Glue laminated timber - The material application for free-span structures
The selection of structural materials and methods for construction are based on a variety of processes executed during the early stages of building procurement. The key drivers for design are invariably determined by the building owners or patrons as part of their project brief. The interpretation and development of this brief is paramount by the building design team for the successful execution of the project. Early in the process, unless specifically requested as part of the brief, the structural solution must be developed.

When compared with other structural materials, glulam has several key advantages. Due to its excellent material properties it is possible to manufacture large structural members in any shape and size. Consequently, the potential of glulam as a structural material is limited only by the architect’s imagination. When it comes to realising extraordinary architectural concepts, glulam is the material of choice. A further advantage is that glulam offers a simple, yet functional aesthetic. This often results in the material being used where the structure is expressed as an architectural feature.

Glulam is processed by state-of-the-art CNC-machines and the members supplied in high-quality strength classes fulfilling the requirements of GL32. As a result of this technology and elaborate production techniques it is possible to supply structural members that can be easily combined with other materials such as steel. All designers are aware that wood is a combustible material, however the fire performance characteristics of glue laminated timber is often misunderstood. In order to fully evaluate the fire safety of timber structures it is necessary to consider the fire performance characteristics of wood in detail. In case of fire, wooden structural members ‘char’ – a layer of charcoal is formed that reduces thermal conduction, combustibility and flame spread, thus protecting the inner part of the cross section. On average, glulam burns at a rate of 0.7 mm per minute, with the cross section of the material therefore reduced by approximately 20 mm after 30 minutes of exposure and by 40 mm after 60 minutes. The respective fire resistance grades R30 and R60 refer to the fire endurance of these wooden members after the specified exposure durations. It is interesting to note that R30 and R60 can be obtained on glulam components without the need for additional flame-retardant treatments. In structures where steel is used for connecting glulam elements the performance of the steel in fire has to be taken into account and the connection methodology reviewed to ensure the integrity of the connection. Nevertheless, it is safe to state that the fire-resistance characteristics of wooden structural members are excellent.

When considering structural material selection it is important to establish the likely roof coverings with attention focused on secondary support and roof pitch.

This document is intended for reference when considering the use of glue laminated components – glulam – during the early stages of design. The information within this document shall offer support with technical guidance, design parameters and worked examples to designers and all involved in the construction of buildings irrespective of size and complexity.

As a material, glulam has many benefits when compared to other structural solutions. In summary, it can be concluded that glulam:

- is a natural product with true eco-credentials with managed harvesting ensuring it remains a truly sustainable building material
- extensive span lengths whilst maintaining an attractive aesthetic
- can be utilised with a variety of roof coverings / solutions
- can be connected easily to a variety of other buildings / structures
- cost effectiveness
- maintenance free
- minimal design constraints ensuring freedom of structure with the most complex of design ideas easily translated in timber
- excellent fire resisting performance
- exceptional material properties: the self-weight is marginal and the load carrying capacity is enormous
- resistance against bio-deterioration and extreme weather conditions
- the material can be supplied custom-made specific to customer requirements ensuring a speedy and efficient construction time
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As the stresses can be transferred efficiently and the profile of the beam matches the outline of the roof pitch, pitched cambered beams with a straight bottom flange are a very effective and simple roof solution. The top edge of the beam continues according to the minimum roof pitch of 2 - 5° which is required to ensure adequate roof drainage.

The formation of a single-edge cantilever or a duo-cantilever over both sides of the walls increases the operating efficiency of the structure, since the moment distribution is optimised. It is important to ensure the length of the cantilever does not exceed 25% of the field length. The construction of the cantilever girders can be carried out according to illustrations 1 - 3 (please see page 6).

In general, pitched cambered beams can be used for industrial building applications, sports halls and recreational buildings.

With regard to the roof-coverings, it is possible for glulam structures to support both warm and cold roofing techniques as well as non-insulated roofing options with no effect on performance and integrity.

Support for the glulam roof structure can be provided by a variety of materials - glulam timber, reinforced insitu or precast concrete or steel columns are all viable options. The columns should be installed with a fixed column base at least on one side of the building, to transfer the wind load into the foundation (please see page 18-19). To ensure services distribution whilst maintaining the integrity of the structure all openings shall be suitably stiffened utilising a plywood support plate on both sides of the holes. This avoids material splitting.

With regard to building design and setting out a width-to-height-ratio of 1:10 should be borne in mind. In addition, there may be a need for roof bracing members between the beams or consideration given to a composite action taking into account the roof components (please see page 19).

**Structural roofing options**

**Pitched cambered beams with straight bottom flange**

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Although this kind of beam offers the same advantages as the pitched cambered beam. A further advantage of pitched cambered beams with hoisted bottom flange is that the roof pitch can be increased up to 20°. These beams could be specified where a concrete / clay tile covering is demanded. However, with the increase in roof pitch, the tensional strength shall also be increased and therefore it shall be necessary to apply threaded bolts or planking to the connection design. It is advisable to mention this procedure in the project specification.

The design options are described on illustrations 1 - 3.

In general, the ridge of the gabled roof is not subject to be used for load transfer and can be replaced by a non load bearing glulam infill. If there is a top-light in the ridge area, the infill is not needed.

During the planning process it is important to keep in mind that the roof pitch is higher therefore the beams may need to be physically larger. Transportation of the building components should always be addressed early in the design. In general, the maximum height that is able to be transported by road is approximately 3.50 m.

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Three pinned hinged frames are a very efficient form of structural design as a result of effective load transmission to ground. Given this efficiency the glulam material consumption can be kept to a minimum. Further, three pinned hinged frames are a very cost-effective solution because the building foundations can be realised at optimal cost.

All in all, the use of three pinned hinged frames is only restricted by transport limitations and the challenge to realise a lightly loaded supporting structure. The photos left hand demonstrate that all is possible.

Three pinned hinged frames are commonly used to free-span equestrian halls, recreational buildings, sports halls, industrial halls and agricultural buildings.

The bending resistant angles can be realised by specialised connection designs and arch systems (please see illustrations on the following page). It is normal practice to detail the frame whereby all connections are within the building fabric thus limiting exposure of the glulam to the elements.

Cantilever girders can be accommodated with the three pinned hinged frame structure. In equestrian applications it may be possible to add stalls for horses as an extension to the frame with a mono pitched lean-to roof addition.

### General Design Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>General span length</td>
<td>15 - 50 m</td>
</tr>
<tr>
<td>General roof pitch</td>
<td>10 - 40°</td>
</tr>
<tr>
<td>Spacing</td>
<td>5 - 7 m</td>
</tr>
<tr>
<td>Cantilever</td>
<td></td>
</tr>
<tr>
<td>- finger-joint frame</td>
<td>conditional (~2,00 m)</td>
</tr>
<tr>
<td>- curved angle</td>
<td>conditional (~3,00 m)</td>
</tr>
<tr>
<td>- haunch with anchor</td>
<td>unproblematic</td>
</tr>
<tr>
<td>Width of members</td>
<td>10, 12, 14, 16, 18, 20, 22 and 24 cm</td>
</tr>
<tr>
<td>Height of structural members</td>
<td></td>
</tr>
<tr>
<td>(design at planning procedure)</td>
<td>h₁ = 1/15 up to 1/22, h₂ = 1/10 up to 1/60</td>
</tr>
<tr>
<td>Purlins</td>
<td></td>
</tr>
<tr>
<td>- joint purlins</td>
<td></td>
</tr>
<tr>
<td>- single purlins in between</td>
<td></td>
</tr>
<tr>
<td>- multiple purlins overhead</td>
<td></td>
</tr>
<tr>
<td>Fire resistance grades</td>
<td></td>
</tr>
<tr>
<td>- R30</td>
<td>unproblematic</td>
</tr>
<tr>
<td>- R60</td>
<td>extra costs</td>
</tr>
<tr>
<td>Preferred strength classes</td>
<td>GL24 for finger-joint haunches, GL28</td>
</tr>
</tbody>
</table>
Arched beams

Arched or curved glulam beams are often used where the structure of a building is exposed as an architectural feature. With regard to cost-effectiveness, self-weight and aesthetic attractiveness, other structural components are far less suited where these criteria are demanded. Curved glulam structures allow lightweight buildings as a result of slender and simple structures and shapes. When compared to other building materials glulam is particularly easy to form into shapes and curves and does so at a significantly reduced premium.

As with all curved structures, the building designer needs to be mindful of the basic design criteria when designing with curves. Although small radii can be produced, those below 7 m attract a further premium over and above larger members. Production costs are greatly increased below 7 m when thinner timber lamellas are required to glue up the members.

<table>
<thead>
<tr>
<th>Possible span length</th>
<th>5 - 25 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spacing</td>
<td>2 - 6 m</td>
</tr>
<tr>
<td>Cantilever</td>
<td>possible on both sides</td>
</tr>
<tr>
<td>Width of members</td>
<td>10, 12, 14, 16, 18, 20, 22, 24 and 26 cm</td>
</tr>
<tr>
<td>Height of structural members</td>
<td>$h_1 = \frac{L}{17}$ up to $\frac{L}{25}$, $r \geq 7m$</td>
</tr>
<tr>
<td>Purlins</td>
<td>joint purlins, single span purlins in between, multiple purlins overhead</td>
</tr>
<tr>
<td>Fire resistance grades</td>
<td>R30 -&gt; unproblematic, R60 -&gt; extra costs, R90 -&gt; possible</td>
</tr>
<tr>
<td>Preferred strength classes</td>
<td>GL28, GL32</td>
</tr>
</tbody>
</table>
Continuous beams are an effective and economic solution for large span structures that may be applicable in large production halls or warehouses. For this construction continuous beams are used as the principal load-bearing elements in order to cover large parallel sections of roof. As the moment distribution of continuous beams is excellent, the bending under load and the stress concentration can be optimised. In the case of extremely large spans, joints in the glulam are factory engineered and executed on site in order to facilitate the transport of the individual structural members.

In order to ensure adequate drainage falls over the roof areas, a roof-pitch of between 2 – 5° is recommended.

Depending on the application area, the internal columns to sub-divide the space and the principal external columns can be executed in different materials (e.g. fixed ended reinforced concrete internal columns whilst pin-ended timber columns are used around the building perimeter).

<table>
<thead>
<tr>
<th>Continuous beams</th>
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<tbody>
<tr>
<td><strong>Continuous beams</strong></td>
</tr>
<tr>
<td><strong>General span length</strong></td>
</tr>
<tr>
<td><strong>General roof pitch</strong></td>
</tr>
<tr>
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</tr>
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</tr>
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</tr>
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<td><strong>General strength classes</strong></td>
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</tbody>
</table>
The bottom profile of these structural members has the form of a parabola and this reflects the ideal moment distribution of the beam. As a result, the stress/strain characteristics of fish belled beams are excellent. Due to their harmonious and aesthetic shape, fish belled beams are often used when the structure of a building is exposed as an architectural feature.

In situations like that of a single nave hall, the roof will be built as a single-pitch roof. If the hall has two or more naves with central support, a gabled roof will be realised.

Fish-bellied beams can be used as ceiling joists, floor joists and as binding beams.

### Fish-bellied beams

- **General span length**: 20 - 35 m
- **Spacing**: 5 - 7 m
- **Cantilever**: possible on both sides
- **Width of members**: 10, 12, 14, 16, 18, 20, 22, 24 and 26 cm
- **Height of structural members (design at planning procedure)**: \( h_1 = \frac{1}{16} \), \( h_2 = \frac{1}{32} \)
- **Purlins**: joint purlins, single span purlins in between, multiple purlins overhead
- **Fire resistance grades**: R30 -> unproblematic, R60 -> extra costs, R90 -> hindered possible
- **General strength classes**: GL28, GL32
Where it is not possible to install the roofing components between primary structural beams due to excessive centres, secondary support is provided with glulam purlins spanning between the primary members.

It is possible to design the purlins to suit a variety of applications: single-span, multiple-span, continuous, cantilevered or jointed purlins are all possible. Due to the efficient moment distribution, multiple-span purlins provide the most cost-effective solution. Care needs to be exercised with such a solution as the most effective placement for the purlins on top of the primary elements, leads to a greater structural depth.

Where building projects demand a double-span solution, it is recommended to design using a multiple-span purlin in order that the stress-concentration can be optimised. This is also true for situations where glulam purlins are used in combination with trapezoidal steel trusses, where the trusses span in longitudinal direction.

With increased roof pitches, purlins are manufactured to match the roof pitch or they are engineered to run perpendicular between the primary beams as single-spanning members. In this case the purlins shall be shaped to suit the roof pitch. This information should be written within the project specification.

In applications where the purlins are considered as single spanning members, the glulam shall be connected to the primary structure utilising proprietary steel connections. These connections, like all others when designing in glulam, shall be properly analysed by the structural engineer to ensure structural integrity and specified accordingly.

Where aesthetic considerations assume less significance the application of unplaned square timber as joint timber purlins may be considered as a cost saving. Although these may be relatively inexpensive, the distance between successive purlins tends to be limited through material section properties and therefore the roof structure is more functional rather than aesthetic. For this reason, joint purlins feature in combination with sheet roofing materials i.e. fibre reinforced cement boards which are used primarily for agricultural applications.

Where composite roofing panels are to be specified, glulam sections provide a more attractive solution. The material section properties allow bigger spans at the correct centres ensuring proper support for the roofing.
When designing structural columns we have to differentiate between structures with rigid, fixed-end columns and those with pin-ended columns. A structure with pin-ended columns usually results in a relatively simple foundation solution. The overall bracing of the structure is often realized using wall- and roof panels. It is considered as a standard for a minimum of one column to be rigidly fixed to the foundation per building axis.

In order to transfer the vertical stresses from the roof and the climatic loads towards the foundations, timber, steel or reinforced concrete columns are utilized. The decision on which material is best suited for this application is often determined on the designated fire performance requirements rather than economics. Where demanded, a fire-resistance of R90 can be easily realised with reinforced concrete columns, however without a secondary treatment steel columns have minimal fire-resistance. Structural steelwork loses its ability to carry load when exposed to temperatures beyond 500 degrees. The steel yields and its plasticity results in structural failure. The advantage that steel columns over concrete have is their relative small section size where plan space is a constraint. In addition, the thermal characteristics of both materials, needs to be considered when detailing the external envelope. Both easily conduct heat and so thermal bridging must be accounted for during the design and installation of the envelope materials.

With both concrete and steel columns secondary support for internal fixtures and fittings can be easily accommodated. The illustrations show a variety of options for column head design and arrangements.

In general, the forked bearing detail should equate to two thirds the height of the beam. During the building planning process it should be kept in mind that there is a need for sufficient bearing areas ensuring they can transfer the loads into the load bearing element. The following formula provides a rule for basic indication which may help to determine the necessary bearing area:

\[ L_{\text{Bearing}} = \frac{1}{3} L_{\text{Beam}} \]

In order to avoid the formation of cracks, it is imperative that the natural swelling and shrinking process of the glulam member is not disturbed. It is recommended therefore to implement the upper drillings required for the connections as elongated holes during manufacture.

As part of the overall structural design and the ultimate building performance for free-span structures, the overturning forces have to be transferred by bracing or rigid shear panels to the foundations ensuring building stiffness. In accordance with the criteria set-out in DIN 1052 (August 1996) the separation between the stiffening elements should not exceed 25 m whilst the distance between the hold point or the attachment point in general amounting to 5 – 7 m. The detailed design of the bracing system should be determined by the overall building structural engineer.

Often the bracing members – constructed in either timber or steel – are designed to ensure the loads are transferred towards the gable walls of the building. Where this is the case, the gable columns should be designed as pin-ended so that they can be dismantled and relocated easily, should the building need to be extended. The bracing members should be designed to accommodate the compressive forces as well as the tensile stressing. Glulam bracing members are economic and the fire resistance grades R30 and R60 can be easily achieved.

Where the roofing structure is intended to brace the structure special care should be taken during the construction phase ensuring adequate fixings are provided as well as temporary propping until the structure is complete.

Where the bracing elements are part of a “closed” roofing system they are only constrained by overturning forces, and in this case it should not be necessary to transfer the loads into the building foundations.
How you can benefit from our know-how

As an organisation, we are recognised in glulam construction and can provide over 80 years of experience within the timber industry. Our know how and experience allows us to develop all kinds of building project solutions irrespective of location. Whether national or international, regardless of complexity, we are always willing to deliver the correct engineered solution.

Glulam (glue laminated timber), a high-tech and truly sustainable construction material, shall become the building material of choice in the future. We are at the forefront of technological development and advancement. Our continual commitment and company ethos ensures we remain market leaders.

Regarding all technical questions, queries or advice, please do not hesitate to contact us, and our highly qualified team of professionals will be delighted to provide you with detailed technical information and share their extensive knowledge.