufacturers, architects, structural engineers, timber certification bodies and academics. The participants are summarised in Table 1. Focus group transcripts were read and re-read by the principal investigator (GF) who coded and extracted common themes using thematic analysis. These themes were then discussed with the research team to ensure concordance.

Table 1. Focus group participants.

Participant	Supply chain representation/Industry background	Focus group
1	Timber Architecture Journalist/Writer	1
2	Wood Furniture Maker	1
3	Land Owner with Sawmill	1 + 2
4	Sweet Chestnut Fencing Manufacturer + Forest Owner	1
5	Forester	1
6	Forestry Consultant	1 + 2
7	Structural Engineer	1
8	Landscape Management Consultant	1
9	Sweet Chestnut Fencing Contractor	1
10	Timber Building Design Consultant	1
11	Timber Framer & Advanced Timber Structures Specialist	1
12	Academic - Timber Architecture	1 + 2
13	Timber Industry Campaign Director	2
14	Academic - Architectural Technologist	2
15	Architect - Timber Specialism	1 + 2
16	Academic - Wood Science & Technology	2
17	Wood Consultant + Wood Journal Editor	2
18	Timber Framer/Carpenter	1 + 2

Design and build of sweet chestnut coppice building components

To facilitate the design and manufacture of the building components, we established a Centre of Research and Development on the Birling Estate in Kent, which is representative of many coppiced woodland estates throughout southern England, the region of the UK with greatest abundance of sweet chestnut coppice. Recommendations from the focus groups and a literature review were used to inform a design brief and a set of manufacturing constraints, which were then used to make experimental timber building components from sweet chestnut coppice. The design brief and processing constraints ensured the prototypes developed would align with existing supply chain skills and production capabilities within the UK.

Design brief

- To make simple, experimental structural building components from small, medium and large diameter, locally sourced sweet chestnut timber ranging from 100 to 300 mm diameter at breast height (DBH).
- The building components should be prefabricated floor, wall and roof structures.
- The components should be detailed for manufacture and assembly, durability, disassembly and re-use.
- The scale and weight of the components must allow safe assembly with commonly available lifting equipment (e.g. telehandler, forwarder.)

Manufacturing constraints

- Unseasoned timber should be used in order to facilitate cleaving.

- Processing of coppiced sweet chestnut on a small mobile sawmill.
- Building sub-components must be liftable by ≤ 2 construction workers to facilitate safe and economical prefabrication.

To inform the design process in real time, 3D digital models of the five building products were drawn in Rhinoceros 7 and parametrically iterated with Grasshopper in accordance with BS EN 1995 Eurocode 5 for a permanent load duration class. These digital models helped us refine the design and form of each component by visualising their structural performance through finite element analysis in Karamba3D. A range of simulated loading conditions were applied to the models, including a vertical deadload and a perpendicular wind load, to forecast structural performance. Sweet chestnut roundwood was supplied in a range of diameters (100–300 mm) from the Birling Estate, Kent. These woodlands are Grown in Britain certified (GiB), ensuring responsible woodland management practices and local provenance. The Birling Estate also provided a covered workshop space for fabrication of the building components and yard space for a mobile sawmill. The design phases of the project were conducted with input from all collaborators through design meetings. On-site build phases were conducted by two of the project collaborators: an experienced timber craftsman/timber frame builder (NM) and an academic with a background in carpentry and timber architecture (GF).

The coppiced timber was unseasoned, having been felled five months prior. The use of green timber ensured that the sweet chestnut could be cleaved as well as sawn. Cleaving or splitting of roundwood is a low waste/high yield conversion process common in the production of sweet chestnut fencing products in the UK.

An industry partnership with Wood-Mizer, one of the largest suppliers of mobile sawmills in the UK, was established. All sawing of our larger diameter coppiced poles (200–300 mm) was carried out on an LT40, one of the most common machines in their range. Use of a commonly available mobile sawmill ensured the potential replicability of our study as well as a low degree of milling waste, thanks to the small kerf of Wood-Mizer saw blades. In keeping with our design brief and processing constraints, low-waste from sawing was essential to give whatever we designed the best chance of being cost-competitive to produce at scale.

Ethical approval for the study was granted by London Metropolitan University Research Ethics Committee (Ref: AAD-4/2021-22) and participant informed consent was provided by through an online form prior to each focus group.

Results

Focus groups

Key themes from the sourcing focus group are summarised in Table 2.

Key themes from the technical challenges focus group are summarised in Table 3.

Design and fabrication of building products

To explore high yield sawmill conversion of small diameter coppice, radial cutting techniques were developed on the Wood-Mizer, whereby the sweet chestnut logs were sawn radially down their length to produce a series of eight longitudinal wedges of timber (Figure 1).

This sawing technique ensured a very low degree of waste compared to traditional rectilinear sawn wood and provided a high timber yield from a small diameter log (approximately 90%). The resulting longitudinal timber wedges were then developed into beams used in an engineered floor panel and a-frame (see 'XR Beam a-frame' Figures 2 and 3).

Through sawmill and cleaving experimentation, we developed five simple building products from a range

Table 2. Sourcing focus group – key themes.

Theme	Description
1) Sorting:	• Better utilising coppice workers skills to accurately batch qualities of coppiced poles so that high quality straight material can be identified for use in the manufacture of construction products.
2) Mixed aged trees:	• Design briefs for building products must reflect the mixed age of coppiced trees that currently grow in coppiced woodlands in England.
3) Capacity to meet demand:	• There is sufficient supply of coppiced timber to meet new construction demand for local architecture in England.

Table 3. Technical challenges focus group – key themes.

Theme	Description
1) Alignment with local processing tools	• The use of simple and widely available processing tools such as mobile sawmills is necessary to align with the reality of the local UK timber processing network.
2) Use of cleaving	• Inclusion of cleaving alongside sawing as a process of roundwood conversion is needed to take advantage of the high timber yield of splitting.
3) Use of unseasoned timber	• Unseasoned coppiced roundwood should be used for ease of cleaving and to embrace the dimensional stability of green sweet chestnut compared to other hardwood species such as oak. There is also limited access to kiln-drying facilities in southern England.
4) Public communication/ stakeholder engagement	• Raise awareness of the benefits of coppice management of sweet chestnut and potential uses in construction.

Figure 1. Radial cutting of 300 mm diameter coppiced sweet chestnut log.

of small, medium and large diameter coppiced sweet chestnut logs (100–300 mm ø) (see Figure 2). The prototypes were exhibited at a knowledge exchange event where industry stakeholders, policy makers, academics and the general public were invited into the coppice woodland to learn about our study and review the building products we developed. Stakeholders were invited from the local, regional and national networks of the research collaborators (academia, timber certification, woodland enterprises, woodland owners, charities, local planners) and the event was promoted publicly on social media.

Curved half-round timber frame wall

A curved panel product was developed, consisting of a series of vertical timbers separated with an air space and held in position by wall plates of softwood plywood. The timber frame panels were half-round sawn coppiced poles cut from a 150 mm diameter log and measured 1200 mm high and 200 mm deep. The cavity between vertical timbers was filled with a continuous sinusoidal thickness of sheep's-wool insulation and the faces of the panels covered with a vapour control layer and vapour permeable membrane to facilitate moisture migration. Curved walls are inherently self-stabilising and this modular product is designed to be jointed on end as well as stacked vertically for multi-storey construction.

Mechanically laminated beam

Five 150–200 mm diameter coppiced poles of 4000 mm in length were sawn with two opposing parallel flat faces on a mobile sawmill. This resulted in five 4 m lengths of timber with parallel flat datums of depths of between 80 and 100 mm that could be stacked on top of one another. This dry stack was clamped and drilled with a series of eight perpendicular 11 mm holes at approximately 400 mm intervals. The pre-drilled stack was then mechanically laminated together with 10 mm steel threaded rod secured with flush-fit washers and nuts. This resulted in a flat, mechanically laminated beam with a web of waney edges and a parallel datum on the top and bottom surfaces, for integration into modern construction methods. The same mechanically laminated beam was digitally modelled to represent a steam-bent version. This beam incorporated a parabolic curvature and the top and bottom off-cuts of the sawing process were used to form a braced lattice between curved beams (see 'mechanically laminated beam' building system Figure 2). A second variant of the same beam design was manufactured replacing the steel threaded rod with polyurethane glued fluted beech dowels of 15 mm diameter.

Cleft spaceframe truss

Small diameter coppiced poles were cut into lengths of 600 mm and split longitudinally into quarters via a manual cleaving process common in the mass production of sweet chestnut fencing. Each quarter-cleft length of timber was axe trimmed to a fine point on each end to form a hardwood strut. A series of these struts were then interconnected to form a three-dimensional space-frame by screwing a 6 × 60 mm self-tapping stainless panhead screw into the end-grain of each strut. This screw secured a 3 mm thick stainless-steel bracket (WangerFlange) to the ends of each strut that were subsequently interconnected with M8 nuts and bolts to form a stiff spaceframe.

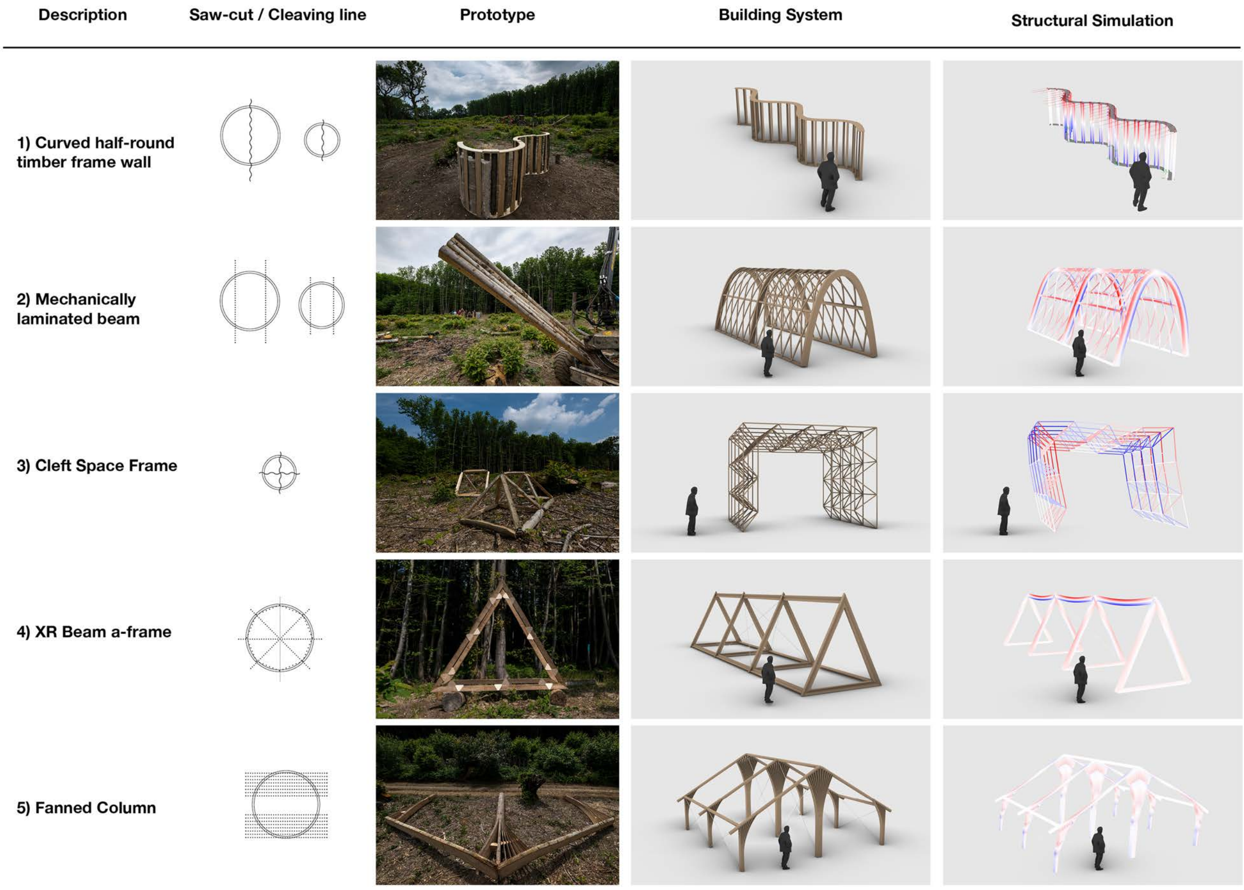

Figure 2. Five building product prototypes and corresponding 3D models and structural simulation.

Figure 3. XR beams used in a prefabricated flooring and a-frame system.

XR beam a-frame

Longitudinally sawn wedges from a 300 mm diameter log were sorted into pairs from opposing 'sides' of the log to balance tension and compression wood and reconnected together via a series of screw-fixed interlocking 6 mm birch plywood gussets to produce a beam with a separated neutral axis. These cross-web reinforced beams were then re-sawn on the sawmill to provide a flat datum to the top and bottom flanges of each beam to facilitate high construction tolerances. Three crossed-web or 'XR' beams were used to assemble a floor panel fitted with 25 mm thick, sawn sweet chestnut floorboards. These beams are a refinement of a prototype developed and strength tested in a previous study (Fereday et al. 2020). An equilateral XR beam a-frame system was also assembled by trimming the ends of each beam to 60° and fitting 10 mm threaded rod building connectors (Figure 3).

Fanned column

A mobile sawmill was used to process a series of controlled 'stopped cuts' at 12 mm depth increments on a 200 mm diameter coppiced log. A 'stopped cut' is where the saw blade cuts through the log a given distance, the machine is stopped, and the saw blade is retracted back out of the body of the log for the subsequent cut. This process resulted in a series of 12 mm planks that were still connected to the main body of the log, which remained un-sawn further down its length. 45° cuts were then made across the 'head' of the log to give an apex roof angle. The resulting stepped saw-cuts were then bent open with a series of half-round sweet chestnut wedges. This resulted in a fanning out of the 12 mm planks that formed a stiffening head of a column. The same stopped-cut sawing process was then conducted on a pair of smaller and shorter 200 mm diameter logs. This produced a pair of fanned 'dwarf columns' at the eaves of a roof when all three fanned columns were connected with 40 mm thick chestnut roofing planks.

Knowledge exchange

All five structural building products were shown in a knowledge exchange exhibition. The site of the exhibition was the coppiced woodland where our poles were felled and the structures were shown alongside the forestry equipment used to extract the roundwood. The exhibition catalogue and a sample XR beam were also exhibited to an international audience at the COP26 UN Climate Change Conference, Glasgow, 2021. The protoypes were also exhibited at London Metropolitan University as part of a making exhibition entitled 'Making Matters' (6–13 May, 2022).

Discussion

Our study developed five speculative designs for UK-grown coppiced sweet chestnut building products, which provide an alternative to the use of imported timber.

The focus groups defined sourcing opportunities and technical barriers to the manufacture of these products. Findings from the focus groups also directly influenced the design brief ensuring it:

(i) addressed current supply chain issues by utilising a broad range of roundwood diameters efficiently batched at source by coppice foresters.
(ii) linked the design of coppiced sweet chestnut building components to widely available and high-yield processing methods (mobile sawmill, cleaving).

We developed five designs in order to showcase the potential of (i) different diameter poles, (ii) different length poles, and (iii) simple and widely available processing techniques. We found that by using shorter length small diameter coppiced materials (≤1000 mm) to produce space frames, we could utilise more non-straight growth coppiced poles. Although shorter component building products require a higher frequency of joints, using a shorter length of timber ensures that natural defects such as knots or curved growth can be avoided and greater yield from the forest inventory. This has potential to reduce the primary cost of roundwood sweet chestnut in construction and the amount of this material burnt as biomass. Our spaceframe and curved wall used cleaving as a means of achieving a high yield from small diameter, non-straight poles – influenced by cleft fencing, which is a low waste, value-added use of the material. For longer length building products, such as our XR beam and mechanically laminated beam, selection of the straightest growth poles was necessary. In keeping with the focus group recommendation, we found it was possible to use the coppice foresters' skills to batch-select this premium material effectively and efficiently at source as part of the felling process. All three of our sawn products were designed to be produced on widely available mobile sawn mills on account of the diminishing number of static sawmills (Forest Research 2022b) and low availability of kiln-drying and finger-jointing facilities in the south of England.

In Europe, sweet chestnut building products derived from coppiced poles are more prevalent than in the UK. In recent years the species has been included in European standards (EOTA 2015; UNI 2016) that have facilitated CE marking of solid and glue-laminated structural timber. Recent studies in Italy, which has a high forest cover of sweet chestnut, identified the need to innovate in sweet chestnut sawmills and architectural design in order to reinvigorate the local-supply chain for coppiced timber (Marini et al. 2021). This led to harmonisation of grading standards for partially sawn roundwood derivatives such as 'Uso Fiume di Castagno' – waney edge beams made from Sweet Chestnut poles. These products have created a new construction market for coppiced poles by using a simple sawmill method that minimises waste slab-wood. Our study has adopted a similar approach by designing products that require minimal processing to achieve a high timber yield.

Limitations

More research is needed to determine whether green sweet chestnut coppiced timber can be used in prefabricated building products with acceptable dimensional stability. Due to budget and time constraints we were unable to undertake timber grading or destructive testing. Instead, we worked with a structural engineer to implement cost effective and expedient digital models that applied BS EN 1995 Eurocode 5 design criteria to inform our designs (BSI 2004). Destructive testing regimes of derivative building products are needed to obtain structural data and enable integration into UKCA certified products.

Forecasts show that availability of UK grown hardwoods is set to increase 395% over the next 25 years (Forest Research 2014). Using more of the UK's coppiced hardwood resource in construction could store carbon long-term in buildings, promote net-gain biodiversity, and create sustainable local jobs that reduce our reliance on imported timber. Using a speculative design-led approach, this exploratory study developed a range of prototype building components with potential to overcome key barriers to use of coppice sweet chestnut identified in our focus groups. Future research is needed to assess the structural performance and economic viability of these prototypes.

Geolocation information

Knowledge exchange exhibition in coppiced woodland: 51°19′57.7″N 0°23′06.8″E

https://goo.gl/maps/MndngyJ72hqKcWMd9

Site of sawmilling and prefabrication: 51°19′28.0″N 0°23′13.2″E

https://goo.gl/maps/TzStSJZBX4TRzcjK7

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Disclosure statement

Dougal Driver is CEO of Grown in Britain Ltd, an independent, not-for-profit organisation, encouraging more demand for home-grown wood. The company promotes the Grown in Britain certification scheme (GiB) that ensures responsible woodland and forest management practices in UK.

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