Glulam – connecting with future developments

Architects and engineers have embraced the benefits of glulam to create elegant and aesthetically pleasing buildings. Andrew Wylie, Graham Clarke and Jonathan Roynon review progress to date and survey the future for this engineered timber technique.

Glued laminated timber (glulam) beams and columns have been used for decades as an engineered timber product that allows designers to span further, carrying heavier loads while retaining all of the benefits of using wood in structures.

Development started in the late 19th century as a method of creating larger and more consistent timber elements, the system of gluing together graded pieces of timber seeks to achieve increased material consistency and strength.

Since then, architects and engineers have embraced the pleasing aesthetic of exposed timber and exploited the enhanced material properties of this engineered product to create elegant and energy-efficient buildings. Typical forms have included beam and column frames with simple shear and axial connections and more recently – encouraged by the development of forming curved glulam beams – arched structures such as the Sheffield Winter Gardens have been realised.

Current innovations in glulam structures

The conventional arch and beam arrangements for glulam structures allow a wide variety of building forms to be achieved, but to truly compete with other engineering materials in all forms it is necessary to look at alternative techniques both in terms of design, detailing and fabrication so open up new possibilities in glulam structures.

The development of more powerful modelling and analysis software has opened up new possibilities for the forms that can be imagined and created. For glulam structures this has been particularly relevant to the creation of free form gridshell-type roof structures which had previously only been possible with physical modelling and/or very bespoke electronic design tools. The advent of parametric 3D modelling has made the interactive iterative development of even the most complex form a far more accessible and cost-effective process. When this is then integrated into a project using building information modelling (BIM) and linked with latest finite element analysis software, it is possible to very quickly analyse an initial concept and then take it through the various design stages to the final drawings in a manner that was never previously possible.

These software tools have been great for the development of ideas and overall designs, but couldn’t deliver these more complex structures without the parallel developments in the design of connections, which are critical to the success of timber structures – more so than in any other material.

Making the connections

Conventional timber connections typically only needed to transfer shear and axial loads, but the more complex modern designs and forms also need to carry bending moments. There were traditionally avoided in timber because it is often very difficult to get sufficient strength and stiffness, due to joint slip, creep and so on. Addressing these challenges is critical to the success of complex structures using glulam. >>
Conventional connections for glulam structures have involved a steel flitch bolted to the glulam beams. In more complex structure these flitches are connected by a steel node that allows rotation of the flitch plates between connecting members to take up the complex form. However, although bolts are a perfectly acceptable connection method for shear and axial connections, they have far too much movement potential to provide sufficiently stiff connections such as those needed for the more complex forms, where the joint often does not coincide with a vertical support.

Replacing the bolts with tight-tolerance dowels greatly improves this stiffness, but brings with it other challenges – not least the need for much tighter fabrication of both the steel and timber to make these joints buildable without the usual tolerances provided by oversized holes. Computer numeric control (CNC) fabrication techniques have allowed this to be achieved although there is still a need to make some allowance within the joint for the uptake of final installation tolerance between members.

Another option successfully deployed on several structures is to use small-diameter self-drilling screws which can be installed through the glulam and steel plate in one operation, hence removing the need for any predrilling and associated tight tolerance fabrication.

Glued-in rods is another solution which has been successfully used on projects such as the Scunthorpe Pods. With these connections the flitch plate is no longer required, reducing steel tonnage, and instead a series of threaded steel bars are glued into the ends of the glulam beams. This allows the beams to be directly connected to the central node.

However, a common issue with all of these connections – and often even with simple shear or axial connections – is that the joining of relatively deep timber members to a steel plate can result in varying degrees of constraint to the timber.

As the building warms and dries out following completion the timber shrinks and the constraint from the steel plates can result in the build-up of across-grain tension stresses, which can eventually lead to splitting of the timber. This splitting can impact the section stiffness/strength and, if the cracks run through the connection lines (which they often tend to due to the natural weakness the fixings produce) there is the potential for a reduction in connection capacity and stiffness.

This problem is one that has not been given a lot of focus in the industry to date, but it is important to address the issue to give clients confidence in glulam structures because cracks, even when not impacting on the structural performance, are often a worry for clients.

There are ways to mitigate this splitting, providing it is considered properly early on in the design. Solutions can include: simply designing extra redundancy into the joint; the use of slotted holes; split connections to reduce the restraining effect; externally applied reinforcing plates; or glued-in reinforcing bars or vertical reinforcing screws.

Timber is weakest when resisting cross-grain tension and as such significant benefits can be achieved by reinforcing perpendicular to the grain direction. Using fully threaded screws to reinforce timber has been shown to be an effective way to increase resistance to splitting of timber, and this can have various benefits including where connections are notched or when resisting localised stresses around penetrations through members.

Other design factors, such as fire resistance, can also have a big impact on connection design. Metallic fasteners are...
susceptible to fire and are often recessed into a member so that timber plugs can be fitted as protection. However, in some cases this can lead to a relatively short length of embedment in the timber and result in an increased number of fasteners being required. Non-metallic fasteners have been the subject of research in recent years including both fibre-reinforced polymers (FRP) and timber fasteners; as have timber connections/structures where no metallic parts are used at all.

**Future developments in glulam**

What will be the next evolution of composite glulam beam? Will new higher-grade materials be used where they provide the most benefit and lower-grade materials be chosen for areas where member stresses are lower?

These are questions that are particularly relevant for long-span structures. The benefits of such ‘optimised hybrid beams’ would include reduced material volumes, reduced variability of material properties and potentially increasing the ductility of failure mechanisms.

One strand of research in improving strength and stiffness of new and existing glulam structures is the use of FRP – for instance, bonding FRP to the timber either to the face of the member or, for new glulam structures, bonding FRP strips or rods in between timber laminations. The FRP spans over defects or discontinuities in the timber laminations, and testing has shown that this gives these hybrid elements a more consistent performance. This research is aiming to improve understanding of behaviour of timber members reinforced with FRP and produce possible design methodology.

The outcome of this research will be products and systems that reduce material use and allow timber members to span further, while at the same time providing predictability of performance. However, although optimisation could be achieved throughout a structure by varying the thickness of FRP reinforcing layers, careful consideration will need to be given if these are to be bonded between lamina layers, because these will be difficult to check on site.

Another area of research is the potential for further development of complex connection forms. As 3D printing becomes more prevalent there may be significant benefits to be made in using this technology to create complex metallic nodes for timber connections. This has the potential to achieve nodal forms that may be difficult to fabricate using tradition welding techniques while delivering both improved aesthetics and increased material efficiency. As many dramatic exposed roof structures require these complex structural nodes, enhancements to their appearance could have a significant impact on the aesthetics of the structure.

Another form of hybrid glulam structure which is the subject on ongoing research and development is timber concrete composite floors. These use glulam beams working compositely with the concrete floor slab to increase the strength and stiffness of the beam. The concrete can provide benefits to the structure, such as improved acoustic separation between floors, while adding thermal mass and improved fire resistance. Connectors have been specifically developed by some manufacturers to provide this composite action and others have been investigating pre-casting composite timber-concrete floors. With further refinement and the development of a codified design methodology the UK construction industry could see benefits from a significant uptake in this form of construction.

Although reinforcing cross-grain splitting in glulam is a technique currently employed on many structures, there are potentially further benefits that require additional research to be fully realised. For instance, large groups of metallic fasteners where their combined capacity will be reduced by splitting of the timber can result in significant reductions in design capacity. The splitting is caused by the combined prying action of the fastener group, but additional reinforcement, in the form of fully threaded screws, has been shown to lead to a significantly smaller reductions in capacity. Further research and testing is required to develop design guidance, but this technique has the potential to lead to more efficient connections and, as connection design can govern member sizing, more efficient structures.

**About the authors**

Andrew Wylie is a group director at BuroHappold. He has worked on several notable projects, from the use of cross-laminated timber for the floor on the Royal Shakespeare Theatre to the construction of a long-span barn sourced from local timber at the Westonbirt Arboretum.

Graham Clarke is a senior engineer and Jonathan Roynon is a technical director, both based in BuroHappold’s Bath office. Their experience ranges from the long-term performance of traditional oak carpentry framing joints and the structural behaviour modern all-timber connections to the design of complex timber roof structures especially gridshells using solid and glue laminated timber.