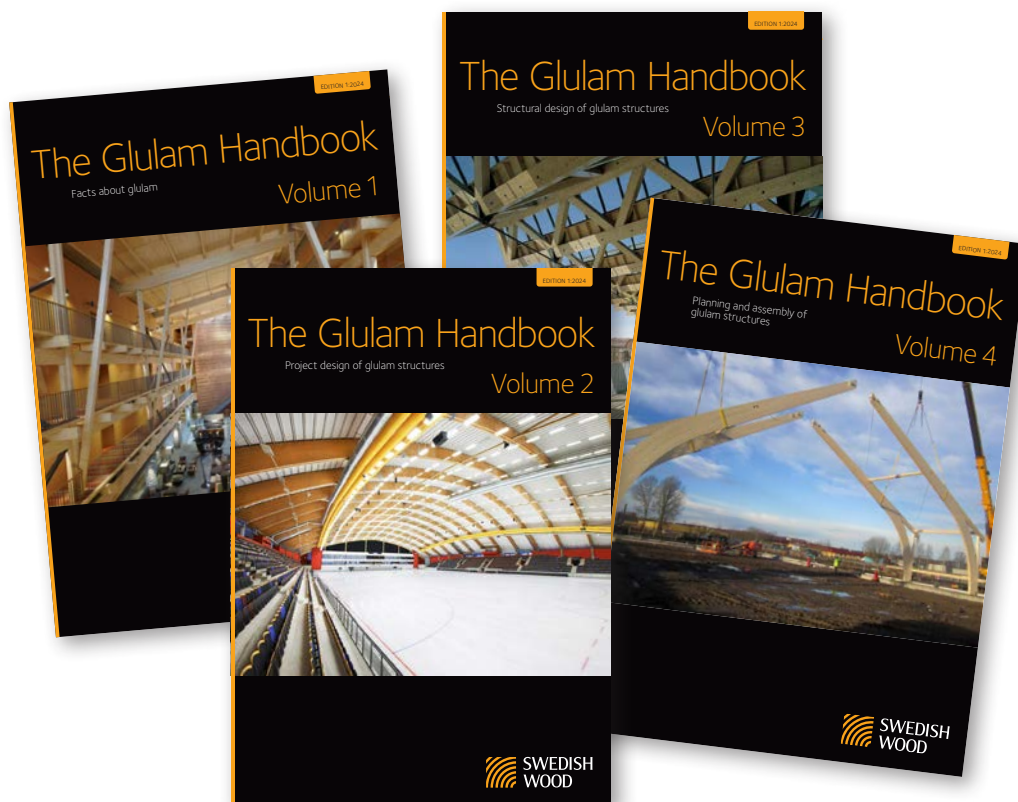# The Glulam Handbook

Facts about glulam

Volume 1

SWEDISH WOOD

The Glulam Handbook Volumes 1–3 are the result of a collaboration between glulam manufacturers and the industry organisations in Finland, Norway and Sweden. *The Glulam Handbook Volumes 1–3* are available in three languages — English, Finnish, Norwegian and Swedish. The content of these versions is adapted to meet Eurocode 5 and the associated national annexes, NA.

The Glulam Handbook Volume 4 is available in Swedish and English. It was produced by Swedish Wood and funded by the Swedish glulam manufacturers.

This publication is the first of the four-part Glulam Handbook.
• Volume 1 contains facts about glulam and planning guidance.
• Volume 2 provides calculations for the structural dimensioning of glulam.
• Volume 3 gives a number of example calculations for the most common glulam structures.
• Volume 4 provides knowledge on the planning and assembly of glulam structures.

Further knowledge, information and practical instructions on wood, glulam, CLT and wood construction are available on Wood Campus, **woodcampus.co.uk**, which is constantly updated with new knowledge and practical experiences. Wood Campus is an extensive resource with tables, drawings and illustrations.

Welcome to **woodcampus.co.uk**.

Information on wood, glulam, CLT and wood construction can also be found at **www.swedishwood.com**.

Stockholm, March 2024

Johan Fröbel
Swedish Wood

Cover: Copperhill Mountain Lodge Hotel, Åre, Sweden.

Contents

Glulam in an office environment.

Glulam as a structural material

Wood is renewable, and the most natural and energy efficient building material. Glulam provides an efficient way of using wood, consuming less raw wood material. Glulam has an established heritage as a wood product for innovators. More than a hundred years of usage has proved its lasting values of load-bearing capacity and beauty.

Strength × performance × beauty = wood³ = glulam

- Glulam is one of the strongest construction materials for its weight, allowing glulam elements to span freely over great distances.
- Glulam provides a wide range of possibilities for architects and structural engineers to create their own designs, whether for the structure of a residential house, a roof for a public building or a road bridge.
- Considering its self-weight, glulam is one of the strongest construction materials. This means that glulam elements can span freely over great distances.
- Architects and structural engineers have practically unlimited possibilities to create their own designs with glulam, whether it applies to a structure for a residential house, a roof for a public building or to a road bridge.
- Glulam is a structural material, which optimizes the technical qualities of a renewable raw material — timber.
- The laminations are finger-jointed to produce great lengths and are industrially bonded with adhesive so as to create the required size.
- Thanks to the lay-up of glulam, very large structural elements can be produced out of timber from smaller trees.
- With the help of glulam, clients, specifiers, contractors and users will enjoy the load bearing capacity, beauty and versatility of large timber elements.

Glulam of course!

- **Strength** — In relation to its weight, glulam is one of the strongest structural materials.
- **Environment** — The raw material is renewable. Glulam can be reused or recycled.
- **Aestethics** — Glulam is an aesthetically pleasing and environmentally creative product.
- **Resource-saving** — Energy use for glulam manufacture is very low compared to other materials.
- **Resistance** — Glulam manages aggressive environments better than many other building materials.
- **Shape** — Glulam can be manufactured in practically any shape.
- **Form stability** — Glulam neither twists nor bends.
- **Fire resistance** — Glulam resists a fire better than many other structural materials. This is also often reflected in insurance premiums.
- **Response** — Glulam can be processed with simple hand tools as well as with power tools. Holes and notches can be made in glulam after consulting an experienced structural engineer.

Office building with frame of glulam posts and beams. Composite floor structure in glulam and concrete.

The history of glulam

Inset image: From the glulam factory in Töreboda in the 1920s. Large image: Main concourse of Stockholm Central Station.

Is there any other material like glulam, which through its development has led to such a radical breakthrough in new building construction and new architecture? The wood's natural limitations of dimension and shape have been conquered. This certainly could have happened earlier by mechanical means, but the development of glulam meant that wood could begin to compete with materials like steel and reinforced concrete in load bearing structures for wide spans.

The development of glued laminated timber

The modern method of joining together boards into beams and wooden arches is to laminate them together into glulam. Glulam is an advanced structural material, which should not be confused with other glued wooden products, for example laminated veneer lumber (LVL), plywood or other glued laminated sheet materials.

Otto Hetzer (1846 – 1911), born in Weimar in Germany, was the first to demonstrate that beams and arches can be laminated together industrially into units with such great composite sections that they could be used in advanced structures for wide spans. Hetzer, who was a qualified carpenter, was also the owner of a sawmill and a gifted structural engineer. Hetzer started a company, Otto Hetzer Holzpflege und Holzbearbeitungs AG, within which he developed new timber components and applied for patents for various types of joined beams. In 1906 Hetzer got the patent for the invention that laminates boards to curved members. In the patent application it can be seen that

Hetzer handled most of the technical aspects, which are still relevant for the production and use of glulam.

New possibilities

Arguments for laminating by gluing together boards were to make the load bearing structure's formation independent of the dimensions of the growing trees and the possibility of manufacturing different shapes and suitable composite sections. An important part of the invention was also to smooth out the effect of defects in the wood. The correct quality timber could be used for the different parts of the composite sections by grading. This improves the quality of the structural element's tension and compression zones.

Hetzer also combined different kinds of timber. Beech wood, which is more compression proof, could be used in the composite section's compression zone and spruce in the tension zone. The outer lamellas, more exposed to stress, were to be unjointed and the less exposed could have suitably spaced out butt joints.

The thickness of the lamellas was governed by consideration of the required radius of curvature. Experiments on test beams were carried out in the beginning of the last century at the materials testing laboratories in Berlin and Dresden. It was discovered that it was possible to apply higher forces on the glued laminated beams than e.g. on similar beams of sawn timber. Hetzer was very careful to create beams of high load bearing capacity and long lifespan during production.

The glue-coated lamellas were placed on each other and pressed together with screw presses. He applied for, but was not granted, the patent for the glue recipe he used and it was therefore kept secret well into the 1950's. The adhesive was of casein type, produced from milk. It is not waterproof but moisture resistant. It does not meet today's requirements, but early glulam load bearing structures under roofs, like the main hall at Stockholm Central Railway Station, are still working very well today.

The breakthrough

Glulam's major breakthrough came with the so-called "Reichseisenbahnhalle" at the World Exhibition in Brussels in 1910. Glulam arches with tie rods had the considerable width span of 43 m. The cross-sections were almost 3 m high and 30 cm wide. The tension allowed for the glued beams was 136 kg/cm² (13.6 N/mm²). This is a strength value, which corresponds well with what is currently applied as a design value for glulam. It was shown that, for large building structures, glulam provided great economical advantages compared to those of reinforced concrete or steel. Otto Hetzer concentrated on buildings with large wide spans and glulam quickly became the natural choice for railway station buildings and aircraft hangars.

Timber performed better than steel in aggressive environments, and as timber structures are dry and ready made from the factory, erection was fast. Even before 1910 Otto Hetzer had built roughly 50 roof structures with relatively large spans. Some years later the first of four aircraft hangers was exported to Chile. From 1908 to 1925 over 20 companies in different countries bought the right to utilise Hetzer's patent. During the First World War the company experienced a boom but post-war reorganisation was considerably more difficult because of the increasing competition from steel, concrete and other efficient timber products. In 1927 Otto Hetzer AG went bankrupt.

Platform roof, Gothenburg Central Station.
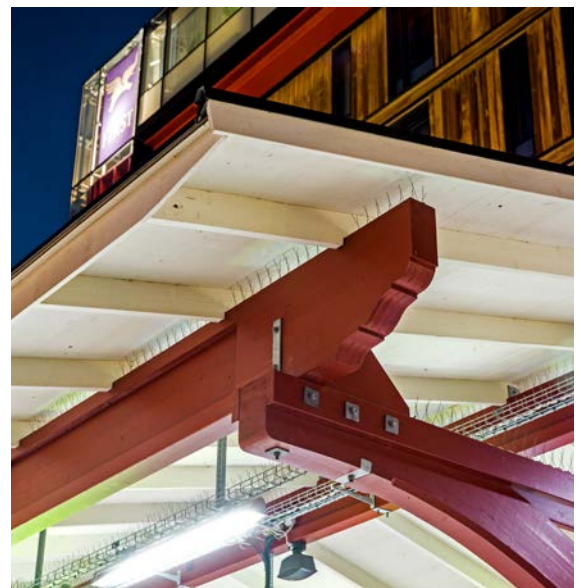
Intersection of glulam arches and beams, Gothenburg Central Station.

Cover of the Swedish patent for the Hetzer Binder.

Nordic glulam

Hetzer's structural timber design came rather early to Norway. Guttorm Brekke (1885–1980) from Drammen, had studied at the Technical University in Charlottenburg outside Berlin. When steel became a commodity in short supply at the beginning of the 20th century, Brekke remembered Otto Hetzer and his structural glued timber products. Right in the middle of the war he went to Weimar and after a period of study in the factory he returned home with the right to the patent. For the large sum of 60,000 NOK Brekke got the sale rights in Norway, Sweden and Finland for so-called Hetzer Binder.

Production began in Norway in Mysen in Östfold and in 1918 the company A/S Trekonstruktioner was formed in Kristiania (now Oslo). Brekke and the technical director Atle Thune built up "know how" by visiting Germany to learn about production and the secretly guarded recipe for the glue. Partner Erik B Aaby functioned as factory owner and MD who, since 1917 owned Ryholms estate by lake Viken and Göta Kanal (canal) outside Töreboda in Sweden.

The factory in Sweden

When the company A/S Trekonstruktioner set up a subsidiary in Sweden in 1919 it was natural to choose Töreboda as the place to get established. Raw timber material from Ryholm could be transported by boat to Töreboda and finished products could be transported by rail via Stockholm and Gothenburgh. Raw material for the glue was also available from local dairies. In Sweden the company was called AB Träkonstruktioner and one shareholder became, besides Brekke and Aaby and others, wholesale dealer Søren Christian Monrad. The latter acquired a large portion of the shares in the hope of later being able to sell some to local interested parties. Some invested small sums of money but Monrad remained the major owner in the company. The company made major investments.

The Norwegian company wanted 100,000 NOK for the patent and "know how" and the Swedish company was under obligation to use Hetzer's name, for example as "Hetzer-Binder", "Hetzertakstol" etc, in marketing. A factory building with Hetzer's three-pin arches was built, and became the first glulam hall in Sweden. In 1920 glulam sections were delivered to among others a cinema in Töreboda and in 1921 for a footbridge over the railway in Älvängen outside Göteborg. The volume was however too small and the company was forced to boost production with the manufacturing of wooden houses.

The need for railway station halls

The following years became a fight for survival for AB Träkonstruktioner. As on the continent, it was the expansion of the railways, with a demand for load bearing structures for wide spans, that provided the breakthrough for glulam. Ola Grundt became the new boss in 1922 and in the same year David Tenning (1888–1956) was appointed structural engineer.

After long negotiations with Swedish Railways, SJ, the company was able to deliver components for the new railway station buildings for Malmö Central Railway Station. Malmö Central had originally been inaugurated in 1856 at the same time as the railway to Lund. Afterwards the station expanded and was altered in several stages.

Malmö Central Railway Station main hall, built in 1923. This is one of the first great deliveries of glulam in Sweden. The station building is today in working order.

The railway station hall, which is still in operation today, was designed by the architect Folke Zettervall (1862–1955). Malmö Central is a reversing station with a hall above the platforms. In 1923 SJ ordered glulam for this hall and in the same year construction was begun. A third of the contract amount was retained during the guarantee period, which was two years, which had consequences for the company's finances. The elegant glulam arches still hold up the roof today, and the site was declared a listed building in 1986.

During 1923 several well publicized halls, besides the building for Malmö Central, were delivered. Despite a relatively good flow of incoming orders, finances were strained. The payments were, as in Malmö, often split up and the final payments arrived late. Profitability was also poor for the company's wooden house production. On top of that was increasing unrest in the employment sector. Solvency finally became too fragile and in 1924 the company went into liquidation.

The company
AB Fribärande Träkonstruktioner

In 1925 a new company was formed, AB Fribärande Träkonstruktioner, for whom David Tenning was appointed manager. Most of the shares were bought by previous blue-collar staff and office employees. The factory with machines, fixtures and fittings, was acquired for 30,000 SEK. The firm held out the prospect of deliveries for the planned rebuilding of Stockholm Central Railway Station, but
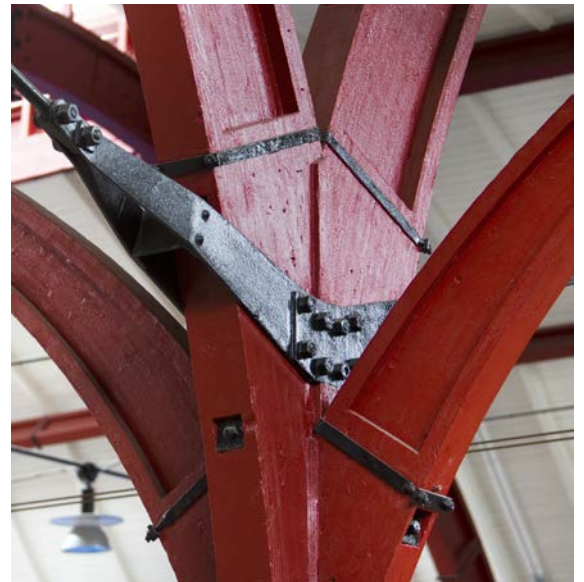
Detail of a joint at Malmö Central Station. Intersection of glulam arches and steel ties.

Glulam viewing bridge in Stegastein, on Aurlandsvegen, Norway.

Glulam is mainly made from spruce.

since the company's share capital was only 30,000 SEK the Railways Board demanded special guarantees before the small company could be given the project.

The station building in Stockholm was originally drawn up by Adolf W. Edelsvärd (1824–1919) and was built in 1867–71. The trains ran into the station building in a station-hall with five tracks. On rebuilding, the track area was moved west and the station-hall was rebuilt into a waiting hall area, 119 m long, 28 m wide and 13 m high. The glued arches have an elliptical form with I-shaped cross-section. At specific distances there are web stiffeners equipped with steel straps (perhaps an indication that the strength of the adhesive was not completely trusted).

Reliable material

Casein adhesive was used in the manufacture of the load bearing structures in Malmö and in Stockholm, structures that serve their functional purpose to this day. During the 1930's adhesive based on phenolic resin was beginning to be used abroad and in 1942 AB Fribärande Träkonstruktioner also started to use such an adhesive. It is an excellent adhesive for members, that are exposed to the effects of the climate, but it produces dark glue lines. The same applies to the phenol-resorcinol adhesive that has been used during recent decades. Nowadays adhesives are mainly based on melamine, which produces light glue lines, sets special demands on the hardening and which has better environmental qualities.

In other countries outside the Nordic countries, e.g. Germany, polyurethane adhesive is often used. The waiting hall at Stockholm's Central Railway Station became a great success and a valuable reference object for glulam manufacturers. New railway station halls with glulam structures were built in Gothenburgh and Sundsvall and glulam was now an established structural material. It was also a material, which became interesting for architects, among them Gunnar Asplund (1885–1940) and Sigurd Lewerentz (1885–1975).

A growing market for Nordic glulam

The structural engineer David Tenning led AB Fribärande Träkonstruktioner up to the end of the year in 1955/56. He was then succeeded by his son Kurt Tenning (1920–2008), who for many years led the factory successfully. During the 1940's a glulam structure was built with the largest free span in the world, 66 m. The factory in Töreboda, which is still operational, is probably the world's oldest existing glulam factory. The company has changed ownership during recent years and is now part of the Norwegian Moelven group — Moelven Töreboda AB.

After the Second World War several more glulam manufacturers were established in Sweden. Of those there are now three remaining: Martinson Group AB, Setra Trävaror AB and Glulam of Sweden AB. The largest of them, Martinson Group AB, developed from a sawmill company that started glulam manufacturing in 1965 in Bygdsiljum. A specialist factory was built in 1970 and the company export a large part of its glulam production. In 1965 Setra Trävaror AB also began glulam manufacturing in Långshyttan. The company specialises in the manufacture of straight standard beams and columns. Setra Trävaror AB also export a large part of their production of glulam. Another glulam manufacturer is in Ljungaverk, Glulam of Sweden AB,

which manufactures straight beams, columns, floor components and laminated logs. The Swedish glulam manufacturers are organized in the Swedish Forest Industries Federation, Swedish Wood, and they are members of the Glulam Committee.

What happened to Guttorm Brekke's Norwegian company? After the First World War the factory had so few orders that it had to close. When it later burnt down, Brekke decided not to rebuild it. The factory in Moelv, which now manufactures glulam in Norway, has its origins in an old industrial company, founded in 1899. At the end of the 1950's the management realised the business possibilities of the glulam and production started in 1960. The company has through acquisition become one of the largest Nordic wood companies.

Moelven Industrier AS received plenty of publicity for the structures of the sports halls in Lillehammer and Hamar, which were built for the 1994 Winter Olympics. In the advanced framed structure, forces in the joints are transferred with lapped-in steel plates and steel dowels. The origins of this was a system developed by the Swiss, Hermann Blumer (1943–) called BSB-system. Moelven employed roughly the same idea but developed their own, more craft work demanding variation. There are also good Swedish and Finnish examples of advanced glulam structures, for example the Swedish pavillion for the world exhibition in Shanghai, China, and the Sibelius Hall in Lahti, Finland.

Highly advanced architecture

This system for force transmission with dowelled assemblies has lifted glulam structures to a new level. In computerized manufacturing, processing of both rods and plates can be automated. This simple method of joining together wooden rods into flat or three dimensional timber framing has given architects and structural engineers a new freedom which, especially in Central Europe, is employed in highly advanced structures. Examples include the Anthroposophical building in Maulbronn and the swimming baths in Bad Dürrheim and Sindelfingen.

Despite the Nordic countries being "wood countries" we are far from biggest in the world for glulam production. Austria produces nearly 10 times per capita as much as Sweden, and Germany about as much as Austria.

In the USA the first glulam hall was built in 1936 by the company Unit Structures Inc. in Pesthito, Wisconsin. In North America, with its strong timber tradition, glulam is an established structural material. The large network dome in Tacoma, Washington, with a span of 160 m, is one of the world's biggest timber structures.

Glulam has, together with steel and concrete, become one of the three great structural materials for load bearing structures, not least for long spans. New, closely related products, for example solid wood, that is to say sheets of cross laminated timber (CLT), laminated veneer lumber (LVL) and Parallam can, in combination with glulam, lift architecture to a new level. These further refined timber products often go by the name Engineered Wood Products, EWP.

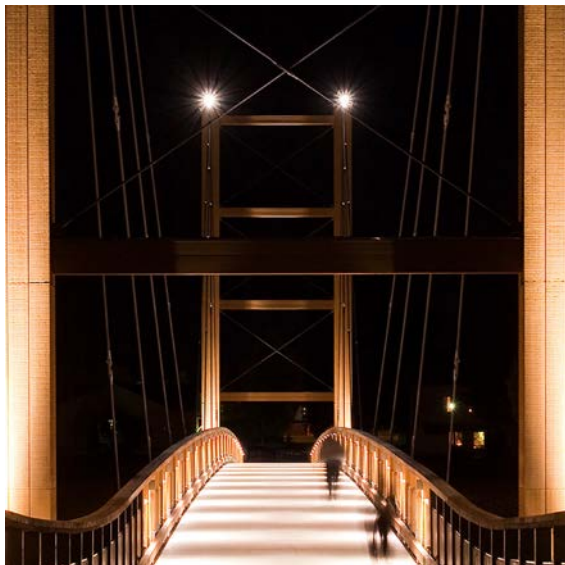The Swedish pavillion for the world exhibition Expo 2010 in Shanghai, China.

The Sibelius Hall, Lahti, Finland.

Facts about glulam

Bathing facilities with glulam frame.

Cable-stay bridge for pedestrians and cyclists.

Glulam is a processed timber product intended primarily for load bearing structures. It is one of the strongest structural materials relative to its weight, has good environmental qualities and is considered to have a lasting aesthetic value, which means it is often used in visible load bearing structures as an environmentally creative structural material. Glulam can also be used for non-load bearing structures, furniture and furnishings.

There are many examples of hall buildings and public buildings. During recent years many multi-storey residential blocks have been built with glulam included in the structure. Another important area is bridge structures.

Glulam and the environment

Glulam is a natural material. It is manufactured industrially by timber laminations that are glued to each other under controlled conditions. A natural product should be used in a sustainable way, reused, recycled or finally taken care of with the minimum possible consumption of resources and without nature being adversely affected. Glulam does not burden the environment in a disadvantageous way during its life-cycle and can easily be reused, recycled or utilized for energy recycling. Glulam contributes to a long-term sustainable environment through binding over 700 kg carbon dioxide (CO_2) per m^3.

Glulam in the life-cycle

Glulam manufacturing is a resource effective process. The raw material is Nordic softwood (mainly spruce, but also pine) and a synthetic adhesive. The percentage of adhesive in the glulam is negligible, less than 1 percent of the weight. On delivery, each glulam product should have a moisture content equivalent to no more than a reference moisture content of 16 %, which can be said to equate to a target moisture content of 16 %.

By-products like biomass are used as fuel mainly in the drying process. In this way electricity usage can be minimized.

As glulam is viewed as a processed timber product and is often "tailor-made" for the buyer, it does not cause significant waste on the site. The packaging consists of materials that can be recycled. During its working life the glulam has no negative environmental factors of significance. The adhesive releases very small amounts of substances that affect the environment. The manufacturer must verify the emission of formaldehyde in Class E1 or E2 according to the European standard EN 14080 by testing.

It is possible to finish and maintain glulam by traditional methods. The repair success rate is high — parts of a glulam element can often be replaced if needed. Glulam can, if necessary, be processed afterwards in different ways, for example by cleaning or polishing.

To some extent and after structural calculations, separate smaller holes and grooves can be made. Glulam products can be recycled based on knowledge of the technical construction prerequisites. The person responsible for checks, or the equivalent expert, should then check

Solar energy

Photosynthesis

O_2

Sustainable forestry

CO_2

Spruce logs

Recycling and
energy extraction

Production
of laminations

Construction
Reuse of glulam

Wood chips and chippings
for reuse as bio fuel

Wrapping

Kiln drying

Planing of
glulam elements

Strength grading

Chippings for reuse as bio fuel

Glueline pressure applied

Finger-jointing

Planing of laminations
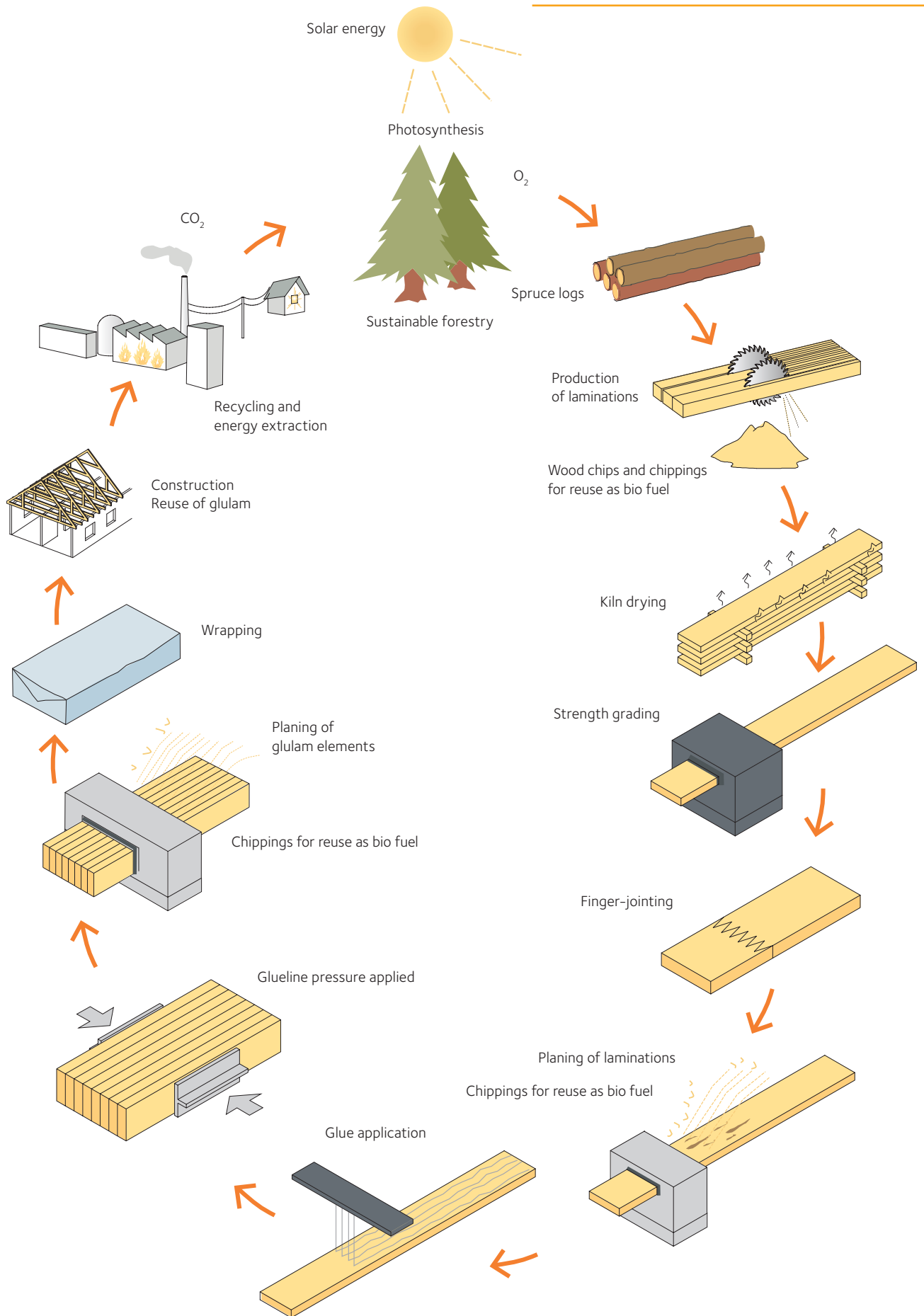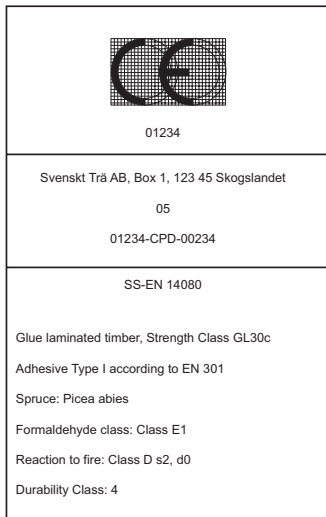
Chippings for reuse as bio fuel

Glue application

Figure 1 **Glulam is part of the carbon cycle**
Schematic of glulam production. Production is a resource-efficient
and climate-neutral process.

Certified glulam is manufactured in different strength classes, according to the harmonised standard EN 14080. The manufacturing standard in Sweden for glulam is strength class GL30, where the letters GL stand for Glued Laminated Timber (Glulam), while the number 30 stands for characteristic bending strength, expressed in N/mm². Depending on the structure of the laminates, a distinction is made between GL30h and GL30c, where the letter h stands for homogeneous glulam, and the letter c for combined glulam. In addition, the strength class designation may include the letter s, which stands for split. Glulam narrower than 90 mm is produced by splitting wider glulam. According to the standard, the glulam is then downgraded from 30 to 28 N/mm², which is why split glulam has a strength class of GL28. *See section Load-bearing capacity, page 18.*

CE

The CE-mark is a manufacturer's declaration that the product meets all the requirements placed on it by the relevant EU directives.

CE
01234
Svenskt Trä AB, Box 1, 123 45 Skogslandet 05 01234-CPD-00234
SS-EN 14080
Glue laminated timber, Strength Class GL30c Adhesive Type I according to EN 301 Spruce: Picea abies Formaldehyde class: Class E1 Reaction to fire: Class D s2, d0 Durability Class: 4

An example of CE-marking of a glulam element, according to EN 14080.

* EES = European Economic Area

** EC = European Community. The EC was replaced in 2009 by the EU = European Union. From 2009, directives are referred to as EU directives.

the glulam and judge the prerequisites for recycling in each particular situation. Like other wood, glulam is combustible and can biodegrade, but with the right design, it has a long lifespan.

The energy content in glulam is equivalent to the energy content in solid softwood. In the development of Nordic glulam products life-cycle thinking is an important starting point. This applies during the whole life-cycle of glulam products — from the choice of raw materials to reuse or recycling. As transportation consumes considerable energy, the manufacturers work actively to minimize high energy-consuming transport. Glulam manufacturers have detailed building commodity statements, which account for the manufacturing and environmental effect of the products.

Certification and control

The structural elements of glulam are manufactured industrially under controlled conditions. With the aid of finger jointing technology, very great lengths can be manufactured. The manufacturing principle is simple — timber lamellas are stacked and glued to each other into large structural sections. The size is limited on the one hand by the possibilities of transportation and on the other by the manufacturers' premises and equipment.

In the Nordic countries there have been several established manufacturers of glulam for a long time. In every Nordic country there are one or more accredited supervisory agencies that deal with certification, checking and testing of glulam products. Good experience of glulam has led to its steadily increasing use in Nordic countries.

CE-marking

The CE mark is a product label within the EU. A product bearing the CE mark can be sold in the EEA* without any further documentation. The CE mark on a product shows that the manufacturer has complied with the basic requirements set out in the EC directives governing this area. The existence of a harmonised standard is a prerequisite for mandatory CE marking.

Swedish glulam is manufactured according to the requirements of harmonised standard EN 14080. To show that glulam products meet the requirements of EN 14080, they must be CE marked and accompanied by a performance declaration. The standard stipulates the documents that are required for verification.

Elements (irrespective of the number of lamellas) manufactured in Sweden are assigned the strength class GL30c or GL30h, while split glulam beams have a strength class of GL28cs or GL28hs. The letter c stands for combined, h for homogeneous, and s for split.

Factory production control

Glulam manufacturing demands great accuracy in relation to milling of the finger joints, as well as the preparation and application of the adhesive, curing pressure and press time. In order to secure an even and high quality for the glulam members, self-checks are made continuously. This means that test specimens are taken out regularly for examination of load capacity and durability.

The accredited test agency supervises self-checking and makes unannounced test visits to the glulam manufacturers. The manufacturers are under the constant supervision of the accredited test agency.

Glulam is produced industrially under controlled conditions. The photo shows the finishing of glulam beams.

Properties

Glulam is primarily a structural material, where strength, stiffness and durability are typically the most important qualities. Glulam products do not therefore generally have the same timber qualities and surface finish as timber for interior furnishings, carpentry and furniture. In most contexts however the standard in stock products should meet normal demands on appearance. The standard appearance grade is Clean planed, no surface repairs, *see section Appearance and surface finishing, page 22*.

Timber species

The wood species in Nordic glulam manufacturing is mainly Nordic spruce (Picea Abies) but pine (Pinus Silvestris) is also used.

Pine is somewhat darker than spruce and the natural colour will darken over time. The heartwood of pine differs from its sapwood by its dark reddish brown colour, whereas the heartwood and sapwood of spruce are visually indistinguishable. Both pine and spruce are characterized by annual growth rings of light spring-wood and darker summer-wood, but spruce is generally whiter than pine.

The knots in spruce are relatively small and not surrounded by resin streaks like in pine. Although strength grading limits the size of knots in the timber, glulam is far from knot-free. Even high-strength timber can contain quite large knots. Spruce often has small pin knots, which pine does not. Pine tends to have oval knots.

Glulam can, if so desired, be manufactured from pine or treated pine. Larch is also used to some extent. As a rule, lamellas of treated pine are soft green in colour on delivery. This green colour is, like glulam's natural colour, not lasting. With regards to the use of glulam made of treated laminations, *see page 76*.

As with other timber, untreated glulam should not be exposed outdoors to all climates, as it becomes grey or greyish brown over time. This is caused by the lignin, which breaks down on the surface.
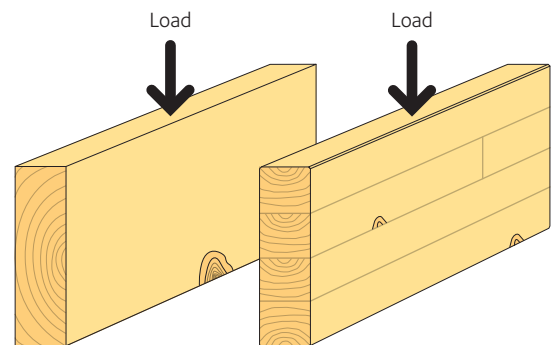
Figure 2 The lamination effect
The effect of any timber defects is evened out in glulam. There is very little risk that defects, such as large knots across multiple layers, will end up in the same cross-section. In a single plank, just one knot can significantly damage its strength.
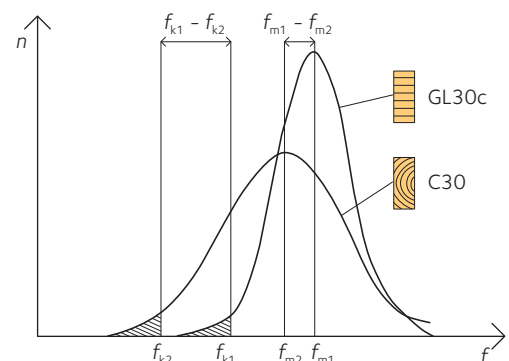
Figure 3 Structural members of glulam have a higher average strength and less variation in strength properties than the equivalent section of constructional timber
$f_{k1} - f_{k2}$ = the difference in characteristic strength value.
$f_{m1} - f_{m2}$ = the difference in the strength's mean value.
n = number of samples.
f = strength.
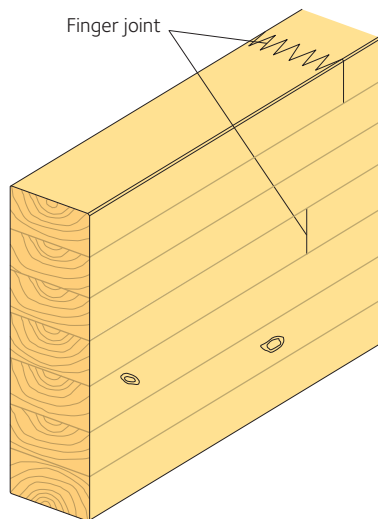The illustration refers to glulam with a large number of laminations.

Glulam frame in cowshed.
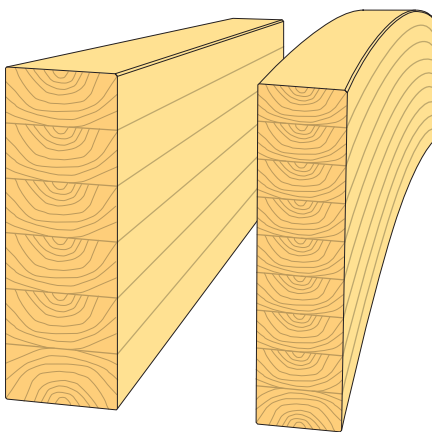

Figure 4 Glulam beam

Figure 5 Different forms of glulam
Glulam can be manufactured in many different forms, including straight beams, curved beams, arches, cambered beams, and so on.

Edge-glued joints

For glulam manufacturing, only adhesives that have been found to have high strength and durability under long lasting loading is used. The formal requirements are given in European standard EN 14080 and in sub-standard EN 301, which classifies two adhesive types, Adhesive type I and Adhesive type II. Alternatively to the requirements in EN 301, the requirements for one-component polyurethane adhesive in EN 15425 must be met.

Glulam manufactured with adhesive according to Adhesive type I can be used independently of the surrounding climate (Service classes 1–3 according to Eurocode 5) while the usage of adhesive according to Adhesive type II is limited to structures that are protected from the weather (Service classes 1 and 2 according to Eurocode 5). Glulam must however be protected from the long-term influence of damp, precipitation, dirt and radiation from the sun. A list of approved adhesives is issued by the accredited supervisory agency in the respective country.

Melamine-urea-formaldehyde-adhesive is currently used almost exclusively for environmental reasons, in everyday language so-called melamine or MUF, which refers to Adhesive type I. Initially melamine glue lines are pale, but can darken over time.

The light melamine adhesive is used almost exclusively for finger joints in lamellas, so that the joints appear only as thin lines on the member's surface.

The labeling should indicate which adhesive type has been used in manufacturing (Adhesive type I or Adhesive type II according to EN 301).

Earlier, synthetic two-component adhesive of the type phenol-re-sorcinol-formaldehyde (PRF) was typically used as a rule in glulam manufacturing. PRF-adhesive refers to Adhesive type I and produces dark reddish brown glue lines. Nowadays gluing with PRF is used only for export to certain countries.

There is continuous development of construction adhesive for the purpose of obtaining improved and even more environmentally-friendly adhesive.

Appearance quality

Surface finishing of glulam sections takes place in conjunction with manufacturing, *see section Appearance and surface finishing, page 22*.

Glulam products can then be surface treated on site as normal timber by stain treatment, top-coat painting, clear varnishing or oil treatment; *see section Surface treatment and maintenance, page 69*.

Size and shape

Glulam technology provides great opportunities to vary cross-sectional form and geometry in the structural sections. The limitations are set by practical issues, such as the transportation logistics, manufacturers' premises and the mechanical equipment.

A straight glulam section with a rectangular cross-section has, similar to sawn and planed timber, thickness, width and length. In Nordic countries, a glulam section is normally labeled with the dimensions b, h and L.

In an application, for example when a section is used as a beam, the sizes will be b for the width, h for the height and L for the length. If a section is intended as a column the sizes will be b for width, h for depth and L for the column height (length).

Size *h*

- Straight members typically have sizes of *h* as a multiple of lamella thickness 45 mm, that is to say 180, 225, 270, 315 and so on.
- Curved members typically have of sizes of *h* as a multiple of lamella thickness 33 mm, that is to say 266, 300, 333, 366 and so on. With a curved radius of less than 7 m, thinner lamellas are required.

Cross-section shape

Rectangular cross-sections are the norm for glulam, but products with other cross-sectional shapes can be manufactured, for example I-, T- and L- cross-sections or hole cross-sections, composed of several glulam members, *see figure 8*.

Largest cross-section size *b* x *h*

The largest size of *b* (width) for a glulam member is limited by the availability of wide lamellas. Normally it is difficult to get hold of sawn timber that is wider than 225 mm, but in some cases it is possible to obtain timber with a width of up to 260 mm. After planing, this is equivalent to a nominal width of 215 mm and 240 mm respectively. By edge gluing the laminations or through gluing together several glulam members sideways, bonded with the shifted glued joint, one can manufacture glulam members up to 500 mm wide.

The largest size of *h* in a glulam section is limited by available mechanical equipment to roughly 2 m. Greater sizes can be achieved by different measures, as for example by gluing on the ridge part of a double-pitched beam at a later stage, greater sizes can be achieved. Glulam members with *h* (depth) up to 3 m can be manufactured in this way.

Largest length

Glulam can normally be delivered in 30 m lengths. For special orders up to 40 m long pieces can be delivered. In practice the length is limited by transport logistics.

Transport takes place mostly by road. Glulam elements of up to 30 m in length are usually no problem, but may require permission from the road authority. If the total vehicle length exceeds 24 m, a special permit is normally required from the transport authorities in the country where the transport takes place. There are common regulations within the EU but different detailed rules can apply in different countries.

Special transport is normally required if the load width 2.6 m or total height 4.5 m are exceeded, which can be the case with portal frame or arch structures.

If railway or sea transport is used, other limits apply. Often the transport problem can be solved by the construction being split up in suitable transport units that are put together later on the building site. Investigating respective manufacturers' size capacities at an early project phase is recommended.
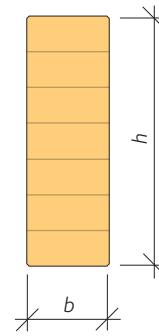

Figure 6 Glulam dimension designations
b = Width
h = Height/depth
L = Length.

Max. height 4.5 m

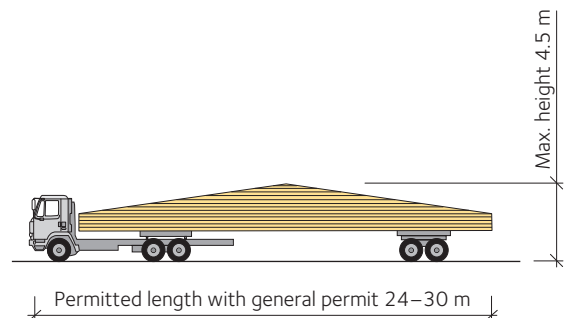Permitted length with general permit 24–30 m

Figure 7 Transporting glulam
The maximum permitted length and height of vehicles without a special permit is the same across Europe. Transport rules may vary in detail from one country to another.
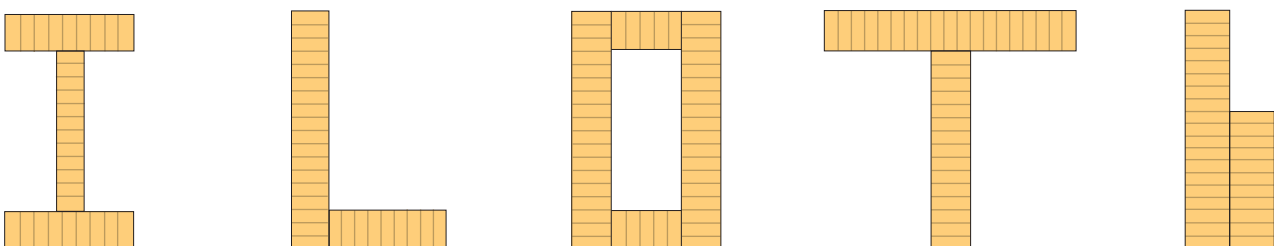

Figure 8 **The most common cross-section for glulam is rectangular.** Examples of other cross-sectional shapes are shown here.

Glulam post in strength class GL30h

All lamellas in
strength class T22

$h < 180$ mm

h

$b \geq 90$ mm

b

Glulam beam in strength class GL30c

Outer zone ≥ 17 %
of height, lamellas in
strength class T22

Inner zone ≤ 66 %
of height, lamellas in
strength class T15

Outer zone ≥ 17 %
of height, lamellas in
strength class T22

h

$h \geq 180$ mm

$b \geq 90$ mm

b

Glulam post in strength class GL28hs

All lamellas in
strength class T22

$h < 180$ mm

h

$b < 90$ mm

b

Glulam beam in strength class GL28cs

Outer zone ≥ 17 %
of height, lamellas in
strength class T22

Inner zone ≤ 66 %
of height, lamellas in
strength class T15

Outer zone ≥ 17 %
of height, lamellas in
strength class T22

h

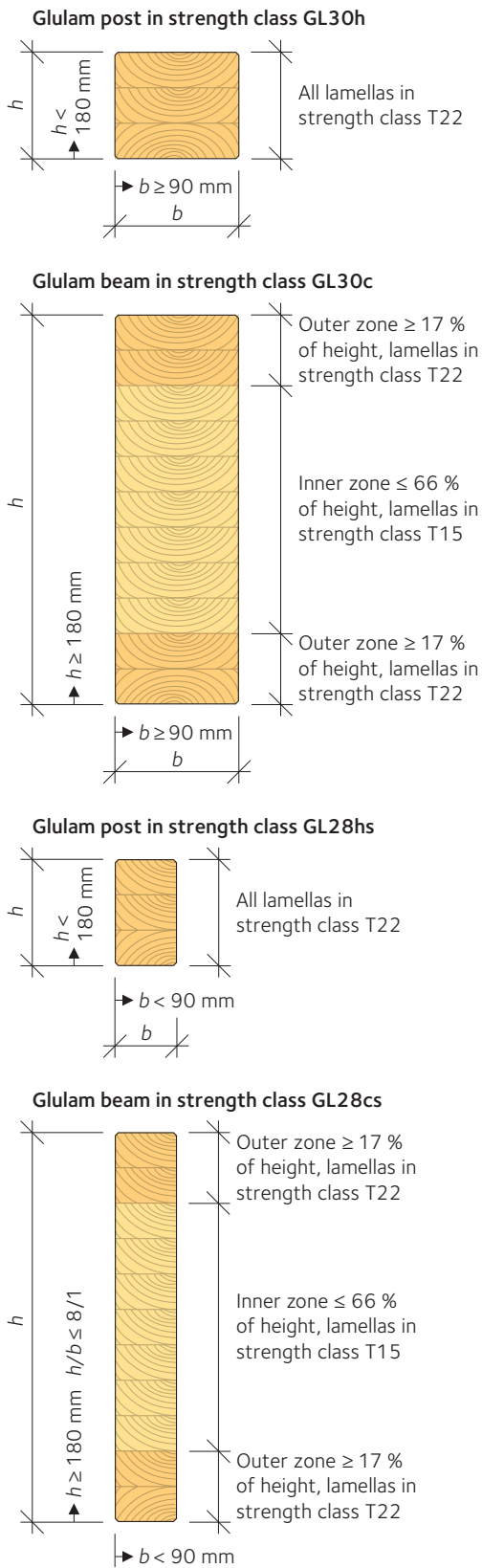$h \geq 180$ mm $h/b \leq 8/1$

$b < 90$ mm

Figure 9 Strength classes for glulam
Glulam cross-sections illustrating the different strength
classes GL30h (homogeneous glulam), GL30c (combined
glulam), GL28hs (homogeneous split glulam) and GL28cs
(combined split glulam). Glulam in strength classes GL28hs
and GL28cs is made by splitting a wider cross-section into
smaller pieces.

Load-bearing capacity

The load bearing capacity of glulam is high in relation to its self-weight, which makes it possible to construct large unsupported spans. In comparison with other structural materials, glulam is one of the strongest, considering its self-weight.

For structural and other construction timber the load bearing capacity is governed in a single plank by the weakest cross-section — normally by a large knot, finger joint or angular fibre. The difference in strength between different planks can be considerable. The members of glulam are on average both stronger and stiffer than normal structural timber of the same dimension. This depends on the so-called laminating effect, which in brief can be explained in the following way:

A glulam section consists of a number of lamellas of structural timber. The risk of strength decreasing defects in several lamellas ending up in the same cross-section is very small. Besides, the lamellas have been graded for strength, and in so-called combined glulam, the strongest lamellas have been placed on the outer sides of the member where the stresses are normally the greatest, *see figure 2, page 15*.

With combined glulam in strength class GL30c, the outer zones must be at least 17 percent of the cross-sectional height. Glulam in strength class GL30c consists of laminated timber in strength class T22 in the outer zones and in strength class T15 in the inner zone, *see figure 9*.

Homogeneous glulam in strength class GL30 is designated with the letter h (h = homogeneous) after the strength class designation. The number 30 represents the characteristic bending strength expressed in N/mm². Glulam in strength class GL30h consists only of laminates in strength class T22. In addition, the letter s (split) may be included in the strength class designation. Glulam narrower than 90 mm is produced by splitting wider glulam. According to the EN 14080 standard, the glulam is then downgraded from $f_{m,g,k} = 30$ to 28 N/mm², which is why split glulam has a strength class of GL28.

The load bearing capacity in a glulam member will be on average greater than an individual lamella of the same dimension, and the difference in strength between different sections will be less than for individual lamellas. With a retained safety level, one can thus generally apply higher stresses for a glulam section than for the incoming lamellas when they are loaded individually. Thus glulam members have higher average strength and less variation in strength properties than equivalent members of structural timber, see *figure 3, page 15*.

When designing glulam structures and timber structures it is usual to proceed from a characteristic strength value, determined on the basis of strength tests under laboratory-like conditions of a large number of test specimens. While knowing the characteristic strength value, the design value is decided in each individual case of different so-called partial coefficients and adjustment factors; *see The Glulam Handbook Volume 2*.

Thermal qualities

In comparison with metal, wood has very small temperature movements. This means that the tensions in glulam due to changes in temperature, seldom cause any inconvenience. Thermal conductivity and heat capacity are equal to normal timber (softwood).

As with other wood products, glulam has relatively good heat insulating qualities. Heat conductivity, the so-called λ-value, which is

expressed in W/m · °C, is comparable with, for example, light-weight concrete, and it is considerably lower than for concrete and steel. The heat conductivity, λ-value, for softwood is 0.11 W/m · °C perpendicular to the grain and 0.24 parallel to the grain. In practice, the value of 0.13 W/m × °C is usually used for glulam.

Glulam has comparatively high specific heat capacity (thermal inertia). It is normally declared at about 1,300 J/kg °C — in comparison with, for example, concrete, which has about 880 J/kg °C. However, because of the small amount of glulam in a building, the possibilities of using glulam in order to even out the variations in climate are limited.

As a result of the glulam's thermal qualities, non-painted glulam surface feels pleasant on body contact.

Moisture content

The term 'target moisture content' is used for a timber batch on delivery from the manufacturer and is defined according to EN 14298. If, for example, a target moisture content of 12 % is ordered, the average moisture content of the timber batch is allowed to vary between 10.5 % and 13.5 %. The concept of target moisture content is not entirely relevant for glulam products. In glulam production, each lamella is required to have a moisture content of between 6 % and 15 %. Two lamellas to be finger-jointed may have a maximum difference in moisture content of 5 %. On delivery, each glulam product should have a moisture content equivalent to no more than a reference moisture content of 16 %, which can be said to equate to a target moisture content of 16 %.

The reference moisture content and surface moisture content should be verified during the acceptance check, assembly and installation by means of random tests using an electrical resistance moisture meter with insulated hammer electrodes.

The term 'surface moisture content' is sometimes used when checking wooden surfaces during installation and is crucial in determining the risk of microbial growth. The value indicates whether precipitation may have dampened the surface, for example, or whether the wood material has a high moisture gradient.
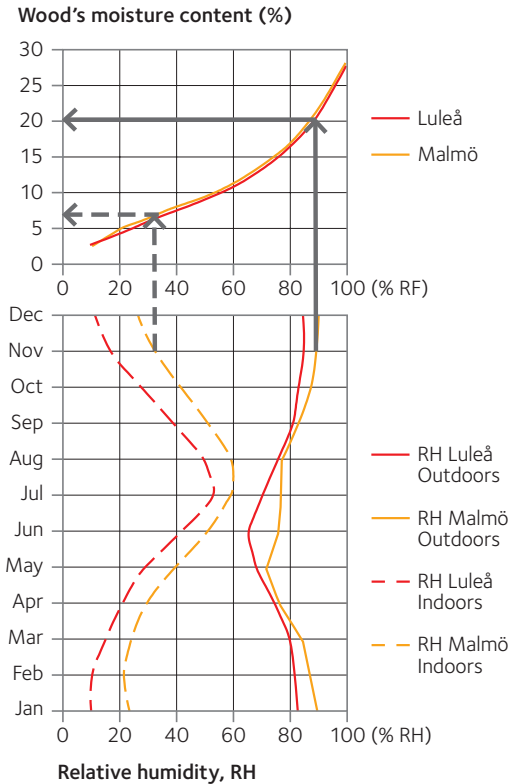
Figure 10 **Wood's moisture content in relation to relative humidity, RH**

The top section shows the correlation between ambient relative humidity (RH) and moisture content. The temperature also affects the correlation, but the effect is less than 1 percent of the moisture content in the temperature range 0−20 °C.

The lower section shows the monthly average value for RH in the north of Sweden (Luleå) and the south (Malmö). The solid curves show RH outdoors and the dotted curves show RH indoors. The RH curves for indoors should be increased by around 18 % RH to account for the moisture added by a normal family (cooking, shower, laundry, breathing, perspiring and so on).

Examples: What is the RH and average moisture content indoors in Malmö in November?
Following the black arrows, RH = 32 % and the moisture content 7 %. (Outdoors, the corresponding figures are RH = 89 % and moisture content = 20 %). At an RH of around 32 %, the wood's moisture content is thus around 7 %.
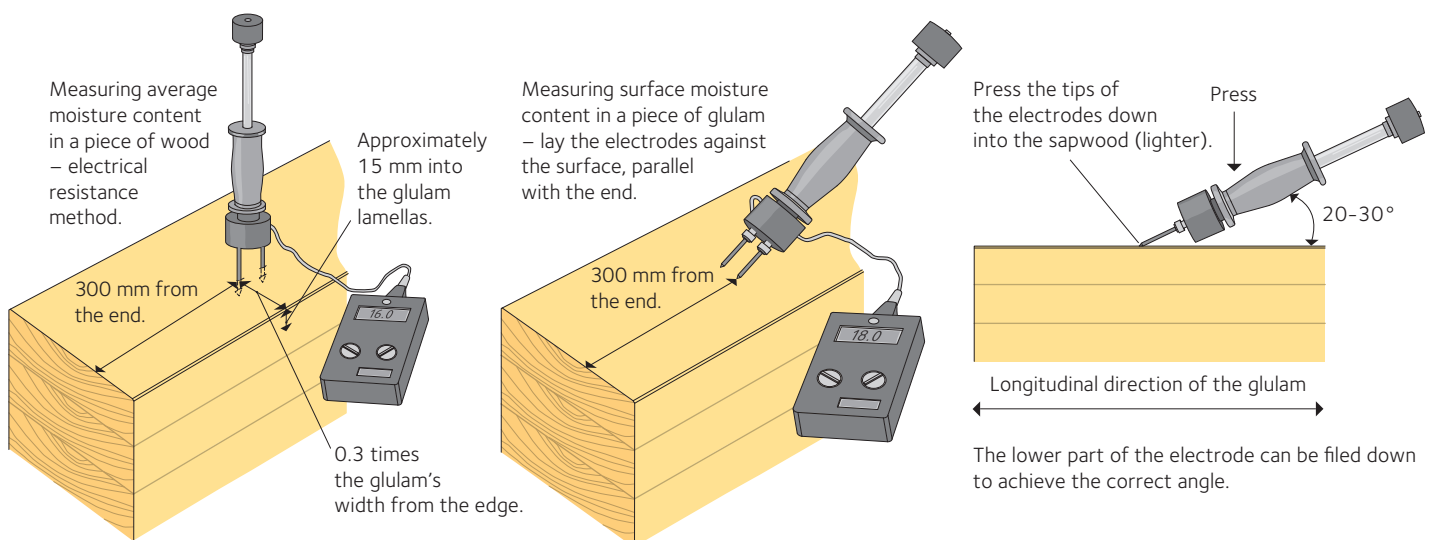
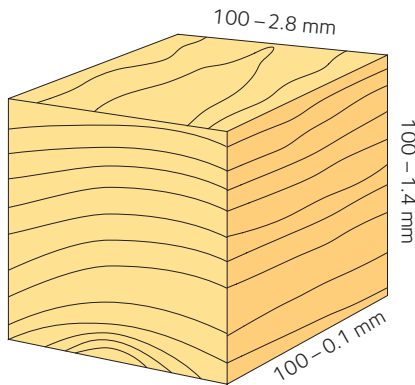**Figure 11** **Measuring average and surface moisture content**

Figure 12 Shrinkage or swelling
Shrinkage in a cube with 100 mm sides during drying from 20 % to 10 % moisture content. The greatest movement is tangential to the fibres, and the least occurs parallel with the fibres.
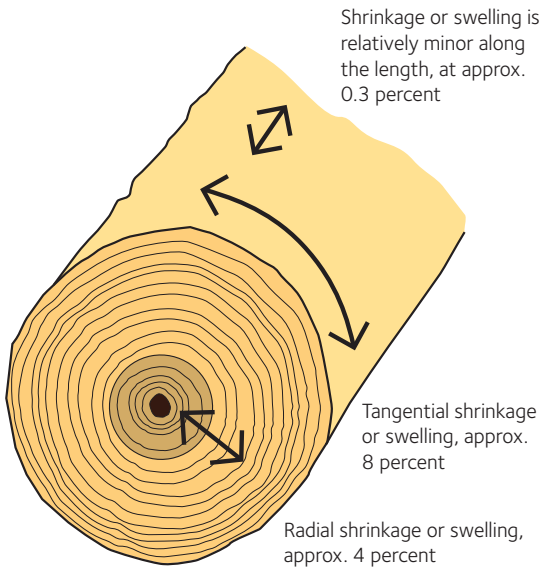

Shrinkage or swelling is relatively minor along the length, at approx. 0.3 percent

Tangential shrinkage or swelling, approx. 8 percent

Radial shrinkage or swelling, approx. 4 percent

Figure 13 Shrinkage or swelling in a softwood log
Shrinkage or swelling in a piece of timber varies depending on how the growth rings are positioned in the wood. The smallest dimensional changes occur in wood where the growth rings are perpendicular with the face, known as vertical grain.
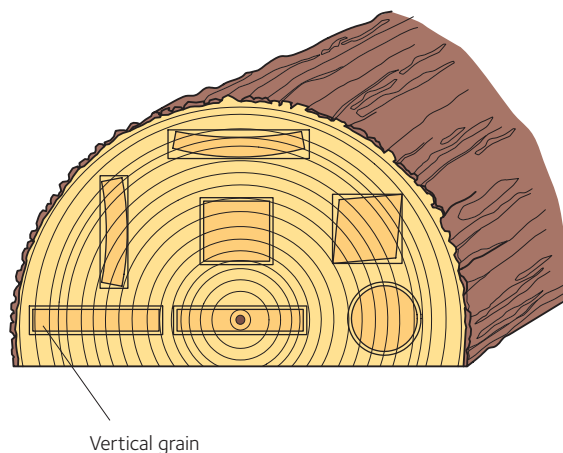

Vertical grain

Figure 14 Growth ring orientation in a piece of wood

According to AMA Hus glulam may have a moisture content at the point of installation equating to no more than a target moisture content of 16 %. Similarly, the surface moisture content during installation may not exceed 18 %, and glulam surfaces to be painted on site may have a surface moisture content of no more than 16 % at the time of painting, *see section Handling glulam correctly, page 78*.

Humidity movement

Glulam elements are manufactured with a reference moisture content of 12 %. On delivery, each glulam product should have a moisture content equivalent to no more than a reference moisture content of 16 %, which can be said to equate to a target moisture content of 16 %. Afterwards the moisture content starts to adjust itself in equilibrium with the surrounding air's relative moisture and follows its variation over the year. Normally the wood's moisture content varies by 4 to 5 percent during the year in the Nordic countries:
- For timber structures in heated, non-moisturized buildings, between 7 percent (winter) and 12 percent (summer)
- For unheated buildings or outdoors under a roof, between 13 percent (summer) and 17 percent (winter).

Glulam, just like other timber, swells when the moisture content increases and shrinks when the moisture content decreases. However the tendency to twist and curve is less for glulam than for solid timber, because of the small difference in moisture content between the lamellas and the layup of glulam.
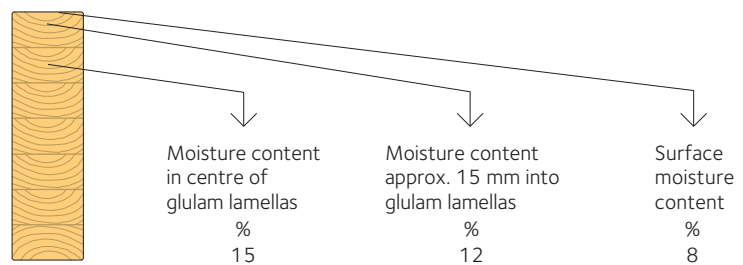

| Moisture content in centre of glulam lamellas % 15 | Moisture content approx. 15 mm into glulam lamellas % 12 | Surface moisture content % 8 |

Figure 15 Moisture gradient in glulam
Example: Moisture content variation in glulam. The moisture content in glulam lamellas may be less than or equal to 15 % at the time of manufacture. A lower moisture gradient may occur in a finished glulam product. In an acceptance check of a glulam batch, the moisture content was measured at 12 % 15 mm into the glulam (outer zone). The surface moisture content was measured at 8 % as an average value. The glulam can thus be included in an ordered glulam batch with a target moisture content of 16 %.

Properties in a fire

Because of their large homogeneous cross-sections, glulam structures have relatively good protective qualities in the event of a fire. Fire resistance increases with increased sizes.

Although glulam is a combustible material, it is relatively resistant during a fire sequence's starting phase because of the often large and homogeneous cross-sections. Ignition is sluggish and it burns slowly.

The generation of heat during a fire is often decisive for the fire to develop or diminish. The layer of carbon that forms on the glulam surface in a fire protects the inner parts and contributes to the glulam retaining its load bearing capacity during subsequent fire stages.

The penetration rate in glulam is generally about 0.5 – 1.0 mm per minute (about 40 mm per hour). Additional fire protection can be achieved with surface finish or fireproof lining, *see further in the section Design with regard to fire, page 62* or *The Glulam Handbook Volume 2*.

Durability

Glulam is an organic product that, correctly used, has good resistance to decomposition by microorganisms. Spruce also has good resistance to wood-staining fungi. If the material is used or handled in an incorrect way it can, under adverse conditions, be attacked by microorganisms.

Microorganisms can be discolouring (blue stain or mould fungi) or wood destroying (rot fungi). Insects that can attack wood include old house longhorn beetles. The presence of old house borer is geographically limited and it is found above all in loft areas.

While the influence of microorganisms can cause damage, it is an advantage that wood is included in the natural life-cycle. During a building's allotted lifespan one must make sure that the timber is protected against the attack of microorganisms — especially timber that is load supporting and which is part of safety-critical structures such as stairs and banisters, or is difficult to replace.

The best method of protecting the timber is to design in such a way that rot cannot occur. Design of timber protection should be concentrated on keeping the timber dry or to allow for quick drying after moistening. Dry timber or timber that is only temporarily moist cannot rot. Only long-term damp timber can rot.

In especially exposed situations treated timber can be used for durability reasons, *see further in the section Glulam with treated laminations, page 76* and *The Glulam Handbook Volume 2*.

Example of a glulam frame in a car repair shop.

Footbridge made of timber and glulam, both pressure-treated.


Footbridge

Glulam products

Glulam products are manufactured as straight or curved members. The most common cross-sectional shapes are rectangular, but other cross-sectional shapes can be manufactured.

Straight members with rectangular cross-sections are standardized in terms of size and quality of appearance. *Table 1, page 23*, is a dimensional and load bearing capacity overview of CE-labeled glulam. For quality of appearance, *see below*.

Appearance and surface finishing

Glulam products are given some kind of surface finish at the manufacturers. Depending on the area of use and demands on appearance Nordic manufactured glulam can be delivered in the following standardized appearance grades:
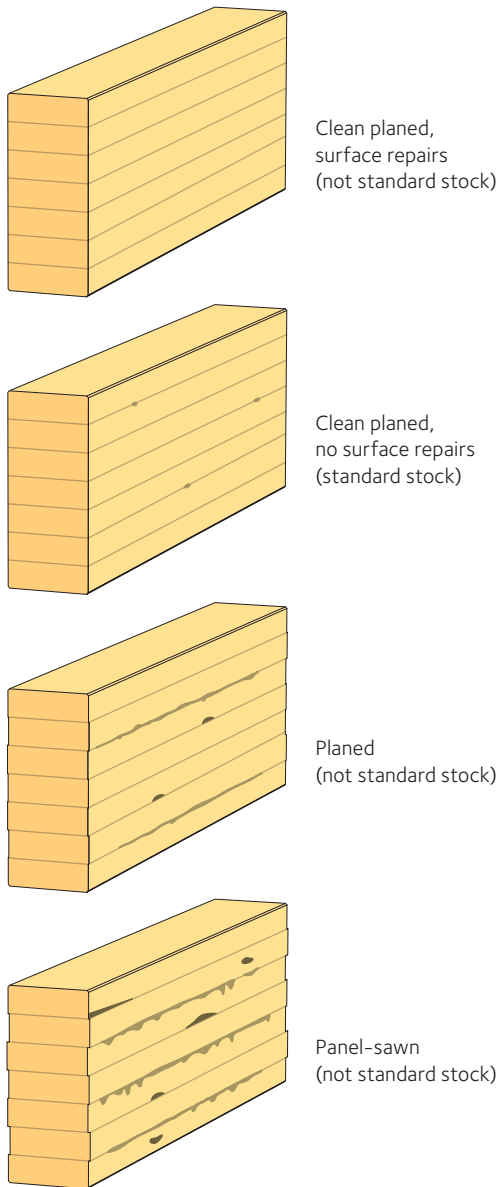
Clean planed, surface repairs (not standard stock)
The sides are to be processed with a plane or similar. Surfaces that are left visible after erection should be repaired so that they are practically free from larger splits, knotholes, chipping and glue-stains. Minor resin pockets, knotholes, chipping and minor glue-stains may however occur. Visible edges are to be beveled.

Clean planed, surface repairs are recommended for visible use where there are extra high demands on appearance, for example housing, schools etc.

Clean planed, no surface repairs (standard stock)
The sides are to be processed with a plane or similar. Minor resin pockets, knotholes, chipping and minor glue-stains can however occur. Visible edges are to be beveled. Clean planed, no surface repairs are standard for stock range in the Nordic countries.

Clean planed, no surface repairs are recommended for visible use, for example roof beams in sports halls, business premises, family homes and the like.

Planed (not standard stock)
The sides are to be processed with a plane or similar. Single lamellas can however be partly unprocessed. Minor glue-stains are allowed. Minor resin pockets, knotholes and chipping can occur. For members placed more than 4 m away from the viewer, Planed can be a sufficient appearance class.

Planed members are recommended for visible use where reasonable demands are made on the appearance, for example roof beams in sports halls, business premises or where function and load bearing capacity is deemed as of great importance, but where one wants to utilize glulam as an environment creative element, for example in industrial premises.

Panel–sawn (not standard stock)
The sides are predominantly allowed to be un-planed. For units not wider than 90 mm (target size) one of the sides is allowed to be a sawn surface. Glue-stains can occur on all sides and laminations with waned edges can occur. Resin pockets, knotholes and chipping can of course occur.

Panel-sawn are recommended for built in or visible use with low demands on appearance, for example in storage premises or for structures, where glulam is invisibly used.

Clean planed,
surface repairs
(not standard stock)

Clean planed,
no surface repairs
(standard stock)

Planed
(not standard stock)

Panel–sawn
(not standard stock)

Figure 16 Appearance grades
Glulam can be supplied in the appearance grades above.

Stock range

Straight glulam elements with a rectangular cross-section and an appearance grade of Clean planed, no surface repairs, are normally stocked in lengths up to 12 m with cross-sectional dimensions as set out in *the section Stock range of glulam columns and glulam beams made in Sweden, page 24*. Glulam with $b \geq 90$ mm and $h < 180$ mm (up to three lamellas) has strength class GL30h (h = homogeneous), while glulam with $b \geq 90$ mm and $h \geq 180$ mm (four lamellas or more) has strength class GL30c (c = combined).

Elements with $b < 90$ mm and $h \geq 180$ mm (four lamellas or more), known as split glulam beams, have strength class GL28cs (cs = combined split). However, the width is at least 38 mm and the height/width ratio must not exceed 8/1 according to EN 14080. Other cross-sectional sizes, strength classes or appearance qualities or larger lengths, can be ordered.

The most common adhesive class is Adhesive type I, which means that stocked products can be used irrespective of the surrounding climate, although they must be protected from precipitation and strong radiation from the sun.

Size tolerances

Tolerances for straight glulam elements, as specified in EN 14080, are given in *table 2* below. The tolerance requirements apply in relation to the nominal dimension (reference dimension) at a moisture content equating to a reference moisture content of 12 %. If the current moisture content, in a glulam unit differs from the reference moisture content, the sizes should be recalculated according to EN 14080.
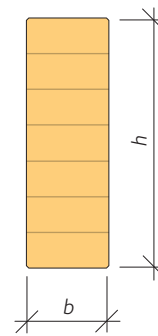

Figure 17 Cross-sectional size
Cross-sectional size $b \times h$ for stocked products of glulam manufactured in the Nordic countries. Lengths up to 12 m are normally in stock.

Note that given size are target sizes in mm. The sizes apply with a moisture content equivalent to a reference moisture content of 15 percent and for glulam with the standard appearance grade Clean planed, no surface repairs.

Facts Resawn glulam

Note that elements with a size of b less than 90 mm (target size) are normally resawn from thicker elements. The saw cut can then go through open or glue filled cracks, which can cause chipping and give visible glue-stains on the cutting side. This applies to all qualities of appearance. For high appearance demands, resawn beams should be avoided – elements with size b less than 90 mm and appearance grade Clean planed, surface repairs, should not be chosen.

Table 1 Material properties for glulam according to EN 14080

Strength values in MPa		GL28cs	GL28hs	GL30c	GL30h
Bending parallel to grain	$f_{m,g,k}$	28.0	28.0	30.0	30.0
Tension parallel to grain	$f_{t,0,g,k}$	19.5	22.4	19.5	24.0
Tension perpendicular to grain	$f_{t,90,g,k}$	0.5	0.5	0.5	0.5
Compression parallel to grain	$f_{c,0,g,k}$	24.0	28.0	24.5	30.0
Compression perpendicular to grain	$f_{c,90,g,k}$	2.5	2.5	2.5	2.5
Shear (shear and torsion)	$f_{v,g,k}$	3.5	3.5	3.5	3.5
Rolling shear	$f_{r,g,k}$	1.2	1.2	1.2	1.2
Stiffness values in MPa		GL28cs	GL28hs	GL30c	GL30h
Elastic modulus parallel to grain	$E_{0,g,mean}$	12,500	13,100	13,000	13,600
Elastic modulus, characteristic	$E_{0,g,05}$	10,400	10,500	10,800	11,300
Elastic modulus perpendicular to grain	$E_{90,g,mean}$	300	300	300	300
Shear modulus	$G_{g,mean}$	650	650	650	650
Density in kg/m³		GL28cs	GL28hs	GL30c	GL30h
Density, characteristic	$\rho_{g,k}$	390	430	390	430
Density	$\rho_{g,mean}$	430	480	430	480

Table 2 Size tolerances for glulam according to EN 14080

Size tolerances for glulam		
Size of b		± 2 mm
Size of h	≤ 400 mm	+ 4 mm to – 2 mm
	> 400 mm	+1 % to – 0.5 %
Size of L	≤ 2.0 m	± 2 mm
	> 2.0 ≤ 20 m	± 0.1 %
	> 20 m	± 20 mm
Angles	Cross-sectional angles can deviate at most 1:50 (circa 1°) from the right angles.	
Straightness (for straight elements)	From two arbitrarily chosen points 2 m apart, on any edge of the glulam element, the deviation must not exceed 4 mm. Cambered beams are excluded.	
Maximum deviation from the nominal arc (over 1 m along the curved shape)	± 4mm (≤ 6 laminations) ± 2 mm (> 6 laminations)	

Table 3 Strength classes for glulam

Glulam element	Strength class
$b \geq 90$ $h < 180$ (up to 3 lamellas)	GL30h
$b \geq 90$ $h \geq 180$ (4 lamellas or more)	GL30c
$b < 90$ $h < 180$ (up to 3 lamellas)	GL28hs
$b < 90$ $h \geq 180$ (4 lamellas or more)	GL28cs

CE marked glulam is manufactured in Sweden in strength class GL30c or GL30h, as stated in *table 3*. Split glulam beams are downgraded to strength class GL28cs or GL28hs. Characteristic values for calculation of load-bearing capacity, stiffness and density, plus average values for stiffness and density, are shown in *table 1* above.

Source: Properties and values according to *EN 14080:2013 table 4 and table 5*.

To rationalize production and thereby minimize delivery times, the Nordic glulam manufacturers have a common manufacturing standard based on EN 14080.
The manufacturing standard encompasses stocked range according to *table 4, page 25*.

- Straight glulam members with $b \geq 90$ mm and up to at least 3 lamellas and Adhesive type I are produced as standard in strength class GL30h.
- Straight glulam members with $b \geq 90$ mm and more than 3 lamellas and Adhesive type I are produced as standard in strength class GL30c.
- Glulam with $b < 90$ mm and $h \geq 180$ mm (four lamellas or more) is manufactured as standard in strength class GL28cs.

Straight glulam members

The most common types of glulam elements are straight units. They are normally manufactured from 45 mm thick timber lamellas and are used for floor beams, roof beams and columns. Straight glulam elements are often included as components in different structural systems, *see further under section Structural systems, page 38*.
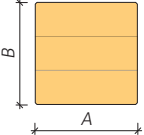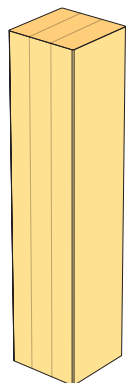
For greater spans there can be the need for a camber of freely supported beams to prevent notable deflection. Such beams can be manufactured to order.

The manufactured range includes a large number of dimensions in addition to the stock range, *see table 4 Range of glulam columns and beams manufactured in Sweden, in relevant strength classes, page 25*.

Stock range of glulam columns and beams made in Sweden

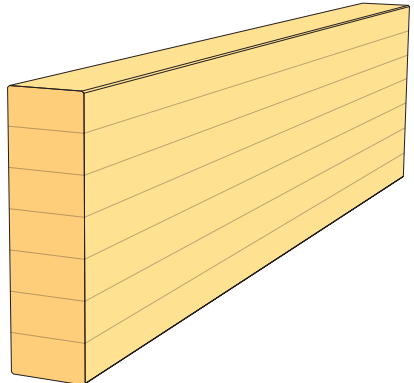| Glulam post	Glulam beam
Standard range for glulam, manufactured in line with EN 14080. Clean-planed finish, no surface repairs. Four bevelled corners. Untreated. Adhesive type I. Dimensions and strength class as per table below.	Standard range for glulam, manufactured in line with EN 14080. Clean-planed finish, no surface repairs. Four bevelled corners. Untreated. Adhesive type I. Dimensions and strength class as per tables below.
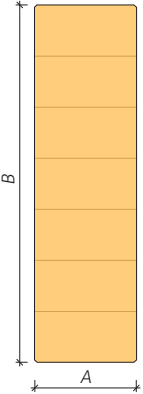
$A \times B$ Strength class GL30h

90 × 90	**115** × 115	**140** × 135 140	**160** × 160	**165** × 165

$A \times B$ Strength class GL28cs

42 × 180 225 270	**56** × 225 270	**66** × 270 315

$A \times B$ Strength class GL30c

90 × 180 225 270 315 360 405 450	**115** × 180 225 270 315 360 405 450 495 630	**140** × 225 270 315 360 405

The above dimensions are normally kept in in stock by the glulam manufacturer. Lengths up to 12 m. More dimensions than those listed here may be kept in stock. Other lengths and cross-sections are manufactured to order (for straight elements, $h = n \times 45$ mm). Glulam beams can of course also be used as posts. See also *table 4 Range of glulam columns and beams manufactured in Sweden, in relevant strength classes, page 25*.

The stock range corresponds to the industry-wide range listed, with dimensions, grades and designations, at **www.traprodukter.se**.

Table 4 Range of glulam columns and beams manufactured in Sweden, in relevant strength classes

Width b (mm)	42	56	66	78	90	115	140	160	165	190	215
Height h (mm)											
90	GL28hs	GL28hs	GL28hs	GL28hs	**GL30h**	GL30h	GL30h		GL30h	GL30h	GL30h
115						**GL30h**	GL30h		GL30h	GL30h	GL30h
135	GL28hs	GL28hs	GL28hs	GL28hs	GL30h	GL30h	**GL30h**		GL30h	GL30h	GL30h
140							**GL30h**				
160								**GL30h**			
165									**GL30h**		
180	**GL28cs**	GL28cs	GL28cs	GL28cs	**GL30c**	**GL30c**	GL30c	GL30c	GL30c	GL30c	GL30c
225	**GL28cs**	**GL28cs**	GL28cs	GL28cs	**GL30c**	**GL30c**	**GL30c**		GL30c	GL30c	GL30c
270	**GL28cs**	**GL28cs**	**GL28cs**	GL28cs	**GL30c**	**GL30c**	**GL30c**		GL30c	GL30c	GL30c
315	GL28cs	GL28cs	**GL28cs**	GL28cs	**GL30c**	**GL30c**	**GL30c**		GL30c	GL30c	GL30c
360	GL28cs*	GL28cs	GL28cs	GL28cs	**GL30c**	**GL30c**	**GL30c**		GL30c	GL30c	GL30c
405	GL28cs*	GL28cs	GL28cs	GL28cs	**GL30c**	**GL30c**	**GL30c**		GL30c	GL30c	GL30c
450		GL28cs	GL28cs	GL28cs	**GL30c**	**GL30c**	GL30c		GL30c	GL30c	GL30c
495		GL28cs*	GL28cs	GL28cs	GL30c	**GL30c**	GL30c		GL30c	GL30c	GL30c
540		GL28cs*	GL28cs*	GL28cs	GL30c	GL30c	GL30c		GL30c	GL30c	GL30c
585			GL28cs*	GL28cs	GL30c	GL30c	GL30c		GL30c	GL30c	GL30c
630			GL28cs*	GL28cs*	GL30c	**GL30c**	GL30c		GL30c	GL30c	GL30c
675				GL28cs*	GL30c	GL30c	GL30c		GL30c	GL30c	GL30c
720				GL28cs*	GL30c	GL30c	GL30c		GL30c	GL30c	GL30c
765				GL28cs*	GL30c	GL30c	GL30c		GL30c	GL30c	GL30c
810					GL30c	GL30c	GL30c		GL30c	GL30c	GL30c
855					GL30c	GL30c	GL30c		GL30c	GL30c	GL30c
900					GL30c	GL30c	GL30c		GL30c	GL30c	GL30c
945						GL30c	GL30c		GL30c	GL30c	GL30c
990						GL30c	GL30c		GL30c	GL30c	GL30c
1,035						GL30c	GL30c		GL30c	GL30c	GL30c
1,080						GL30c	GL30c		GL30c	GL30c	GL30c
1,125						GL30c	GL30c		GL30c	GL30c	GL30c
1,170							GL30c		GL30c	GL30c	GL30c
1,215							GL30c		GL30c	GL30c	GL30c
1,260							GL30c		GL30c	GL30c	GL30c
1,305							GL30c		GL30c	GL30c	GL30c
1,350							GL30c		GL30c	GL30c	GL30c
1,395							GL30c		GL30c	GL30c	GL30c
1,440									GL30c	GL30c	GL30c
1,485									GL30c	GL30c	GL30c
1,530									GL30c	GL30c	GL30c
1,575									GL30c	GL30c	GL30c
1,620									GL30c	GL30c	GL30c

Bold = Stock range of glulam columns and beams made in Sweden.

* Split glulam in strength classes GL28cs and GL28hs must have a height/width ratio h/b ≤ 8/1.
However, if a split glulam beam with a height/width ratio h/b > 8 meets any strength requirements, the height of the glulam beam may be increased with the same width if desired (although for practical reasons a maximum height/width ratio h/b = 10 is recommended).
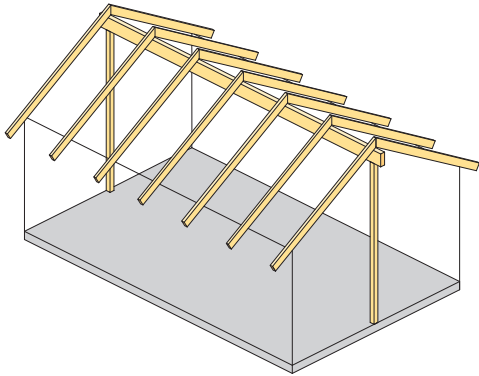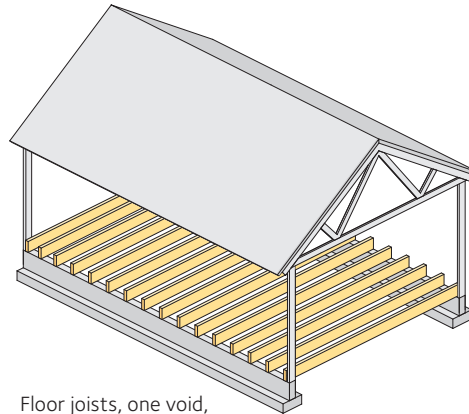
Key:
h = homogeneous glulam,
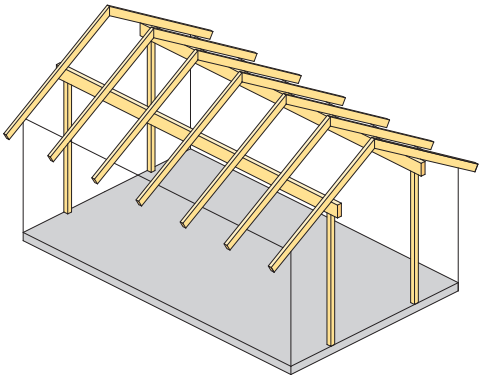c = combined glulam,
s = split glulam.

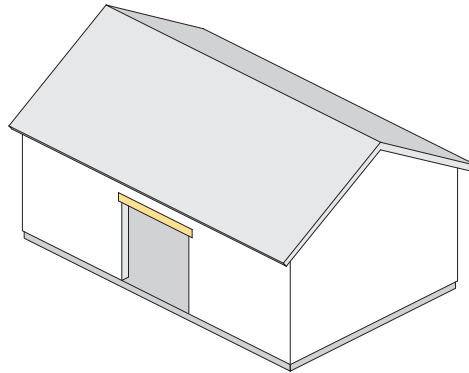## Examples: Use of glulam posts and beams in a small house

Ridge beam, longitudinal, two support posts.
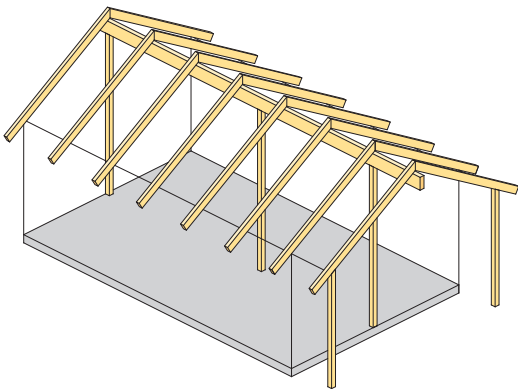Rafters, transverse, two supports.
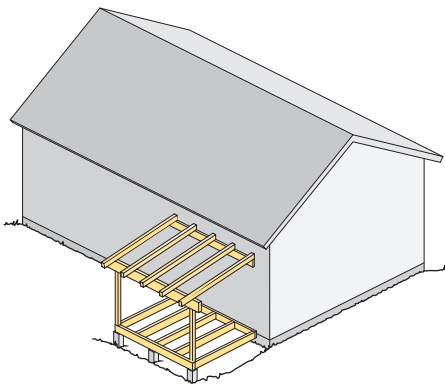

Floor joists, one void,
two supports.

Purlins, two longitudinal, two support posts.
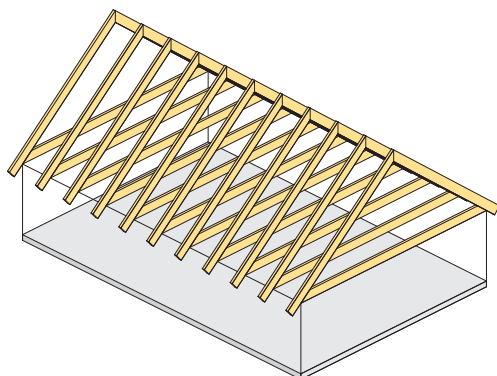Rafters, transverse, two supports.

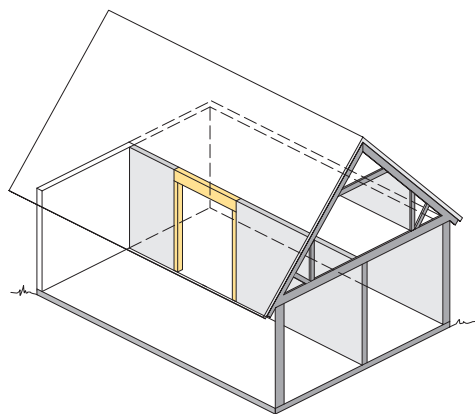Lintel over door or window opening in external wall.

Ridge beam, longitudinal, three support posts.
Rafters, transverse, two supports.
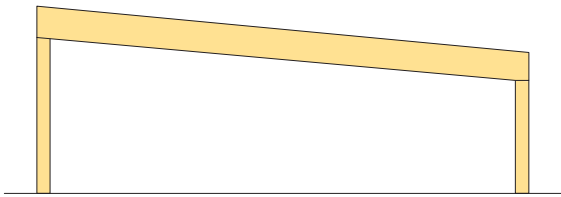

Terrace – roof joists, floor joists, binders and posts.

Roof trusses in 1 ½-storey house – upper and
lower frames.

Lintel over opening in core wall.

Examples: Use of glulam in larger buildings – range of spans

Straight beams on columns 10 – 30 m.
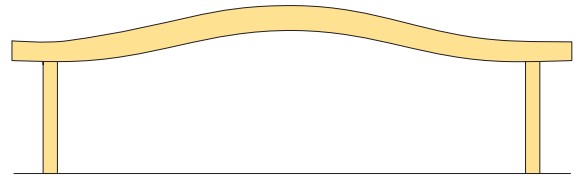
Curved beams 10 – 20 m.
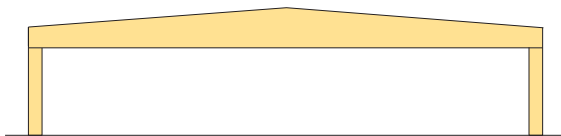
Double pitched beams on columns 10 – 30 m.
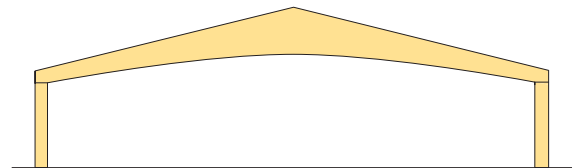
Pitched cambered beams on columns 10 – 20 m.
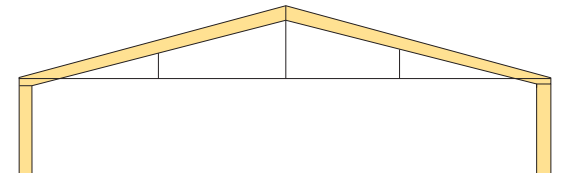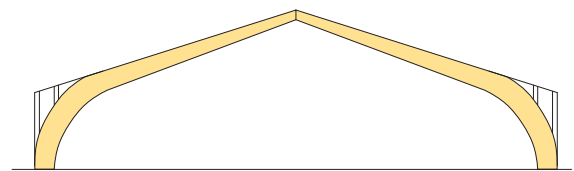

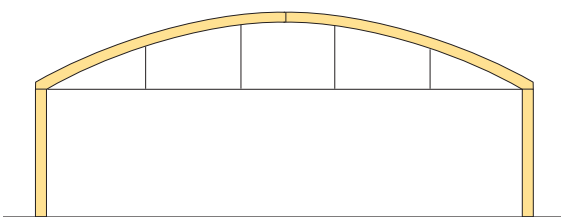Three-pin trusses with tie on columns 15 – 50 m.
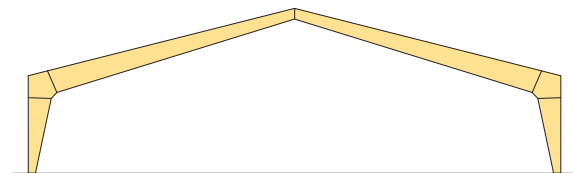
Three-pin portal frames with finger jointed haunches 15 – 25 m.
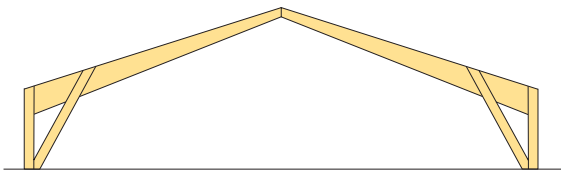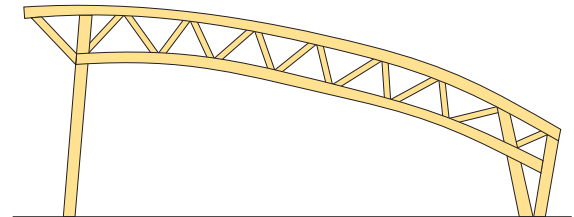

Three-pin portal frames of a composite type 10 – 35 m.

Three-pin portal frames with curved haunches 15 – 40 m.

Three-pin arches on columns 20 – 60 m.

Trusses 30 – 85 m (straight or curved).

Curved glulam members

Curved glulam elements are used in portal frames or arch structures but also as curved beams, for example pitched cambered beams.

When possible curved glulam elements should be made with constant cross-sectional height within curved parts in the form of arches or portal frames. Pitched cambered beams and portal frames with curved haunches can be made with eaves lathes or, if the appearance so requires, with glued, loose nailed on, or screwed on ridge or haunches.
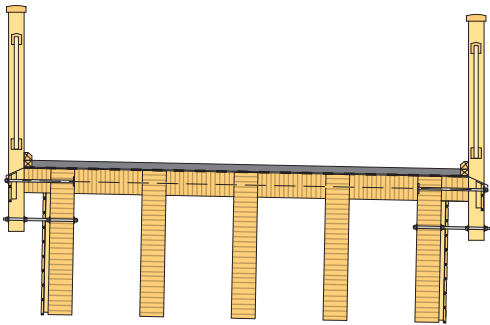
The lamella thickness for curved members is normally 33 mm, but for a curved radius of less than 7 m, thinner lamellas are required.

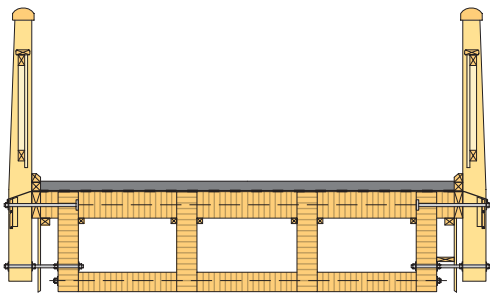# Examples: Use of glulam for timber bridges – range of spans
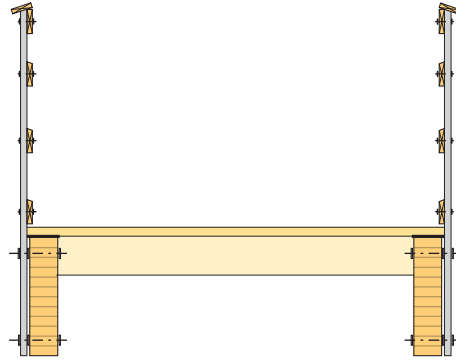
Pedestrian bridges and bridges for cyclists
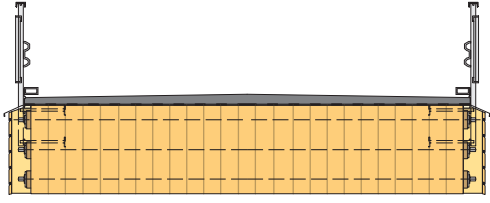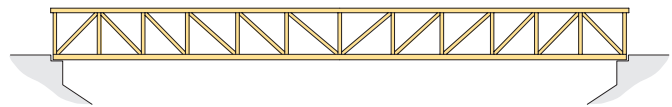
Transverse tension plate ≤ 20 m
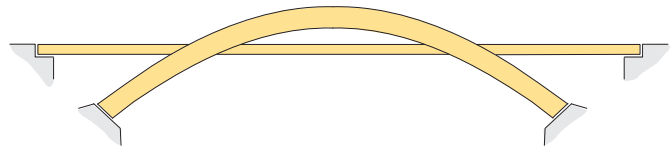
T-beam bridge ≤ 30 m
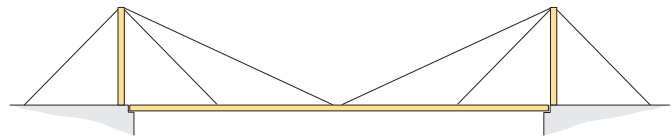
Box girder bridge ≤ 30 m

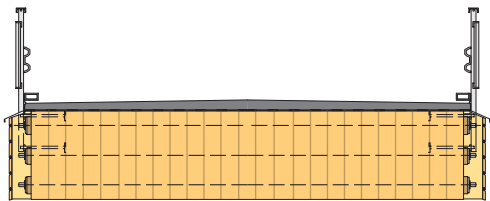Beam bridge ≤ 20 m

Truss bridge 25 – 40 m
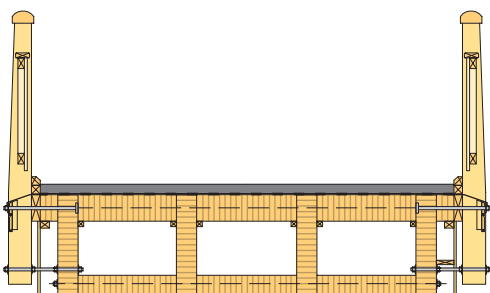
Arch bridge 25 – 60 m
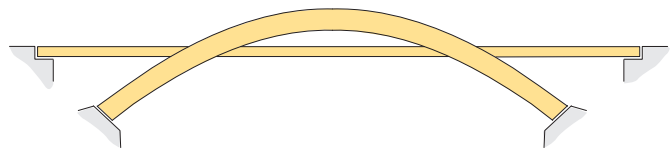
Pylon bridge 40 – 100 m

Road bridges

Transverse tension plate ≤ 20 m

Box girder bridge ≤ 20 m

Arch bridge 25 – 50 m

Transport protection

The glulam elements are wrapped at the manufacturers, usually individually, and with environmentally friendly material. The packaging is designed to protect against moisture, precipitation, UV-light, dirt and a certain amount of mechanical damage during transport, storage and possibly in connection with erection.

On receipt of a glulam delivery the person who accepts the delivery is responsible for ensuring that the glulam products are stored in a proper way. This can, for example, mean that the packaging must be opened in order to prevent condensation, or so that water from condensation that has already resulted is able to pour out of the package. The recipient is to make sure that the glulam products are stored well in stacks and protected from ground dampness, precipitation, dirt and radiation from the sun. Long-term storage on the building site should be avoided, *see further under section Handling glulam correctly, page 78*. Upon receipt, the moisture content is checked using an electrical resistance moisture meter with insulated hammer electrodes to ensure that it corresponds to the ordered target moisture content.

Erection

The erection of glulam structures almost always requires availability of some form of lifting appliance, as a rule a mobile crane. Lifting the glulam members directly from the lorry to their place in the building is ideal. However, this is seldom possible and as a rule a certain period of storage on the building site can be expected. Therefore the instructions provided by the supplier should be followed.

On receipt of the delivery, check that the number of glulam elements and fittings matches the order, *see also the section Handling glulam correctly, page 78*.

It is important that the erection has been planned before the glulam units are taken from the transport vehicle so that time-consuming reloading can be avoided. If a special loading order is required this must be clearly specified when ordering. Clear and systematic marking of individual glulam elements and fittings is also decisive for a rational erection.

Until the building's permanent stabilizing system is complete, temporary measures must be taken to secure the structure against wind and other actions during the time of construction. Portal frame and arch structures are best secured with steel wires, which are fastened with rigging screws. Steel wires are also used to fix the structures in the correct position until the wind bracers or equivalent are mounted.

Plastic wrapping must be opened underneath in order to prevent moisture inside the plastic. The packaging can also be taken off completely, but then one should be aware of the risk of the visible structure becoming soiled during the erection time. Especially at risk are roof structures with high profiled steel sheeting directly on the roof beams, where water leaks in the steel sheet joints will soil the beam sides before the insulation and cardboard cover are in place.

Three-pin portal frames and arches consist of two parts, which are connected to the concrete foundation or columns and are connected together with steel fittings in the ridge. Larger structures are assembled most easily and safely with the aid of a mobile crane and a movable assembly tower under the ridge. For the erection each frame-half or arch-half is lifted into place with a mobile crane. The frame base should be secured to the base fitting or column top and the ridge section is placed on the assembly tower and is joined to the other frame-half. As soon as the stabilizing is complete the assembly tower can be moved to the next line.

Glulam arches with glulam gable posts and purlins.

Planning

Library with glulam roof beams on concrete posts.

This second main part of *The Glulam Handbook Volume 1* contains the foundation for the planning of structures and premises where glulam is included. The planner needs to know the possibilities and limitations of glulam products at an early stage in the planning. The building technical conditions for good architecture are dealt with and the most common structural systems are presented here.

In this section there is also guidance on the possibilities and limitations of using glulam. Examples of optimal constructional solutions with glulam are given in the section *Structural Systems, page 38*.

The required preliminary dimensions are presented in tables on pages 46 – 51, under the section *Dimension tables*. Tabulated values are meant to be used at an early stage of the planning and cannot replace structural calculations in each individual case. As an aid for more thorough calculations, *see The Glulam Handbook Volume 2 and Volume 3*.

Glulam is often used as a load bearing structure in larger one-storey buildings, for example halls, while the European fire regulations make it possible to use timber structures even in multi-storey buildings. It is important for the planner to be aware that the fire regulations do not limit the usage of glulam, *see section Design with regard to fire, page 62*.

An important area within the planning work is colouration and surface treatment. Glulam's natural colour is often used as an intended part of the design. Different surface treatments can give several alternative effects. In some cases the glulam must be surface treated for technical reasons, or even be impregnated. These questions are dealt with in a special section that, among other things, gives the basis for a technical description, *see from page 69*.

Questions on durability have in recent times had greater importance. Knowledge of the material and being aware of its maintenance needs even during the planning stage is important in order to achieve the optimal technical solution. No material is maintenance free but the maintenance can be more or less demanding, *see section Surface treatment and maintenance, page 69*.

Structural conditions

Few structural materials can match glulam when it comes to structural and architectural expression.

The timber logs provide the limitations for the dimensions of structural timber. Gluing technique on the other hand, provides the opportunity to manufacture thick, wide and very long structural members, for example beams with a width of up to 240 mm (215 mm in Sweden) and a height of up to 2 m depending on the manufacturer's equipment. Besides straight units, curved units can be manufactured in different shapes.

Structural members of glulam can take greater stresses than structural timber with the same dimension. This ties in with the so-called laminating effect: "The risk that weakening qualities will be oriented in the same section are obviously less in a timber section that consists of several glued laminations". *See section Facts about glulam, page 15*.

Traditional timber building technology, like sawing, planing, nailing, screwing and use of building fittings etc. is used to advantage and with simplicity together with glulam. Glulam is included as a natural component in timber building technology.

The costs of glulam components can be reduced with increased structural height. The effective height means the distance in the cross-section between the resultant of compression stresses and the resultant of tension stresses, *see figure 18*.

In common with wider timber building technology, glulam technology increasingly makes use of steel fittings. In the older timber building technology the joints were normally shaped to transfer compressing stress and could only transfer traction to a limited extent.

Steel joints transfer forces in a more concentrated and defined way than was possible earlier. A pin, that is to say a joining of two structural members without moment absorbing capacity, can in reality be shaped as a pin.

A pin should always be placed in the system lines' crossing point in order to avoid torque in the connecting point. System lines should thus cross one another in one point — the pin-point, *see figure 19*.

Statically undetermined systems can give rise to compulsive forces. By the use of pins, the statically indefinite system can be made statically definite, that is to say natural for structural design. A two-pinned arch for example is statically indefinite, while a three-pin arch is statically determined, *see figure 20*.

The design of steel fittings is often connected with structural limitations, as for example contact pressure between steel and glulam.

It is possible to design recessed or surface mounted fittings that function as pins or that can transfer moment. Examples of connections are:

- Foundation details.
- Supporting details, like the joining of column to beam or beam to beam.
- Connecting points, that is to say joint and joining together of glulam members or tension rods, which meet at a point.
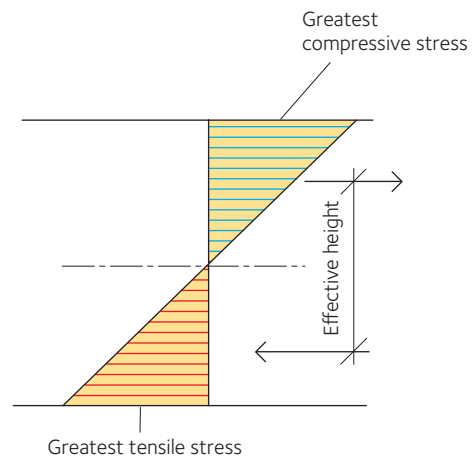

Figure 18 The effective height is the distance between the resultant compression stresses and the resultant tension stresses
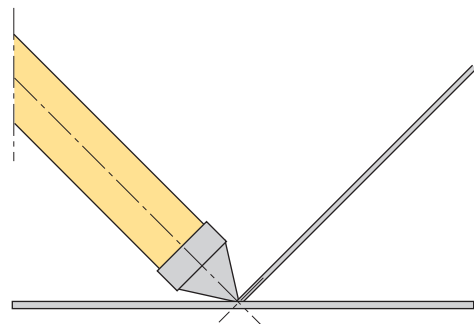
Figure 19 The system lines should preferably meet in one point – otherwise moment will occur in the connecting point
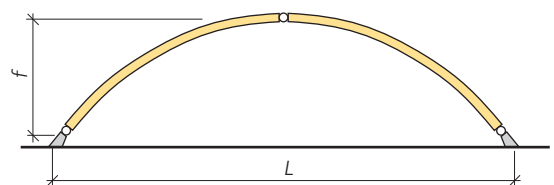
Figure 20 Three-pin arch – a statically determined structure

Table 5 Size designations
The following designations are used in this section:

Designation	Description
L	Span
b	Beam width
h	Beam height/depth
q	Load
f	Arrow height
M	Bending moment
V	Shear force
σ	Tension
d	Hole diameter
W	Moment of resistance
H	Maximum height of pitched beam
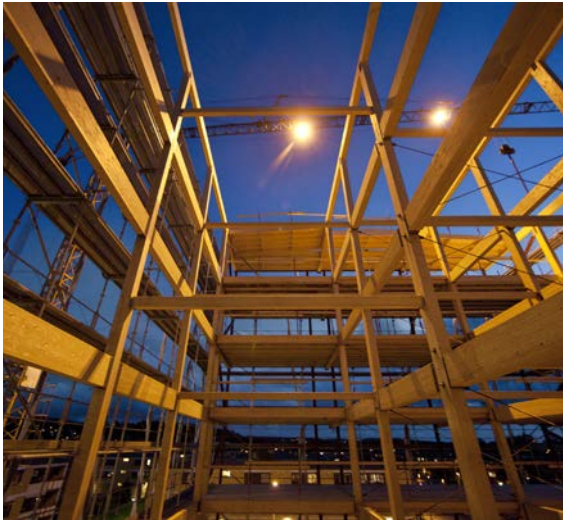
Although there are standard fittings like nailing plates, angular fittings, hangers and strip steel on the market, normally capacities and glulam sizes are so great that steel details are better designed for manufacture in a blacksmith's workshop. Steel details often provide character for a structure and should be given special attention. There are also solutions with hidden fasteners.

Often glulam structures are naturally visible as they are a part of the architecture. Glulam retains its load bearing capacity even at an early stage of a fire sequence. The protective carbon layer that forms on the surface, contributes to this. Demands in relation to the fire protection of the steel details must be adhered to. A hidden, inbuilt fastener is better fire protected than a surface mounted one, *see further under section Design with regard to fire, page 62*.

The choice of structural system cannot be decided without considering the system's details solution. In this context it is natural to point out that the planner should influence and perhaps spend much time considering the design of the visible steel details.

In the planning process, early sketches normally provide information on the functional and geometric conditions and possible span widths for good design of the structural elements.

Collaboration at an early stage between architect and structural engineer makes for good solutions.

Structural aspects of glulam structures

The most common building part where glulam comes into its own is the roof structure. Roof covering material is often roof felt, roof sheet metal or roof tiles on different bases, which can be roof felt on timber boards, laminated veneer lumber or plywood panels, stiff insulating sheets on profiled sheet metal or reinforced, self-bearing and heat insulated wood-wool elements. Secondary beams, which can be of glulam, normally have a centre-distance 1.2 m for timber boards or plywood, 2.0 m or 2.4 m for wood-wool elements or 2 to 7 m with profiled roof sheet metal. The secondary beams are supported by the primary load-bearing glulam structure. Naturally glulam can be combined with other structural materials, for example steel or concrete.

Below are a few examples of structural considerations that can be included at an early stage of the planning process. Some of the basic terms and simple formulas for strength that should be taken into account are presented here.

Beams

For the structural design of beams, the total load q (in which is included the structure's self-weight and surface loads like snow and so on) should be calculated. Self-weight, snow + any imposed loads are the design loads. Safety factors and other partial coefficients must be taken into consideration according to current Boverket's (the Swedish National Board of Housing, Building and Planning) Application of the European construction standards, EKS.

A common approach to determining initial design values is trial and error. Suppose you test a simply supported beam of width b and height h on two supports with an evenly distributed load, as shown in *figure 21*.
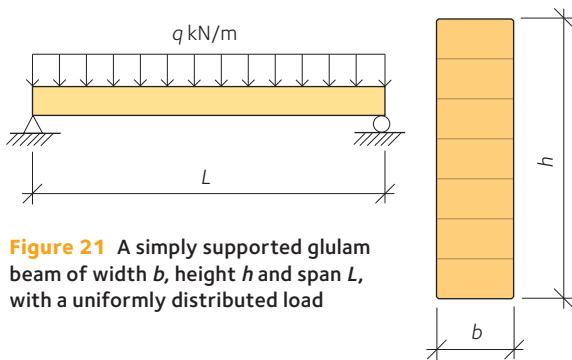
Six-storey residential building with glulam frame.

Figure 21 A simply supported glulam beam of width *b,* height *h* and span *L,* with a uniformly distributed load

The beam is exposed to an outer moment $M = q \times L^2/8$. That moment shall be carried by the beam by building up an inner, resisting moment M_i = bending stress σ_k × beam's bending moment resistance $W = b \times h^2/6$. The bending stress σ_k is equivalent to the characteristic bending strength value according to Eurocode 5. The bending strength in a beam increases thus by the square of the height, *see figure 22*. A width increase gives only a linear increase of the bending moment resistance W.

Suppose the tested beam proves to have insufficient load bearing capacity. In other words the bending moment resistance W must be increased. The examples below illustrate how that can happen:

- As the cost of a glulam beam usually can be related to volume, so an increase in the effective height reduces the beam cost compared to an increase in width.
- There can be other aspects in a project that are affected by an increased beam height. Perhaps the whole building needs to be raised in order to maintain free height under the beams with increased costs for façades, heating etc. as a result.
- Normally the deformation requirement, usually the largest allowed deflection, governs the lowest construction height. Typical limiting values for deflection are given in *The Glulam Handbook Part 2*.
- Another easier way is to use dimension tables, *see section Dimension tables, page 46*.

Installations make up a considerable part of the function and affect the architectural experience. One question, which often comes up is if it is possible to make holes and notches in glulam members.

The whole glulam beam's cross-sectional area contributes to taking current transverse forces, which are largest at the supports. Therefore it is not normally suitable to have a hole or recesses adjacent to the supports. Tension distribution in the beam of outer moment is illustrated in *figure 25*. The inner parts of the beam are less exposed to bending stresses than the outer ones, along the top and bottom edges. The above argument expresses the general principle. On individual projects, the structural engineer can give instructions on feasible holes and notches. Smaller holes are generally acceptable, as shown in *figure 24*.
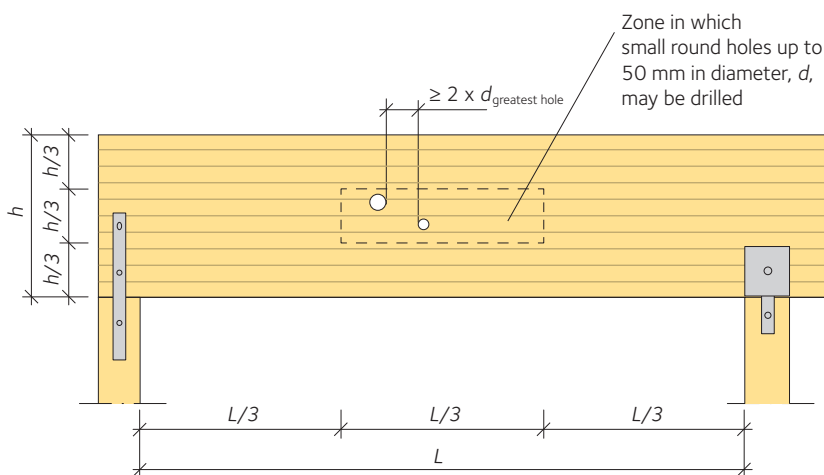

Figure 22 The strength of a glulam beam increases by the square of the height

$2 \times b => 2W$

$2 \times h => 4W$
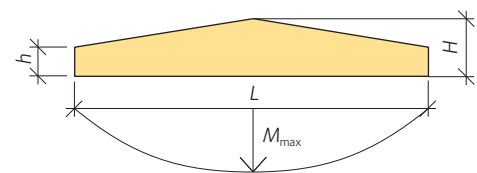
Figure 23 A double-pitched beam, freely supported, follows in principle the moment curve. It is therefore more economical than a straight, equally high beam.

Zone in which small round holes up to 50 mm in diameter, d, may be drilled

$\geq 2 \times d_{\text{greatest hole}}$

Figure 24 Holes in glulam beams should be handled with great care. Within the region above, some small holes could be accepted after confirmation from the structural engineer. Further information about holes in glulam beams, *see The Glulam Handbook Volume 2.*
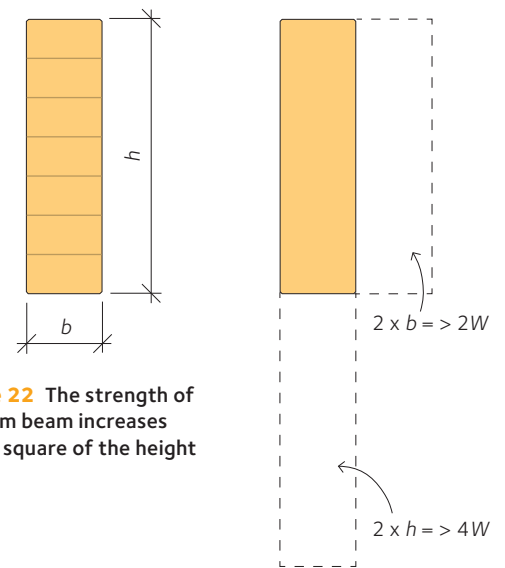

$q\,\text{kN/m}$

L

$M_{\text{max}} = \dfrac{qL^2}{8}$

$V_{\text{max}} = \dfrac{qL}{2}$

Figure 25 External moments and shear forces for a simply supported beam under a uniformly distributed load q.

Figure 26 Arches permit an effective utilization of material, but require either fixed supports or tension rods

a) Glulam beam

b) Glulam arch

Figure 27 The tensions in a loaded beam are distributed like this: Pressure tensions and tensile tensions. The tension in the middle of the beam's cross–section is 0. An arch, as opposed to a beam, can take pressure tensions through the whole cross–section.
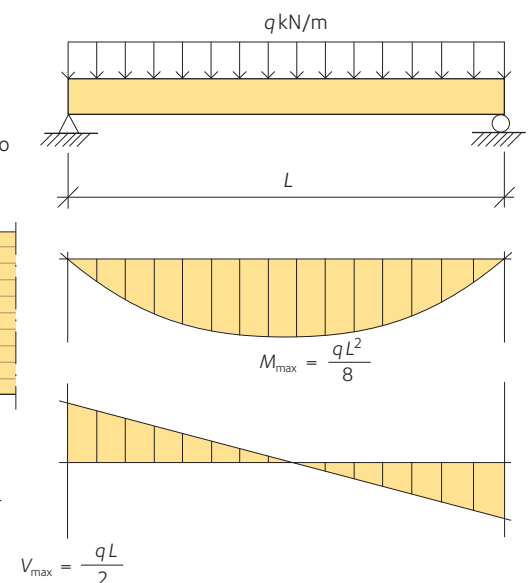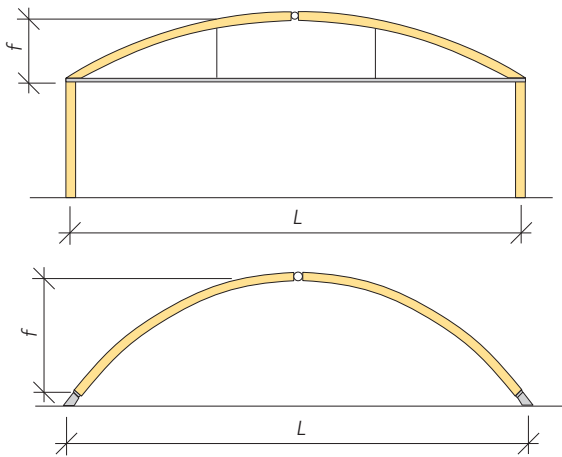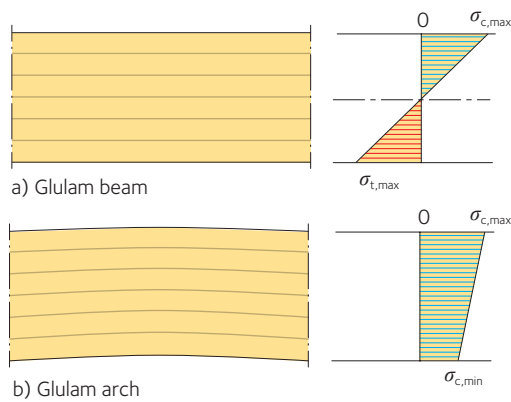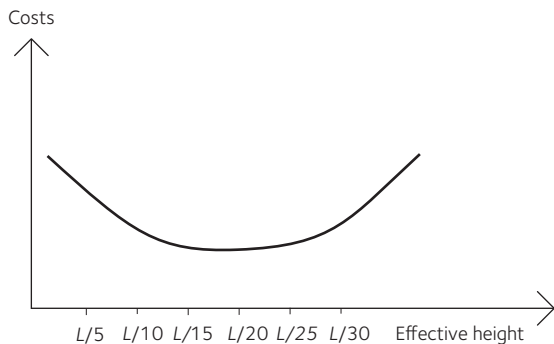

Figure 28 For roof structures the effective height of between $L/15$ and $L/20$ is often cost–effective

Arches

In order to manage large spans, arches of glulam can be used. An arch functions at its very best if it can follow the so-called pressure line, that is to say the line where the cross-section is exposed to constant compression stress over the whole cross-section. The difference between a beam's and an arch's performance is illustrated in *figure 27*. Through the material being better utilized in an arch, the height of the cross-section can be made lower, about $L/50$ or roughly 1/3 of the equivalent beam height.

An arch requires fixed supports, which can need another foundation construction or consist of tension rods. By fixed supports is meant supports that can take up horizontal forces. Tension rods can be placed invisibly or under the floor construction in a hall building.

Trusses

With more complex glulam components, like trusses and beams with tension rods, more comprehensive planning work is required for the design of details.

The architect should play a part in the design of these glulam elements. Today there are companies who work with customized steel fittings, such as tension rods and jointing points.

The installations can in many cases be localized near the upper members, over the lower tension rods, which do not need to be seen as obstacles in the room. The room design can be felt as following the upper members and the inside of the insulated roof construction. Compressed bars are formed of glulam where the whole cross-section is utilized, while tensioned bars can be of structural steel.

The effective height is the distance between the system lines of lower and upper member. Here the planners often have great freedom to vary the effective height.

As an under-tensioned beam structure of glulam is mainly exposed to pressure forces and thereby is better utilized, the amount of glulam used is less than for a pure glulam beam. In return there are additional costs for the under-tensioned steel details, *see figure 30*.

With increased effective height for a structure there is an equivalent decrease in the pressure and tension forces. The product of the pressure forces × effective height = tension forces × effective height = the moment capacity. Special checks should be carried out to ensure the transverse force's capacity is sufficient at the supports.

With trusses, under-tensioned beams and three-pin roof trusses, portal frames and arches can increase the effective height and thereby provide a more optimal material usage.

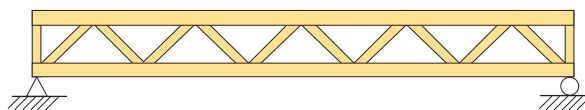Special measures to ensure the load capacity and fire safety can be necessary.

Figure 29 Trusses consist of different bars, which form a connected structural section

Figure 30 Examples of under–tensioned beam

Columns

Columns of glulam normally have good load bearing capacity. A cantilever, which is not supported at the upper end, has a buckling length that is roughly double the column height. For a normal column, a so-called pendulum column, which is a pin attached at the top and bottom, buckling length = column height is applicable.

Generally house design creates natural opportunities to support the column at the top, for example through a connecting roof structure. With low buildings, up to 3 – 4 m high, it is normally economical to fix the column in the foundation construction in order to manage load bearing capacity and stability. The foundation construction must then be designed for the performing moments. For greater heights, the most economic way normally is to mount diagonal braces or so-called wind braces. The columns can be designed as tapered towards the supports, which are organized so that the forces are centralized.

Bracing of glulam structures

Wind loads from the façades are transferred through the roof structure to wind braces placed on the roof's floor and normally near the ends and along the façades. The forces from the wind bracing in the roof are transferred through the vertical wind bracing down to the foundations. Some examples are shown below.

Figure 31 Principle design of reducing the buckling length and thereby column size is to design free-standing columns with pressure rods

Pressure rods

Tension rods

Stabilising corrugated metal or LVL roof panels as an alternative to wind trusses.
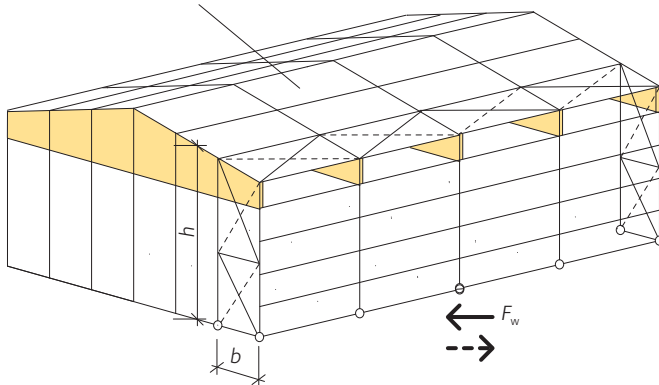
Figure 32 Stabilising glulam frame with wind trusses and wind braces for wind loads on the long side. Illustration of principle.
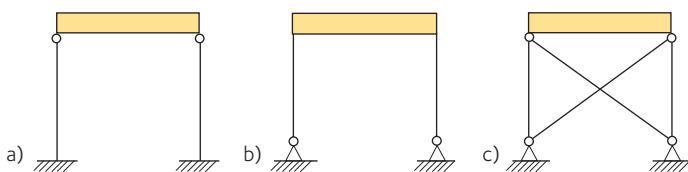
Figure 33 Examples of structures, which are stable:
a) Rigidly fixed cantilever of column feet; a pinned connection between beam and column.
b) Pinned cantilevering of column feet; rigidly fixed cantilevering between beam and column.
c) Pinned attachments of column feet and column top; diagonal braces of steel or timber.

Figure 34 Examples of devices of wind bracing for portal frame and arch structures. A further description of how the bracing of glulam structures are suitably designed is in *The Glulam Handbook Volume 2.*

Figure 35 Principle design of profile sheet material or roof tiles on felt covered tongued and grooved timber boards, insulation, rafters and ridge beam of glulam

Building envelope

The roof, with its heat insulation, is best placed above the primary beams of glulam in order to make these visible. Glulam as the main load bearing structure in the roof is often combined with some of the following alternative principle solutions:

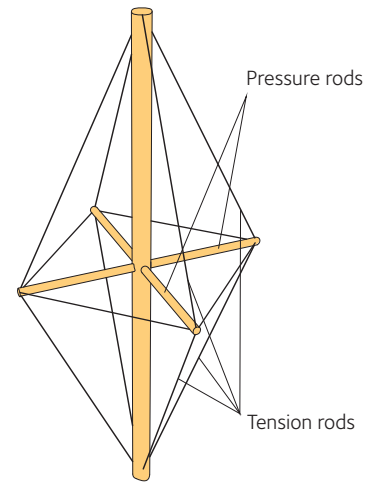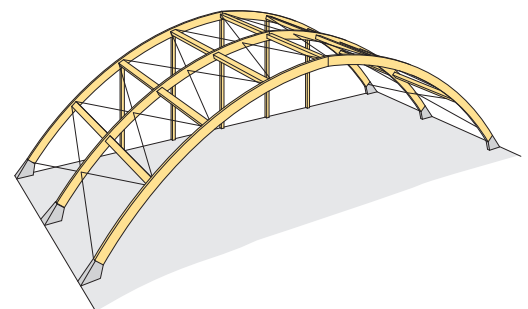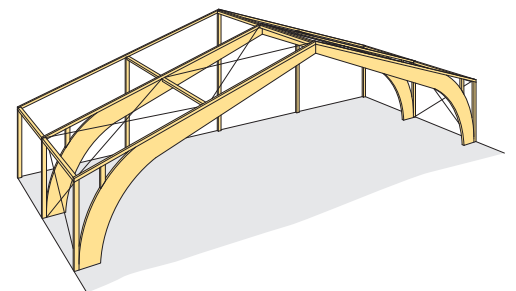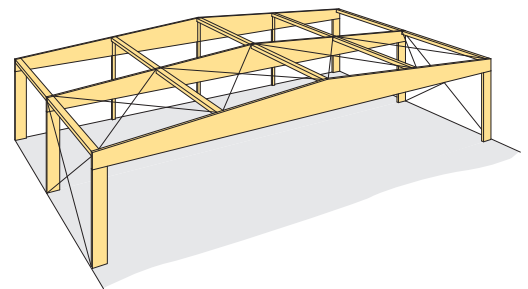- Simple glulam roof beams. Glulam purlins with insulation in between. Felt or sheet metal roofing.
- Glulam ridge beam. Roofing on simple glulam roof beams with insulation in between.
- Simple glulam roof beams. Reinforced wood wool element. Extra expanded foam insulation. Felt or sheet metal roofing.
- Simple glulam roof beams. Box profile sheet metal. Insulation such as hard mineral wool boards. Felt or sheet metal roofing.
- Glulam roof trusses. Roof tiles on sheathing, with or without insulation and internal cladding.

Figure 36 Principle design of a roof structure with reinforced load-bearing wood-wool elements above glulam beams
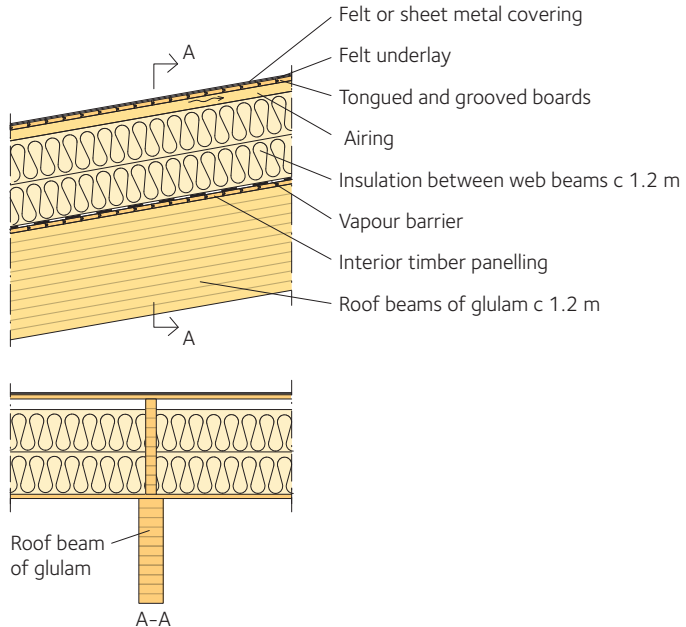
Figure 38 Principle design of a roof structure with heat insulation between roof beams above visible glulam roof beams.
Note the importance of the correct design of different details, such as ventilation.
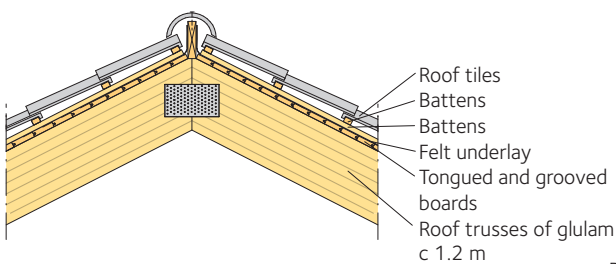
Figure 37 Principle design of a roof structure with thermal insulation on load bearing profile sheet metal and roof beams of glulam
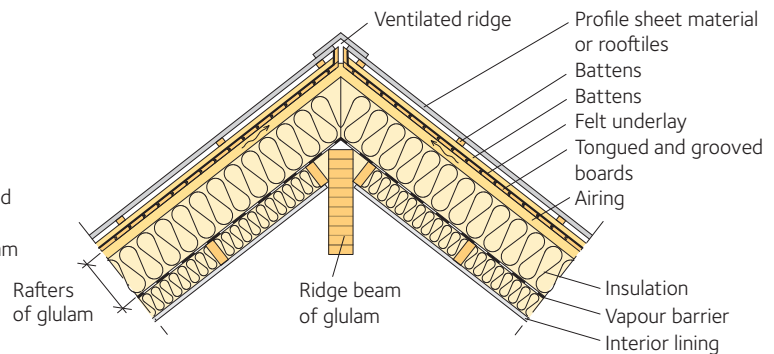
Figure 39 Principle design of roof trusses of glulam with underlay of felt covered, tongued and grooved timber boards or plywood for roof tiles

Moisture protection

Glulam should be protected against the long-term affects of damp. Shown below are some principle examples of moisture protection. *See also the section Connection details, page 53.*
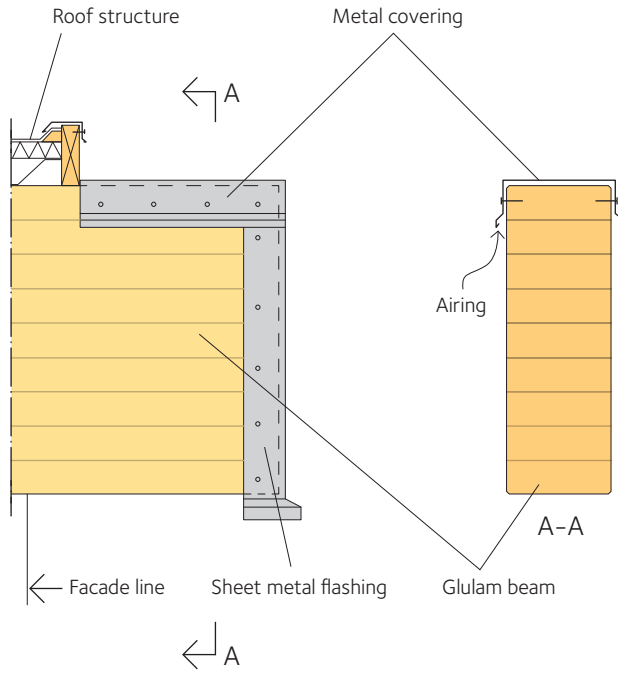
Figure 40 **Moisture protection of an external cantilevering glulam beam**
Sheet metal covering on top surface and endgrain.
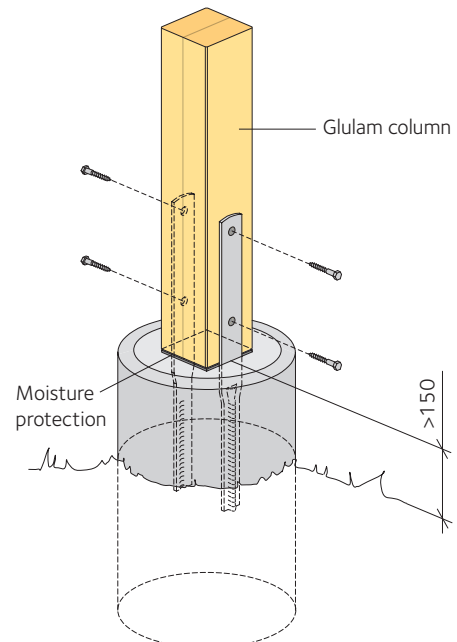
Figure 41 **Column foot outdoors**
Sheet metal and moisture protection membrane between glulam and concrete. Small loads.
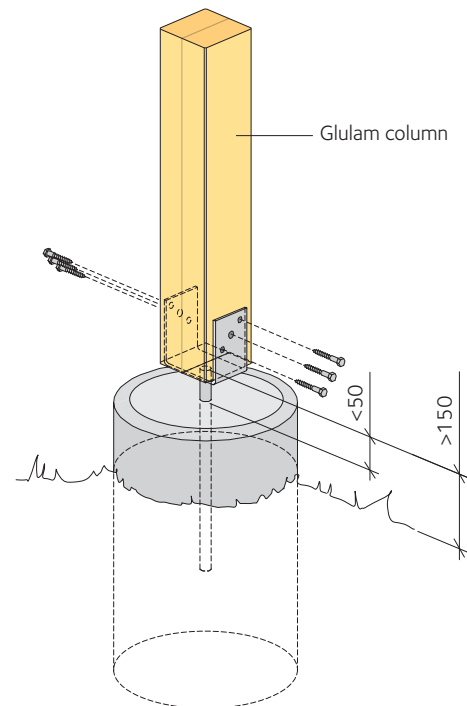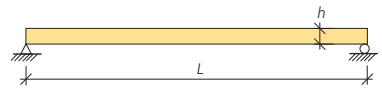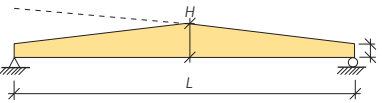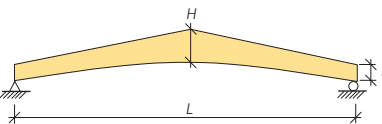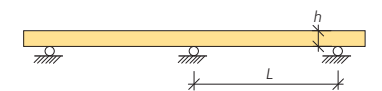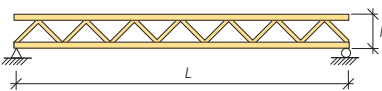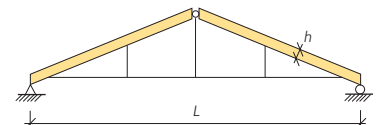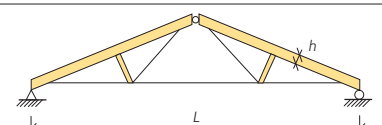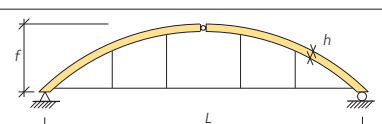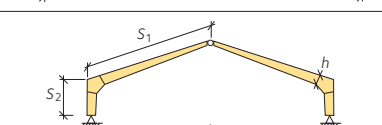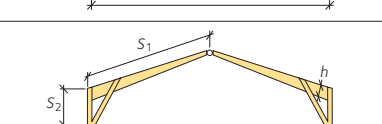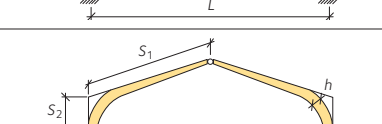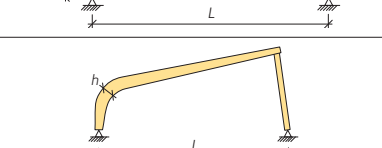
Figure 42 **Column foot outdoors**
Post shoe made of hot-dip galvanised steel. The glulam post is not in direct contact with the concrete. Small loads.

Structural systems

In this section some different ways to design glulam structures are described for general plans of hall buildings — from simple systems with columns and beams to portal frame, arch and shell structures, which all in different ways and to varying degrees use the possibilities of the glulam technique.

Table 6 Structural systems – an overview
Structure's c/c spacing is approximately 6 m. Suitable span ranges and approximate cross-sectional height of the glulam elements.

System	Name	Roof pitch	Span L	Height h
	Straight beam on two supports	$\geq 3°$	< 30	$L/17$
	Double pitched beam on two supports; single pitched beam	$3 - 10°$	$10 - 30$	$h \approx L/30$ $H \approx L/16$
	Pitched cambered beam on two supports	$3 - 15°$	$10 - 20$	$h \approx L/30$ $H \approx L/16$
	Continuous beam on two supports	$\geq 3°$	< 25	$L/20$
	Truss on two supports	$\geq 3°$	$30 - 85$	$L/10$
	Three-pin roof truss with or without tie	$\geq 14°$	$15 - 50$	$L/30$
	Three-pin roof truss with tie and trussed beams	$\geq 14°$	$20 - 100$	$L/40$
	Three-pin arch with or without tie	$f/L \geq 0.144$	$20 - 100$	$L/50$
	Three-pin portal frame with finger-jointed haunches	$\geq 14°$	$15 - 25$	$(S_1 + S_2)/13$
	Knee braced portal frame	$\geq 14°$	$10 - 35$	$(S_1 + S_2)/15$
	Three-pin portal frame with curved haunches	$\geq 14°$	$15 - 40$	$(S_1 + S_2)/15$
	Half portal frame with pinned columns	$\geq 20°$	$10 - 25$	$L/25$

Beam to column system

In its simplest and most common form the structure consists of freely supported beams on columns. For small spans, equally high beams are most often preferred, while for greater spans it can be more economic to let the cross-sectional height vary with the forces in the beam. An example of this is the double-pitched beam, which is given the largest cross-sectional height in the middle where the bending moment is greatest.

Beams are often designed with a straight underside, but they can also be curved to a greater or lesser extent for aesthetic or functional reasons. A normal form is the so-called pitched cambered beam — a double-pitched beam with a curved underside.

Glulam in multi–storey buildings

Because of revised regulations for building structures, it has been possible to build timber buildings of more than two storeys in Europe for several years. The national regulations can be different. Meanwhile experiences of existing multi-storey timber buildings have been positive. High degrees of prefabricated components like frames, outer roof, façade, beams and floor sections are under major development and can shorten building time and thereby minimize building costs.

The load bearing frames in multi-storey timber houses can consist of glulam members or cross-laminated timber panels (CLT). Glulam members can be columns and beams, while floor and façade sections can be made of panels of cross-laminated timber, *see example in figure 44*.

There are system solutions for several multi-storey timber buildings with prefabricated components of glulam in the form of columns as tall as the building, which support floor beams or beams and floor sections. Columns are best placed in the façade. Floor beams and floor members can then simply be consoled out from the façade wall so that oriels, balconies and access balconies can be made in a natural way.

The stabilization in a multi-storey glulam structure is managed with the aid of sheet material or surface sections, for example panels of cross-laminated timber. A timber structure makes dry building possible by mounting the outer roof directly after the erection, which is done relatively quickly. Sections for the beams, joists and façades can then be mounted weather protected.

Columns and beams of glulam can be totally separate from the building envelope, and the lack of load bearing walls makes highly flexibility layouts possible. A glulam frame is assembled using wood screws or coach bolts and steel fittings, allowing for easy disassembly and possible reassembly elsewhere. Moreover, such a building can be adapted to different needs and to changing future needs.

Multi-storey timber buildings have good fire protective qualities. One can consider whether to add active fire protection to the building with a residential sprinkler system. The local fire authorities should be consulted. There are designs that meet the fire safety and acoustic requirements for partition walls and floors between apartments by a wide margin.

The low weight of a timber building makes for a relatively simple foundation. For narrow multi-storey timber buildings the risk of tilting must be accounted for.

Straight beam on posts

Pitched beam on posts

Boomerang beam on posts
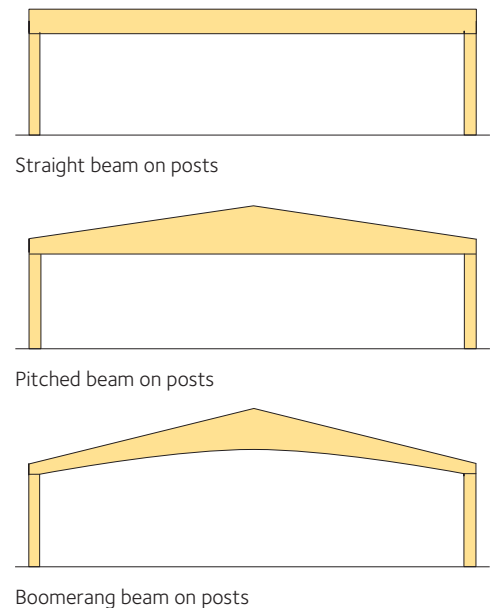
Figure 43 Beam – column system
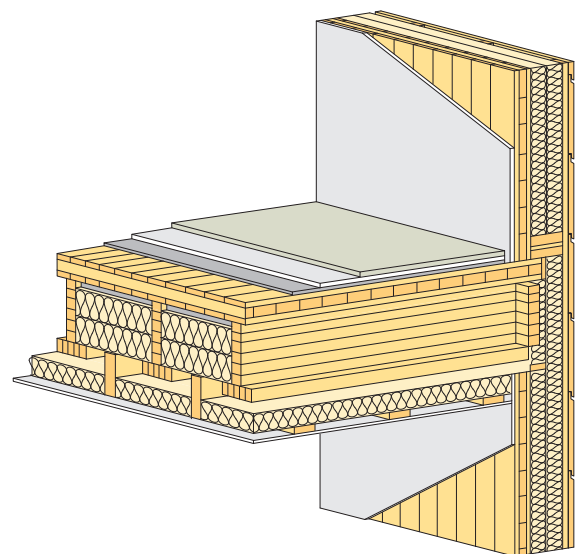
Figure 44 Example of structure in an apartment building
The floor system above with glulam load–bearing beams meets the requirements for structures that separate apartments. External wall in cross–laminated timber (CLT) with external thermal insulation. Design principle.
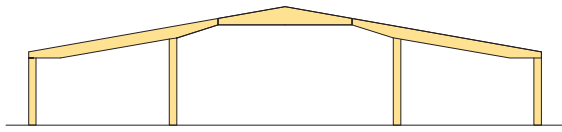
Optimised beams with overhang and inset pitched beam

Figure 45 **Continuous beam using the Gerber system**
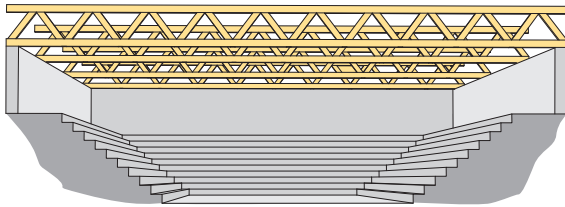
Trusses

Figure 46 **Trusses**
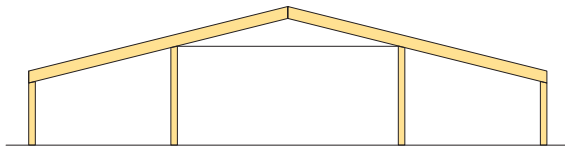
Three–pin roof truss
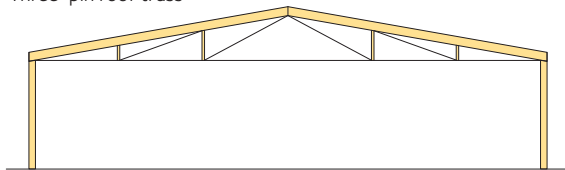
Three–pin truss with steel ties

Figure 47 **Three–pin roof trusses**
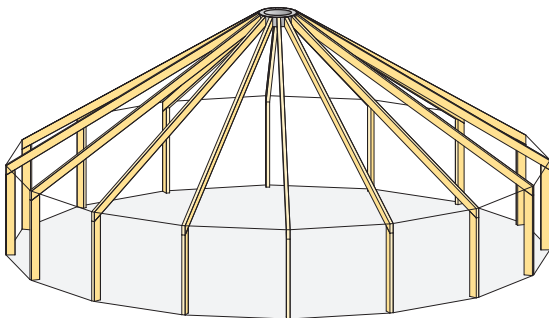
Space load–bearing structure with steel outer tension ring

Figure 48 **Space load–bearing structure**

Prefabricated buildings with industrially manufactured components are a rational way to build — just in time-deliveries eliminate on-site storage and direct erection gives a shorter erection process.

Continuous beams

Beams on several supports or beams with cantileverage permit more effective material usage than that which can be achieved with freely placed double supported beams. Continuous beams are implemented with the advantage of the so-called cantilever system. The joints are then created as pins (of the hinge type) and are placed so that a beneficial moment distribution and suitable transport lengths are obtained.

The system with continuous beams is especially suitable for roof structures, for example as secondary beams (purlins).
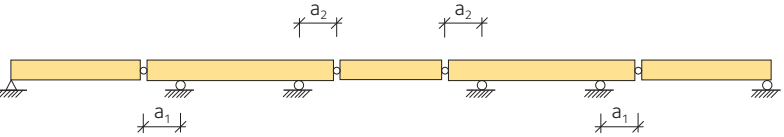
Continuous beam using the Gerber system. *See also table 17, page 50.*

Trusses

With large spans, when a solid beam tends to be too unwieldy and requires too much material, some types of trusses or tension rods structure can be an effective solution.

Glulam is most suitable for the demands of a low roof pitch and where the effective height is not excessively restricted.

One of the benefits of a truss is that it can be manufactured in a factory in units suitable for transport, which then are erected on the building site. Many and often complicated connecting points and generally lower fire resistance may be seen as a disadvantage.

Three–pin roof trusses

Three-pin roof trusses or trussed beams can be a solution when the demands of the span width rule out solid beams and when arches or portal frames cannot be used for different reasons.

Three-pin roof trusses are created in their simplest form from two beams leaning towards each other, connected in the ridge nock. The base ends are similarly pinned securely in foundations, united with tension rods — often steel ties. In the latter case the truss is normally laid on the column. The beams are often formed straight and of equal heights but the shape can vary even here. Trussed beams are considered as an intermediate shape between solid beams and trusses. The connecting points are however fewer and simpler in their configuration than in a truss frame.

Different basic forms are often combined. The middle illustration describes an example of a combination of trussed beams and three-pin roof trusses. Three-pin roof trusses can usefully be formed as so-called space load bearing structures. The roof beams are arranged from a common ridge point and the steel ties are replaced with a polygon shaped (multi-cornered) tension ring, which binds together the base points along the periphery, *see figure 48*. Problems often arise at the erection stage when more than four sections meet at one point.

Three-pin arches

Glulam is an interesting structural material not least because of the ease of creating curved structures like arches, portal frames, shells etc. For each type of load the most effective form can be chosen — with uniformly distributed loads normally in a parabolic shaped arch, with concentrated loads a polygon (multi-cornered).

Together with the high load bearing capacity, the design possibilities make glulam structures especially competitively viable for large spans. Arches with a free span of over 100 m have been achieved.

The parabolic arch is the most common form for large spans, the circular arch for small. In order to increase the free height close to the supports, an elliptic or other arch form can be preferable. This can also be achieved if the arch is laid on columns. Then the arch in the girder must be provided with tie rods between the supports to take up the horizontal reactions.

Arches are normally created with pinned attachments in the supports and also mostly with pinned joints in the ridge (three-pin arch). For greater spans, several joints can be desirable to allow for transport. These are placed within the area with small moment and are created as moment stiff.

The three-pin arch is statically determined, which means simple structural design and insensitivity for ground wielding. It is also stable in its own plane and therefore gives no clamping moment in the foundation structure.

With arches radially arranged in a circle, a cupola like building shape is obtained. In a genuine dome, the shell effect is also used, which demands special design of the load bearing structure in a tangential direction. For large spans and in particular if the surface to be covered has great dispersion in several directions, a dome is also a financially attractive solution. In Tacoma, USA, there is an example of a dome building designed in glulam with a span of over 160 m.

Three-pin portal frames

Although a parabolic arch makes efficient use of the material, different arch shapes may be used for functional, aesthetic or other reasons. The demand for a certain free height within the whole building often leads to a, typical for glulam, three-pin portal frame with curved frame haunches or, with high demands on the usage of building volume, finger jointed frame haunches.

The building's function is improved in both cases at the expense of a somewhat lower material efficiency. The three-pin portal frame has otherwise the same advantages as a three-pin arch — simple structural design and foundation structure. It is especially suitable with a poor foundation-bed, as it does not provide any bedding moment in the foundation structure.

The traditional shape is level symmetrical but other spaces can be achieved by combinations with other structural sections, curved or straight, or through three-dimensional arrangements.

Parabolic arch with steel ties, supported on posts

Parabolic arch on concrete supports
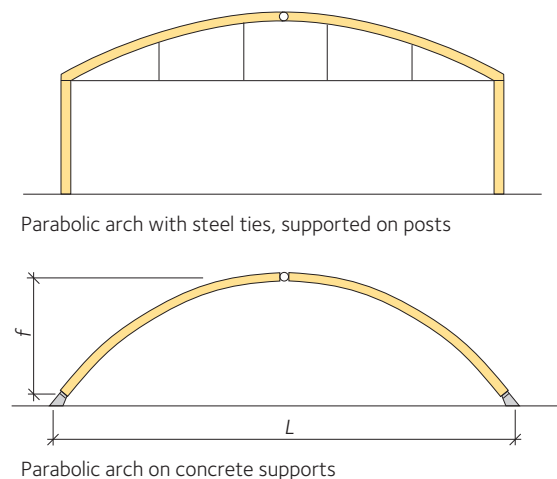
Figure 49 Three-pin arches

Three-pin frame with curved corner

Three-pin frame with finger-jointed corner

Frames in three-dimensional pattern
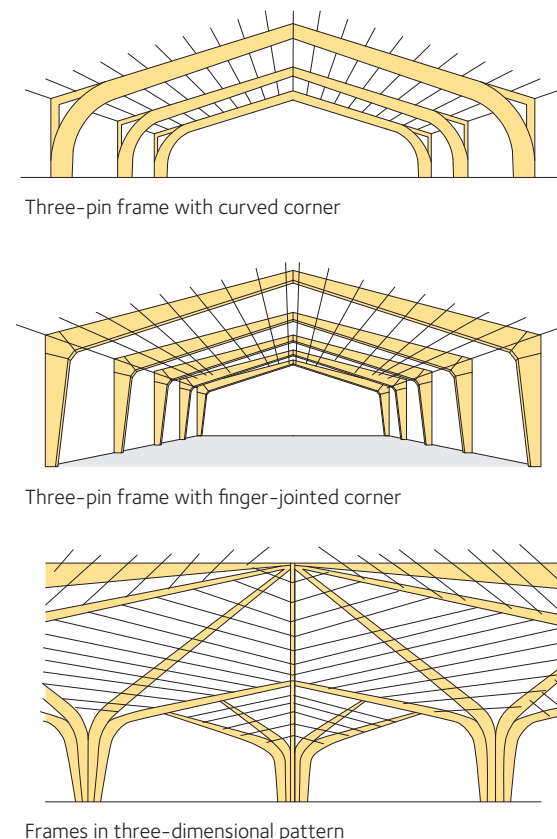
Figure 50 Three-pin portal frames
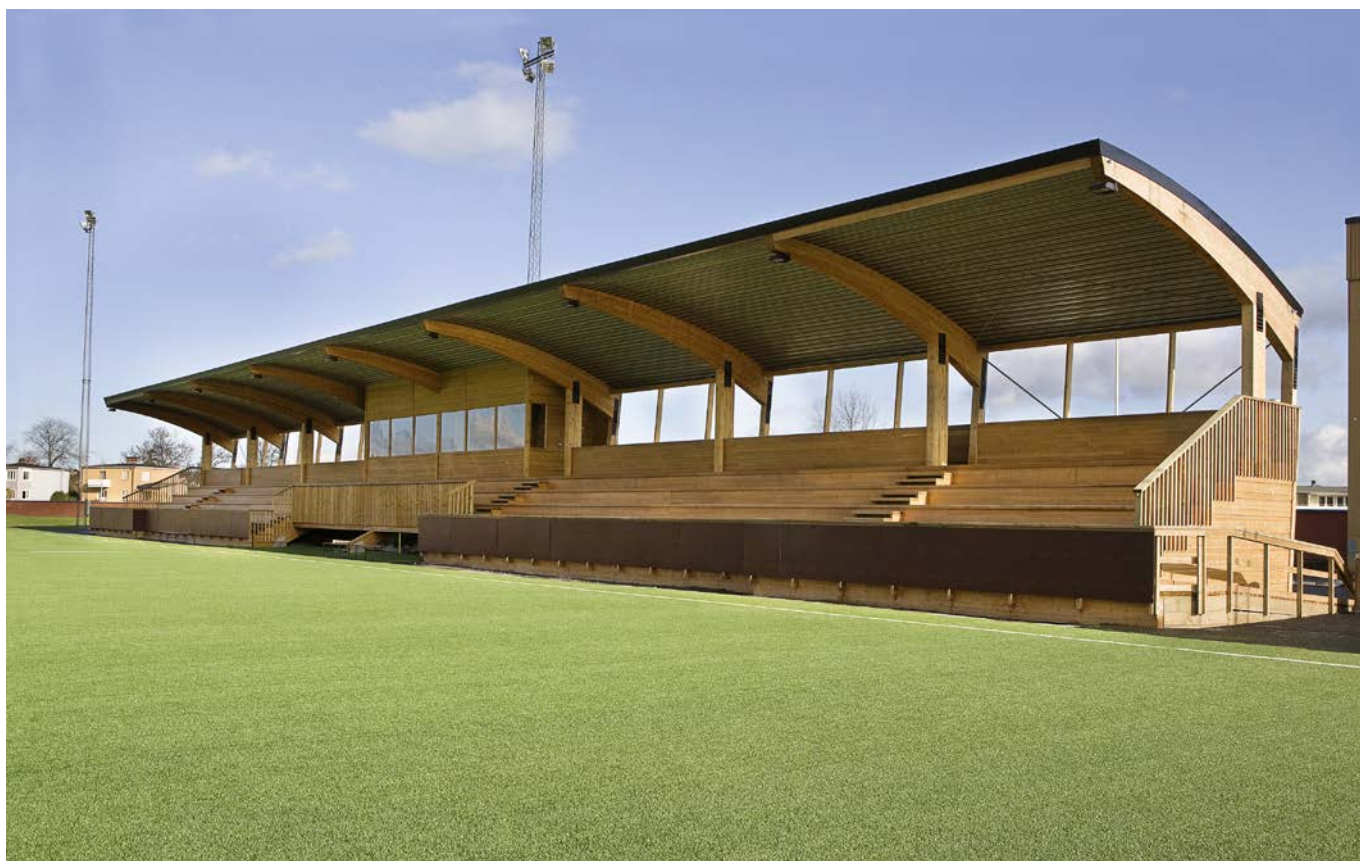
Glulam grandstand.

Cantilevers

In many contexts the building's function demands that one or both long sides are open and free from columns. Examples of such buildings are open-air stages, platform roofs and outdoor arena stands.

Here the glulam technique offers solutions in the form of cantilever piles, straight beams or curved consoles — half frames. In both cases significant bedding moment must be transferred to connecting structures.
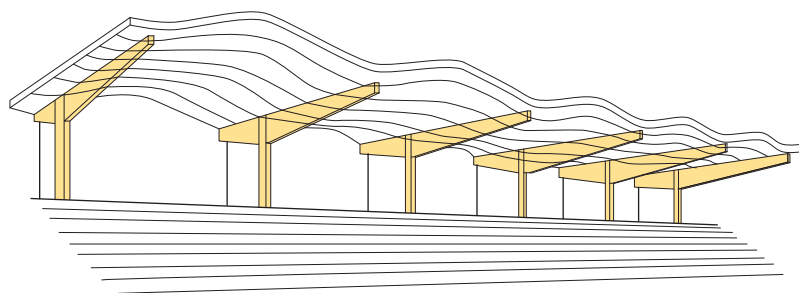
Cantilevered beams on posts
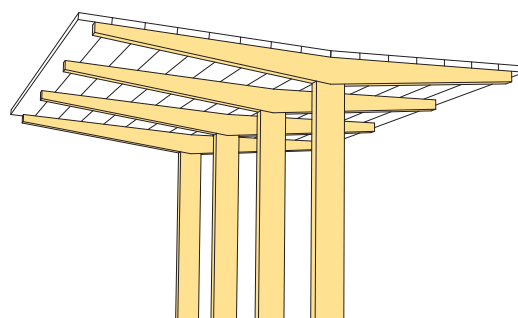
Cantilevered beam

Figure 51 Cantilevers

Shell constructions

Shell constructions offer many possibilities for advanced design and large spans without supporting columns. Many different shapes can be created by combining several shell sections, *see example in figure 52*.

Composite systems

Combinations of different statistical systems often offer excellent solutions. Requests for abundant daylight can be fulfilled with a saw-tooth roof consisting of three-pin roof trusses, which are laid on continuous trimmers.

Troublesome foundation conditions can be mastered by the support reactions that are concentrated to a few points, which are foundation reinforced. In the combined arch-beam structures in the two middle illustrations the main part of the roof load is carried down in the arch's abutment.
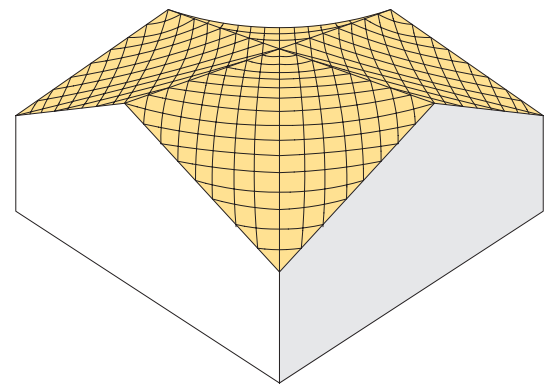
Hyperbolic paraboloid (HP) shell.

Figure 52 Shell constructions
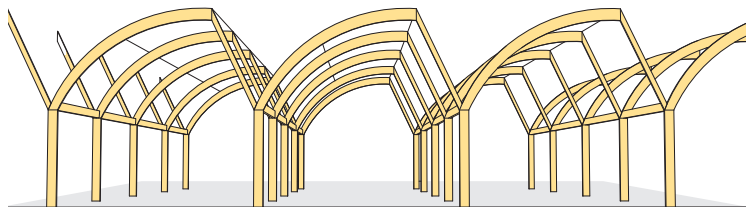
Composite system of arches and posts
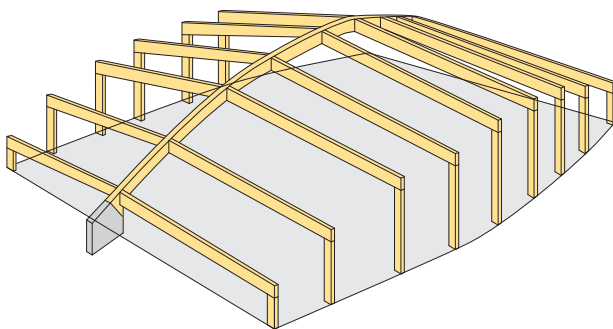
Arched beam frame
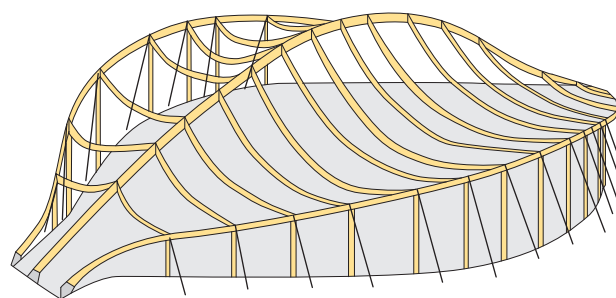
Arched beam frame with inverse arches
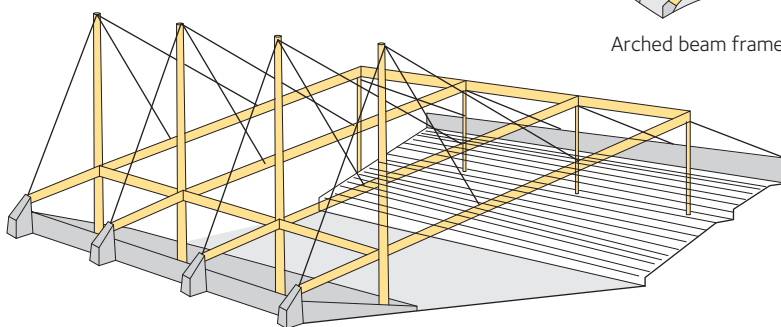
Composite system of suspended roof and steel ties

Figure 53 Composite systems

Snow load zones (kN/m²)

☐ 1,0		☐ 3,0	
☐ 1,5		☐ 3,5	
☐ 2,0		☐ 4,5	
☐ 2,5		☐ 5,5	

—— County border
—— Municipal boundary

Figure 54 **Characteristic value for snow load according to EKS 10.** Snow load on the ground: Snow zones for ground snow load, s_k, which with a probability of 0.98 is not exceeded once a year (equivalent to 50 year mean return period) based on measured data from 148 meteorological stations.

Conceptional structural design

Glulam structures in buildings shall be designed and checked according to the standards EN 1995-1-1 and EN 1995-1-2 (Eurocode 5) and applicable national additional documents, currently (2015) Boverket's (the Swedish National Board of Housing, Building and Planning) Application of the European construction standards, EKS 10 (BFS 2015:6).

Dimension tables

The tables on the following pages provide the required cross-sectional sizes for some normal glulam structures for different spans and loads. The values have been calculated with based on timber building design standard Eurocode 5. In addition every country has, for some aspects, their own national agreed parameters that should be used.

The table values are intended to be used for estimate design, for example during an early stage of the planning and do not take the place of a proper calculation that must be made at a later stage. For more thorough calculations refer to the *The Glulam Handbook Volume 2* and *Volume 3*.

Design load for roof beams and trusses

Design loads for a roof beam or rafter depend, among other things, on spacing of the roof beams/roof trusses and on the building's geographical and topographical site. The snow load varies especially between different parts of the Nordic countries.

So as not to limit the conditions unnecessarily, the tables have been designed and dimensioned with load per m (in ultimate limit state) as an initial value. This can be explained more in detail:

1. Find out the value of s_k, snow load on the ground, where the building is situated with the aid of the nationally applied snow load values. Every country's building authorities issue information on current basic values for snow and wind loads.

2. The current snow load on a roof expressed in kN/m² is obtained by multiplying by the form factor μ. For monopitch roofs with pitches of $0-30°$, this has a value of 0.8 and at pitches of $30°-60°$ the value decreases linearly to 0. For pitched roofs, the μ value on one side of the ridge is the same as for monopitch roofs. On the other side of the ridge, the μ value for roof pitches of less than 20° is 0.8 + roof pitch / 20 × 0.3. For roof pitches of $20°-60°$, the μ value decreases linearly from 1.1 to 0. Where pitched roofs have snow guards (which in most cases cannot be ruled out), there is no reduction in the snow load for roof pitches above 22.5° (μ = 1.03125). Special consideration is given to snow drifts.

3. Multiply the snow load by the appropriate partial coefficient for variable load and by the safety factor for the current safety class according to current EKS.

4. Add on the current outer roof's self-weight multiplied by the appropriate partial coefficient for permanent load and by the safety factor for the current safety class according to current EKS. Examples of self-weight for some normal types of roof are given in *table 8, page 45*.

5. The load per m of beam is then calculated by multiplying the resulting design load per m² roof area by the beam's centre-distance. An even more thorough value is obtained if one can estimate the beam's self-weight and add to the result. Take into account that the glulam has a self-weight of 5 kN/m³.

Tables for conceptional structural design

Table 7 Basic value s_k and current snow load on roofs multiplied by the form factor μ for roof pitches 0–30° according to the Swedish annex to Boverket's (the Swedish National Board of Housing, Building and Planning) building regulations, EKS 10 (BFS 2015:6).

Basic value s_k (kN/m²)	Snow load [1] (kN/m²)
1.0	0.8 – 1.1
1.5	1.2 – 1.65
2.0	1.6 – 2.2
2.5	2.0 – 2.75
3.0	2.4 – 3.3
3.5	2.8 – 3.85
4.0	3.2 – 4.4
4.5	3.6 – 4.95
5.0	4.0 – 5.5
5.5	4.4 – 6.05

[1] The design load per metre in the ultimate limit state is determined using partial coefficients according to current EKS: (snow load on roof × 1.5 × γ_d + self-weight × 0.89 × 1.35 × γ_d) × c/c spacing

For calculation of self-weight, *see table 8.*
γ_d = Safety class of building, *see table 9.*
For design at the serviceability limit, *see The Glulam Handbook Volume 2.*

Table 8 Rough values for self-weight for some normal roof structures (exclusive of glulam)

Roof structure	Self-weight (kN/m²)
Profile sheet-metal + heat insulation	0.3
Profile sheet-metal + heat insulation + sheet-metal	0.4
Wood-wool sections + insulation + roof felt	0.8
Roof tiles + heat insulation + roof lining	0.9
Roof tiles + timber boards + felt + batten + heat insulation	1.0
Felt coverage + timber boards + heat insulation	0.3

Table 9 Safety class of buildings

Safety class	γ_d
1	0.83
2	0.91
3	1.00

Table 10 Material values stock range – glulam posts and beams made in Sweden

$b \times h$ (mm)	Strength class	Weight (kg/m)	Volume (m³/m)	W_y (mm³ ×10³)
42 × 180	GL28cs	3.59	0.008	227
× 270	GL28cs	5.39	0.011	510
56 × 225	GL28cs	5.99	0.013	473
× 270	GL28cs	7.18	0.015	680
66 × 270	GL28cs	8.46	0.018	802
× 315	GL28cs	9.88	0.021	1,091
90 × 90	GL30h	3.85	0.008	122
× 180	GL30c	7.70	0.016	486
× 225	GL30c	9.62	0.020	759
× 270	GL30c	11.54	0.024	1,094
× 315	GL30c	13.47	0.028	1,488
× 360	GL30c	15.31	0.032	1,940
× 405	GL30c	17.31	0.036	2,460
× 450	GL30c	19.24	0.041	3,040
115 × 115	GL30h	6.28	0.013	254
× 180	GL30c	9.83	0.021	621
× 225	GL30c	12.29	0.026	970
× 270	GL30c	14.75	0.031	1,400
× 315	GL30c	17.21	0.036	1,902
× 360	GL30c	19.67	0.041	2,480
× 405	GL30c	22.12	0.047	3,144
× 450	GL30c	24.58	0.052	3,881
× 495	GL30c	27.04	0.057	4,696
× 630	GL30c	34.41	0.072	7,607
140 × 135	GL30h	8.98	0.019	4,253
× 140	GL30h	9.31	0.020	4,573
× 225	GL30c	14.96	0.032	1,180
× 270	GL30c	17.96	0.038	1,700
× 315	GL30c	20.95	0.044	2,320
× 360	GL30c	23.94	0.050	3,020
× 405	GL30c	26.93	0.057	3,827
160 × 160	GL30h	12.16	0.026	6,827
165 × 165	GL30h	12.93	0.027	7,487

Dimension tables
Straight roof beams

Table 11 Dimension table – straight roof beams

Load (kN/m)	Span L (m)					
	5	6	7	8	9	10
2	42 × 315	56 × 360	56 × 405	66 × 450	66 × 495	78 × 495
3	56 × 315	56 × 405	56 × 450	66 × 495	78 × 495	78 × 585
4	56 × 360	56 × 405	66 × 450	78 × 495	78 × 585	90 × 585
5	56 × 405	56 × 450	66 × 495	78 × 540	90 × 585	90 × 630
6	56 × 405	66 × 450	78 × 495	78 × 585	90 × 630	90 × 675
7	56 × 450	66 × 495	78 × 540	78 × 585	90 × 630	90 × 720
8	66 × 405	66 × 495	90 × 540	90 × 585	90 × 675	90 × 720
9	66 × 450	78 × 495	78 × 585	90 × 630	90 × 675	90 × 765
10	66 × 450	78 × 495	78 × 585	90 × 630	90 × 720	115 × 720
12	66 × 495	78 × 540	90 × 585	90 × 675	115 × 720	115 × 765

Load	11	12	13	14	15	16	17	18
6	90 × 720	115 × 765	115 × 810	115 × 855	140 × 855	140 × 900	140 × 990	140 × 1,035
7	115 × 720	115 × 765	115 × 855	115 × 900	140 × 900	140 × 990	140 × 1,035	140 × 1,080
8	115 × 765	115 × 810	115 × 900	115 × 945	140 × 945	140 × 990	140 × 1,080	140 × 1,125
9	115 × 765	115 × 855	115 × 900	140 × 945	140 × 990	140 × 1,035	140 × 1,125	140 × 1,170
10	115 × 810	115 × 855	115 × 945	140 × 945	140 × 1,035	140 × 1,080	140 × 1,170	165 × 1,170
12	115 × 855	115 × 945	115 × 990	140 × 1,035	140 × 1,080	165 × 1,080	165 × 1,170	165 × 1,215
15	115 × 900	140 × 945	140 × 1,035	140 × 1,080	165 × 1,125	165 × 1,170	165 × 1,260	165 × 1,305
18	140 × 900	140 × 990	140 × 1,080	165 × 1,080	165 × 1,170	165 × 1,260	190 × 1,260	190 × 1,350
20	140 × 945	140 × 1,035	140 × 1,125	165 × 1,125	165 × 1,215	165 × 1,305	190 × 1,305	190 × 1,395
25	140 × 1,035	140 × 1,125	165 × 1,125	165 × 1,215	190 × 1,260	190 × 1,350	190 × 1,395	190 × 1,485
30	140 × 1,080	165 × 1,125	165 × 1,215	190 × 1,260	190 × 1,305	190 × 1,395	215 × 1,440	215 × 1,530

- Strength class GL30c. Resawn beams GL28cs. Adhesive type I. Clean planed, no surface repairs. Service class 1.
- Uniformly distributed, downward load. The beams are assumed to be braced against tilting. The distance between the bracket points can then be at most 15 × the beam's width.
- Deflection in serviceability limit state borderline of variable load is at most 1/375 or of the total load at most 1/300 of the span.
  (Deformation criteria have been chosen according to *The Glulam Handbook Volume 2, Chapter 6, Table 6.1, Roof beams for schools, shops and the like*).

Double pitched beams

Table 12 Dimension table – double pitched beams

Load (kN/m)	Span L (m)							
	12	13	14	15	16	17	18	19
6	90 365 – 740	90 404 – 810	115 353 – 790	115 381 – 850	115 410 – 910	115 429 – 960	115 458 – 1,020	140 416 – 1,010
7	90 415 – 790	115 374 – 780	115 402 – 840	115 431 – 900	115 460 – 960	115 489 – 1,020	140 448 – 1,010	140 466 – 1,060
8	115 385 – 760	115 414 – 820	115 443 – 880	115 471 – 940	115 510 – 1,010	140 459 – 990	140 488 – 1,050	140 516 – 1,110
9	115 415 – 790	115 454 – 860	115 483 – 920	115 521 – 990	140 480 – 980	140 509 – 1,040	140 538 – 1,100	140 566 – 1,160
10	115 445 – 820	115 484 – 890	115 523 – 960	115 561 – 1,030	140 520 – 1,020	140 549 – 1,080	140 577 – 1,140	140 616 – 1,210
12	115 515 – 890	115 554 – 960	115 593 – 1,030	115 641 – 1,110	140 590 – 1,090	140 629 – 1,160	140 668 – 1,230	165 616 – 1,210
15	115 595 – 970	115 644 – 1,050	140 603 – 1,040	140 651 – 1,120	140 690 – 1,190	140 739 – 1,270	165 688 – 1,250	165 726 – 1,320
18	115 675 – 1,050	140 644 – 1,050	140 693 – 1,130	140 741 – 1,210	165 700 – 1,200	165 749 – 1,280	165 788 – 1,350	165 826 – 1,420
20	140 635 – 1,010	140 684 – 1,090	140 742 – 1,180	165 711 – 1,180	165 750 – 1,250	165 799 – 1,330	165 847 – 1,410	165 896 – 1,490
25	140 735 – 1,110	140 794 – 1,200	140 863 – 1,300	165 821 – 1,290	165 880 – 1,380	165 929 – 1,460	190 898 – 1,460	190 946 – 1,540
30	140 865 – 1,240	140 934 – 1,340	165 873 – 1,310	165 931 – 1,400	165 990 – 1,490	190 959 – 1,490	190 1 018 – 1,580	215 986 – 1,580
	20	21	22	23	24			
6	140 435 – 1,060	140 454 – 1,110	140 482 – 1,170	140 501 – 1,220	140 520 – 1,270			
7	140 495 – 1,120	140 514 – 1,170	140 543 – 1,230	140 561 – 1,280	165 520 – 1,270			
8	140 545 – 1,170	140 574 – 1,230	165 523 – 1,210	165 551 – 1,270	165 570 – 1,320			
9	140 595 – 1,220	165 554 – 1,210	165 573 – 1,260	165 601 – 1,320	165 630 – 1,380			
10	140 645 – 1,270	165 594 – 1,250	165 623 – 1,310	165 651 – 1,370	165 680 – 1,430			
12	165 655 – 1,280	165 684 – 1,340	165 712 – 1,400	165 751 – 1,470	190 700 – 1,450			
15	165 765 – 1,390	165 804 – 1,460	190 763 – 1,450	190 791 – 1,510	190 830 – 1,580			
18	190 795 – 1,420	190 834 – 1,490	190 873 – 1,560	190 911 – 1,630	190 950 – 1,700			
20	190 855 – 1,480	190 894 – 1,550	190 933 – 1,620	190 981 – 1,700	215 940 – 1,690			
25	190 995 – 1,620	190 1,044 – 1,700	215 1,003 – 1,690	215 1,051 – 1,770	215 1,100 – 1,850			
30	215 1,035 – 1,660	215 1,094 – 1,750	215 1,143 – 1,830	215 1,191 – 1,910	215 1,240 – 1,990			

- Strength class GL30c. Adhesive type I. Clean planed, no surface repairs. Service class 1.
- Uniformly distributed, downward load. The beams are assumed to be braced against tilting. The distance between the bracket points can then be at most 15 × the beam's width.
- The deflection in serviceability limit state of variable load, initial deformation, is at most 1/200 or quasi-permanent deformation of the total load at most 1/160 of the span.
- The sizes in the table are given in two rows with beam widths in the upper row and smallest – biggest beam height in the lower. Procambered beams are required.
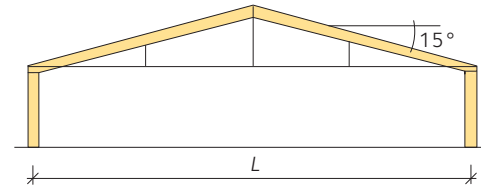
Three-pin roof truss with steel ties

Table 13 Dimension table – Three-pin roof truss with steel ties

Load (kN/m)	Span L (m)					
	15	20	25	30	35	40
6	115 × 405	115 × 540	140 × 630	140 × 765	165 × 855	165 × 990
7	115 × 450	115 × 585	140 × 675	165 × 765	165 × 900	190 × 990
8	115 × 450	115 × 630	140 × 720	165 × 810	165 × 945	190 × 1035
9	115 × 495	140 × 585	140 × 720	165 × 855	190 × 945	190 × 1035
10	115 × 495	140 × 630	140 × 765	165 × 855	190 × 945	215 × 1035
12	115 × 540	140 × 675	165 × 765	165 × 900	190 × 1,035	215 × 1,125
15	140 × 540	140 × 765	165 × 855	190 × 945	215 × 1,035	215 × 1,215
18	140 × 630	140 × 810	165 × 945	190 × 1,035	215 × 1,125	215 × 1,305
20	140 × 720	165 × 810	190 × 900	215 × 1,035	215 × 1,170	215 × 1,350
25	140 × 765	165 × 900	190 × 1,035	215 × 1,170	215 × 1,350	215 × 1,530
30	165 × 765	165 × 990	215 × 1,080	215 × 1,260	215 × 1,485	215 × 1,710

- Strength class GL30c. Adhesive type I. Clean planed, no surface repairs. Service class 1.
- Uniformly distributed, downward load. The beams are assumed to be braced against tilting. The distance between the bracket points can then be at most 15 × the beam's width.
- Deflection in the serviceability limit state of initial deformation not exceeding 1/300 or of quasi-permanent deformation not exceeding 1/240 of the span.

Note: With tie rods of round steel, for example quality 8.8, single or double rods can be chosen, with a diameter that varies according to the span and load.
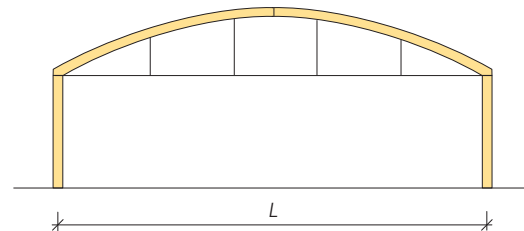
Three-pin arches with steel ties

Table 14 Dimension table – three-pin arches with steel ties

Load (kN/m)	Span L (m)						
	20	25	30	35	40	45	50
10	115 × 540	115 × 630	140 × 720	165 × 765	165 × 900	190 × 945	190 × 1,035
15	115 × 630	140 × 720	140 × 855	165 × 945	190 × 990	215 × 1,080	215 × 1,170
20	140 × 675	140 × 810	165 × 900	190 × 990	190 × 1,080	215 × 1,215	215 × 1,350
25	140 × 720	165 × 810	165 × 1,035	190 × 1,125	215 × 1,125	215 × 1,350	215 × 1,440
30	140 × 765	165 × 945	165 × 1,125	190 × 1,215	215 × 1,305	215 × 1,485	215 × 1,665

- Parabolic arches with height of arch $f = 0.144 \times$ the span L.
- Strength class GL30c. Adhesive type I. Clean planed, no surface repairs. Service class 1.
- Downward load. The beams are assumed to be braced against tilting. The distance between the bracket points can then be at most 15 × the arch's width.

Note: With tie rods of round steel, for example quality 8.8, single or double brackets can be chosen, with a diameter that varies according to the span and load.
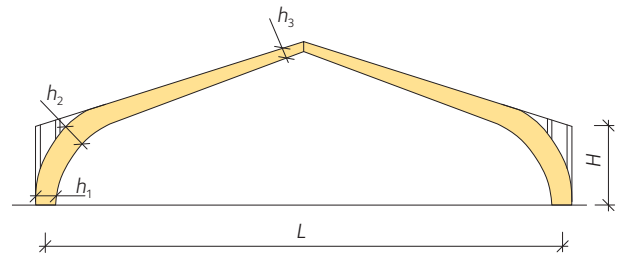
Three-pin portal frames

Table 15 Dimension table – three-pin portal frames

Load (kN/m)	Wall height H (m)	Span L (m) $(b \times h_1 - h_2 - h_3)$				
		15	**20**	**25**	**30**	**35**
10	4.0	140 × 450 – 570 – 300	140 × 600 – 690 – 450	140 × 700 – 810 – 650	165 × 800 – 870 – 750	165 × 900 – 990 – 900
	4.5	140 × 450 – 600 – 300	140 × 600 – 750 – 450	165 × 650 – 810 – 550	165 × 800 – 930 – 700	165 × 900 – 1,050 – 850
	5.0	140 × 450 – 630 – 300	140 × 600 – 780 – 400	165 × 650 – 870 – 500	165 × 800 – 990 – 650	190 × 800 – 1,020 – 750
15	4.0	140 × 550 – 630 – 300	140 × 700 – 780 – 500	165 × 800 – 870 – 600	165 × 900 – 990 – 750	190 × 950 – 1,050 – 900
	4.5	140 × 550 – 690 – 300	140 × 700 – 840 – 450	165 × 800 – 930 – 550	165 × 900 – 1,050 – 700	190 × 950 – 1,110 – 850
	5.0	140 × 550 – 720 – 300	165 × 600 – 810 – 400	165 × 800 – 990 – 500	190 × 850 – 1,050 – 650	190 × 950 – 1,170 – 800
20	4.0	140 × 600 – 660 – 350	140 × 750 – 840 – 500	165 × 900 – 930 – 650	190 × 1,000 – 1,020 – 750	190 × 1,100 – 1,170 – 900
	4.5	140 × 600 – 720 – 350	165 × 750 – 840 – 450	165 × 900 – 990 – 600	190 × 1,000 – 1,050 – 700	215 × 1,000 – 1,140 – 800
	5.0	140 × 600 – 780 – 350	165 × 750 – 870 – 400	165 × 900 – 1,050 – 550	190 × 1,000 – 1,140 – 650	215 × 1,000 – 1,230 – 750
25	4.0	140 × 650 – 720 – 400	165 × 750 – 840 – 500	190 × 900 – 960 – 650	190 × 1,050 – 1,140 – 750	215 × 1,150 – 1,200 – 900
	4.5	140 × 650 – 780 – 400	165 × 750 – 900 – 450	190 × 900 – 1,020 – 600	215 × 1,050 – 1,140 – 650	215 × 1,150 – 1,290 – 850
	5.0	140 × 650 – 840 – 400	165 × 750 – 960 – 450	190 × 900 – 1,080 – 550	215 × 1,050 – 1,200 – 650	215 × 1,150 – 1,350 – 800

- Curved haunches with overriding laminations.
- Strength class GL30c. Adhesive type I. Clean planed, no surface repairs. Service class 1.
- Downward load. The beams are assumed to be braced against tilting. The distance between the bracket points can then be at most 15 × the arch's width.
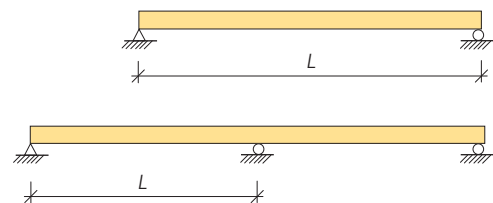
Floor beams

Table 16 Dimension table – floor beams

Cross-sectional dimensions $b \times h$ (mm)	Residential space				Offices, schools			
	Glued and screwed flooring grade chipboard		Screwed flooring grade chipboard		Glued and screwed flooring grade chipboard		Screwed flooring grade chipboard	
	Span L (mm)		Span L (mm)		Span L (mm)		Span L (mm)	
	Two supports	Three supports	Two supports	Three supports	Two supports	Three supports	Two supports	Three supports
42 × 180	3,790	3,800	2,870	2,870	3,800	3,800	2,870	2,870
225	4,480	4,640	3,730	3,730	4,640	4,460	3,730	3,730
56 × 225	4,810	4,960	4,180	4,180	4,960	4,960	4,180	4,180
270	5,520	5,880	5,170	5,170	5,850	5,880	5,170	5,170
66 × 270	5,750	6,120	5,500	5,500	6,100	6,120	5,500	5,500
315	6,450	7,100	6,450	6,550	6,840	7,100	6,550	6,550
90 × 315	7,040	7,800	7,040	7,460	7,470	7,800	7,460	7,460

- Maximal spans for floor beams on two or three supports.
- With beams on three supports the middle support should lie within the area 0.4 and 0.6 of the beam's total length. The beam's centre distance (c-distance) is 600 mm.
- Subfloor of at least 22 mm glued and screwed flooring grade chipboard type P5 or better, or screwed only.
- Strength class GL30c for beams with a width ≥ 90 mm.
- Strength class GL28cs for beams with a width < 90 mm (resawn glulam beams). Adhesive type I. Clean planed, no surface repairs. Service class 1.
- The stiffness in the floor joists has been checked according to Eurocode 5.
- Moreover the largest deflection in the serviceability limit state u_{fin} has been limited to 20 mm for residential housing, respectively 30 mm for office floor joists.
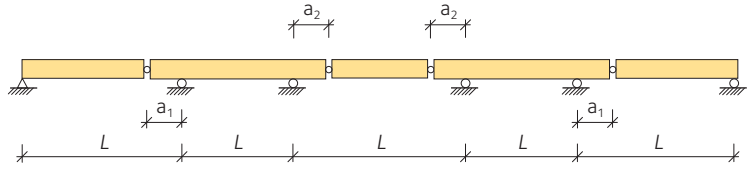- Self-weight = 0.5 kN/m².

Roof purlins

Table 17 Dimension table – roof purlins

Load (kN/m)	Span L (m)							
	4.8		6		7.2		9.6	
	Outer bay	Inner bay	Outer bay	Inner bay	Outer bay	Inner bay	Outer bay	Inner bay
4	56 × 225	42 × 225	66 × 270	56 × 270	66 × 315	56 × 315	90 × 360	66 × 360
5	66 × 225	56 × 225	78 × 270	56 × 270	90 × 315	56 × 315	90 × 405	66 × 405
6	56 × 270	56 × 270	78 × 315	56 × 315	115 × 315	66 × 315	115 × 405	78 × 405
7	66 × 270	56 × 270	90 × 315	56 × 315	90 × 360	66 × 360	115 × 450	78 × 450
8	66 × 315	56 × 315	90 × 315	66 × 315	115 × 360	78 × 360	115 × 450	78 × 450
9	66 × 315	56 × 315	115 × 315	78 × 315	90 × 405	78 × 405	140 × 450	90 × 450
10	78 × 315	66 × 315	78 × 405	66 × 405	115 × 405	78 × 405	115 × 495	90 × 495
12	90 × 315	78 × 315	90 × 405	78 × 405	115 × 450	90 × 450	140 × 540	90 × 540
15	78 × 405	78 × 405	90 × 450	90 × 450	115 × 495	90 × 495	165 × 540	115 × 540
18	90 × 405	90 × 405	90 × 495	90 × 495	115 × 540	115 × 540	140 × 630	115 × 630
a_1	0.60		0.75		0.90		1.20	
a_2	0.70		0.88		1.05		1.40	
	12		15		18			
	Outer bay	Inner bay	Outer bay	Inner bay	Outer bay	Inner bay		
4	90 × 450	66 × 450	115 × 540	78 × 540	115 × 630	90 × 630		
5	115 × 450	78 × 450	140 × 540	90 × 540	140 × 630	90 × 630		
6	115 × 495	78 × 495	140 × 585	90 × 585	165 × 630	115 × 630		
7	140 × 495	90 × 495	165 × 585	115 × 585	165 × 675	115 × 675		
8	140 × 540	90 × 540	165 × 630	115 × 630	190 × 675	115 × 675		
9	140 × 540	115 × 540	190 × 585	140 × 585	190 × 720	115 × 720		
10	140 × 585	90 × 585	190 × 630	140 × 630	190 × 765	115 × 765		
12	140 × 630	115 × 630	190 × 675	140 × 675	190 × 810	140 × 810		
15	190 × 630	140 × 630	190 × 765	140 × 765	215 × 855	140 × 855		
18	190 × 675	140 × 675	215 × 765	165 × 765	215 × 945	140 × 945		
a_1	1.50		1.88		2.25			
a_2	1.75		2.19		2.63			

- Purlins with a constant cross-sectional height, continuous over two or several intermediate supports. Moment free joints placed so that support and field moment will be equal in the inner bay, so-called Gerber-system.
- Strength class GL30c ($b \geq 90$ mm) or GL28cs (split glulam beams $b < 90$ mm). Adhesive type I. Clean planed, no surface repairs. Service class 1.
- Uniformly distributed, downward load. The purlins are assumed to be braced against tilting.
- The deflection in serviceability limit state are at the most 1/130 of the span initially and 1/100 of the span quasi-permanent.
- a_1 and a_2 are distances (m) from the centreline of the support to the centreline of the Gerber joint.
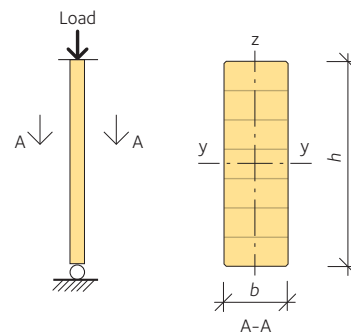
Columns

Table 18 Dimension table – columns

Buckling length (m)		2		3		4		5		6		7		8	
Buckling axis		y–y	z–z	y–y	z–z	y–y	z–z	y–y	z–z	y–y	z–z	y–y	z–z	y–y	z–z
Cross-sectional dimensions $b \times h$ (mm)	Strength class														
90 × **90**	GL30h	86	86	41	41	23	23	15	15	11	11	8	8	6	6
135	GL30h	204	129	129	61	77	35	50	23	35	16	26	12	20	9
180	GL30c	244	159	218	78	159	45	109	29	78	20	58	15	45	11
225	GL30c	311	199	296	97	260	56	199	36	147	25	110	19	86	14
270	GL30c	377	239	366	116	345	67	301	43	239	30	185	22	145	17
115 × **115**	GL30h	197	197	106	106	62	62	40	40	28	28	21	21	16	16
135	GL30h	232	261	165	124	98	72	64	47	45	33	33	24	26	19
180	GL30c	311	270	278	156	204	91	139	59	99	42	74	31	57	24
225	GL30c	397	338	378	195	332	114	254	74	187	52	141	38	110	30
270	GL30c	482	405	467	234	440	137	385	89	305	63	236	46	186	36
315	GL30c	566	473	553	273	534	160	499	104	436	73	356	54	286	41
140 × **135**	GL30h	318	318	201	201	119	119	78	78	55	55	40	39	31	31
140	GL30h	335	335	221	221	133	133	87	87	61	61	45	45	35	35
180	GL30c	379	362	338	262	248	161	170	106	121	74	90	55	69	42
225	GL30c	484	452	460	327	404	201	310	132	228	93	172	69	133	53
270	GL30c	587	542	569	393	536	242	468	159	372	112	288	83	226	64
315	GL30c	689	633	674	458	650	282	608	185	531	130	434	96	348	74
160 × **160**	GL30h	456	456	351	351	221	221	146	146	103	103	76	76	59	59
165 × **165**	GL30h	489	489	387	387	249	249	165	165	116	116	86	86	66	66
180	GL30c	447	442	399	374	292	254	200	170	142	121	106	90	82	69
225	GL30c	570	552	542	468	477	317	365	213	269	151	203	112	157	86
270	GL30c	691	662	670	561	632	381	552	255	438	181	339	134	266	104
315	GL30c	812	773	794	655	767	444	717	298	626	211	511	157	410	121
360	GL30c	931	883	916	748	894	508	859	340	798	241	699	179	584	138
190 × **180**	GL30c	515	515	459	459	336	336	230	230	164	164	122	122	94	94
225	GL30c	656	647	624	591	549	455	420	317	309	227	233	169	181	131
270	GL30c	796	777	772	709	728	546	635	380	504	272	390	203	307	157
315	GL30c	935	906	914	827	883	637	825	444	721	317	589	237	472	183
360	GL30c	1,073	1,035	1,055	945	1,029	728	989	507	919	363	805	271	673	209
215 × **225**	GL30c	743	740	707	699	621	596	476	443	350	323	264	242	205	188
270	GL30c	901	888	873	838	823	716	719	531	571	387	442	291	347	225
315	GL30c	1,058	1,036	1,035	978	999	835	934	620	815	452	666	339	534	263
360	GL30c	1,214	1,185	1,193	1,118	1,165	954	1,119	709	1,040	516	911	388	761	301
405	GL30c	1,365	1,333	1,351	1,258	1,326	1,074	1,291	797	1,235	581	1,142	436	1,006	338

- The load bearing capacity in kN for axial-loaded glulam columns with rectangular cross-sections and pinned in both ends (pendular columns).
- The shortest lasting load types in load combinations are of type M, for example snow loads.
- Strength class GL30c with four or more laminates or GL30h for glulam posts with up to three laminates. Adhesive type I.
  Clean planed, no surface repairs. Service class 1 or 2.

Design software

In the Nordic countries, there are several approved design software programs for glulam structures. Here are some that are currently used by glulam producers and structural engineers:

- **Focus Konstruktsjon** (2D- and 3D-software for statistical analyses and calculations of columns, beams, frames and trusses.
- **RFEM** — general software for calculation and structural design.
- **RSTAB** — general software for calculation and structural design.
- **TIMBER PRO** — calculation module to RFEM and RSTAB.
- **RX–TIMBER** — design of beams and columns according to EC5.
- **Finnwood** — design of beams and columns according to EC5.
- **StatCon Structure** — design of beams and columns according to EC5.
- **StatCon Glulam** — software for arch structures, single or double-pitched beams, frames etc.

In addition, there are some design programs for glulam that are currently used by building consultants:

- **StruSoft Ramanalys** — 2D-software for columns, beams, portal frames etc.
- **StruSoft FemDesign** — 3D-software, which even calculates panels.

For further information about software programs, check with the glulam manufacturers.

Three-pin glulam arches in cowshed.

Connecting details

This section describes examples of standard solutions for joining points and fittings are reported. Fixing details are shown in the information diagrams below. The material used for fittings and fixings must have rust protection tailored to the relevant corrosivity class — as a rule at least equivalent to hot-dip galvanized steel with a zinc layer ≥ 55 µm (micrometres). The described standard fittings meet these requirements. They are manufactured from hot-dip galvanized steel or, in some cases, from acid-resistant stainless steel (known as austenitic stainless steel A4).

Pinned (hinged) attachments transfer horizontal and vertical forces but not moment. Connection points, which should be able to transfer moment must be (fixed) clamped. For more detailed instructions refer to *The Glulam Handbook Volume 2*.

Technical development

Besides standard solutions, new fittings and attachments for glulam structures are being developed all the time. Different demands ensure new solutions are found. Built-in fittings have many advantages in comparison with surface mounted, for example improved resistance to fire. Timber building screws make simple and economic connectors.

Fittings for one family houses

1. Nailing plates (fish-plates)
Nailing plates can be used as joint fixings in glulam beam and roof structures or for securing column bases. In order to avoid eccentric loads, two plates per joint should be used (so-called double fittings). The plates are manufactured from hot galvanized steel or stainless acid-proof steel of thicknesses 1.5, 2.0 and 2.5 mm. Hole diameter 5 mm.

2. Roof ridge fastener
Roof ridge brackets are used for roof structures and cross beams, mainly for the anchoring of roof ridges to primary beams. They are especially usable in structures that are to be provided with cladding outside the building structure, or where it is unimportant if the fitting is visible. They are manufactured in some different types, as left and right fittings, from hot-galvanized steel sheet metal. Hole diameter 5 mm.

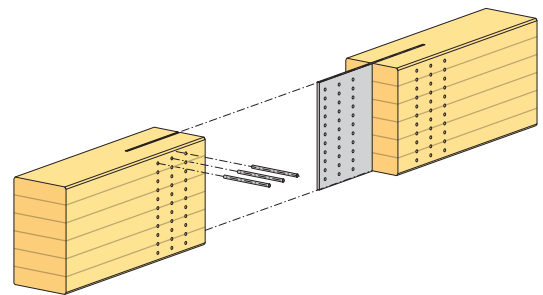**Figure 55** Connection with slotted-in sheet metals and steel dowels

Figure 56 Dowel connector with inset plate
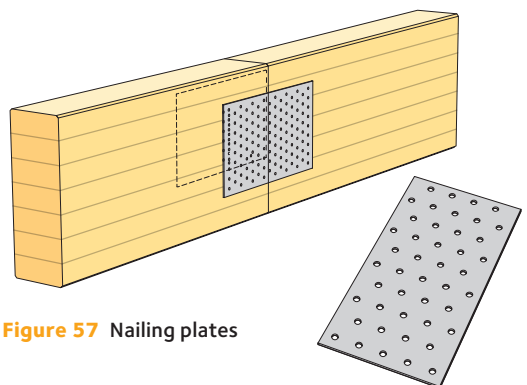
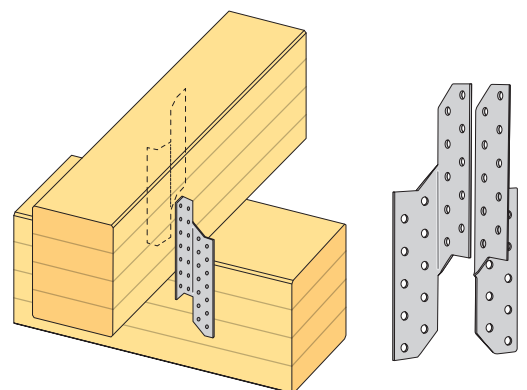**Figure 57** Nailing plates

Figure 58 Roof ridge fastener

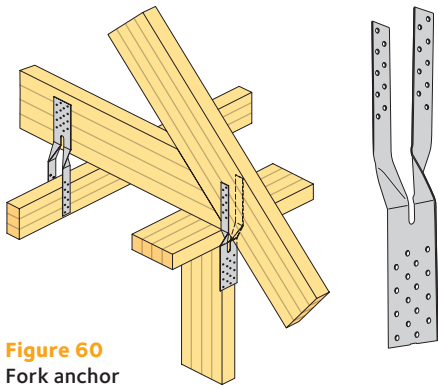**Figure 59** Fittings for one family houses – information overview
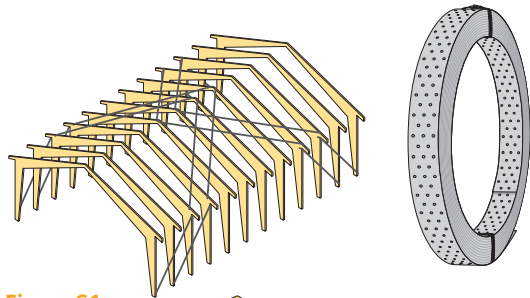
Figure 60
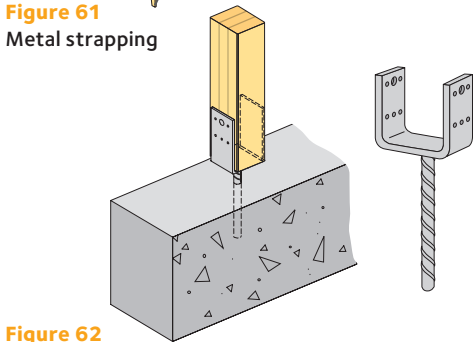Fork anchor

Figure 61
Metal strapping

Figure 62
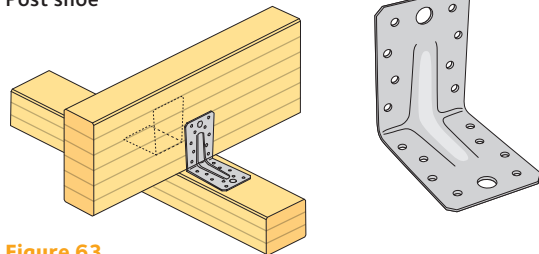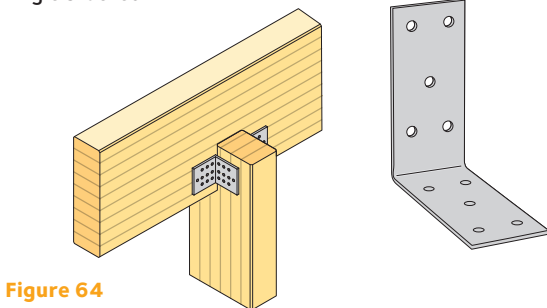Post shoe

Figure 63
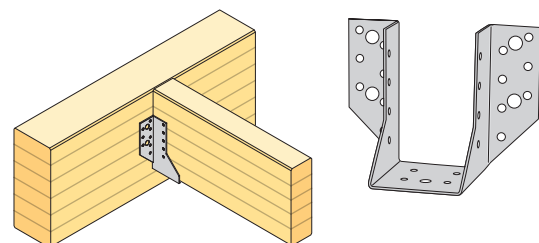Angle bracket

Figure 64
Nailing plate angle

Figure 65 Hanger with external fixing flanges

3. Fork anchor

Fork anchors are used mainly as connections between trusses and underlying structures but can also be used for cross-joints in glulam timber structures. They are manufactured in different types from hot galvanized steel sheet metal of thickness 1.5 mm. Hole diameter 5 mm.

4. Metal strapping

Metal strappings are used for stabilizing of roof structures. They are also used for wind bracing in floors and walls. They are manufactured from hot galvanized steel sheet metal. Hole diameter 5 mm for mounting of anchor nails.

5. Post shoe

Pole climbers are used for embedding or mounting in concrete for the embedding of glulam posts, for example for fences and verandas. They are manufactured in different types, with or without adjustable design, from galvanized steel sheet metal.

6. Angle bracket

Angle brackets are used as cross connectors in structural timber and glulam. They can also be used for bolt fasteners in timber — concrete. There are several dimensions for adjustment to the load in question. They are manufactured from hot-galvanized or stainless steel sheet metal of thickness 2 or 3 mm. Hole diameter 5 mm for anchor nails or anchor screws, and larger holes for expansion screws.

7. Nailing plate angle

Nailing sheet metal angles can be used for joints between posts and sills or for connections with moderate loads. They are manufactured from hot-galvanized or stainless steel sheet metal of thickness 2 or 4 mm. Hole diameter 5 mm.

8. Hanger

Hangers are used for the connection of beams on the same level and for connection between columns and beams of glulam. There are many different types of hanger with edges of different widths. Within each type there are a number of heights. Beams' shoe edges can be bent both inwards and out. Manufactured from hot-galvanized steel sheet metal with a thickness of 2 mm. Hole diameter 5 mm.

9. Gerber joints

Gerber fittings are used to join beams in the same plane, where the joints are non-moment transferring. In order to avoid eccentric loads, two fittings per joint should be used (so-called double fittings). They are manufactured from hot-galvanized or stainless steel sheet metal with a thickness of 2 mm. Hole diameter 5 mm.
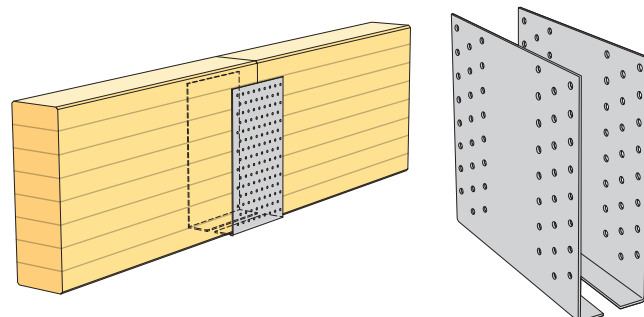

Figure 66 Gerber joint

10. Fastening with wood screws

Joining with special wood screws, universal screws or wood construction screws is another simple solution for smaller structures such as conservatories and carports. *Figure 68* opposite shows the use of universal screws to connect a secondary beam to a primary beam. They can also be used to reinforce glulam beams at their supports. The screw has a drill tip to avoid splits in the timber. It is often inserted at an angle (oblique).

Connecting details for larger buildings
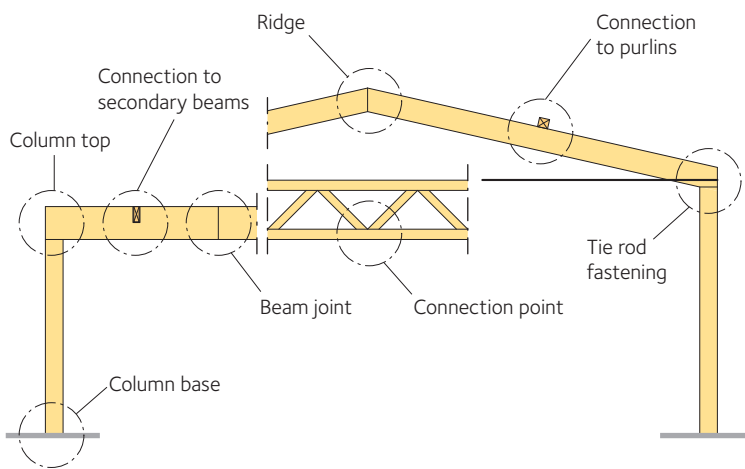
Figure 69 Information overview of reported connecting details for larger buildings

Column base

Nailing plates

Pinned or lapped-in attachments of column bases with nailed sheet metal on either side. A simple solution, suitable for both small and large horizontal and vertical forces (lift).
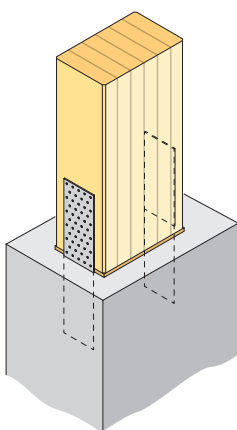
Anchor screw. Used in combination with metal plates.

Anchor nail. Used in combination with metal plates.

Self-drilling dowel. Used to fit inset steel plates to wooden structures.

Universal screw. With upper and lower threads to anchor two pieces of wood.

Wood construction screw. With specially designed threads. No need for pre-drilling.

Figure 67 Examples of nails and wood screws used for glulam joints

Screwing obliquely into the glulam.

Figure 68 Universal screw

Figure 70 Nailing plates of sheet metal on either side. Moisture protection between glulam and concrete.
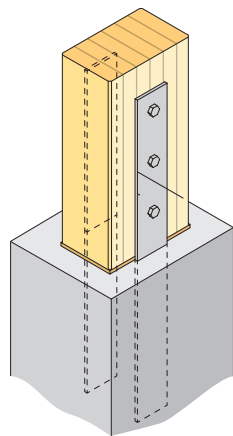
Figure 71 Flat rolled steel on either side. Moisture protection between glulam and concrete.
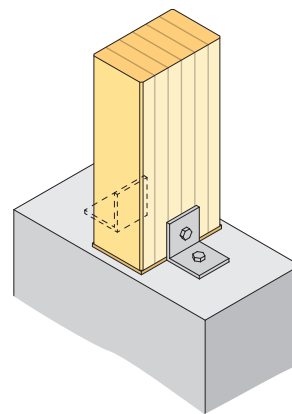
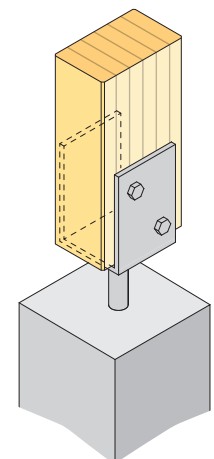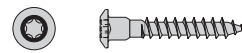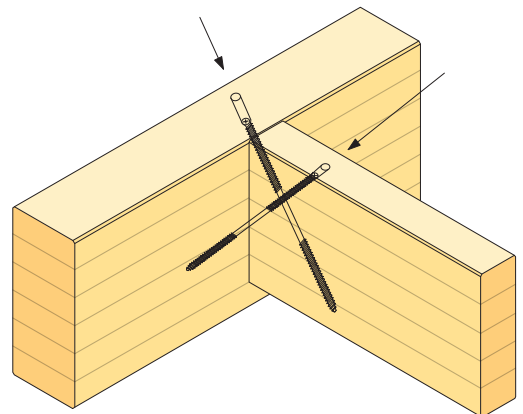**Figure 72** Angle steel on either side. Moisture protection between glulam and concrete.

Figure 73 Pole climber of U-shape with a welded on anchoring rod

Detail of connection point in ridge.

For pinned attachments, the nailed sheet metal is placed in the stud on the column's wide sides — for fixed support, normally on the column's narrow sides. The fitting can either be moulded solidly in concrete structures or welded to an embedded fixed metal sheet. Force transfer occurs with anchor nails or screws. End grain surfaces should be moisture protected against concrete and other moisture absorbing material and preferably be accessible for vapour protection maintenance, *see further under section Moisture protection, page 37*.

Special measures for fire protection can be required, for example fire protection painting or cladding, *see section Design with regard to fire, page 62*.

Flat rolled steel

Pinned or clamped attachments of column bases with flat rolled steel are equally good alternatives to nailed sheet metals.

With pinned attachments, the flat rolled steel is placed in a stud on the column's wide side — with fixed support on the column's narrow sides. The flat rolled steel is moulded into the concrete construction or is welded to an embedded fixed metal sheet.

The force transfer is with through-screws or some type of timber construction screw. End grain surfaces should be vapour protected against concrete and other moisture absorbing materials and preferably be accessible for vapour protection maintenance, *see further under section Moisture protection, page 37*.

Special measures for fire protection can be required, for example fire protective painting or cladding.

Angle steel fastener

Pinned column base with angled steel screwed to the column is a simple solution and suitable for small horizontal and vertical forces (lift).

Angular steel is tightly screwed in the concrete construction with expander screws or so-called cramps, which makes thorough measuring possible and minimizes the risk of mis-placement. A symmetrical angle steel on each side of the column is the most common solution. End grain surfaces shall be vapour protected and preferably be accessible for vapour protection maintenance, *see further under section Moisture protection, page 37*.

Pole shoe

For pinned attachments outdoors, or in premises where there is running tap water, and if the forces are small, a pole climber is a suitable solution, as water absorption through the column's end grain is prevented. The fitting often consists of a U-profile and a welded-on anchoring rod. As a rule, the lower part of the anchoring rod is moulded into the concrete structure, but the rod can also be welded to an embedded fixed metal sheet. The force transfer normally occurs with the aid of screws. Adjustable standard fittings are also available.

Glued–in screw

With pinned or lapped in attachments with glued-in screws the attachments are completely hidden. A hidden fitting gives approved fire protection. Fixed support is suitable only with a relatively small moment. Glued-in screws cannot be used in structures in Service class 3 (outdoor structures) or in structures intended for dynamic loads (for example vehicles) or fatigue loads.

The connection to the ground structure is shaped as a stud with an end metal plate on the column's end surface. The end metal plate is threaded on the glued-in screw. The column can also be joined with projecting screws, which are welded to the recesses in the foundation structure.
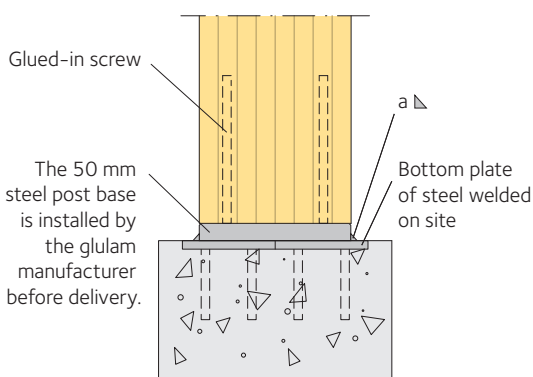

Glued–in screw

The 50 mm steel post base is installed by the glulam manufacturer before delivery.

a

Bottom plate of steel welded on site

Figure 74 Steel post base with glued–in rods and a cast steel base plate

Glued–in dowel pin

A simpler, non-force transferring variation is a glued-in dowel pin, which can be sufficient when only the steering of the column is required. Dowel pins can be made from fully threaded bars in strength class 4.6 or 8.8 and with diameter M12, M16, M20 or M24, as specified by the customer. The quality of the glue corresponds to that used for glued-in screws, although glued-in dowel pins are not covered by the type approval for glued-in screws. Thus, no strength may be ascribed to them. The product does not need to be tested or labelled.

Note that gluing may only be carried out by an approved glulam manufacturer. Holes in the concrete base are drilled with a diameter that is 2 mm larger than the diameter of the dowel pin, or a slightly larger hole that is finished on site with filler. The foot of the post must be provided with moisture protection against the concrete, for example in the form of 4.8 mm tempered wet-process hardboard, *see figure 75*.

Column top

Nailing plates

Wired connections with nailed metal plates on either side of the section are simple and suitable for both small and large loads. The metal plates, which are found in standard catalogues, have thicknesses which limit the usage to moderate loads. The manufacturer's instructions should be carefully followed. Load transference occurs with the aid of anchor nails or screws. The metal plates should be placed as close to the column's inner edge as possible so as not to prevent the beam's angular changing. Special measures of fire protection can be required, for example protection painting or cladding, *see section Fire protection of connections and fittings – General viewpoints, page 66*.

Flat rolled steel

Pinned connections with flat rolled steel on either side of the section are also, like nailed metal plates, simple and effective. Flat rolled steel, type flat rod or universal rod, is suitable for both small and large forces. Material thickness is chosen from the standard series 5, 6, 8, 10, 12, 15 or 20 mm with at least 0.3 × screw-/bolt diameter. The screw hole should be approximately 1 mm larger than the screw diameter or be made as a vertical, oval hole. Special measures for fire protection can be required, for example protective painting or cladding, *see section Fire protection of connections and fittings – General viewpoints, page 66*.
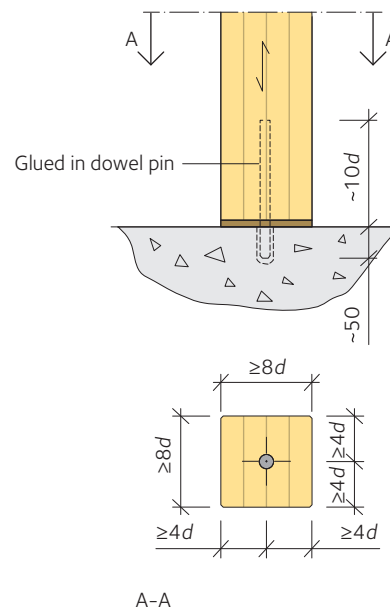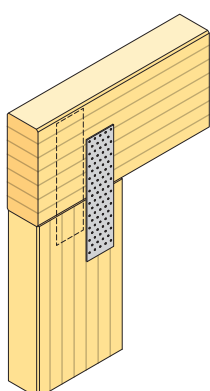

Figure 75 Glued–in dowel pin

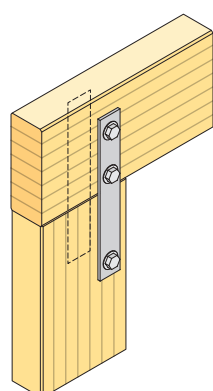**Figure 76** Nailed metal sheet on either side of the glulam section

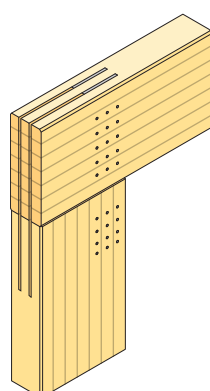**Figure 77** Flat rolled steel on either side of the section

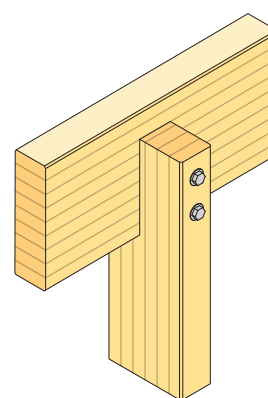**Figure 78** Slotted–in metal sheets and steel dowels

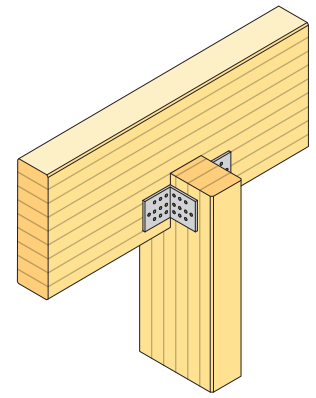**Figure 79** Inset beam and coach bolts with nut and washer.

Figure 80 Built–in beam and metal sheet angles

Screwing obliquely from above
into the glulam.

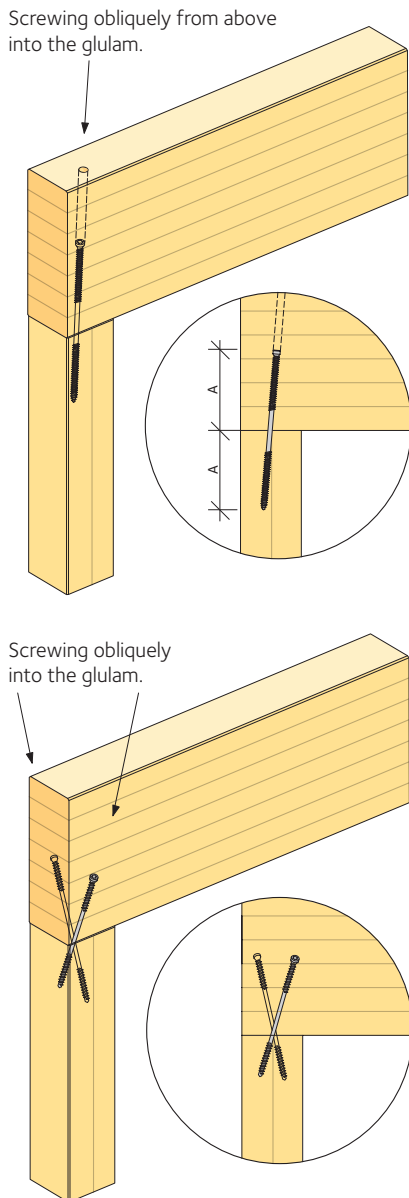Screwing obliquely
into the glulam.

Figure 81 **Two examples of post–beam connections with universal screws – one screw from the top (above), two screws from the sides (below).** Universal screws should be driven into end-grain wood at a minimum 30° angle to the grain to obtain an acceptable withdrawal force.
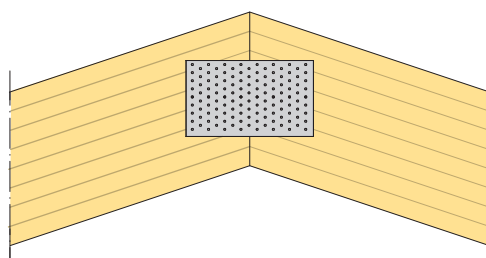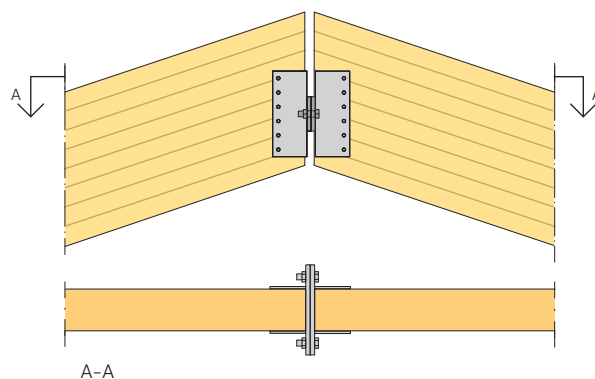
Slotted–in metal sheet

For pinned connections with slotted-in steel metal sheet and steel dowels the attachments are completely hidden. The steel dowels can be counter sunk in the beam and covered with wooden plugs. From a fire technological viewpoint a completely hidden fitting provides approved protection, *see figure 78, page 57*.

Countersunk beam

Counter sunk beams are often used for corner columns in order to transfer the column's horizontal forces to the beam. The groove in the column is often made as big as the width of the beam. The transference of force between the beam and column generally occurs with the aid of the through-screw, nut and washer. For small horizontal and vertical (lift) forces attachments with the aid of metal sheet angles or axial-loading screws or even coach screws, can also be used.

Universal screw

Joints with special universal screws are another simple solution for both small and large structures, such as conservatories, carports, floor systems and hall frames. These screws have many applications, including those shown in *figures 67 and 80*. An angle of at least 30° should be sought when screwing into end-grain wood; pre-drilling is generally not needed and the screw is easily countersunk so that the unthreaded part is always located where the elements meet.

Ridge

Pinned ridge joints transfer horizontal and vertical forces. The moment is not transferred. The attachments should be designed so that angular changes are not prevented. If angular changes cannot occur freely, extra tensions occur that can cause unforeseen damage to the glulam structure.

Nailing plates metal sheet

Pinned ridge joints (apex connections) of nailed metal plates on either side are simple and effective. Nailed covering plates of metal sheet are suitable for both small and large forces. The manufacturer's instructions should be followed carefully. Force transference between nailed metal plates and glulam occurs with the help of anchor nails or screws. The metal plate should be placed as close to the beam's lower edge as possible so that it does not prevent the beam's change of angle. Suitable distance between the lower edge beam and the lowest row of nails is 10 × nail-/screw diameter. There are pre-bored

Figure 82 **Ridge joints, pinned, with nailed metal sheet on either side**

A–A

Figure 83 **Steel ridge fixing designed by Limträteknik i Falun AB**

nailed metal plates of hot-galvanized steel metal sheet in stock in different sizes and thicknesses between 1.0 and 5 mm.

Another suitable ridge fixing has been developed by Limträteknik i Falun AB, *see figure 83, page 58.*

Beam joints

Pinned beam joints transfer horizontal and vertical forces. Moment is not transferred. Attachments should be designed so that the beams' change of angle is not prevented. If the change of angle cannot occur freely, extra tension arises that can cause unforeseen damage to the glulam structure.

Nailed metal sheets

Pinned beam joints with cover plates of metal sheet are simple and effective. They are suitable for small or moderate forces. The manufacturer's instructions should be followed carefully. The metal sheets should be placed centrally with reference to the glulam beam's middle line = system line. The transfer of forces between the metal sheets and glulam occurs with the aid of anchor nails or screws.

Welded gerber joints

Pinned beam joints with gerber joints are recommended if large cross forces are transferred and if the forces always have the same direction. Lesser transverse forces in the opposite direction are transferred through screw straps in the side metal plates. The forces are mainly transferred by means of abutment. If the gerber joint is to transfer tension forces it is complemented with welded flat steel bars. So as not to oppose the beams' angle change, the side screws are placed as close to the top respective bottom metal plate as possible. Suitable edge distance is 2 × screw diameter if the screw only transfers horizontal forces and 4 × screw diameter if the screw also transfers vertical forces.

Factory made gerber fixtures

There are factory made gerber joints in stock. They are manufactured from hot-galvanized steel metal sheet and are suitable for small and moderate transverse forces. The manufacturer's instructions should be followed carefully. The fittings can be whole or divided. The whole ones are suitable for fixed cross-sectional sizes for glulam beams, while the divided ones as a rule are independent of the beam's cross-sectional sizes. The forces are transferred mainly with the aid of anchor nails or screws. When using double angle brackets, of the type shown here, the risk of flaking must be taken into consideration, *see The Glulam Handbook, Volume 2.* A rule of thumb is that the height to the highest nail/screw (he) divided by the beam height *h* should be ≥ 0.7.

Connection to a secondary beam

The secondary beam placed on top of the primary beam transfers vertical forces and small horizontal forces in the primary beam's direction. The secondary beam suspended on the primary beam's side also transfers horizontal forces in the secondary beam's direction. If necessary the fitting can be shaped so that moment is also transferred.

Screw fastening with universal screw

Axial load-bearing screws can be used for small or moderate cross forces. The manufacturer's instructions should be followed carefully.
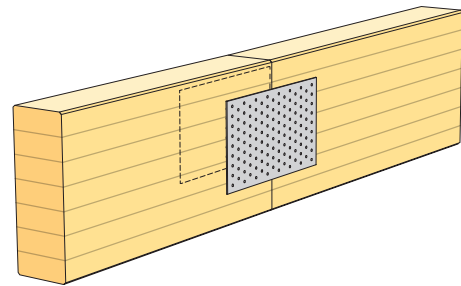

Figure 84 Nailed metal sheet on either side of the joint
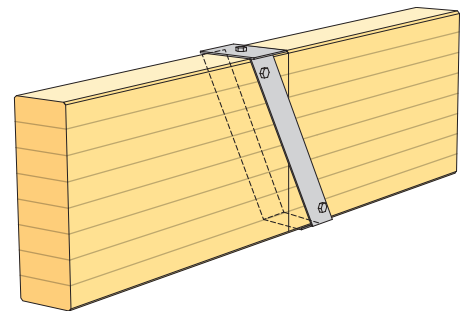

Figure 85 Gerber fastener of flat rolled steel
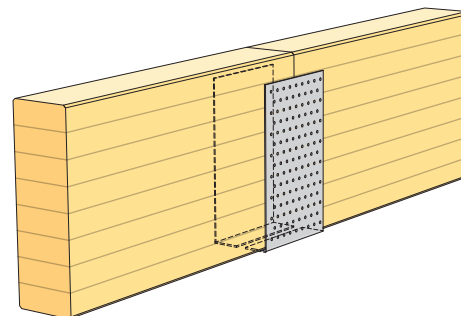

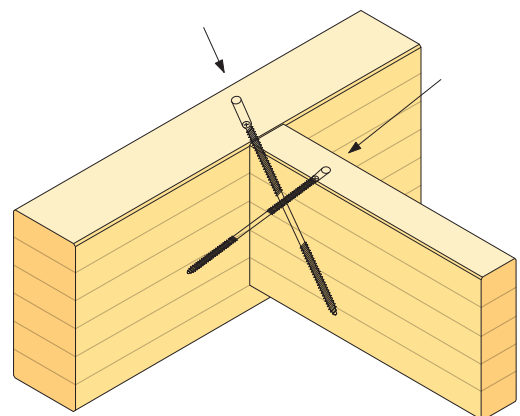**Figure 86** Standard gerber fixtures on both sides of a glulam beam

Figure 87 Connecting a secondary beam to a primary beam using a universal screw
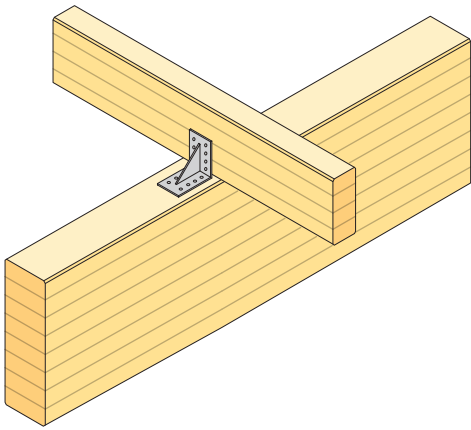
Figure 88 Purlin fixing using hot–dip galvanized steel angle brackets
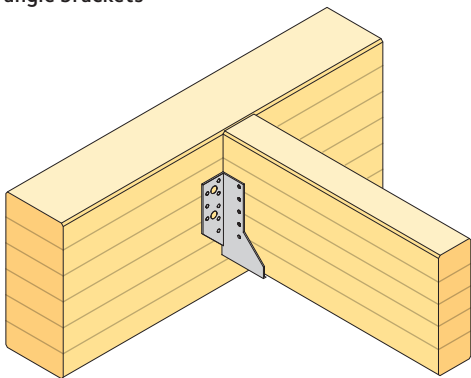

Figure 89 Hanger of steel metal sheet or structural steel. The steel plate option is available as a standard fixing.
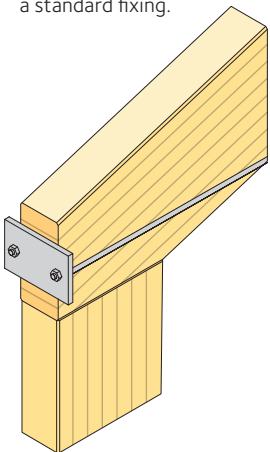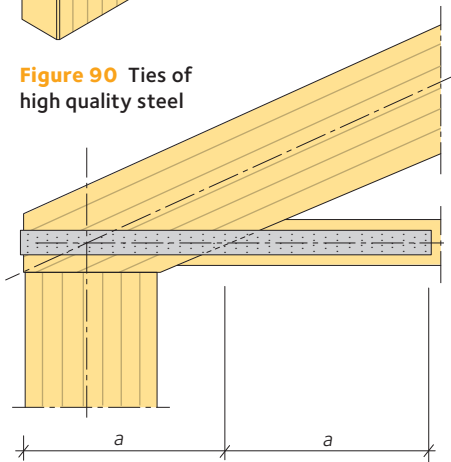

Figure 90 Ties of high quality steel

Figure 91 Ties of glulam and sheet steel/ nailed metal sheet that go around the beam end

Ridge fastening
Fastening of ridges in the primary beam's upper side is generally done with the aid of factory made fittings of cold formed, galvanized steel metal sheet, for example angle brackets. The fittings can be designed with reinforced grooves, or so-called cleats. The transfer of forces occurs mainly through contact pressure and with the aid of anchor nails or with screws. The manufacturer's instructions should be followed carefully.

Standard hanger and welded hanger
Connecting the secondary beam with a standard beam base is a simple and effective solution, above all when the beam's upper side lies at the same level. The transfer of forces occurs mainly through contact pressure and with the aid of anchor nails or screws. The manufacturer's instructions should be followed carefully. When large support reactions (transverse forces) are transferred from the secondary beam welded beam bases of hot rolled steel (flat rods or universal rods) are generally required.

The transfer of forces between the secondary beam and welded beam bases occurs mainly through contact pressure, while the transference of force between beam bases and primary beam occurs with the aid of nails, through-screws or some type of timber construction screw. Beam bases can be designed in different ways.

Tension rod fastening
Tie fastenings transfer only horizontal traction to the beam. As a rule the tie is formed by two or more steel rods. For small traction the tie can also be made of glulam. Normally the fastening is formed so that the tension forces act as close as possible to the point of intersection between the beam's and column's system lines.

Ties of steel
High strength ties are suitable for both small and large forces. The simplest fastening is obtained with a tie on each side of the beam. For moderate forces the two ties can be replaced with a single tie through a central hole in the beam. This however should be avoided with very high beams for manufacturing reasons. With large forces the two ties on the sides can be supplemented with a third, centrally placed tie. The steel sheet towards the beam's end timber surface is provided with nail holes for ease of assembly. The transfer of force occurs mainly via contact pressure from the metal sheet to the end-grain surface.

Ties of glulam
Glulam ties are suitable for use with small forces. The fastening of the ties in the beam can be made of flat steel bars that either go around the beam end or that end a short distance from the end of the glulam tie. The length of the flat steel or nailing plate should then be as shown in *figure 91*. With small forces the sheet steel can be exchanged for a nailed metal sheet. The transfer of horizontal forces occurs through contact with the aid of the welded-on anchor metal sheet and anchor nail or screw.

Dimensioning

Clear, correct and unambiguous dimensioning of a glulam element promotes a well-made glulam construction and lessens the risk of errors and delays when completing an item. An example of a correct dimensioning is given in *figure 92 below*.

All required views must be drawn up and figured. Cut arrows ease comprehension. Meanwhile it is often enough to draw up the beam or column viewed from the side. The glulam element is best oriented horizontally or vertically on the finishing work drawing, in order to save on drawing space and simplify the figuring.

For measuring, start from the unfinished glulam element and include all the sizes in the x- and y-axis required to be able to finish the beam. It is best to start from the same point on the figuring of for example a notch, even if it takes up more drawing space. If holes are made at the site, hole diameters and possible notches plus reinforcings are to be set out. If there are slits or glued on wooden parts these are dimensioned in a suitable way. Explanatory text can complement the figuring.

Modern 3D- drawing software normally generates 2D-drawings, which will need the figuring to be checked to ensure it is complete. If the 3D-models of glulam elements can be inserted in the finishing work drawing this simplifies the understanding with complicated processing.
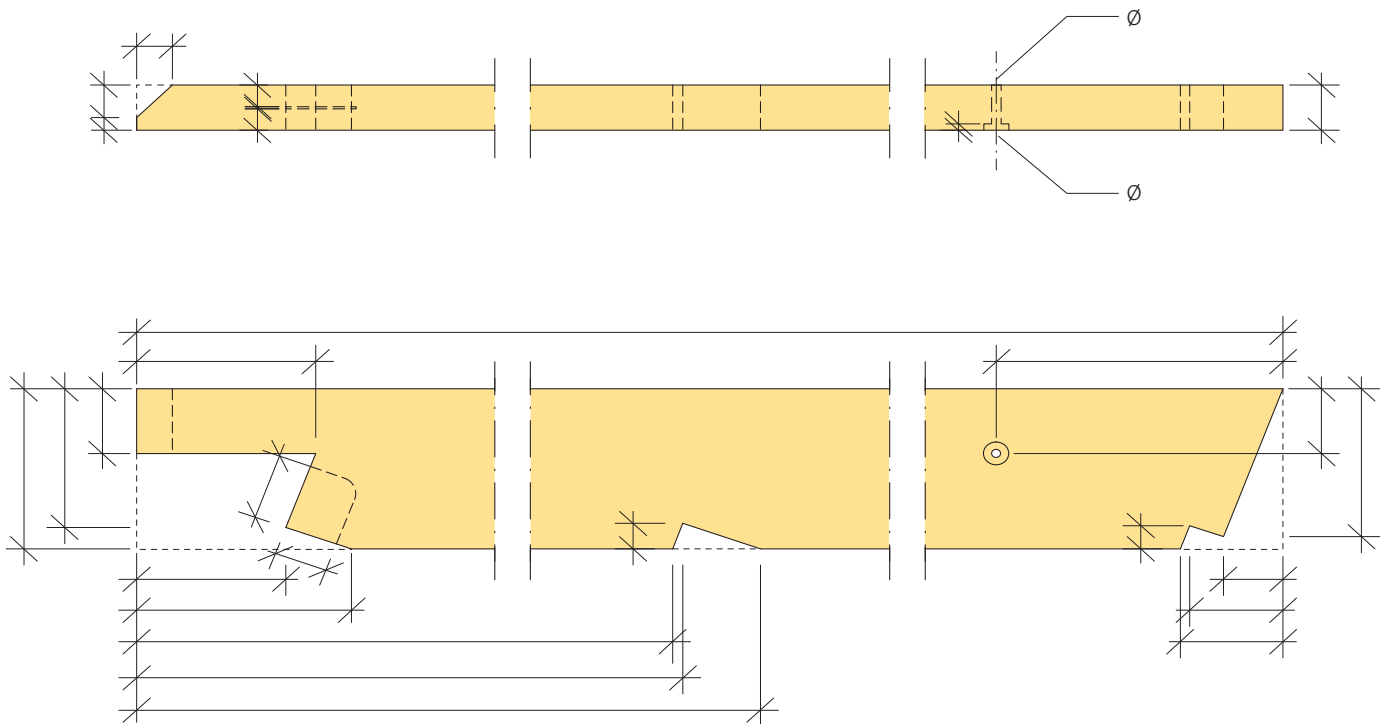

Figure 92 Examples of clear figuring for manufacture finishing work

Machine shed made of three-pin frames with finger-jointed corners.

Charred layer   Pyrolysis zone   Unaffected wood

Figure 93 Fire penetration

Design with regard to fire

Historically several fire catastrophes involving timber buildings have occurred — events which have left a trail in building legislation in the form of different restrictions for the use of timber in buildings. Experience has however also shown that in particular large timber structures retain a great deal of their load bearing capacity even during the initial stages of a fire. This experience has been mirrored for a long time both in the authorities' demands in building regulations, in which unprotected glulam and solid timber structures can be used even in fireproof buildings and in premium refunds of the insurance companies, where there is parity between structures of glulam and structures of concrete.

The rescue services often prefer glulam to other structural materials. Experience from many years of fires has shown that it is extremely rare for glulam structures to collapse in fires because the load bearing capacity remains satisfactory over a relatively long period of time. There are examples of a glulam structure being restored after a fire and used in the restored building.

Since the middle of the nineties a transition has been made to functional demands in fire regulations. This, along with an increased knowledge of correct structural design for fire protection and the implementation of timber structures, has brought with it new possibilities for timber structures that meet fire safety requirements. Therefore light timber joist structures are nowadays used even in multi-storey buildings.

Glulam and fire

If a timber structure is subjected to the effects of fire its surfaces will catch fire. Combustion then continues inwards with more or less constant speed. Penetration however takes place slowly because the carbon layer that forms is heat insulating and opposes the flow of heat from the fire room to the pyrolysis zone. In the pyrolysis zone the temperatures reached are between 250 °C and 350 °C and there combustible gases are generated that diffuse through the carbon layer until they meet the gases on the surface and start to burn. A clear boundary between the carbon layer and the remaining cross-section is established at 300 °C. With wide cracks and outer corners the penetration is greater. Metallic fasteners like screws, bolts, dowels etcetera can also contribute to increased heat flow in to the glulam's inner cross-sections and increased penetration.

The glue-lines have no negative effect on glulam's fire resistance, on condition that approved adhesives are used, for example melamine adhesive (MUF). Other adhesives, both old and new, can lose their strength at low temperatures and cause delamination, increased penetration and further reduction of the glulam's load bearing capacity.

Glulam's beneficial qualities in a fire are mainly because it "protects itself", that is to say through the carbon layer. Glulam's self-protection is only likely to be insufficient at the timber joints; here extra fire protection can be provided by securing cladding sheets of, for example, timber or plaster on the outside of the joint parts. An effective way to achieve secure fire protection is to use hidden fastenings with, for example, slotted-in sheets and dowels of steel. The dowels are protected from the effects of fire by concealing them with wooden plugs.

The temperature in the unburned parts of a large timber structure generally remains unaffected even during a long lasting fire. Temperatures of more than 100 °C occur only in a roughly 10 mm
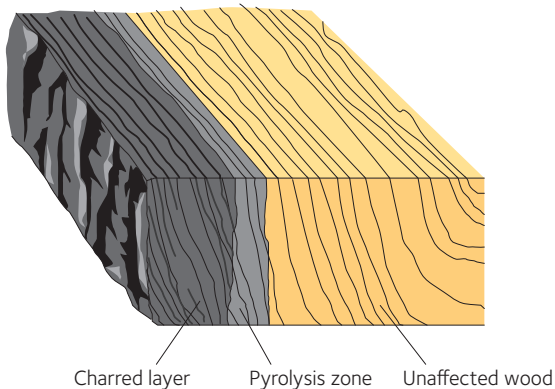
deep zone immediately under the carbon layer, where the strength and stiffness are considerably lower than in the unaffected timber. Temperature movements during a fire will therefore be negligible in a glulam structure as opposed to a steel or concrete structure, where linear expansion in a fire can provide a cause of secondary damage in, for example, supports or adjoining walled structures. Nor does a glulam structure deform as significantly in a fire as an unprotected steel structure. This is one reason why the total damage after a fire is as a rule less in buildings with a glulam structure than in those with a steel structure.

Fire technical demands in building regulations

The technical building fire protection demands in the Nordic countries are formulated as demands for a certain fire resistance in a structure or part of a building or on a certain fire technical class in the surface layer. There is also a class division for whole buildings that governs demands that apply to evacuation, and how great the risk is for serious personal injury if a fire should start. Factors like the building's size, number of floors and for what purpose it will be used, for example residential housing, affect the building's technical fire class.

If the risk of personal injury is very great the authorities demand that the building must be fireproof, that is implemented in building class Br 0 or Br 1. For other buildings, fire resistance implementation is required, that is class Br 2. For most one-floor buildings however, class Br 3 is sufficient, with the lowest requirements.

Structural sections

Load bearing structures should, according to national directives, be designed and dimensioned so that safety against failure is satisfactory in the event of a fire. That the requirement is met can be shown by calculating the load bearing capacity for realistic conditions relating to the temperature sequence (so-called natural fire sequence).

For timber structures the calculation methods are insufficiently developed to be used in practice. Therefore a simplified standard method is used, in which the temperature-time curve follows a given relation (standard fire). The load bearing structure is then built up of fire technically classified parts dimensioned for standard fires of different duration according to the national directives.

Fire technical class for load-supporting or separating building parts irrespective of material are referred to by names such as R15, R30, R60 and so forth, or EI30, EI60 and so forth where R means load bearing capacity, E integrity (tightness referring to fire gases and flames) and I insulation referring to temperature increase on the side not subject to the fire. The figures refer to the time in minutes for which the part of the building is capable of resisting the effects of fire in a standard fire, without losing its load bearing or separating function. A loadbearing and separating wall can for example need to meet the requirement REI60, that is to say resist a standard fire for an hour according to criteria referring to all three requirements.

Beams and columns of glulam are normally included in a building structure, which should be both load bearing and separating. Often the glulam members are visible and they will then also form a part of the building's roof or wall surface. When it comes to the load bearing and separating function for beams and columns, glulam can be used in all types of buildings, including multi-storey buildings, although the requirements relating to surface layers can in certain areas involve limitations.

Before fire   After 30 min   After 60 min

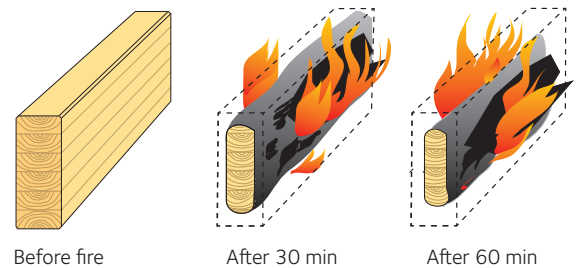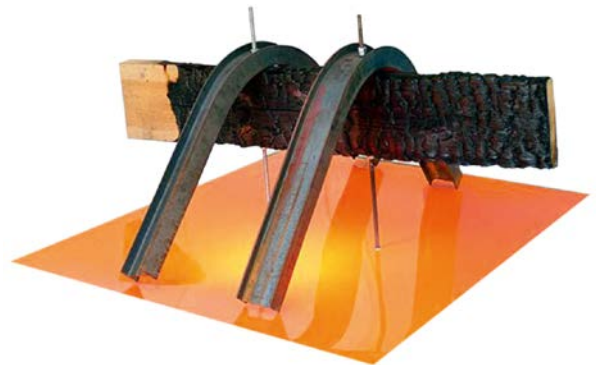**Figure 94** **Glulam retains a significant load bearing capacity even during a fire.** The protective carbon layer that forms on the burnt surface contributes to this. The picture illustrates a glulam cross-section before fire (on the left), after 30 minutes of fire (middle) and after 60 minutes of fire (on the right) with a four sided fire attack.

Glulam retains its load-bearing capacity in a fire, in contrast to unprotected steel.
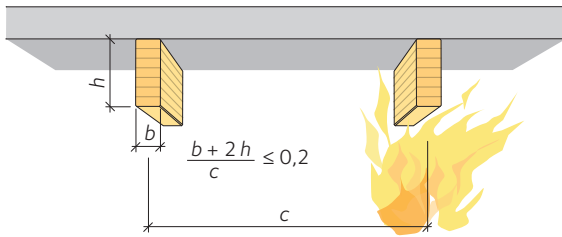
$$\frac{b + 2h}{c} \leq 0{,}2$$

Figure 95 The glulam beam's surface can be up to 20 percent of the floor area without demands of treatment in order to achieve a higher surface layer class than European Class D

Parking garage with glulam and cross–laminated timber (CLT) frame.

Surface layers

Surface layers are defined as the outer part of a building structure that can be exposed in the early stages of fire and indicate the ability to prevent or delay the flash point and smoke emissions in a fire. The surface layer can be an unprocessed wood surface, but if it is surface treated, the paint or varnish will be included. European classes for the surface layer, so-called Euro classes, are given in *table 19, page 65*. The classes have the denotation A1 – F with additions for smoke and − drop classes, which however are not normally decisive for the choice of material. Class B is the highest class, which can be obtained for combustible products and class D is equivalent to qualities in unprocessed timber paneling.

Glulam has generally been shown to meet the requirements for class D-s2,d0 according to the harmonised product standard for glulam EN 14080, *see table 19, page 65*. In the national regulations no detailed demands on surface layers are given apart from those that apply to emergency exit routes. The advisory text says however, that roof surfaces in fire proof buildings (class Br 0 and Br 1) should have surface layers that are equivalent to class B and wall surfaces to class C. Fire retardant buildings (class Br 2) should have surface layers class C in the roof and class D on the walls. For roof surfaces in both cases an underlay of non-combustible material or ignition protective cladding is recommended, for example plasterboard.

Demands on surface layers of higher class than class D (unprocessed timber) can be met by choosing an approved type of paint system. There are both translucent and opaque alternatives. However, naturally the demand for underlay of non-inflammable material or ignition protective cladding cannot be met for the parts of a roof or wall surface that consist of visible glulam.

In practice several materials are often found within the same roof or wall surfaces with different combustible qualities. It can then be difficult to decide if the standard demands on surface layer class are met. Normally the glulam structure should be completely or partly visible in a space where the national regulations demand surface layer Class B or C on non-inflammable underlay.

Currently the way a partly combustible surface works in terms of flame spreading and flash point is insufficiently known. It is however clear that small exposed glulam surfaces at a large distance from one another do not significantly affect the fire technical function of an otherwise non-inflammable surface.

In connection with the above named advice regarding surface layer class the Swedish regulations (the Swedish National Board of Housing, Building and Planning building regulations, BBR) say the following: "For smaller building parts, where surface layers lack importance in the outbreak of fire, the surface layer can be made of a lower class, however at least Class D." The same applies to small rooms when the surface layer does not affect the evacuation safety in the building. The authorities have in their judgment normally assumed that the surface layer class of a non-inflammable floor slab (for example load bearing wood-wool elements) supported on untreated glulam beams is unaffected if the exposed total area (the sum of the surface exposed to fire) does not exceed 20 percent of the floor area. Beams, which are surface treated to Class B, can be generally acceptable.

The installation of an automatic sprinkler system can make so-called technical exchange possible. This means that a passive fire protection system, for example a fire classed construction, is replaced by an active system like a sprinkler. The demand for surface layer class can for

Table 19 European surface layer classes according to EN 13501–1

Fire class	Smoke class	Droplet class	Older Swedish class	Examples of products
A1	–	–	Non-inflammable	Stone, concrete
A2	s1 – s3	d0 – d2	Non-inflammable	Plasterboard, mineralwool
B	s1 – s3	d0 – d2	Class I	Fire protected timber
C	s1 – s3	d0 – d2	Class II	Wall paper + plasterboard
D	s1 – s3	d0 – d2	Class III	Timber, glulam, wood-sheets
E	–	–	Unclassified	Certain plastics
F [1]	–	–	Unclassified	Certain plastics

[1] Does not fall into class E and must not be used in buildings under Boverket's (the Swedish National Board of Housing, Building and Planning) Building Regulations (BBR).

example be reduced with the installation of a sprinkler system. There are also advanced models for the design of separate buildings where classification gives far too simplified a solution, for example through so-called fire safety engineering.

Fire resistance of glulam structures

The national regulations in the Nordic countries for verifying methods for timber structures at risk of fire are limited. Calculation models on penetration and strength reduction can be obtained from Eurocode 5, while safety parameters (partial coefficient, load reduction factors etcetera) must be obtained from the applicable national additional document, EKS.

The design of a fire exposed glulam beam has two stages. First the residual composite section is calculated, that is to say the composite section, which is left when the carbon layer has been subtracted. The carbon layer's thickness increases by 0.7 mm/minute. If that value is used the increased penetration at corners is taken into consideration.

As capacity reduction happens partly because of partial heating of the residual cross-section, one can, according to a simplified method, reduce the residual cross-section area through an equivalent increase of the penetration depth by a maximum 7 mm after 20 minutes exposure to fire. The effective residual cross-section thus obtained is then deemed to have the same qualities as the cold cross-section. In other words: design in the case of fire is carried out with a reduced composite section as at normal temperature.

The design strength value for the effectively reduced cross-section is then the characteristic strength (at the normal temperature) divided by the partial coefficient for the action (γ_m = 1.00). According to Eurocode 5 the strength can increase by 15 percent. The recalculation factor for the reduction of the designed strength with reference to load duration and service class for design at normal temperature is irrelevant in the case of fire.

Glulam beams

Examples of glulam beams with rectangular cross-sections, which meet the fire technical classes R30 and R60 are given in *table 21, page 67*.

The table gives the required sizes when the fire attacks from three or four sides. The table values apply if no risk of tilting exists. On loss of the stabilizing element, for example with roof ridges, tilting must be taken into consideration in the design.

Table 20 Class of reaction to fire performance for glulam, according to EN 14080

Material	Min. density, average value (kg/m³)	Min. thickness (mm)	Class
Glulam	380	40	D – s2, d0

Barn with glulam load-bearing structure.

Universeum, Gothenburg, Sweden.

In the event of fire, a reduced load is assumed, *see EN 1995-1-2 section 2.4.2*. The load effect in a fire, $E_{d,fi}$, on a single structural element is calculated as $E_{d,fi} = \eta_{fi} \times E_d$, where E_d is the design load effect when designing for the main load combination at normal temperature according to the relevant EKS and η_{fi} is the reduction factor for the design load in a fire, depending on the load ratio $Q_{k,1}/G_k$ and the combination factor ψ_{fi} for frequent value for variable loads.

The recommended figure for general calculations is $\eta_{fi} = 0.6$. Under an imposed load in category E as set out in EKS (areas susceptible to accumulation of goods, including access areas), the recommended value is $\eta_{fi} = 0.7$. The reduction factor η_{fi} can be lower for lightweight floor systems. For example, for snow loads in snow zone 3, the recommended value is $\eta_{fi} = 0.3$. It is however simpler to calculate the effective reduced cross-section directly according to the above and to compare load bearing capacity with the given load effect. *See The Glulam Handbook Volume 2*.

Glulam columns

Fire resistance for glulam columns can be calculated according to the same principle as for beams. As the column's slenderness increases in time with the fire reducing the cross-section, so the result cannot be summed up in a simple table, but a special calculation must be made for each individual case. Often fire technical class R30 is achieved without the cross-section size needing to be increased with regards to the fire effect while class R60 normally requires a certain over-dimensioning.

Fire protection of connections and fittings – General viewpoints

While the actual glulam element has excellent qualities in connection with a fire, the bindings and connecting details of steel often comprise weak points, which need to be fire protected, if the structure as a whole is to meet the demands of a certain fire technical class. Some rules for fire technical classifying of fastening details are given in *The Glulam Handbook, Volume 2*. Additional dimensioning is found in EN 1995-1-2 (Eurocode 5) on which the information below is based.

According to a simplified rule of thumb in Eurocode 5, an unprotected nail, timber-screw or screw joint which is fully used at normal temperatures also manages exposure to fire for at least 15 minutes and an unprotected pinned joint at least for 20 minutes depending on the configuration of the joint. By less use, fire resistance can, for example in the pinned joint, increase to up to 40 minutes. In order to achieve normal fire resistance requirements for fire technical class R30 or R60 either greater glulam sizes, extra fire protection insulation or reduced degree of usage is required, that is to say through over-dimensioning. The measures can be combined.

The fire protection insulation's function is to delay the critical temperature condition after 15 or 20 minutes for an unprotected strap so that it appears at the earliest after 30 or 60 minutes.

Surface mounted steel details can be protected with fire protective paint according to the respective paint-manufacturer's instructions. Effective protection of a joint is achieved when it is enclosed with timber or glulam, plywood, plasterboard or rock-wool. Fire protection insulation of wood or plywood should preferably be sufficiently thick to not burn away during the time the classification refers to.

Table 21 Minimum beam height with reference to fire safety class for glulam beams with rectangular cross-section. [1]

Fire class	η_{fi}	90	115	140	165	190	215
				Glulam beam width (mm)			
Three-sided fire attack							
R30	0.3	90	90	90	90	90	90
	0.4	135	90	90	90	90	90
	0.5	225	115	90	90	90	90
	0.6	495	180	135	135	90	90
	0.7	–	225	180	135	135	135
R60	0.3	–	–	225	180	135	135
	0.4	–	–	360	225	180	180
	0.5	–	–	–	315	225	180
	0.6	–	–	–	540	315	270
	0.7	–	–	–	–	495	360
Four-sided fire attack							
R30	0.3	180	135	135	135	135	135
	0.4	270	180	180	135	135	135
	0.5	405	225	180	180	180	180
	0.6	945	315	225	225	180	180
	0.7	–	450	315	270	225	225
R60	0.3	–	–	405	360	270	225
	0.4	–	–	720	405	315	315
	0.5	–	–	–	585	450	360
	0.6	–	–	–	1,080	585	495
	0.7	–	–	–	–	990	675

[1] Assumptions: Glulam GL30c, climate class 1 or 2, safety class 3 and load duration class M. *See also section 16.2 in The Glulam Handbook Volume 2.*

Table 22 Examples of fire protection insulation of different joints
Insulation thicknesses in mm. [1]

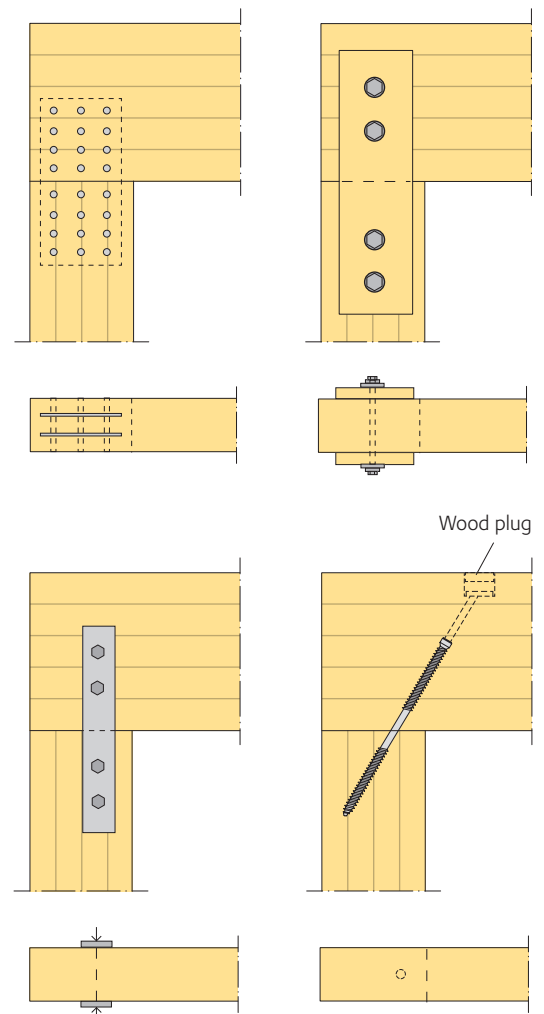| Material	Min. density, average value (kg/m³)	Nail, wood screw, screwed joints		Dowel joints	
		R30	R60	R30	R60
Particleboards [2]	600	19	[3]	14	[3]
Plywood, LVL	450	23	[3]	16	[3]
Construction timber, glulam	350	16	44	10	40
Normal plasterboard (type A)	–	12.5	3 × 12.5 [4]	9	2 × 12.5 [4]
Fire-resistant plasterboard (type F)	–	12.5	2 × 12.5 [4]	12.5 [5]	2 × 12.5 [4]
Gypsum fibreboard	–	12.5	3 × 12.5 [4]	9	2 × 12.5 [4]
Stone wool board	30	60	140	45	125
Stone wool board	120	40	80	35	75

[1] Standard thicknesses can be greater.
[2] Chipboard, fibreboard, OSB.
[3] Multiple layers can be calculated according to EN 1995–1–2.
[4] Nailing or screwing of each layer.
[5] Minimum thickness available in Sweden.

The reason is that the gains of fire protection insulation subside very quickly after the protection has fallen away. The same applies for normal plasterboard, which can fall down when the timber has begun to char behind the plasterboard, while plasterboard type F (fibre glass reinforced) stays considerably longer.

Cladding with surface mounted fire protection is more effective than the equivalent over-dimensioning of timber parts, as it also prevents increased heat conduction into the cross-section through the connectors. Sheets of glulam or plywood are glue-nailed against the glulam surface. Instead of gluing, painting with fire protective paint on each contact surface is an effective way to block up possible cracks. For pinned joints, very effective fire protection is obtained through increased glulam sizes plus wooden plugs that protect the pinned joints from exposure to fire. In the screw joint it is important that the screw head is countersunk and is covered by fire protective insulation.

Table 22 gives examples of required thicknesses for classes R30 and R60 for different fire protection insulation for pinned joints with slotted-in steel sheets and for nailed metal sheet plates. In certain cases lower load usage is required in the joint at a normal temperature. The cheapest alternative is normally rock wool but appearance-wise cladding with glulam, plywood or painting with fire protection paint is preferred.

Wood plug

Figure 96 Examples of different types of glulam post–beam connections that meet certain fire resistance requirements

Other glulam products

Glulam exterior cladding

Wide exterior cladding is manufactured from glulam, with cross-sectional dimensions of 25 × 225 or 25 × 325 mm. The raw material is spruce and the glulam cladding has a vertical grain for increased longevity, dimensional stability and durability. There is one profile for vertical and another for horizontal glulam cladding. The visible front face is finely sawn. Glulam exterior panels can be supplied primed, or primed and undercoated.

Vertical glulam exterior cladding*

Fine-sawn front face.
Three planed sides.
Rebate and bevels are grooved.
Vertical installation is recommended.
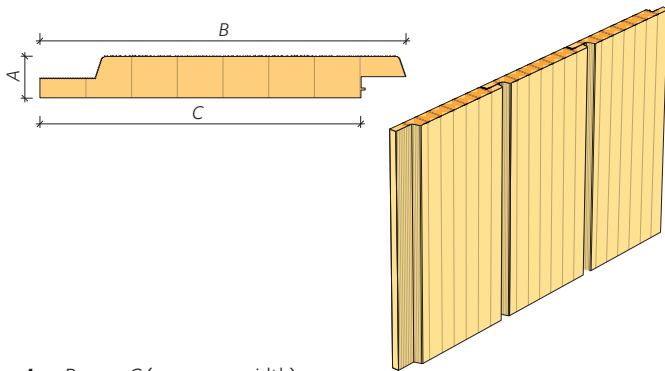
A × **B**	**C** (coverage width)
25 × 225	200
325	300

* Not Swedish standard.

Horizontal glulam exterior cladding*

Fine-sawn front face.
Sawn vertically from a glulam beam.
Three planed sides.
Rebate and bevels are grooved.
Horizontal installation is recommended.
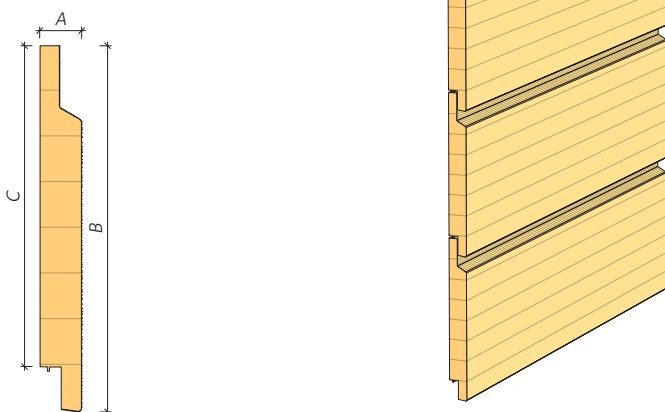
A × **B**	**C** (coverage width)
25 × 225	200
325	300

* Not Swedish standard.

Custom production

Where unusually large spans, loads or other circumstances determine the design, glulam is manufactured according to drawings and associated documents, in consultation with the glulam manufacturers. Custom-made glulam is available in virtually any dimension and shape to meet the client's requirements and circumstances.

Examples of common custom glulam products include cambered beams, curved beams, tapered beams, pitched beams, frames and arches.

The cambering of glulam elements is done by the glulam manufacturer according to the client's drawing and description. The size of the camber must correspond to the calculated deflection. Camber is not needed on shorter beams.

Glulam exterior cladding on façade.

Surface treatment and maintenance

In order to get a long-term sustainable surface on the glulam, surface treatment with associated maintenance must be carried out on site, especially if the glulam will be exposed to the weather outdoors (of course protected under roof). Load bearing glulam structures should be protected against precipitation and moisture, for example ground moisture. Outdoors exposure can however occur, for example to columns at the entries and façades of glulam panels.

Many surface treatments provide a certain protection against moisture uptake and drying out. Certain surface treatments also have a somewhat protective effect against the attack of microorganisms. With damp protective surface treatment, deformations and the formation of cracks are prevented to a certain degree. Most cracks that appear on glulam surfaces generally present no risk with regards to load bearing capacity. If unsure however, the glulam supplier or a structural engineer should be contacted for an opinion. Paint manufacturers can provide detailed information on different methods of surface treatment and maintenance. Some general advice is given here.

Surface treatment

Considering the surface treatment's formation one differentiates between film formation and non-film formation.

- Stain finishing, top-coat paint systems, clear varnishes and special surface layers, for example polyurethane, are film formation surface treatments.
- Colourless wood oils and different kinds of chemical surface treatments, for example green-vitriol treatment (iron sulphate), which are used to accelerate the ageing of a timber surface, are non-film formation surface treatments.

A film forming surface treatment makes the surface easier to clean and protects the glulam against mechanical damage. There are also special top-coat paints and clear varnishes that counteract flame spread and smoke emission in a fire, *see further under section Design with regard to fire, page 62*.

Generally glulam can be surface treated with the substances and methods used for timber. Technical, economic and aesthetic conditions decide the choice in each individual case. Glulam of treated lamellas certainly provides an effective protection against rot, but must be surface treated and maintained in the same way as normal glulam.

The manufacturer generally delivers glulam with a moisture content that corresponds at most to a target moisture content of 16 %. During installation, the surface moisture content of the glulam may be a maximum of 18 %. When painting, the surface moisture content may be a maximum of 16 %.

**Glulam indoors – surface treatment advice**

- In premises with normal humidity no surface treatment of the glulam is required unless a different colour than its own wood colour is chosen. Then all types of wood surface treatments can be used — top-coat paint systems, stain finishing, clear varnishes or wood oil. For maintenance painting the same type of surface treatment should be used as was originally used.
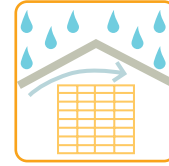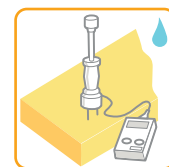
Protect from precipitation

Protect from sun
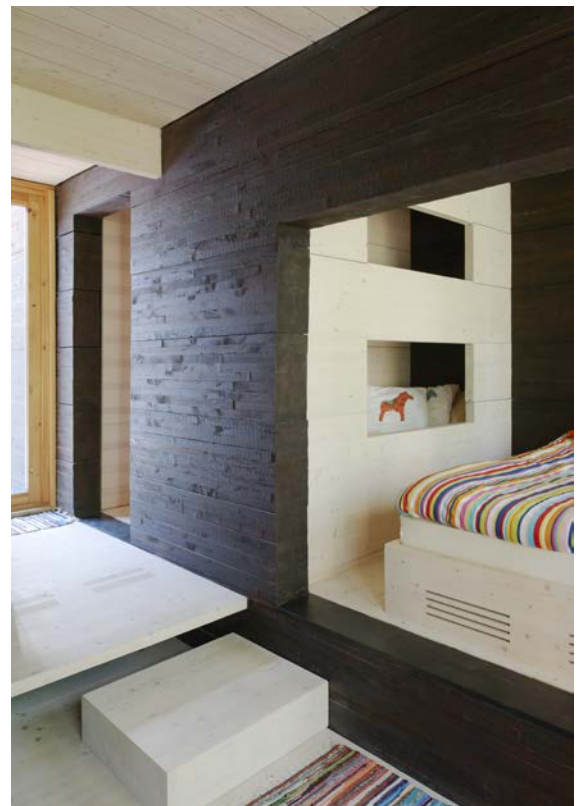
Forest sauna

Moisture meter

Check the moisture content

Guidance on the choice of surface treatment for interior glulam

Combination options for new painting and maintenance: ■ = Suitable   ■ = Possible   ■ = Unsuitable

Table 23 Guidance on the choice of surface treatment for interior glulam

Paint type	Linseed oil paint	Alkyd paint	Acrylic paint [1]	Wood preservative [2]	Clear varnish	Wood stain [3]
New painting						
Untreated, new	■ Suitable	■ Suitable	■ Suitable	■ Suitable	■ Suitable	■ Suitable
Maintenance						
Previously painted, linseed oil paint	■ Suitable	■ Possible	■ Possible	■ Unsuitable	■ Unsuitable	■ Unsuitable
Previously painted, alkyd paint	■ Possible	■ Suitable	■ Suitable	■ Unsuitable	■ Unsuitable	■ Unsuitable
Previously painted, acrylic paint	■ Unsuitable	■ Unsuitable	■ Suitable	■ Unsuitable	■ Unsuitable	■ Unsuitable
Previously oiled, wood preservative	■ Suitable	■ Suitable	■ Possible [4]	■ Suitable	■ Possible	■ Possible
Previously varnished	■ Possible	■ Possible	■ Suitable	■ Unsuitable	■ Suitable	■ Possible
Previously painted, wood stain	■ Possible	■ Possible	■ Possible [5]	■ Unsuitable	■ Possible [6]	■ Suitable

[1] Alkyd paints are recommended for interior countertops in wood and the intermediate faces of coupled windows. Solvent–based paints and water–based paints are available.

[2] Commercial products are usually a combination of various drying and non–drying oils plus fungicides. Relatively short maintenance intervals. Oils that contain wax should be avoided.

[3] Accentuates the structure and grain of the wood. Various binders are used, including alkyd and acrylic. Water–based and solvent–based stains are available.

[4] Oiled wood surfaces should be primed with an alkyd undercoat before applying the topcoat.

[5] Stained wood surfaces should be primed with an alkyd undercoat before applying the topcoat.

[6] Clear varnish is used as a protective topcoat on stained surfaces that are subject to heavy wear.
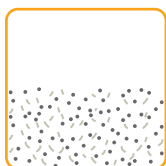
Protect glulam:

From precipitation

From sun

From dirt

Against ground moisture

- In high humidity premises, for example swimming baths and wet rooms or other premises with a risk of condensation, one should be careful with treatments that require major pre-treatment for maintenance, for example top-coat paint systems and clear varnishes. Choose a more maintenance-friendly surface treatment, for example stain finishing or wood oil.

Glulam outdoors – surface treatment advice

- Untreated glulam that has been surface treated with a non-pigmented treatment (colourless wood oil or clear varnish) becomes grey after a period of outdoor exposure. An untreated glulam timber surface can absorb moisture from precipitation, melted snow water, and splashed water, which leads to discoloration, deformation and surface cracks.
- The major destructive factors of outdoor exposure of glulam are sun radiation, precipitation, dirt and ground moisture. Changes between rain and sunshine provoke considerable stress on the glulam surface.
- In sunshine a surface can quickly reach a high temperature — dark surfaces can reach up to 70 °C. This gives a rapid drying out of the surface and movement, with the risk that the timber surface and any film forming surface treatment successively begin to crack.

Avoid crack formation

Glulam products that are designed to be exposed outdoors, e.g. façade boards, can be delivered industrially base-treated, to be top-painted after mounting. With such a treatment, the primer should

Guidance on the choice of surface treatment for exterior glulam

The properties are divided into three classes: **3** = Very good **2** = Good **1** = Less good
The properties may vary due to e.g. film thickness, non-volatile matter, pigment type.
Combination options for new painting and maintenance: ■ = Suitable ■ = Possible ■ = Unsuitable

Table 24 Guidance on the choice of surface treatment for exterior glulam

Paint type	Linseed oil paint	Alkyd paint	Acrylic paint [1]	Distemper [2]	Translucent coating [3]	Wood stain	Wood oil [4]	Wood tar [5]
Properties								
Moisture protection	3	3	3	1	2	2	2	2
UV protection and colourfastness	3	3	3	3	2	1	1	2
Gloss retention	1	2	3	1 [6]	2	1	1	1
Mechanical protection	3	3	3	2	2	1	1	1
Drying time	1	2	3	3	3 [7]	3 [8]	1	1
New painting								
Untreated, new	green	green	green [11]	green	green	green	green	green
Untreated, surface aged	yellow	yellow	yellow [11]	yellow	yellow	yellow	yellow	yellow
Pressure treated, wood protection classes NTR A and NTR AB [9]	green	green	green	green	green	green	green	green
Pressure-treated, wood protection class NTR B [10]	green	green	green	red	yellow	yellow	green	yellow
Maintenance								
Previously painted, linseed oil paint	green	yellow	red	red	red	red	red	red
Previously painted, alkyd paint	yellow	green	green	red	red	red	red	red
Previously painted, acrylic paint	red	green	green	red	red	red	red	red
Previously painted, distemper	red	red	red	green	red	red	yellow	yellow
Previously painted, wood stain	yellow	yellow	yellow	red	green	green	red	red
Previously oiled, wood preservative	green	green	yellow	red	green	green	green	yellow
Previously oiled, petroleum oil	red	red	red	red	red	red	red	red
Treated with wood tar	red	red	red	red	red	red	yellow	green
Treated with iron sulphate	yellow	yellow	yellow [11]	yellow	yellow	yellow	yellow	yellow

[1] When using acrylic paint on untreated wood, the surface of the wood should be primed with a penetrating priming oil and undercoated with an alkyd oil paint in line with the manufacturer's instructions.
[2] Distemper is usually red, but other pigments do occur. Water-based. Only on unplaned wood surfaces. Linseed oil content max 8 percent of the wet paint's weight.
[3] May have different binders, e.g. alkyd, acrylic or alkyd + acrylic. Water-based or solvent-based.
[4] Commercial products are usually a combination of various drying and non-drying oils, sometimes with a small amount of fungicide for protection against microorganisms. Oils that contain wax should be avoided.
[5] Different grades are available. Dries very slowly. Strong odour.
[6] Distemper has a matt finish.
[7] For solid wood stain with alkyd as binder, drying time is **2**.
[8] For wood stain with alkyd as binder, drying time is **2**.
[9] Use of treated wood and wood preservatives is regulated by the Swedish Chemicals Agency.
[10] Used for pine windows and garden furniture, for example, and is oil-based.
[11] Wood surfaces should be primed with penetrating priming oil and then a coat of alkyd oil undercoat before applying the top coat.

have a film thickness of at least 60 µm (micrometres) as a dry layer. 60 µm is the same as 0.06 mm, which thus means that 1 litre of paint is required for around 6 m².

Small, so-called drying cracks, are in general so superficial that they do not create any greater nuisance. Larger cracks allow water to penetrate into the glulam. They also create pockets for moisture holding rubbish and dirt, which can speed up the attack of microorganisms.
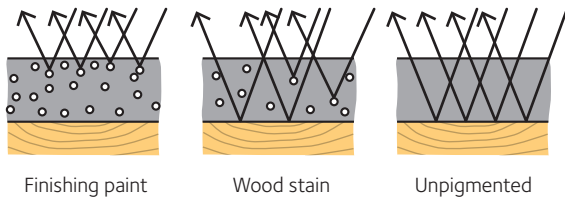
Finishing paint   Wood stain   Unpigmented

Figure 97 **The sun's UV rays break down the surface of the wood**
The illustration shows the difference in the treatments' ability to inhibit such decay.

Metropol Parasol in Seville with protective polyurethane coating.

Follow the checklist provided   Check the glulam

Especially in horizontal surfaces and in large cracks where the water can remain for some time, there is high risk of rot. These cracks should be filled with suitable material to prevent continued crack formation.

The right building design and building technology can minimize long-term moisture absorption. Heating from heat induction pipes or hot air blowing in, risk local drying out and crack formation. Rapid changes in moisture content can be alleviated with moisture protecting cladding or surface treatment.

End-grain absorbs moisture significantly quicker than other timber surfaces. Glulam elements that have exposed end-grain surfaces and upper sides must as a rule be protected with a ventilated cladding, of for example metal sheet. If that is not possible, the exposed surfaces should be treated regularly with moisture protection, for example a penetrating oil, a wood preservative or similar product with equivalent effect.

Prevent destruction by UV–radiation
Using a pigmented surface treatment gives better protection against UV-radiation. The higher the percentage of pigment, the better the protection — a top-coat paint gives optimal UV-protection and good durability. Stain finishing treatments give limited UV-protection and thereby less durability compared to the top-coat paint system.

Clear varnish and colourless wood oils provide insufficient protection against UV-radiation and should not be used for outdoor exposed glulam that is hard to replace, unless the superficial weather greying is unacceptable. Clear varnish on exterior glulam can gradually begin to crack and flake off, which makes maintenance difficult. There are some clear varnishes with built in UV-filters. In certain contexts, for example for the spectacular building Metropol Parasol in Seville, glulam can be treated with a protective surface layer of polyurethane.

Maintenance in general

Maintenance of buildings accounts for a major part of the total running and maintenance costs. Looking after buildings requires understanding, knowledge, care and judgment. A building, which is not maintained deteriorates. Wooden bridges are subject to regulatory requirements for regular inspections.

The purpose of maintenance is to keep a building and its functions working over time. Regular yearly inspections of different parts of the building are included in the running maintenance and are necessary in order to discover reduced function or incipient damage in time to take suitable remedial measures.

There are no specific maintenance intervals for individual materials and structures. External impacts can vary so much that it is impossible to generalize about how often an inspection needs to be made and what maintenance intervals are needed for different measures.

Maintenance planning

A maintenance plan should contain measures that are required during the period in question, normally 10 – 15 years. In the maintenance plan the measures, which will be carried out annually, are reported during the period including range and costs.

The conditions of a glulam structure from a maintenance viewpoint can be determined by different methods. The most common and simplest way is by visual assessment on site. An experienced surveyor can get a good picture of the glulam structure's maintenance status.

Measuring the moisture content in the glulam is a standard way of assessing moisture conditions. If there is an attack of microorganisms, special companies can determine the type and species by cultivation.

Overviews and checks should be done regularly and systematically in the form of regular maintenance inspections. The result of the maintenance survey then serves as a foundation for the assessment of the measures that should be taken and when these measures must be carried out at the latest.

For glulam structures, the following should be observed:
• Load bearing capacity.
• Occurence of rot.
• Occurence of microorganisms.
• Moisture content in the glulam.
• Occurence or traces of insects.
• Occurence of cracks and delamination.
• Occurence of slots and gaps.
• The joints' function.
• Occurence of excess sag (floor joists/balconies/verandah floor beam).
• Deformations, for example abnormal deflections or other changes in shape.
• Condition of fixings, e.g. presence of corrosion.

Outdoor exposed glulam

Sensitive points for glulam include eaves with cantilever beams and outdoor columns. End surfaces are especially sensitive to moisture absorption and therefore require regular inspections.

Horizontal glulam surfaces should be covered with metal sheet or protected in a comparable way against precipitation. Plates and plate coverings should be regularly checked so that they meet their intended function.

Paint layers protect the timber surface from the destructive UV-radiation and as a rule also against moisture absorption. As soon as a year after painting visible defects appear in a paint layer, which successively increase with the years.

Exterior effects vary widely between buildings on the coast and those further inland. Even the compass points have different effects — a south facing façade is more exposed to different climatic influences than the other façades. North facing façades are colder.

Measuring average moisture content in a piece of wood – electrical resistance method

Approximately 15 mm into the glulam laminates.

300 mm from the end.

0.3 times the glulam's width from the edge.

Measuring surface moisture content in a piece of glulam – lay the electrodes against the surface, parallel with the end.

300 mm from the end.

Press the tips of the electrodes down into the sapwood (lighter)

Press

20–30°

Longitudinal direction of the glulam

The lower part of the electrode can be filed down to achieve the correct angle.

Figure 98 Measuring average and surface moisture content

Cowshed with glulam frame.

Glulam bridge for heavy traffic.

Example of an arch with inset steel plates and steel dowels.

The altitude of buildings can also have various effects. Wooden bridges over waterways are exposed to large amounts of moisture.

Changes in air humidity can lead to moisture movements, which in their turn can cause cracks in the timber surface and in the paint layer. The maintenance needs for different paint systems varies just as much as the climate varies.

Materials outdoors are exposed to intensive soiling from air pollution. For technical and aesthetic reasons painted surfaces can need to be cleaned. Water and a soft brush are as a rule sufficient. A high pressure cleaner is effective on painted surfaces but care should be taken with the outer environment and with the working environment, making sure that the façade is not exposed to great amounts of moisture that cannot disperse within reasonable time.

The painted surfaces should be regularly checked with regards to the occurrence of discolouring, blistering and cracking. The glulam should be free from rot and microorganisms (mould and bruising). Large, penetrating cracks in glulam make unsuitable base treatment (priming) for top-coat paint systems, which is why such timber should be replaced during maintenance. Cracks that allow moisture ingress and are impossible to eradicate with paint, should not be permitted in glulam exposed outdoors.

After determining the structural state of the glulam, what remains is to suggest and undertake necessary maintenance measures. If the existing paint layer should be removed one is free to choose the type of paint for repainting. If the existing paint layer is in such condition that substantial parts can be allowed to stay, one should, when choosing paint, take into careful consideration the existing paint layer.

Maintenance painting

Painting is not allowed on glulam that has rot damage or large cracks. There are always minor cracks, which normally do not cause any problems if treated liberally with penetrating primer oil and primer paint.

During maintenance, glulam that is damaged or otherwise unsuitable as priming support for paint should be replaced before the painting work can begin. Surfaces that are attacked by micro-organisms should be cleaned.

Fresh timber surfaces intended for top-coat painting must be protected against light decay as soon as possible, as the wood surface deteriorates even after a few weeks' exposure outdoors, reducing the durability of certain paint types, especially for modern top-coat paint systems. After checking the surface moisture content, such glulam should therefore be surface treated as soon as possible following installation.

It is important to minimize the risk of moisture absorption by the outer glulam layer, so as to counteract crack formation, deformations and biological attack. The most effective and durable moisture protective surface treatment is obtained with a top-coat, film-forming paint system.

Repainting as a rule can be done on existing paint layers on condition that the paint layer is well anchored in the wood surface. Flaking paint layers should be removed. The same paint type should be used for repainting as the existing outer paint layer, providing that the existing paint has not caused rot. If the existing paint layer is too thick or cracking after a number of maintenance paintings, paint removal should be considered.

When top-coat painting, start with a primer that can penetrate the glulam surface. When using traditional paint types like linseed oil paint and solvent borne alkyd oil paint, priming can as a rule consist of either diluted ready mixed paint or a special primer (in some cases diluted topcoat).

In a modern top-coat painting system the primer treatment is in generally a two step treatment with a penetrating primer oil and a sealing primer paint. The penetrating primer oil will give moisture protection and contain functional constituents against attack from microorganisms. The primer paint should be penetrating and give further moisture protection. The finishing paint, top-coat, is normally alkyd oil paint or acrylic paint, but other paint types also occur, for example mixtures of alkyd and acrylic. Technically the top-coat should protect the primer paint against decay. A modern topcoat system has water-based products that are gentle on the environment and people. The paint manufacturer's instructions should be carefully followed.

The original surface treatment has from the beginning been chosen with regards to several different factors. Top-coat paint systems give good colour and weather durability, but often require major preparation for maintenance.

Stain treatments give less colour and weather durability compared with the top-coat paint system but are simpler to maintain. The choice of surface treatment is also determined by aesthetics.
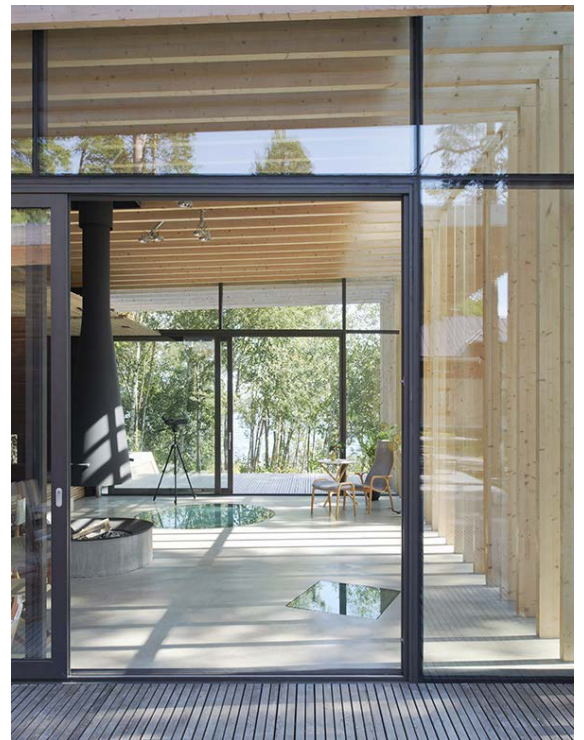
Forest sauna. Walls with linseed oil glaze, floor untreated heartwood pine, glulam pergola roof in grey–white oil glaze.

Finishing top coat

Undercoat

Penetrating priming oil

Figure 99 Paint systems

Pressure–treated glulam post.
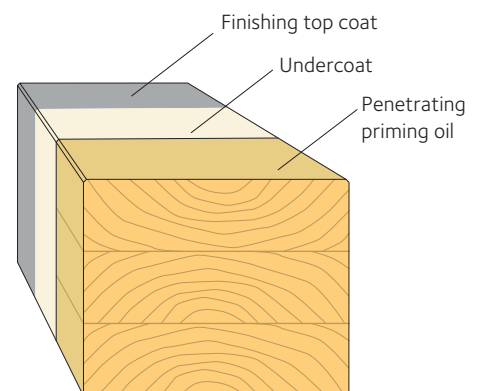
Wood protection

Glulam with treated lamellas

Where wood protection design is deemed insufficient and where failure carries a risk of serious personal injury, glulam made of treated lamellas should be used.

In certain situations, using glulam manufactured from treated lamellas provides long-term effective protection against rot. It can however not replace good technical wood protection design, but should be seen as a complement. Moisture, absorbed by a structure can cause other problems than rot, for example deformations.

Treated timber is sold in the Nordic countries in four different wood protection classes, NTR M, NTR A, NTR AB, NTR B, NTR Spruce and NTR GW, which are suitable for different areas of use. Wood protection classes NTR M are meant for use in sea-water, where there is risk of attack by shipsworm. Class NTR A is intended for permanent ground contact, and class NTR AB for use above ground.

Class NTR B is intended for external carpentry and is used almost exclusively for impregnating timber for wooden windows and doors.

Treated timber, according to these classes is produced according to common Nordic rules established by the Nordic Wood Preservation Council (NTR) based on European standards. The companies producing classified, treated timber are certified according to a set of rules that has also been drawn up by the NTR.

Glulam can be manufactured with lamellas of treated timber and the protection effect can be further increased by post-treatment with penetrating primer oil or even pressure impregnation.

Note that glulam products cannot be NTR classified, only the timber lamellas.

The national chemical authority's directives regulate the use of treated timber. These directives are different in the Nordic countries. Timber for structures requiring especially good protection against wood destroying organisms may be treated in wood protection class NTR A in the following situations:

- Structures in permanent contact with ground, fresh or brackish water.
- Structures above ground where personal safety requires that they are not weakened, or which may be difficult to inspect and replace.
- To provide protection against wood-destroying fungi and insects.

Bridge structures are examples of areas of use for glulam manufactured from treated timber lamellas.

Check list for description and ordering

A well-constructed glulam structure requires a correct and unambiguous description. On planning and creation of paperwork the following information should be provided:

No.	Description	Date	Sign
1	Element labeling for identification.		
2	Number of units. For different units the number of units for these should be specified, for example 20 columns of length 5,400 mm, 10 columns of length 3,200 mm and so on. **Note** that a three-pin portal frame or a three-pin arch consists of two elements.		
3	Type of structural element, for example straight beam, column, double pitched beam or reference for plan.		
4	Target sizes shall be given. *See also section Figuring, page 61.*		
5	A glulam beam is set out with width b, height h and length L.		
6	A glulam column is set out with width b, depth h and height L.		
7	For beams with different height sizes, for example double pitched beams, set out the lowest height/greatest height. For special element types the size is set out on the plan. Processing, giving notches and sawing, can be carried out by the manufacturer according to the figuring plan, *see section Dimensioning, page 61.*		
8	Strength-class, according to the standard EN 14080, for example GL30c.		
9	Adhesive type. Manufacturing standard is Adhesive type I.		
10	Appearance grade. The stock standard in Sweden is Clean planed, no surface repairs, which is designated R. Clean planed, surface repairs, is designated RL. Planed surfaces are designated H. Adjusted surfaces are designated J. Appearance grades are set out in *the section Appearance grades, page 22*.		
11	If Clean planed, surface repairs are specified, indicate which surfaces will be exposed to view after assembly.		
12	If camber is requested, indicate the size for camber in mm.		
13	If another species of timber than spruce is requested, for example pine.		
14	If glulam with treated lamellas is required, state the wood protection class of the constituent timber or whether the entire glulam element is to be pressure-treated, along with any surface treatment		
15	Special requirements with regards to packaging, for example individual packing, edge protection for crane mounting etc.		
16	If other size tolerances are required than the standardized, indicate required plus and minus tolerances, *see page 23.*		

Table 25 Example of specifications in connection with an order

Type of element	Amount (pc.)	b (mm)	h (mm)	L (mm)	Appearence grade	Strength class/Adhesive	Note
Straight beam	12	90	405	9,000	R	GL30c / Type I	Packaging: PE–film
Column	24	90	315	3,500	R	GL30c / Type I	Primer painted 60 µm

Note Some glulam manufacturers have their own goods description for quality of appearance.

Protect from
precipitation

Well-drained
ground

Keep wood for
outdoor use
ventilated and
protected

Protect from dirt

Protect from sun

Check that
the packaging is intact

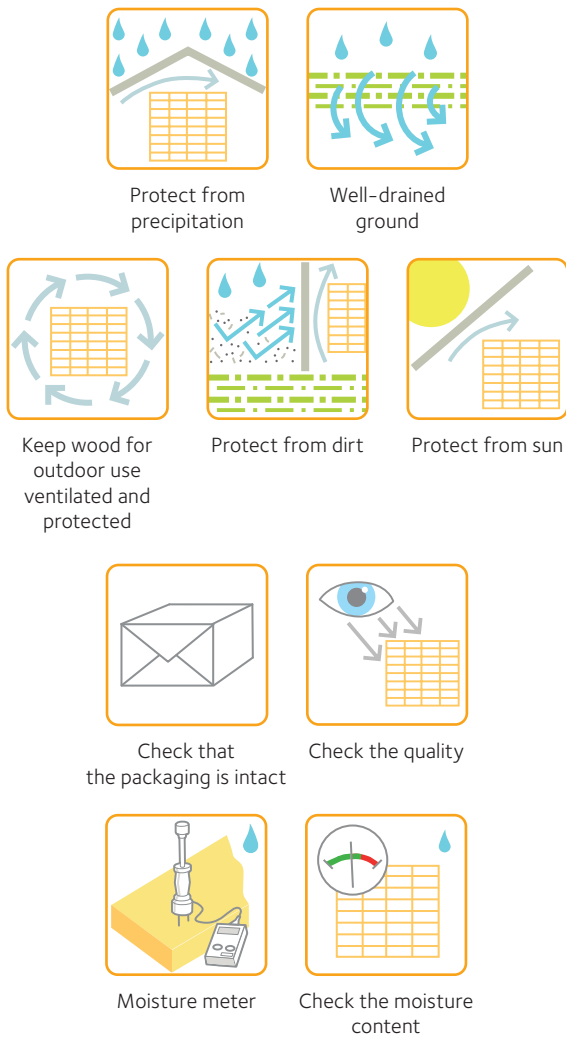Check the quality

Moisture meter

Check the moisture
content

Figure 100 **Storage of glulam**
Example of how to give glulam short-term protection on
the construction site.

Ventilation under
tarpaulin

Protect from sun

Stack the glulam
on spacers if it
gets damp

Handling glulam correctly

Handling of glulam demands great care and can affect not only
the structure's design but also the project's budget and planning. In
order to be able to erect glulam elements, access to some form of lift-
ing equipment is almost always a requirement.

For protection against precipitation, radiation from the sun, dirt
and ground dampness during transport, storage and erection glulam
elements are as a rule delivered packaged, in a batch or individually.

On delivery

- Plan erection in good time before delivery for avoidance of time
  consuming re-loading.
- Check that the packaging is complete.
- Check that the number of glulam elements and fittings corresponds
  with the order and delivery note.
- Check the delivery, noting any visible damage. Tick off strength
  class and labeling against order and delivery note.
- Measure the moisture content on a number of elements with
  an electronic moisture meter with insulated hammer electrodes to
  get an indication that the correct moisture content has been
  delivered.
- Label glulam elements and fittings clearly and systematically to
  ease erection.
- Drain any moisture inside the package by cutting it on the bottom
  side.
- Check that the glulam is free from dirt.

On storage

- Never put glulam elements directly on the ground.
- Do not place the glulam where there is a risk of soiling and splash-
  ing from guttering or traffic, for example.
- The ground should be cleared of snow.
- Make sure the storage location is in the shade in spring, summer
  and autumn. Sunlight makes the surfaces of glulam hotter than
  the ambient temperature, which can lead to splitting or condensa-
  tion, which in turn increases the risk of microbial growth.
- Rest the components on clean supports, at least 300 mm off
  the ground or the floor to provide good ventilation. Make sure
  there are enough bearers to prevent the glulam bending.
- The ground should be dry and flat so that the glulam elements do
  not become bent or warped.
- Lay clean counter battening between the glulam elements and
  place the battening vertically, one above the other.
- For outdoor storage the glulam elements are protected for example
  with tarpaulins, which are laid on clean studs so that sufficient
  ventilation is obtained under the tarpaulins. Do not let the tarpau-
  lins reach the ground.
- Long-term storage outdoors on the building site should be avoided.

Note If the glulam has become damp, it must be given the opportu-
nity to dry out slowly to prevent cracking. It is however normal for
cracks to occur from the drying out that the glulam is exposed to
during the building's first year.
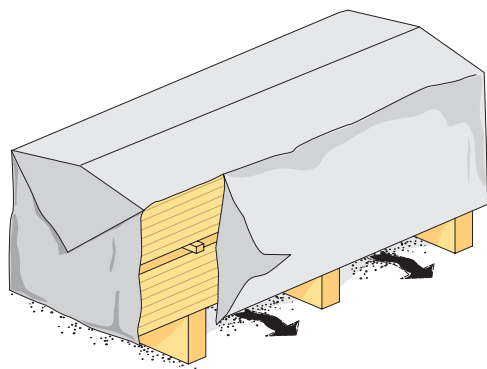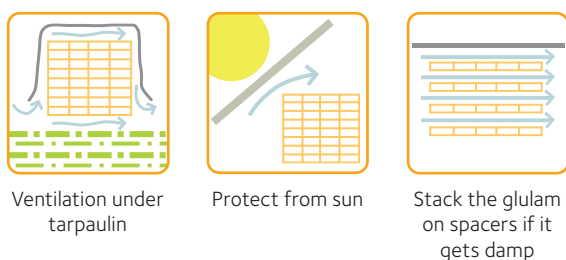
Erection

- Check the moisture content and surface moisture content before using the glulam product, and check that there is no microbial growth.
- Use wide, clean straps for crane lifting and protect the glulam element's edges with steel angles or other edge protection, so that no lift marks occur.
- Make sure that building gloves, straps and other lift equipment are free from dirt.
- Do not walk on surfaces that will be visible after erection.
- Take necessary measures in order to secure the structure against wind and other actions during the time of construction.
- Fix the structural elements in the correct position until the wind trusses or equivalent are mounted.
- Let the packaging stay on after erection as protection against soiling and precipitation during the time of construction.
- Fittings made of hot-dip galvanized steel and anchor nails or anchor screws are the preferred choice for installation. Various types of standardised construction fittings are available from builders' and timber merchants.
- Check that the surface moisture content is no more than 18 % at installation and no more than 16 % when painting. Take samples with an electric resistance moisture meter with insulated hammer electrodes.

Weight figures for handling

Use the following weight figures when handling glulam:
- Glulam   approx. 500 kg/m³.
- Pressure-treated glulam   approx. 600 kg/m³.

Safeguard the moisture content

The moisture content of a batch of glulam usually equates to a target moisture content of maximum 16 % on delivery from the glulam manufacturer. Glulam is covered to protect it in transit. If the packaging is fully sealed, glulam can be stored outside under a roof for a short time.

If the packaging is broken, it must be mended (even minor tears) or removed entirely, then storing the glulam in a dry and warm place if being used indoors. Glulam that is to be used in unheated buildings or in an outdoor climate, protected under a roof, can be stored in a cold place, well protected from precipitation.

Managing waste

Sort wood waste from glulam into a separate area so that it can be chipped and burned for energy recovery. Waste from pressure-treated glulam should be handled according to instructions from the local authority's environmental office.

Use clean gloves, slings and edge protectors when lifting with a crane.

RIGHT

WRONG

Do not walk on the glulam product.

Six-sided packaging

Wood for indoor use should be stored indoors

Waste

Figure 101 **Handling glulam correctly**

Askims Torg,
Gothenburg, Sweden.

Symbols

Symbols in EN 1995-1-1.

Symbol	Explanation
Latin upper case letters	
A	Cross-sectional area
A_{ef}	Effective area of the total contact surface between a punched metal plate fastener and the timber; effective total contact surface perpendicular to the grain
A_f	Cross-sectional area of flange
$A_{net,t}$	Net cross-sectional area perpendicular to the grain
$A_{net,v}$	Net shear area parallel to the grain
C	Spring stiffness
$E_{0,05}$	Fifth percentile value of modulus of elasticity
E_d	Design value of modulus of elasticity
E_{mean}	Mean value of modulus of elasticity
$E_{mean,fin}$	Final mean value of modulus of elasticity
F	Force
$F_{A,Ed}$	Design force acting on a punched metal plate fastener at the centroid of the effective area
$F_{A,min,d}$	Minimum design force acting on a punched metal plate fastener at the centroid of the effective area
$F_{ax,Ed}$	Design axial force on fastener
$F_{ax,Rd}$	Design value of axial withdrawal capacity of the fastener
$F_{ax,Rk}$	Characteristic axial withdrawal capacity of the fastener
F_c	Compressive force
F_d	Design force
$F_{d,ser}$	Design force at the serviceability limit state
$F_{f,Rd}$	Design load-carrying capacity per fastener in wall diaphragm
$F_{i,c,Ed}$	Design compressive reaction force at end of shear wall
$F_{i,t,Ed}$	Design tensile reaction force at end of shear wall
$F_{i,vert,Ed}$	Vertical load on wall
$F_{i,v,Rd}$	Design racking resistance of panel i or wall i
F_{la}	Lateral load
$F_{M,Ed}$	Design force from a design moment
F_t	Tensile force
$F_{t,Rk}$	Characteristic tensile capacity of a connection
$F_{v,0,Rk}$	Characteristic load-carrying capacity of a connector along the grain
$F_{v,Ed}$	Design shear force per shear plane of fastener; Horizontal design effect on wall diaphragm
$F_{v,Rd}$	Design load-carrying capacity per shear plane per fastener; Design racking load capacity
$F_{v,Rk}$	Characteristic load-carrying capacity per shear plane per fastener
$F_{v,w,Ed}$	Design shear force acting on web
$F_{x,Ed}$	Design value of a force in x-direction
$F_{y,Ed}$	Design value of a force in y-direction
$F_{x,Rd}$	Design value of plate capacity in x-direction
$F_{y,Rd}$	Design value of plate capacity in y-direction
$F_{x,Rk}$	Characteristic plate capacity in x-direction
$F_{y,Rk}$	Characteristic plate capacity in y-direction
$G_{0,05}$	Fifth percentile value of shear modulus
G_d	Design value of shear modulus
G_{mean}	Mean value of shear modulus
H	Overall rise of a truss
I_f	Second moment of area of flange
I_{tor}	Torsional moment of inertia
I_z	Second moment of area about the weak axis
K_{ser}	Slip modulus
$K_{ser,fin}$	Final slip modulus
K_u	Instantaneous slip modulus for ultimate limit states
$L_{net,t}$	Net width of the cross-section perpendicular to the grain
$L_{net,v}$	Net length of the fracture area in shear
$M_{A,Ed}$	Design moment acting on a punched metal plate fastener
$M_{ap,d}$	Design moment at apex zone
M_d	Design moment
$M_{y,Rk}$	Characteristic yield moment of fastener
N	Axial force
$R_{90,d}$	Design splitting capacity
$R_{90,k}$	Characteristic splitting capacity
$R_{ax,d}$	Design load-carrying capacity of an axially loaded connection
$R_{ax,k}$	Characteristic load-carrying capacity of an axially loaded connection
$R_{ax,\alpha,k}$	Characteristic load-carrying capacity at an angle α to grain
R_d	Design value of a load-carrying capacity
$R_{ef,k}$	Effective characteristic load-carrying capacity of a connection
$R_{iv,d}$	Design racking capacity of a wall
R_k	Characteristic load-carrying capacity
$R_{sp,k}$	Characteristic splitting capacity

Symbols

$R_{to,k}$	Characteristic load-carrying capacity of a toothed plate connector
$R_{v,d}$	Design racking capacity of a wall diaphragm
V	Shear force; volume
V_u, V_l	Shear forces in upper and lower part of beam with a hole
W_y	Section modulus about axis y
X_d	Design value of a strength property
X_k	Characteristic value of a strength property

Latin lower case letters

a	Distance
a_1	Spacing, parallel to grain, of fasteners within one row
$a_{1,CG}$	Minimum end distance to the centre of gravity of the screw in each timber member
a_2	Spacing, perpendicular to grain, between rows of fasteners
$a_{2,CG}$	Minimum edge distance to the centre of gravity of the screw in each timber member
$a_{3,c}$	Distance between fastener and unloaded end
$a_{3,t}$	Distance between fastener and loaded end
$a_{4,c}$	Distance between fastener and unloaded edge
$a_{4,t}$	Distance between fastener and loaded edge
a_{bow}	Maximum bow of truss member
$a_{bow,perm}$	Maximum permitted bow of truss member
a_{dev}	Maximum deviation of truss
$a_{dev,perm}$	Maximum permitted deviation of truss
b	Width
b_i	Width of panel i or wall i
b_{net}	Clear distance between studs
b_w	Web width
d	Diameter; outer thread diameter
d_1	Diameter of centre hole of connector; inner thread diameter
d_c	Connector diameter
d_{ef}	Effective diameter
d_h	Head diameter of connector
$f_{h,i,k}$	Characteristic embedment strength of timber member i
$f_{a,0,0}$	Characteristic anchorage capacity per unit area for $\alpha = 0°$ and $\beta = 0°$
$f_{a,90,90}$	Characteristic anchorage capacity per unit area for $\alpha = 90°$ and $\beta = 90°$
$f_{a,\alpha,\beta,k}$	Characteristic anchorage strength
$f_{ax,k}$	Characteristic withdrawal parameter for nails
$f_{c,0,d}$	Design compressive strength along the grain
$f_{c,w,d}$	Design compressive strength of web
$f_{f,c,d}$	Design compressive strength of flange
$f_{c,90,k}$	Characteristic compressive strength perpendicular to grain

$f_{f,t,d}$	Design tensile strength of flange
$f_{h,k}$	Characteristic embedment strength
$f_{head,k}$	Characteristic pull-through parameter for nails
f_1	Fundamental frequency
$f_{m,k}$	Characteristic bending strength
$f_{m,y,d}$	Design bending strength about the principal y-axis
$f_{m,z,d}$	Design bending strength about the principal z-axis
$f_{m,\alpha,d}$	Design bending strength at an angle α to the grain
$f_{t,0,d}$	Design tensile strength along the grain
$f_{t,0,k}$	Characteristic tensile strength along the grain
$f_{t,90,d}$	Design tensile strength perpendicular to the grain
$f_{t,w,d}$	Design tensile strength of the web
$f_{u,k}$	Characteristic tensile strength of bolts
$f_{v,0,d}$	Design panel shear strength
$f_{v,ax,\alpha,k}$	Characteristic withdrawal strength at an angle α to grain
$f_{v,ax,90,k}$	Characteristic withdrawal strength perpendicular to grain
$f_{v,d}$	Design shear strength
h	Depth; height of wall
h_{ap}	Depth of the apex zone
h_d	Hole depth
h_e	Embedment depth; loaded edge distance
h_{ef}	Effective depth
$h_{f,c}$	Depth of compression flange
$h_{f,t}$	Depth of tension flange
$h_{r\ell}$	Distance from lower edge of hole to bottom of member
h_{ru}	Distance from upper edge of hole to top of member
h_w	Web depth
i	Notch inclination
$k_{c,y}$, $k_{c,z}$	Instability factor
k_{cr}	Crack factor for shear resistance
k_{crit}	Factor used for lateral buckling
k_d	Dimension factor for panel
k_{def}	Deformation factor
k_{dis}	Factor taking into account the distribution of stresses in an apex zone
$k_{f,1}$, $k_{f,2}$, $k_{f,3}$	Modification factors for bracing resistance
k_h	Depth factor
$k_{i,q}$	Uniformly distributed load factor
k_m	Factor considering re-distribution of bending stresses in a cross-section
k_{mod}	Modification factor for duration of load and moisture content
k_n	Sheathing material factor

k_r	Reduction factor
$k_{R,red}$	Reduction factor for load-carrying capacity
k_s	Fastener spacing factor; modification factor for spring stiffness
$k_{s,red}$	Reduction factor for spacing
k_{shape}	Factor depending on the shape of the cross-section
k_{sys}	System strength factor
k_v	Reduction factor for notched beams
k_{vol}	Volume factor
k_y or k_z	Instability factor
$l_{a,min}$	Minimum anchorage length for a glued-in rod
l	Span; contact length
l_A	Distance from a hole to the centre of the member support
l_{ef}	Effective length; Effective length of distribution
l_V	Distance from a hole to the end of the member
l_z	Spacing between holes
m	Mass per unit area
n_{40}	Number of frequencies below 40 Hz
n_{ef}	Effective number of fasteners
p_d	Distributed load
q_i	Equivalent uniformly distributed load
r	Radius of curvature
s	Spacing
s_0	Basic fastener spacing
r_{in}	Inner radius
t	Thickness
t_{pen}	Penetration depth
u_{creep}	Creep deformation
u_{fin}	Final deformation
$u_{fin,G}$	Final deformation for a permanent action G
$u_{fin,Q,1}$	Final deformation for the leading variable action Q_1
$u_{fin,Q,i}$	Final deformation for accompanying variable actions Q_i
u_{inst}	Instantaneous deformation
$u_{inst,G}$	Instantaneous deformation for a permanent action G
$u_{inst,Q,1}$	Instantaneous deformation for the leading variable action Q_1
$u_{inst,Q,i}$	Instantaneous deformation for accompanying variable actions Q_i
w_c	Precamber
w_{creep}	Creep deflection
w_{fin}	Final deflection
w_{inst}	Instantaneous deflection
$w_{net,fin}$	Net final deflection
v	Unit impulse velocity response

Greek lower case letters	
α	Angle between the x-direction and the force for a punched metal plate; Angle between the direction of the load and the loaded edge (or end)
β	Angle between the grain direction and the force for a punched metal plate
β_c	Straightness factor
γ	Angle between the x-direction and the timber connection line for a punched metal plate
γ_M	Partial factor for material properties, also accounting for model uncertainties and dimensional variations
λ_y	Slenderness ratio corresponding to bending about the y-axis
λ_z	Slenderness ratio corresponding to bending about the z-axis
$\lambda_{rel,y}$	Relative slenderness ratio corresponding to bending about the y-axis
$\lambda_{rel,z}$	Relative slenderness ratio corresponding to bending about the z-axis
ρ_k	Characteristic density
ρ_m	Mean density
$\sigma_{c,0,d}$	Design compressive stress along the grain
$\sigma_{c,\alpha,d}$	Design compressive stress at an angle α to the grain
$\sigma_{f,c,d}$	Mean design compressive stress of flange
$\sigma_{f,c,max,d}$	Design compressive stress of extreme fibres of flange
$\sigma_{f,t,d}$	Mean design tensile stress of flange
$\sigma_{f,t,max,d}$	Design tensile stress of extreme fibres of flange
$\sigma_{m,crit}$	Critical bending stress
$\sigma_{m,y,d}$	Design bending stress about the principal y-axis
$\sigma_{m,z,d}$	Design bending stress about the principal z-axis
$\sigma_{m,\alpha,d}$	Design bending stress at an angle α to the grain
σ_N	Axial stress
$\sigma_{t,0,d}$	Design tensile stress along the grain
$\sigma_{t,90,d}$	Design tensile stress perpendicular to the grain
$\sigma_{w,c,d}$	Design compressive stress of web
$\sigma_{w,t,d}$	Design tensile stress of web
τ_d	Design shear stress
$\tau_{F,d}$	Design anchorage stress from axial force
$\tau_{M,d}$	Design anchorage stress from moment
$\tau_{tor,d}$	Design shear stress from torsion
ψ_0	Factor for combination value of a variable action
ψ_1	Factor for frequent value of a variable action
ψ_2	Factor for quasi-permanent value of a variable action
ζ	Modal damping ratio

Source: EN 1995-1-1:2004, 1.6

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The raw materials come from Swedish forests and the finished products meet the European standard for CE-marked glulam. All the glulam manufacturers have an environmental declaration and are certified by accredited certification bodies.

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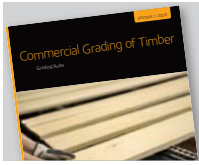
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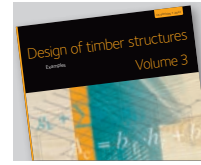The recently updated basic manual for grading timber.
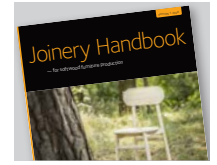*81 pages. A5 format.*

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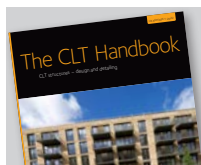*60 pages. A4 format.*
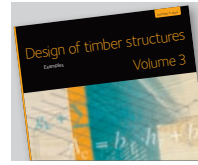
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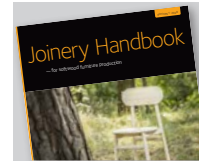
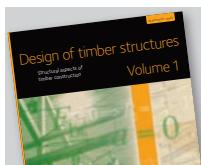**Joinery Handbook**
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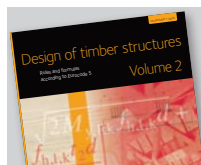## Digital publications

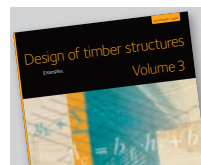Available at **www.swedishwood.com/publications**.

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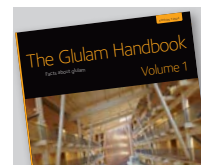CLT structures – design and detailing.
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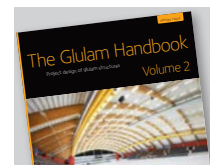Structural aspects of timber construction.
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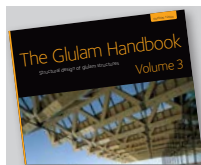Rules and formulas according to Eurocode 5.
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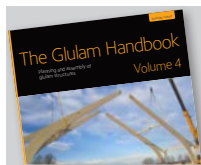Examples.
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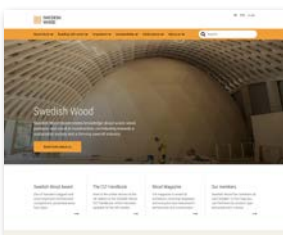
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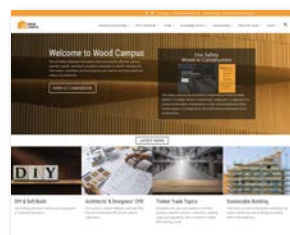
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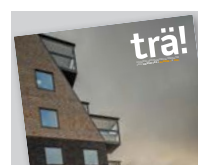
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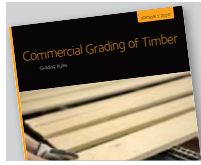
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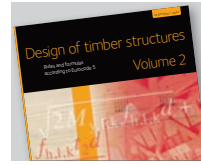
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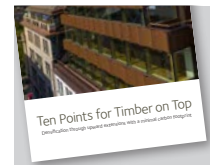*76 pages. A4 format.*

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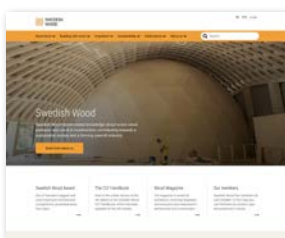*24 pages. A4 format.*

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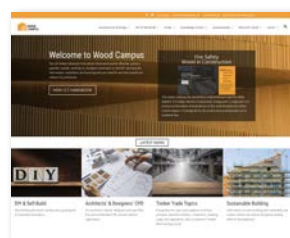*20 pages. A4 format.*

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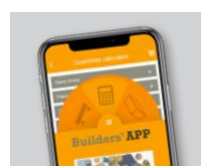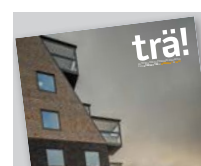
Websites

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