GLULAM HANDBOOK
VOLUME 1

2013-10-17

GLULAM HANDBOOK Volume 1

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INTRODUCTION

GLULAM AS A STRUCTURAL MATERIAL

Wood is renewable and the most natural and energy efficient building material. Glulam provides an even better material use than sawn timber. The consumption of raw wood material is less if the glulam technique is utilized. Therefore the use of glulam is right. Glulam is a classical engineered timber product for new designers. More than a hundred years of usage has proved its lasting value of load-bearing capacity and beauty.

PHOTO: Ardefors building, Sweden. Photographer:

STRENGTH x PERFORMANCE x BEAUTY = $WOOD^3$ = GLULAM

• Glulam holds no bounds for technical timber building possibilities.

• Glulam is a structural material, which optimizes the technical qualities of a renewable raw material – timber.

• Glulam members are built with individual laminations of structural timber and give an effective material usage.

• 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 also in the future enjoy the load bearing capacity, beauty and versatility of large timber elements without the need to use powerful solid timber from old forests.

• Glulam is stronger and stiffer than the equivalent dimension of structural timber.

• Considering its self-weight, glulam is stronger than any other construction material. 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 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.

Aestethic additional value – Glulam is an environmentally creative product and therefore eagerly used by architects.

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.

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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 both simple hand tools and with power tools.

PHOTO: The glulam bridge Älvsbackabron, Skellefteå, Sweden?
Photographer: Martinson Group, Bygdsiljum, Sweden.
Must be checked by Proservice.

THE HISTORY OF GLULAM

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 glueing together boards (laminations) 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 zone. 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 laminations, more exposed to stress, were to be unjointed and the less exposed could have suitably spaced out butt joints. The laminations’ thickness 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 laminations 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 wide 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/cm^2 (13,6 N/mm^2). This is a strength value, which corresponds well with what is currently applied as 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 the erection was fast. Even before 1910 Otto Hetzer had built roughly 50 roof structures with relatively large wide spans. Some years later the first of four aircraft hangers were 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.

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.


Hetzer praktiserade ett otal konstruktionsystem med trä och lim som komponenter och resulterade i 17 olika patent, som han också sökte bland de flesta industriländerna i Europa. Det första patentet, som Hetzer sökte och fick prioriterat i Sverige, gällde från den 21 juni 1906. [4]

PATENT N:o 28715.

BESKRIFNING

KUNGL. PATENT- OCH REGISTRERINGSVERKET.

O. HETZER.

Klass 27:c.

PHOTO: Cover of the Swedish patent for the Hetzer Binder, anno 1906.

Production began in Norway in Mysen in Östfold and in 1918 the company AS 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 AS 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 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 the company AB Träkonstruktioner. As on the continent it was the railway's expansion, which demanded load bearing structures for wide spans, and it was here that glulam made its breakthrough. Ola Grundt became the new boss in 1922 and in the same year David Tenning (1888-1956) was appointed as 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. 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 roof is still today held up by the elegant glulam arches and the site was, in 1986, declared a listed building.

During 1923 several well publisized halls, besides the building for Malmö Central, were delivered. Despite a relatively good flow of incoming orders the 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 the arrival of unrest in the employment sector. Solvency finally became too fragile and in 1924 the company went into liquidation.

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PHOTO: 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.
Architect: Folke Zettervall, SJ Arkitektkontor, Stockholm.
Photographer:

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 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 drove 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, which even today

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serve their functional purpose. 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 adhesive. It is an excellent adhesive for members, which are exposed to the affects of the climate but it produces dark glue lines. The same applies to the phenol-resorcinol adhesive, which has been used during recent decades.

Nowadays adhesives are based on melamine, wich produces light glue lines, are used mainly, which sets special demands on the hardening and which have 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 successfully led the factory. During the 1940's a glulam structure was built, which had 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, Martinsons Trä AB, Setra Trävaror AB and Glulam of Sweden AB. The largest of them, Martinsons, developed from a sawmill company, which started glulam manufacturing in 1965 in Bygdsiljum. A specialist factory was built in 1970 and the company export a large part of the 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 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 reconstruct it again. 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 product glulam and production started in 1960. The company has through acquisition become one of the largest Nordic wood companies. In Norway there are besides Moelven AS, two more glulam manufacturers, Sørlaminering AS and Vestlandske Limtre Industri AS. The Norwegian manufacturers are organized in the Norwegian Glulam Producer’s Association.

In Finland glulam manufacturing was begun in 1945 when the company Oy Laivateollisuus AB (Skeppsindustrin AB) manufactured the first glulam hull ships. Glulam was used for the ships frame, its deck beams and masts. The ships were delivered as war reparations to the U.S.S.R. The deliveries continued for about a decade. Roughly at the same time as the deliveries ceased, production was started on halls made of glulam by turning the ships’ arches upside down. Glulam in Finland has been used in the building industry since 1958.

In Finland there are currently four large glulam manufacturers and besides this a number of smaller manufacturers of glulam. These are: Finland Laminated Timber Oy, Finnlamella Oy, Keitele Engineered Wood Oy, Kestopalkki LPJ Oy, Late-Rakenteet Oy, Metsä Wood/Finnforest Kuningaspalkki, PRT-Lami Oy, Safewood Oy and Versowood Oy. The Finnish manufacturers are organised in the Finnish Glulam Association.

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, EXPO 2010, 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 automatized. 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. As examples the Anthroposophical building in Maulbronn and the swimming baths buildings in Bad Dürrheim and Sindelfingen can be named.

PHOTO: The swimming baths building in Sindelfingen, Germany. *Should be changed. Proservice får välja ut.*

Despite the Nordic countries being ”wood countries” we are far from biggest in the world for glulam production. Per capita Austria produces nearly 10 times as much as in 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, Wis. In North America, with its strong timber tradition, glulam is an established structural material. There is the large network dome in Tacoma, Washington, with a span of 160 m, which makes it one of the world’s biggest timber structure.

PHOTO: The Tacoma Dome, Tacoma, USA. 23.000 seats. Diameter of 160 m. Height of 46 m. Construction year 1983. Architects: McGranahan and Messenger. Photographer: ?. *Should be changed. Proservice får välja ut.*

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

FACTS ABOUT GLULAM

Glulam is a processed timber product intended primarily for load bearing structures. Besides that glulam, in relation to its weight is one of the strongest structural materials, has good environmental qualities and is considered to have a lasting aesthetic value – therefore glulam is often used in visible load bearing structures – as an environmentally creative structural material. Glulam can advantageously be used even 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 in which glulam is included in the structure. Another important area is

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bridge structures.

GLULAM AND THE ENVIRONMENT

Glulam is a natural material. It is manufactured industrially by timber laminations, which are glued to each other, well monitored. What is produced from nature should in a sustainable way be used, 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 it 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 is used) and a relatively small amount of adhesive. The ready-made glulam products are delivered dry with a moisture content, which corresponds to 12 percent.

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, which can be recycled. During its working life the glulam has no negative environmental factors of significance. The adhesive releases very small amounts of substances which affect the environment – besides this the percentage of adhesive in the glulam is negligible, roughly 1 percent of the weight. The manufacturer must by testing, verify the emission of formaldehyde in Class E1 or E2 according to the European standard EN 14080.

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 the glulam and judge the prerequisites for recycling in each particular situation. Glulam is, like other timber products, combustible and it can, with unsuitable usage or incorrect construction design, break down biologically.

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 the glulam products – from the choice of raw materials to reuse or recycling. As transportation is a considerable energy guzzler the manufacturers work actively on minimizing high energy consuming transport. Glulam manufacturers have detailed building commodity statements, which account for the manufacturing and environmental effect of the products.

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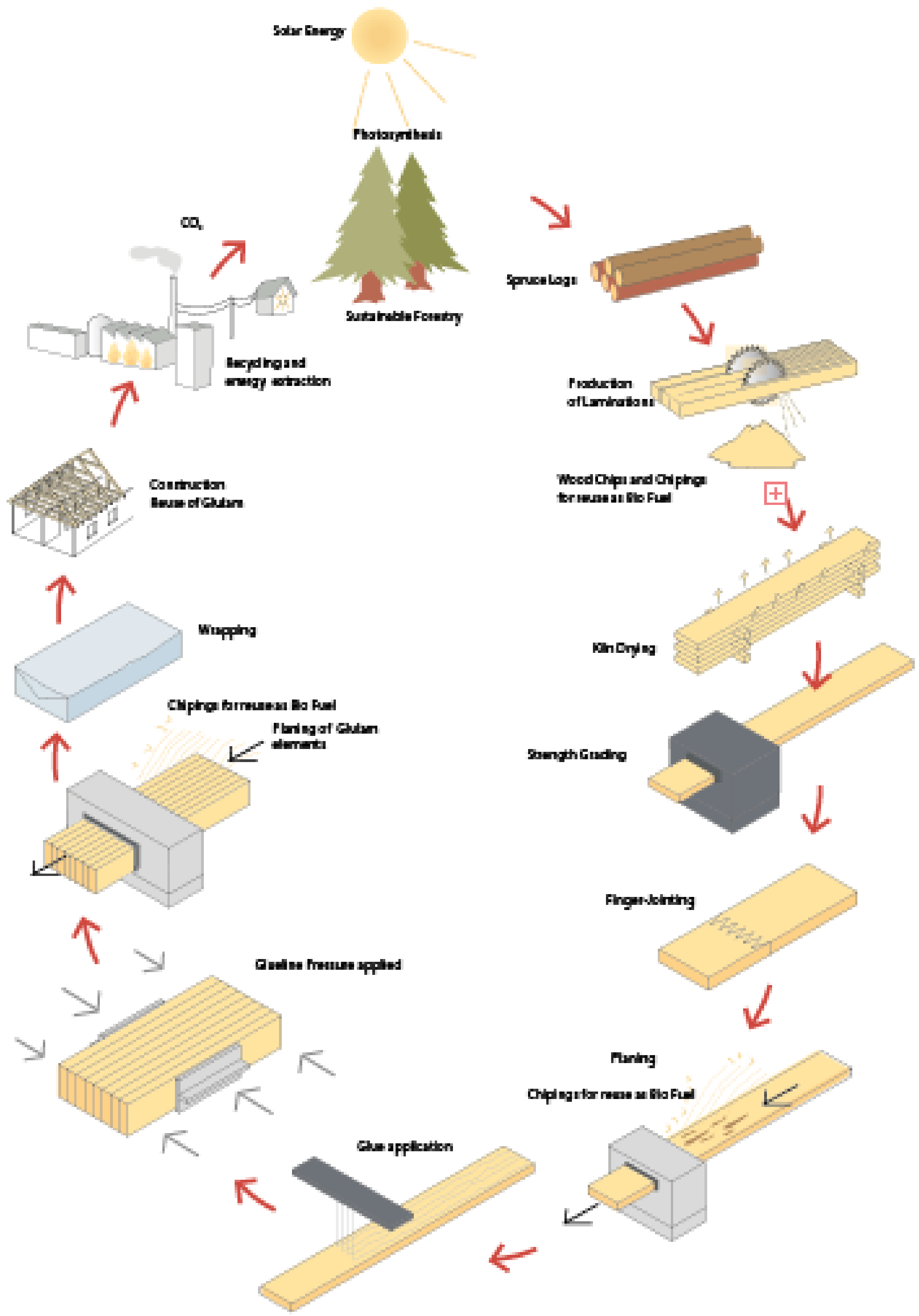

ILLUSTRATION: Life-cycle of glulam products. Glulam is a processed timber product. Glulam manufacturing is a resources efficient process.

CERTIFICATION AND CONTROL

The structural elements of glulam are manufactured industrially under controlled forms. With the aid of finger jointing technology very great lengths can be manufactured. The manufacturing principle is simple –

timber laminations 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, which deal with certification, checking and testing of glulam products. Thanks to good experience of glulam, the use of glulam in the Nordic countries is steadily increasing.

CE-MARKING

Nordic glulam is manufactured in accordance with the requirements in the European standard EN 14080, which is standard in all European countries. To show that the products meet the requirements of EN 14080 they shall be durable marked.

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

01234

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01234-CPD-00234

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

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

Glulam members, irrespective of the number of laminations, are in the Nordic countries normally manufactured in strength class GL30c. However members with only 2 or 3 laminations shall be GL30h.

Resawn glulam beams (b < 90 mm) are normally manufactured from original beams in class GL30. After split up in a band saw, the remaining parts may have lost less than 2 N/mm^2 (MPa) of their bending strength and are classified as GL28cs. For more information, see Load-bearing capacity.

FACTORY PRODUCTION CONTROL

Glulam manufacturing demands great accuracy in relation to milling of the finger joints, also 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 supervise self-checking and make unannounced test visits to the glulam manufacturers. The manufacturers are under the constant supervision of the accredited test agency.

PHOTO: Universeum in Ghothenburgh, Sweden. Part of the roof construction. Photograph:

PROPERTIES

Glulam is primarily a structural material, where strength, stiffness and durability as a rule are the most important qualities. Glulam products do not therefore in general have the same timber qualities and surface finish as interior furnishings carpentry and furniture. In most contexts however the standard in stock products should meet normal demands on appearance.

TIMBER SPECIES

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

Appearance-wise one cannot differentiate between heartwood and sapwood from spruce.

As with spruce the wood of a pine tree is characterized by annual growth rings of light spring-wood and darker summer-wood but the spruce wood is generally somewhat more whitish than pine timber.

The knots in spruce are comparatively small and not surrounded by resin streaks as in pine. Strength grading means that the size of the knots in the wood is limited. Even timber with high load bearing capacity can contain rather large knots.

Glulam can, if so desired, be manufactured from pine or treated pine. To some extent larch (Larix Decidua) is used. Appearance-wise pine is somewhat darker than spruce and the natural colour will darken over time. The heartwood of pine differs from sapwood by its dark reddish brown colour.

As a rule laminations of treated pine are on delivery soft green in colour. This green colour is, like glulam’s natural colour, not lasting. With regards to the use of glulam made of treated laminations, see page?

As with other timber, untreated glulam, should not be exposed outdoors to all climates as it with time becomes grey or greyish brown. It is the lignin, which is broken down on the surface. In the long term, outdoor exposed timber will rot.

ADHESIVES

For glulam manufacturing, only adhesives, which have 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 class 1 – 3 according to Eurocode 5) while the usage of adhesive according to adhesive type II is limited to structures, which are protected from the weather (Service class 1 and 2 according to Eurocode 5). Glulam must however be protected from the long-term influence of damp, rain and sun. A list of approved adhesive 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. Melamine glue lines are in the beginning light but can with time acquire a somewhat darker nuance.

For finger joints of laminations the light melamine adhesive is used as good as exclusively. Therefore finger joints appear only as thin lines on the members' surface. Polyurethane adhesive (PUR) can also be used for finger jointing.

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-resorcinol-formaldehyde (PRF) was 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 the section Appearance and surface finishing, page ? Glulam products can then be surface treated on site as normal timber by stain treatment, top-coat painting, clear varnishing or oil treatment; see the section Surface treatment and maintenance, page?

SIZE AND SHAPE

Glulam technique provides great opportunities to vary cross-sectional form and geometry in the structural sections. The limitations are set by the practical circumstances like 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 practice a glulam section is in the Nordic countries normally labeled with the dimensions *b*, *h* and *L*.

PHOTO: Straight glulam elements are available in several sizes and they are above all used for beams and posts.

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).

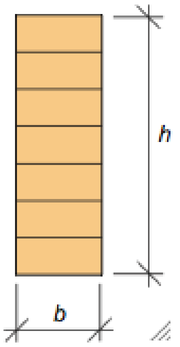

ILLUSTRATION: A cross section of a glulam element is normally labeled with the sizes *b* and *h*.

Size *h*
Straight members have as a rule sizes of *h* as a multiple of lamination thickness 45 mm, that is to say 90, 135, 180, 225, 270, 315 and so on.

For curved members the quantity of sizes of *h* is normally a multiple of lamination thickness 33 mm, that is to say 266, 300, 333, 366 and so on. With a curved radius of less than 7 m, thinner laminations 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.

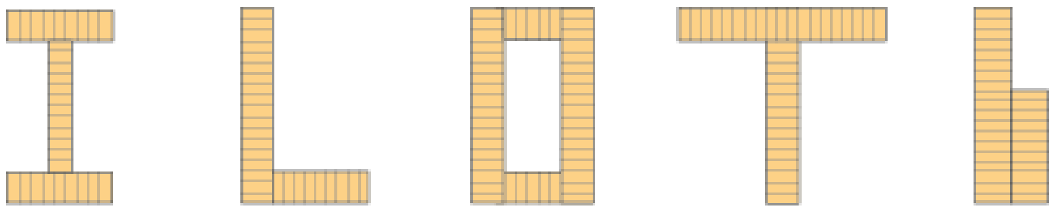

ILLUSTRATION: Examples of possible cross-sectional shapes.

Largest cross-section size *b* x *h*
The largest size of *b* (width) for a glulam member is limited by the availability of wide laminations. Availability varies between the Nordic countries and over time. Normally it is difficult to get hold of sawn timber, which 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 respectively 240 mm.

By edge gluing the laminations or through gluing together several glulam members sideways, bonded with the shifted glued joint, one can manufacture glulam members, which are up to 500 mm wide.

The largest size of *h* in a glulam section is limited by available mechanical equipment to roughly 2 m. By different measures, as for example to glue 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. Up to 30 m long pieces might require permission by the transport Authority. If the total vehicle length exceeds 25.25 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 2.55 m or total height 4.5 m are exceeded, which can be the case in connection with portal frame or arch structures.

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

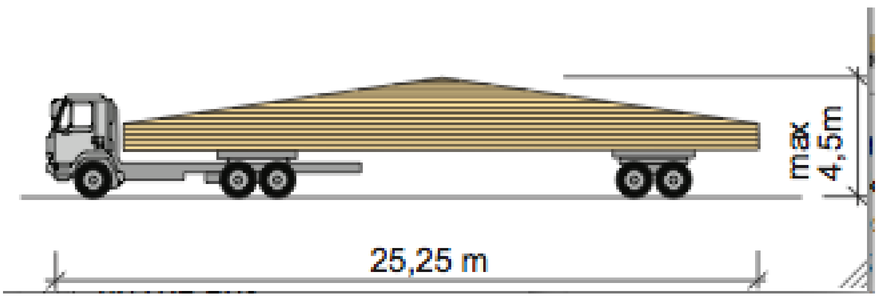

ILLUSTRATION: The greatest permitted length and height for vehicles without special permission. Transport regulations can vary between different countries.

LOAD-BEARING CAPACITY

The load bearing capacity of glulam is high in relation to its self-weight, which makes possible building with great free span. In comparison with other structural materials glulam is one of the strongest, considering its self-weight.

For structural timber 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 fiber. 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 laminations of structural timber. The risk of strength decreasing defects in several laminations ending up in the same cross-section is very small. Besides the laminations have been graded for strength and in so-called combined glulam the strongest laminations have been placed as outer laminations where the stresses normally are the greatest.

Structural components of glulam have higher average strength and a smaller spread of strength characteristics than corresponding components of structural timber.

Glulam can be combined or homogenious. For combined glulam the outer zones of lamination grades shall be at least the proportion given in the illustration below. Combined glulam of strength-class GL30c, consists of structural timber of strength-class T22 in the outer zones and of strength-class T15 or T14 in the inner zone. Homogenous glulam of strength-class GL30h consists, on the hand, solely laminations of strength-class T21 or T22.

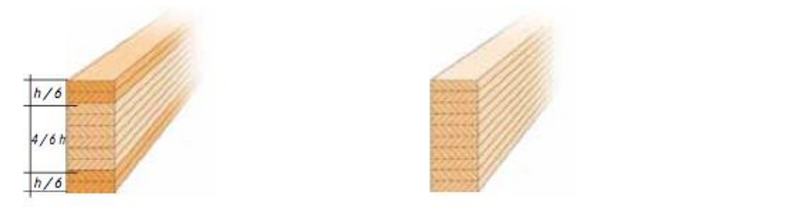

ILLUSTRATION: Glulam can be combined (left) or homogenious (right) from a strength point of view. Homogenous glulam has laminations of the same T- class right through. Regarding combined glulam, see an example in the illustration below.

The load bearing capacity in a glulam member will be on average greater than an individual lamination of the same dimension and the difference in strength between different sections will be less than for individual laminations.

With a retained safety level one can thus generally apply higher stresses for a glulam section than for the incoming laminations 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 illustration below.

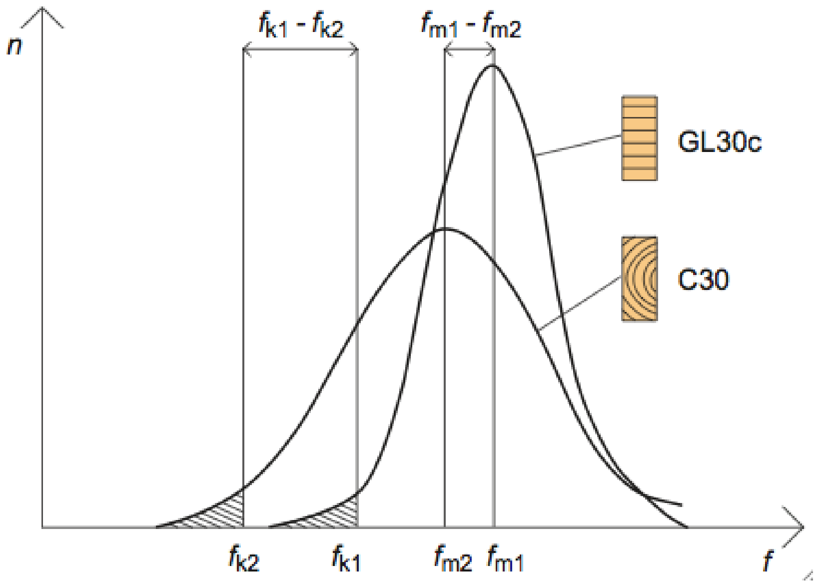

ILLUSTRATION: Structural members of glulam have a higher average strength and less variation in strength properties than the equivalent section of constructional timber. f_{k1} - f_{k2} = the difference in characteristic strength value.
f_{m1} - f_{m2} = the difference in the strength’s mean value. The illustration refers to glulam with a large number of laminations.

When designing glulam structures and timber structures in general one proceeds 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 Glulam Handbook Volume 2.

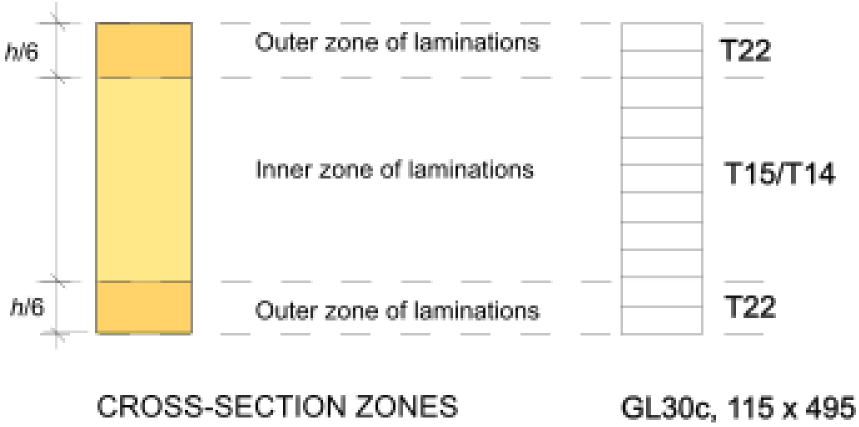

ILLUSTRATION: For combined glulam the outer zone of laminations have a higher strength class. For Nordic combined glulam GL30c, at least 2 x 17 % of the cross-section height, shall consist of outer laminations. This means that glulam consisting of up to 10 laminations can have at least 1 + 1 outer laminations, but glulam consisting of more than 10 laminations need at least 2 + 2 outer laminations. For more information, see EN 14080.

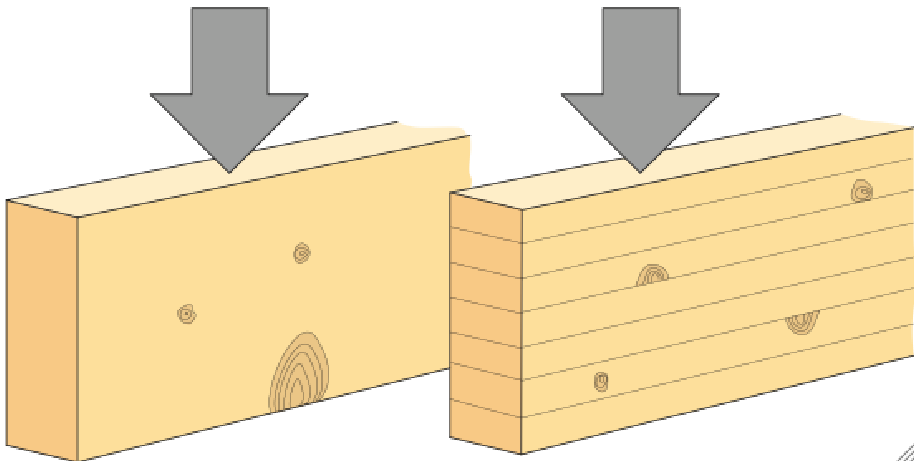

ILLUSTRATION: The laminating effect; Glued laminated timber will be stronger than an individual plank with the same cross-sectional size. In glulam the risk that defects in several laminations will end up in the same cross-section is very small.

THERMAL QUALITIES

In comparison with metal, wood has very small temperature movements. This means that the tensions in glulam, because of changes in temperature, seldom cause any inconvenience.

Thermal conductivity and heat capacity are equal to normal timber (softwood). Glulam has, similar to other wood products, 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.

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 "reference moisture content" is used for glulam according to EN 14080. The reference moisture content for every single lamination is between 8 and 15 percent. The delivering moisture content in a single glulam element should be less than 15 percent. That the correct reference moisture content has been delivered can be ascertained at an acceptance inspection.

The term "surface moisture content" is often used on inspection of timber for built-in purposes and is decisive if the risk of microbial attack exists and shows if the surface has become damp by for example rain.

The reference moisture content and surface moisture content can be inspected according to the publications Handle timber correctly (Hantera virket rätt; The Swedish Forest Industries Federation) and Moisture in wood for the building trade (SP Trätek, Sweden) or other national publications.

Glulam shall, in conjunction with erection and for built-in purposes have a moisture content, which at most is equivalent to a so-called target moisture content of 16 percent. Such glulam, which is to be painted, should have a surface moisture content of at most 16 percent, at the time for painting.

HUMIDITY MOVEMENT

At assembly the moisture content in every lamination shall be between 6 and 15 percent. However the moisture content of two laminations, shall not differ more than 5 percent.

Glulam members are normally delivered with a moisture content equivalent to a reference moisture content as most 15 percent. 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 4 to 5 percent during the

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year in the Nordic counties:

- For timber structures in heated, non-moisturized buildings, between 7 percent (winter time) and 12 percent (summer time)

- For unheated buildings or outdoors under a roof, between 13 percent (summer time) and 17 percent (winter time).

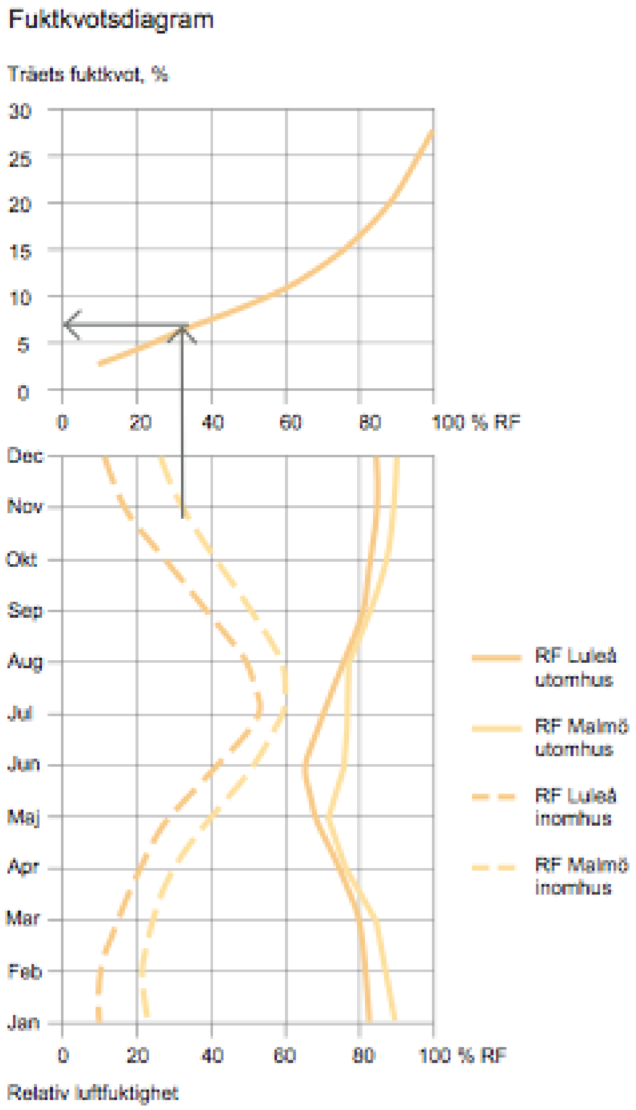


ILLUSTRATION: Moisture content in wood in relation to relative humidity in the surrounding air in different places.

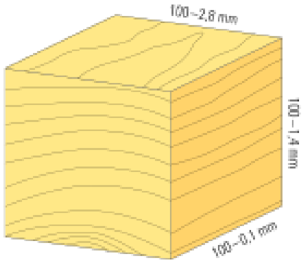


ILLUSTRATION: Moisture movements in different directions of softwood. The movements are largest in tangentiell direction (as greatest 8 %). Moisture movements in glulam are in practice lower than the movements in a piece of wood.

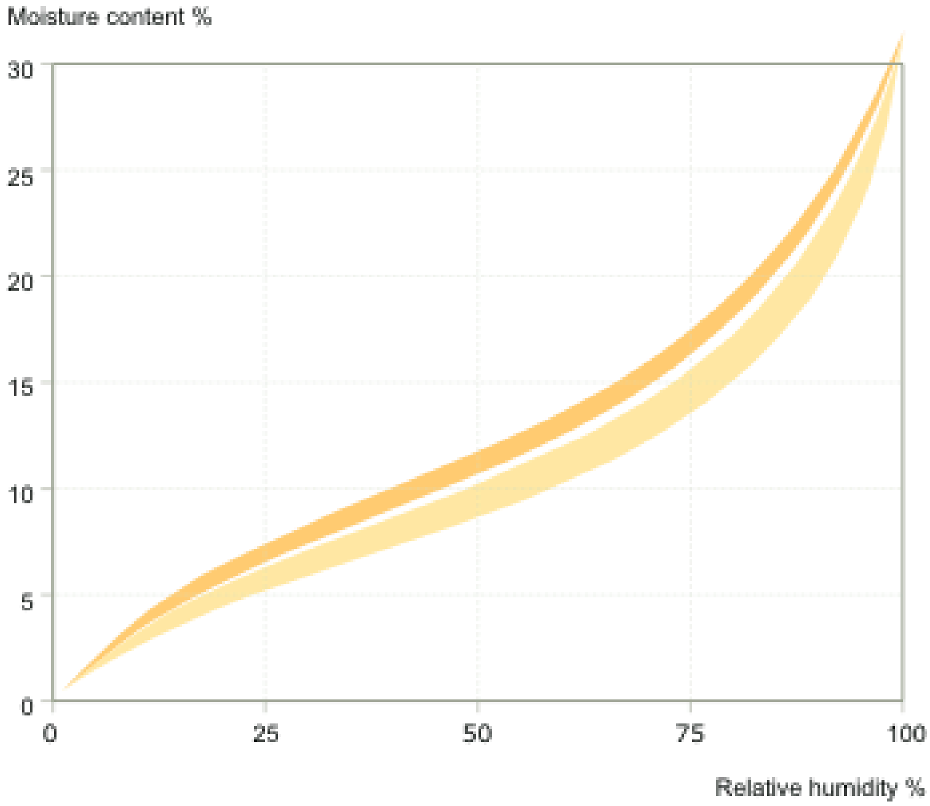


ILLUSTRATION: The moisture content in timber with
different relative moisture in the surrounding climate. Air temperature 20 °C.

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 laminations and the layup of glulam.

PROPERTIES IN A FIRE

Glulam structures have, because of large homogenous cross-sections, relatively good protective qualities in the event of a fire. Fire resistance increases with increased sizes.

Glulam is a combustible material but because of the often large and homogenous cross-sections it is relatively resistant during a fire sequence's starting phase. 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, which forms on the glulam surface in a fire protects the inner parts and contributes to the glulam retaining its load bearing capacity during the continuing fire sequences. The speed of penetration is normally about 0.6 – 1.0 mm/minute. Additional fire protection can be achieved with surface finish or fireproof lining, see further in the section Design for fire resistance, page ? or Glulam Handbook Volume 2.

DURABILITY

Glulam is, like wood, an organic product, which, correctly used, has good resistance to decomposition by microorganisms. In each particular case this can seem to be a disadvantage but seen from an ecological point of view it must be counted as one of the major advantages of the material. During the lifetime of the building the structure must, however, be protected against such attacks. This is done primarily by detail design, which ensures that the conditions, which produce rot do not arise.
If the material is used or is handled in an incorrect way it can, under adverse conditions, be attacked by microorganisms.

Microorganisms can be discoloring (blue stain - or mould fungi) or wood destroying (rot fungi). Insects, which can attack wood, are for example 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 such timber that is load supporting and which is included in safety devices (for example stairs and banisters) or is difficult to replace.

The best method to protect 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 temporarily moist timber cannot rot. Only long-term damp timber can rot. In especially exposed situations the use of treated timber can be motivated by durability reasons**,** see further in the section Glulam with treated laminations, page ? and Glulam Handbook Volume 2.

GLULAM PRODUCTS

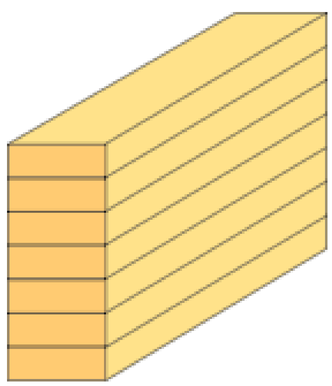
Glulam products are manufactured as straight or curved members. The most common cross-sectional shapes are rectangular but other cross-sectional shapes can be manufactured.

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

Fact box:
RANGE OF PRODUCTS IN STOCK
In order to make possible rational production and minimize delivery time, the Nordic manufacturers have agreed on a manufacturing standard, based on EN 14080 in terms of strength properties and adhesive class. Stocked dimensions (cross-sectional sizes) of glulam products can be found in the table on page? The sizes vary between the Nordic countries.

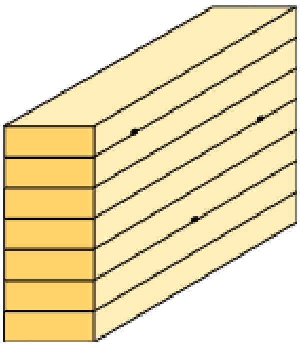
APPEARANCE AND SURFACE FINISHING

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:



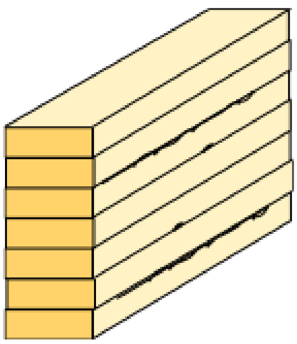
• Clean planed, repaired surfaces (not stock standard).
The sides are to be processed with a plane or similar. Surfaces, which are left visible after erection should be repaired so that they are practically free from larger splits, knotholes, chipping and glue-stains. Minor resin pockets, knotholes, chipping and minor glue-stains may however occur. Visible edges are to be beveled.

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



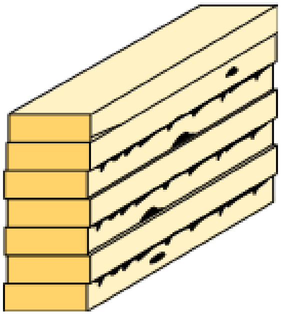
• Clean planed, unrepaired surfaces (stock standard).
The sides are to be processed with a plane or similar. Minor resin pockets, knotholes, chipping and minor glue-stains can however occur. Visible edges are to be beveled. Clean planed, unrepaired surfaces are standard for stock range in the Nordic countries.

Clean planed, unrepaired surfaces are recommended for visible use, for example roof beams in sports halls, business premises, family homes and the like.



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

Roughly planed surfaces 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.



• Equalized surfaces (not stock standard).
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.

Equalized surfaces 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.

Fact box:
RESAWN GLULAM
Please observe 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, that is elements with size *b* less than 90 mm and appearance grade Clean planed, repaired surfaces, should not be chosen.

STOCK RANGE
Straight glulam members with appearance grade clean planed, unrepaired surfaces, are kept in storage to a varied extent in lengths up to 12 m and with cross-sectional size according to the table below. Glulam with less than four laminations normally has a strength class of GL30h while glulam with at least four laminations, h ≥ 180 mm, normally has a strength class of GL30c, but even GL30h can occur.

Members with *b* less than 90 mm, so-called resawn glulam, are normally manufactured from original beams in class GL30. After split up in a band saw, the remaining parts may have lost less than 2 N/mm^2 (MPa) of their bending strength and are classified as GL28cs.

Other cross-sectional sizes, strength classes or appearance qualities or larger lengths, can be ordered.

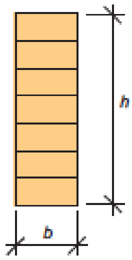
The most common adhesive class is adhesive type I, which means that stocked products in principle can be used independently of the surrounding climate, however not unprotected from rain and strong radiation from the sun.

Strength class:
Glulam section *b* ≥ 90 mm and ≤ 3 laminations: GL30h.
Glulam section *b* ≥ 90 mm and > 3 laminations: GL30c.
Glulam section *b* < 90 mm and > 3 laminations: GL28cs.

TABLE: Cross-sectional size *b* x *h* for stocked products of glulam manufactured in the Nordic countries. Lengths up to 12 m are normally in stock. Observe 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, unrepaired surface.

Stock range for straight glulam
Width x Height = *b x h* in mm

Strength Class GL28cs	**Strength Class GL30c**	**Strength Class GL30h**
b x h	*b x h*	*b x h*
42 x 180	**90** x 180	**90** x 90
x 225	x 225	
x 270	x 270	**115** x 115
	x 315	
56 x 225	x 360	**140** x 135
x 270	x 405	x 140
	x 450	
66 x 270		**160** x 160
x 315	**115** x 180	
	x 225	**165** x 165
	x 270	
	x 315	
	x 360	
	x 405	
	x 450	
	x 495	
	x 630	
	140 x 225	
	x 270	
	x 315	
	x 360	
	x 405	



Several more dimensions than the ones given here can be stocked at the glulam suppliers. Other sizes can be ordered (for straight members, cross-section height *h* is *n* x 45 mm). For export markets other lamination thicknesses than 45 mm can occur.

Comments relating to high resawn glulam beams (*b* < 90 mm): Resawn beams should have a width/height relationship $b/h \leq 1/8$. If a resawn beam with a width/height relationship $b/h \geq 1/8$ manages strength-wise however, the beam height *h* can be increased by the retained width if so required, to the maximum width/height relationship *b*/*h* 1/10.

Example: If a resawn beam 42 x 315 manages the strength demand but a higher beam is required because of for example insulation thickness, the height of the resawn beam can be increased to a maximum height of 405 mm. For a serviceability limit calculation the full beam height can be credited.

SIZE TOLERANCES

TABLE: The tolerances for glulam are according to EN 14080. The tolerance requirements apply in relation to target sizes at a moisture content of 15 percent (reference moisture content) according to EN 14298. If the current moisture content in a glulam unit differs from the reference moisture content the sizes should be recalculated according to EN 14080:

Size of *b* (width)	± 2 mm	
Size of *h* (depth)	≤ 400 mm	+ 4 mm to – 2 mm
	> 400 mm	+1% to – 0,5 %
Size of length *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 from the right angles.	
Length of a straigt member or developed length of a curved member	$L \leq 2$ m	± 2 mm
	$2 \text{ m} \leq L \leq 20$ m	± 0,1 %
	$L > 20$ m	± 20 mm
Longitudinal warping measured as the maximum gauge over a length of 2000 mm of straight members disregarding precamber		≤ 4 mm
Gauge per m developed length for curved glulam members	≤ 6 laminations	± 4 mm
	> 6 laminations	± 2 mm

MANUFACTURING STANDARD

To make possible rational 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 the table above.

Straight glulam members with $b \geq 90$ mm and up to at least 3 laminations and adhesive type I are produced as standard in strength class GL30h.

Straight glulam members with $b \geq 90$ mm and more than 3 laminations and adhesive type I are produced as standard in strength class GL30c.

Resawn beams ($b < 90$ mm) with more than 3 laminations are are normally manufactured from original GL30c-beams. After split up in a band saw, the remaining parts may have lost less than 2 N/mm^2 (MPa) of their bending strength and are therefore classified as and marked GL28cs.

STRAIGHT GLULAM MEMBERS
The most common types of glulam elements are straight units. They are normally manufactured from 45 mm thick timber laminations and are used for floor beams, roof beams and columns. Straight glulam elements are often included as components in different structural systems, see further in the section on Structural systems, see page?

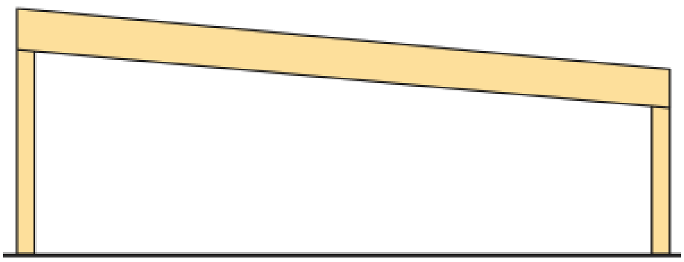
For greater spans there can be the need for a camber of freely supported beams to prevent notable deflection. Such beams can be manufactured to order.

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

When possible curved glulam elements should, in the form of arches or portal frames, be made with constant cross-sectional height within curved parts. Pitched cambered beams and portal frames with curved haunches can advantageously be made with eaves lathes or if the appearance so requires, with glued, loose nailed on, or screwed on ridge or haunches.

The lamination thickness for curved members is normally 33 mm, but for a curved radius of less than 7 m, thinner laminations are required.

Examples of use of glulam for hall buildings.



Straight beams on columns ≤ 30 m

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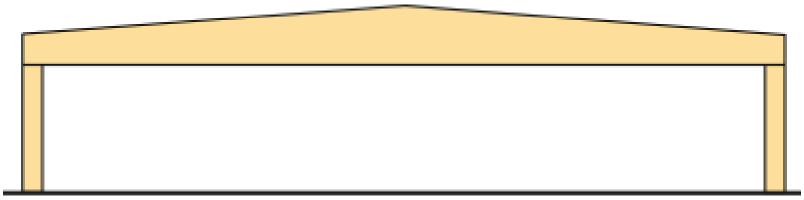
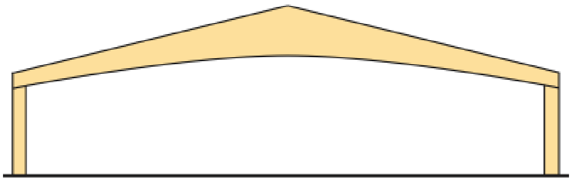
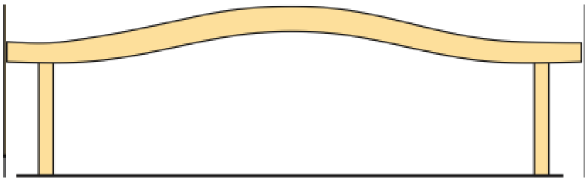


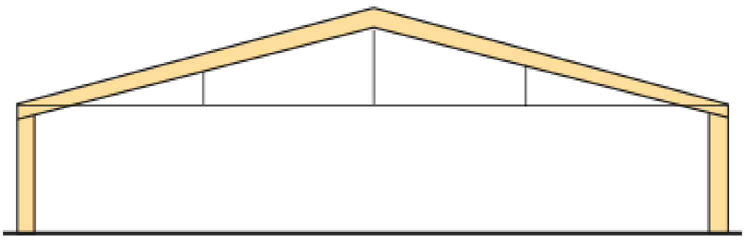
Double pitched beams on columns 10 – 30 m



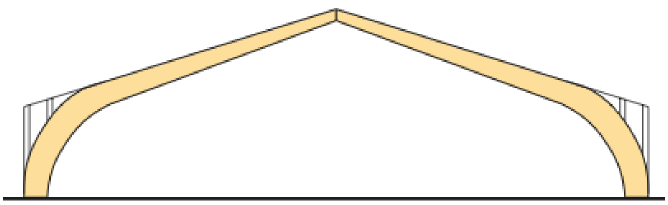
Pitched cambered beams on columns 10 – 20 m



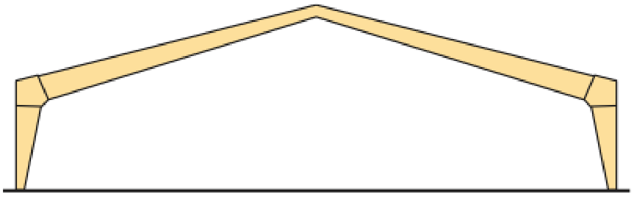
Curved beams 10 – 20 m



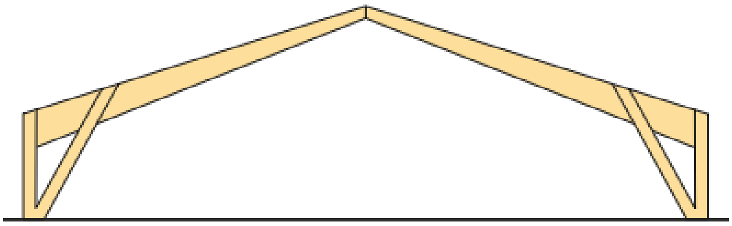
Three-pin trusses with tie on columns 15 – 50 m



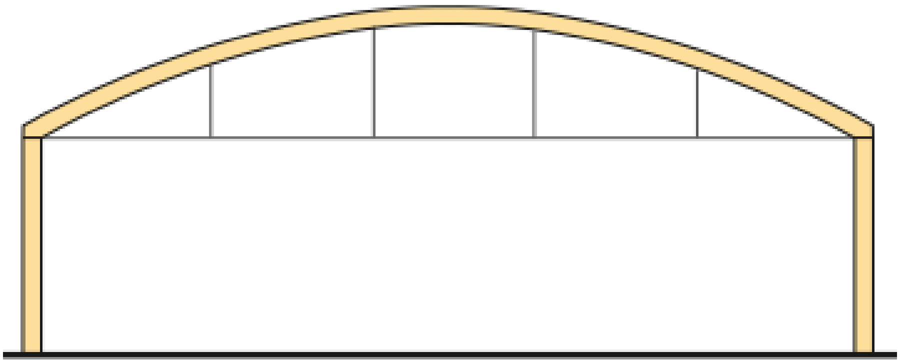
Three-pin portal frames with curved haunches 15 – 40 m



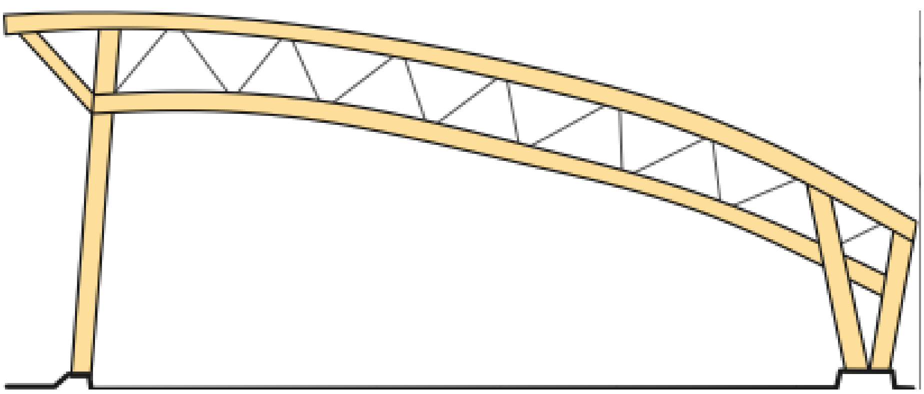
Three-pin portal frames with finger jointed haunches 15 – 25 m



Three-pin portal frames of a composite type 15 – 35 m

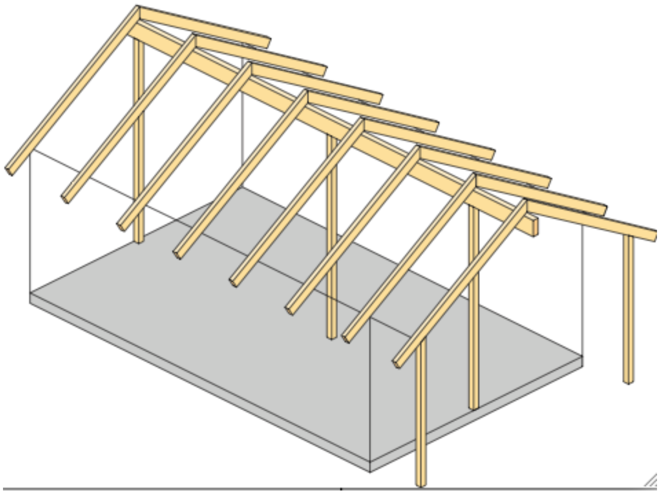


Three-pin arches on columns 20 – 100 m

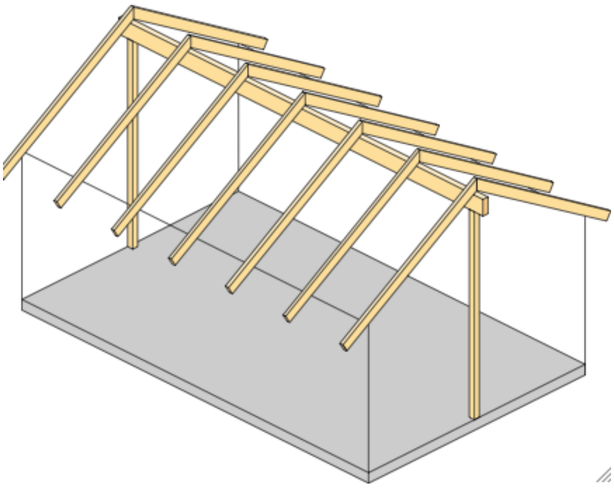


Trusses 30 – 85 m

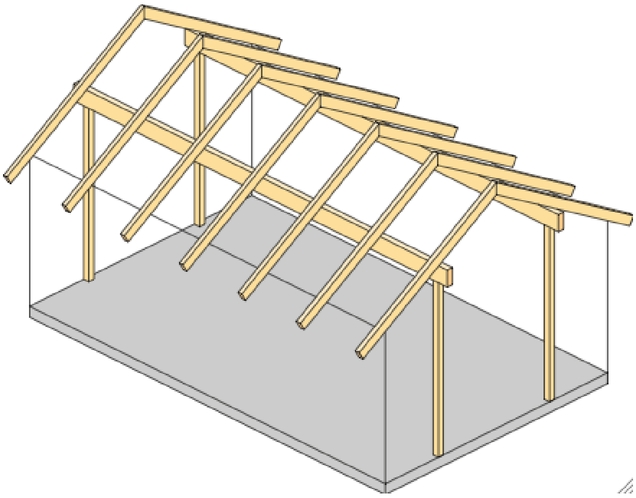
Examples of use of glulam for one family houses.



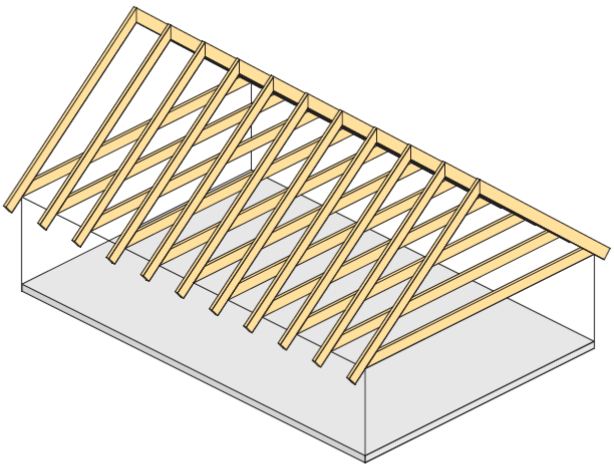
Primary beam in the ridge with or without in between support



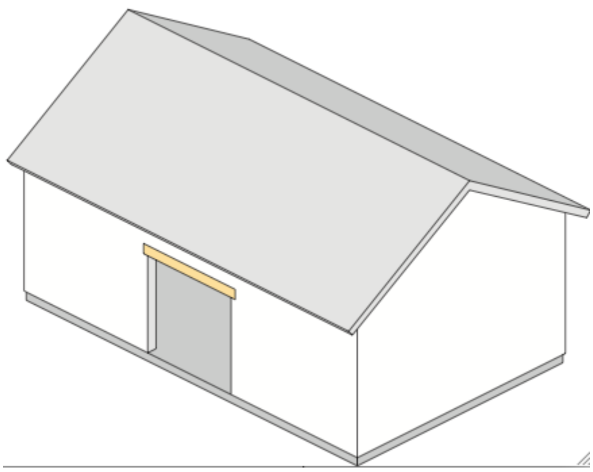
Rafters supported on a primary ridge beam



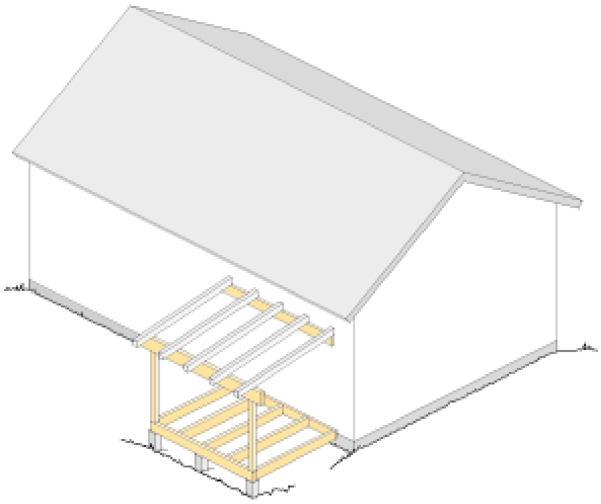
Rafters supported on two primary beams



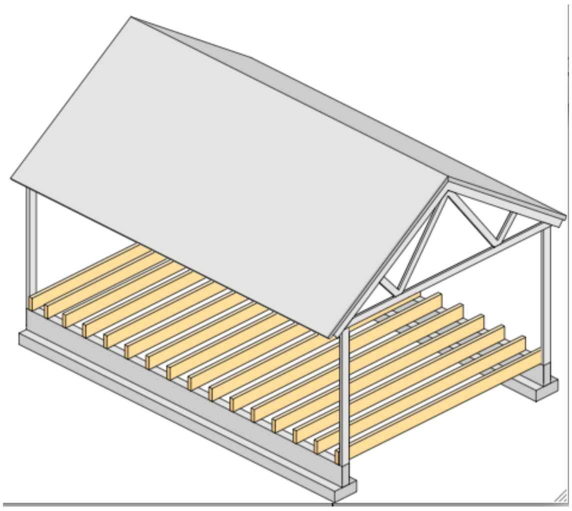
Roof trusses



Beams over opening in load bearing walls



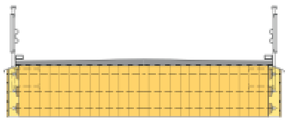
Conservatories



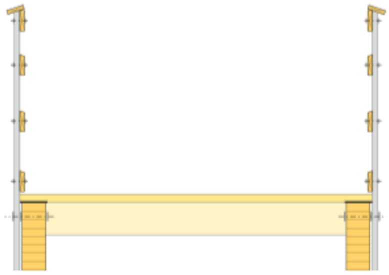
Floor beams

Examples of use of glulam for timber bridges

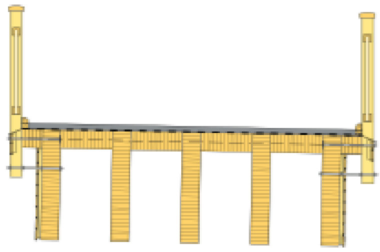
Pedestrian bridges and bridges for cyclists



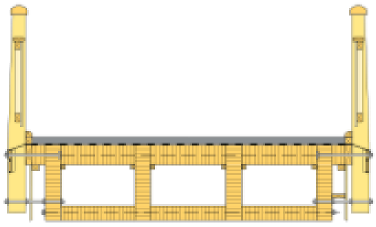
Transverse tension plate $\leq$ about 20 m



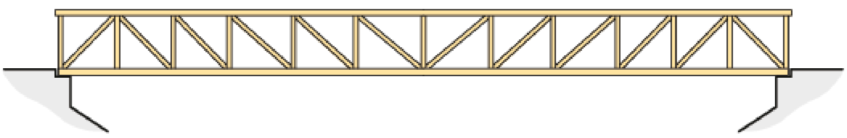
Beam bridge $\leq$ about 20 m



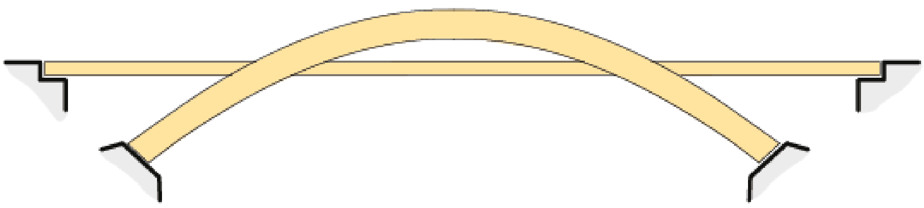
T-beam bridge $\leq$ 30 m



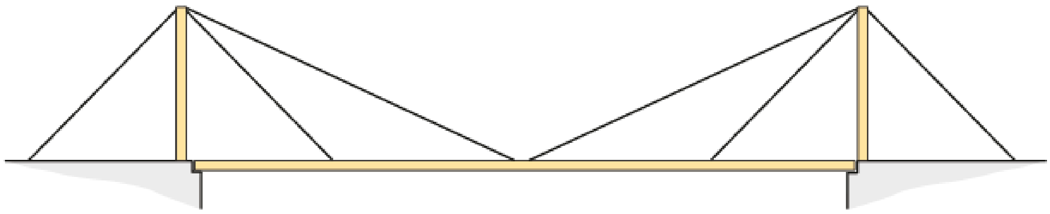
Box girder bridge $\leq$ 30 m



Truss bridge about 25 – 40 m

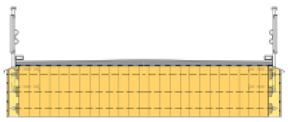


Arch bridge about 25 – 60 m

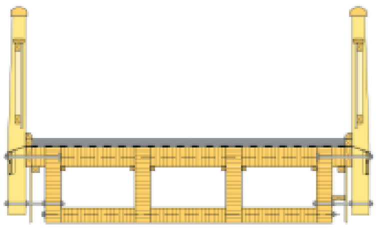


Pylon bridge about 40 – 100 m

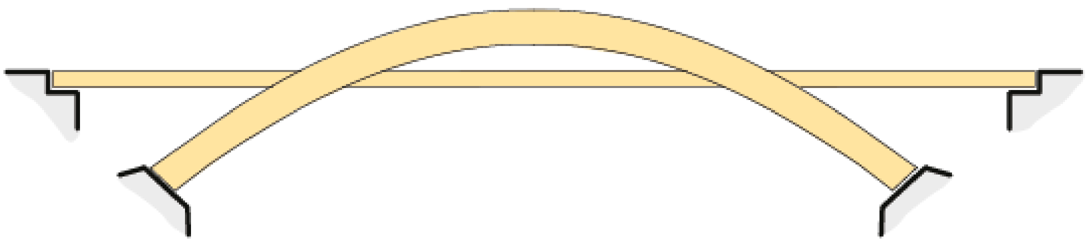
Road bridges



Transverse tension plate $\leq$ about 20 m



Box girder bridge $\leq$ about 20 m



Arch bridge about 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, UV-light and a certain amount of mechanical damage during transport, storage and possibly in connection with erection.


PHOTO: Example of individually wrapped glulam beam.

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, which 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 in the section Handling of glulam, page ? On receipt the reference moisture content should be checked for conformity with the ordered reference 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. This is however 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.

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 underside 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.

PLANNING

This second main part of the Glulam Handbook Volume 1 contains the foundation for the planning of structures and premises where glulam is included. At an early stage in the planning the planner needs to know the possibilities and limitations of glulam products.

The building technical conditions for good architecture are dealt with and the most common structural systems are presented here.

The required preliminary sizes are presented in tables later on. 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 Glulam Handbook Volume 2 and Volume 3.

Glulam is often used as a load bearing structure in larger one-storey buildings, for example halls. The European fire regulations make it however 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 under Design with regard to fire, page?

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 possibilities of expression. 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, which among other things gives the base for a technical description.

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 ?

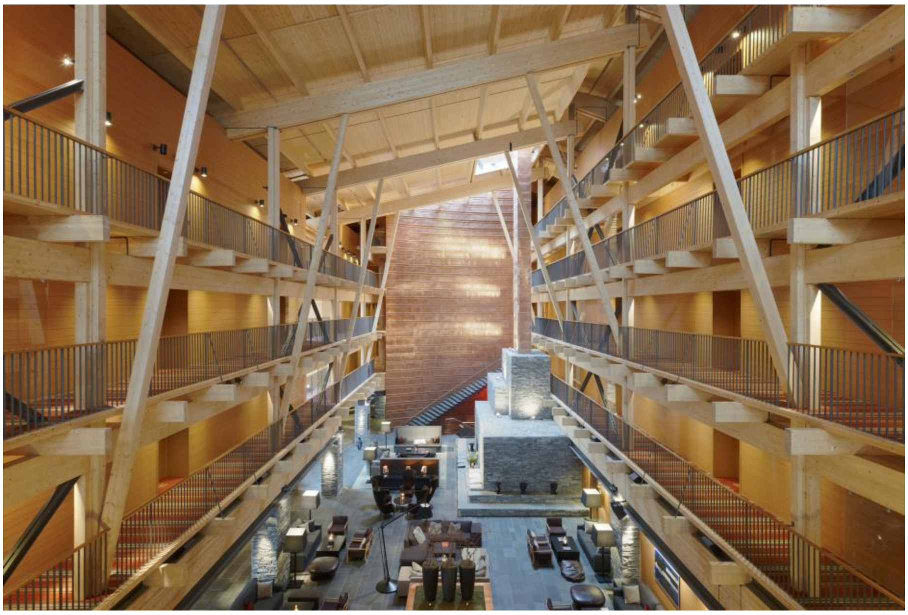


PHOTO: Copperhill Mountain Lodge, Åre, Sweden. Interior.
Photografer: ?

PHOTO: Copperhill Mountain Lodge, Åre, Sweden. Exterior.
Photographer: ? *We don´t have a high solution.*

STRUCTURAL CONDITIONS

Few structural materials can match glulam when it comes to structural and architectural possibilities of 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 which consists of several glued laminations”. See the section Facts about glulam, page?

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

In the section there is also guidance given on the possibilities and limitations on usage of glulam. Examples of optimal constructional solutions with glulam are reported in the section Structural Systems on page ?

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 illustration beside.

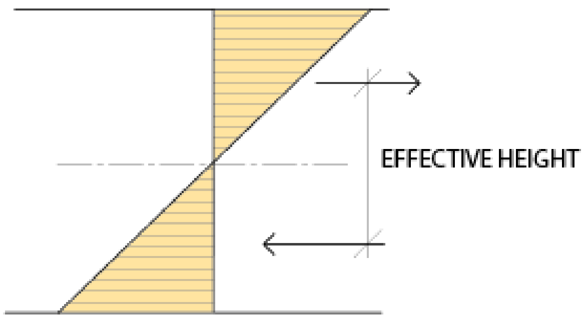


ILLUSTRATION: The effective height is the distance between the resultant compression stresses and the resultant of tension stresses.

A tendency, which applies within timber building technology, as well as in glulam technology, is increased usage of steel fittings. In the older timber building technology the joints were normally shaped to transfer compressing stress and could only to a limited extent transfer traction.

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.

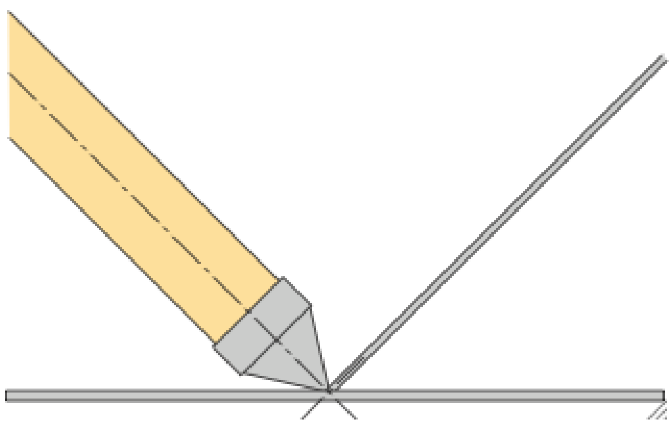


ILLUSTRATION: The system lines should preferably meet in one point – otherwise moment will occur in the connecting point.

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.

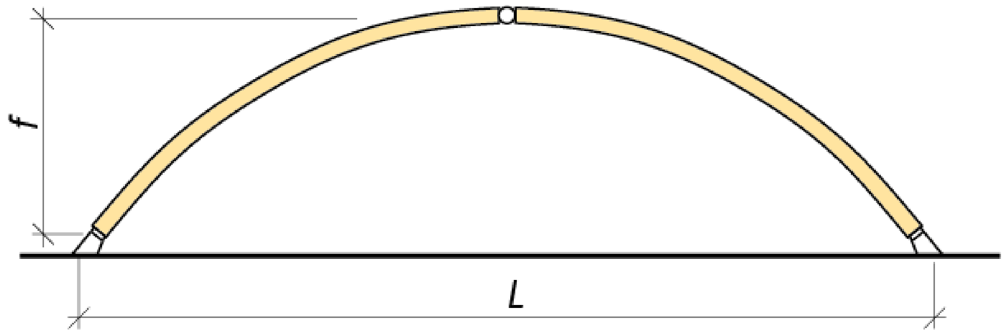


ILLUSTRATION: Three-pin arch – a statically determined structure.

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, which function as pins or which can transfer moment. Examples of connections are:

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

There are usable standard fittings like nailing plates, angular fittings, beam shoes and strip steel on the market. Normally however 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, which 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 in the section Planning considering fire, page?

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.

A collaboration at an early stage between architect and structural engineer makes for good solutions possible.

STRUCTURAL ASPECTS OF GLULAM STRUCTURES

The most common building part where glulam comes into its own is the roof structure. Frequent roof covering material is 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 material, for example steel or concrete.

Below are a few examples of structural considerations, which can be included at an early stage of the planning process. Some basic terms and simple formulas from strength doctrine should be taken into account and these 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 Eurocode 5.

A common way for conceptional design is to use the tables, which are in this part of the handbook.

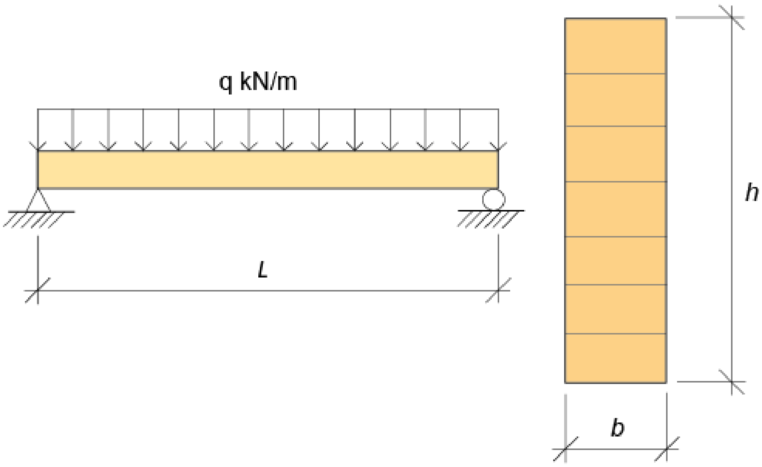


ILLUSTRATION: A simply supported glulam beam with width *b*, height *h* and span *L*.

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 = strength f_k x beam's bending moment resistance $W = b \times h^2/6$. Strength f_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. A width increase gives only a linear increase of the bending moment resistance *W*.

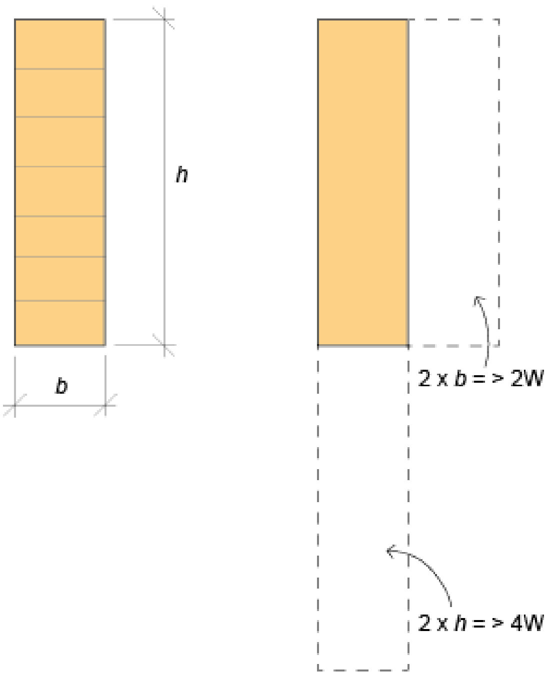


ILLUSTRATION: The bending strength of a beam increases by the square of the height.

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 normally 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 which 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 etcetera 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 Glulam Handbook Part 2.

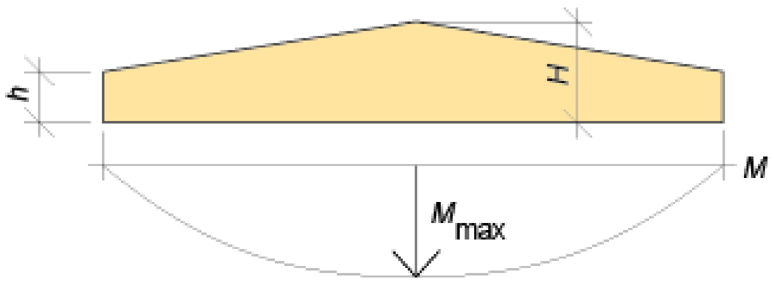


ILLUSTRATION: A double-pitched beam, freely supported, follows in principle the moment curve. It is therefore more economical than a straight, equally high beam.

• Installations make up a considerable part of the function and they 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 normally unsuitable with a hole or recesses adjacent to the supports. Tension distribution in the beam of outer moment is illustrated in illustration ? The inner zone of the beam is less exposed to stresses than the outer zones. The reasoning above is of principal nature. In the individual project the structural engineer can give instructions on possible holes and notches.

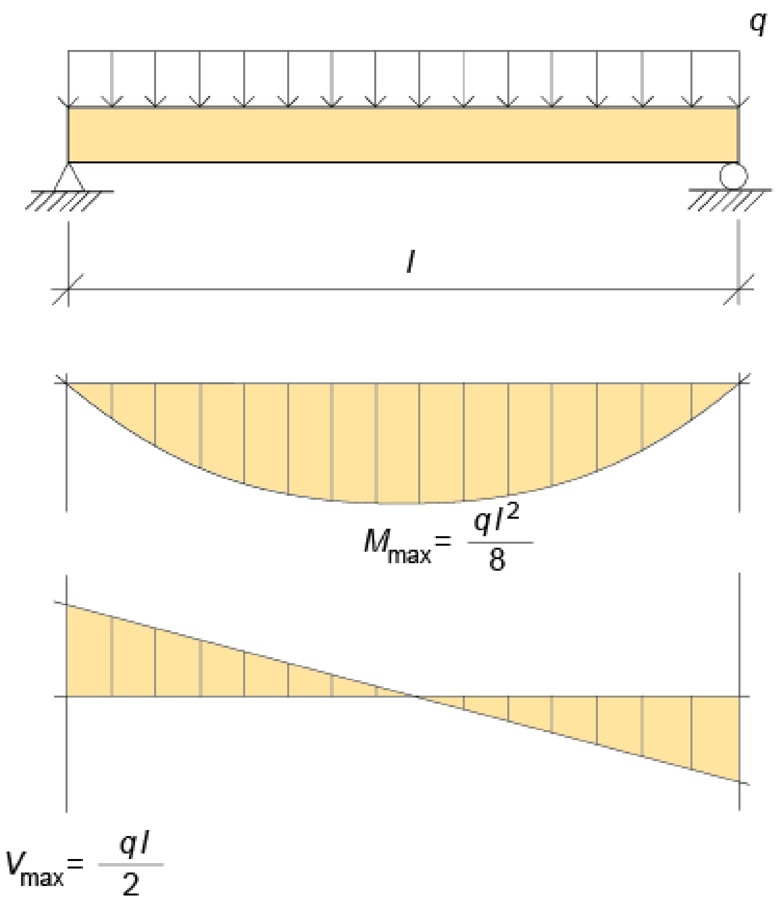


ILLUSTRATION: The outer moment and transverse forces for simply supported beams, loaded with an uniformly distributed load *q*.

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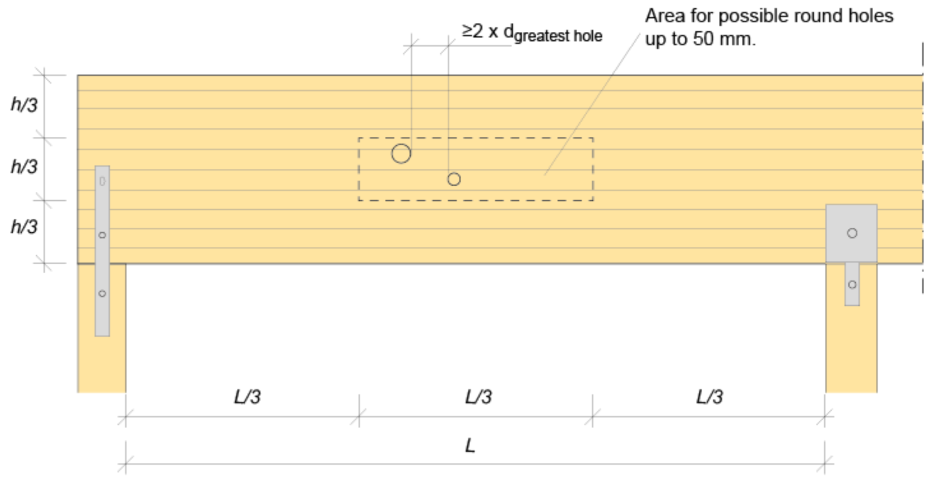
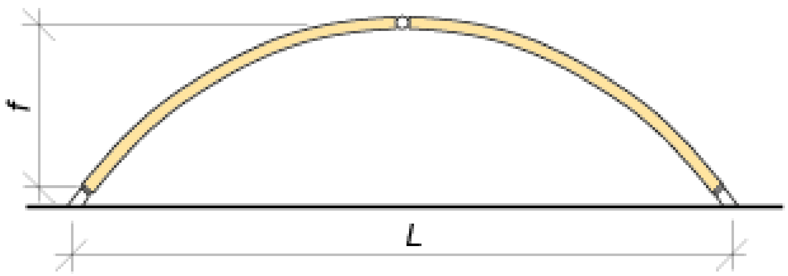


ILLUSTRATION: Holes in glulam beams should be handled with great care. Within the region above, some small holes could be accepted after confirmation from the structural engineer. Further information about holes in glulam beams, see Glulam Handbook Volume 2.

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 below. Through the material being better utilized in an arch, the high of the cross-section can be made lower, about *L*/50 or roughly 1/3 of the equivalent beam height, while it normally is *L*/15 – *L*/20 for straight beams.



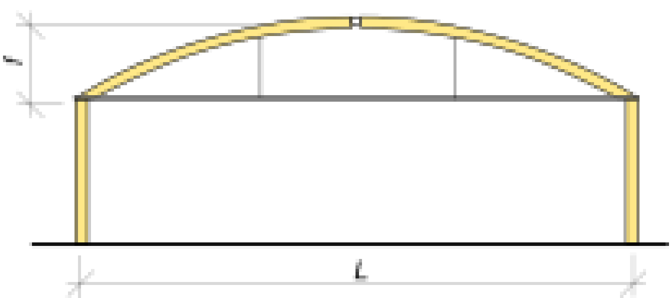


ILLUSTRATION: Arches permit an effective utilization of material, but require either fixed supports or tension rods.

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

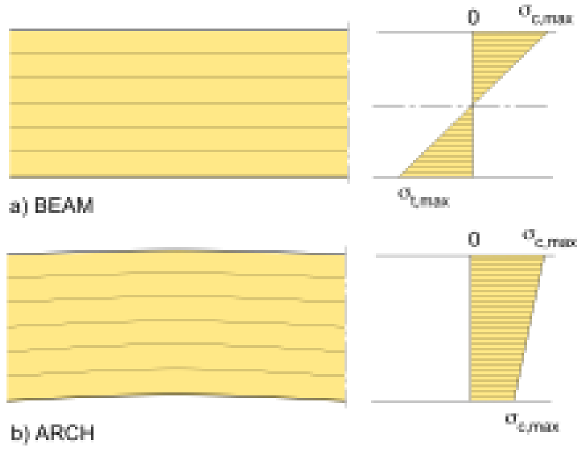


ILLUSTRATION: The tensions in a loaded beam are distributed like this: Pressure tensions and tensile tensions. The tension in the middle of the beam’s cross-section is 0. An arch can, as opposed to a beam, take pressure tensions through the whole cross-section.

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, like for example tension rods and jointing points. The installations can in many cases for example 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.

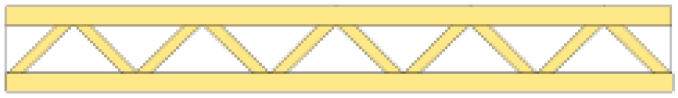


ILLUSTRATION. Trusses consist of different bars, which form a connected structural section.

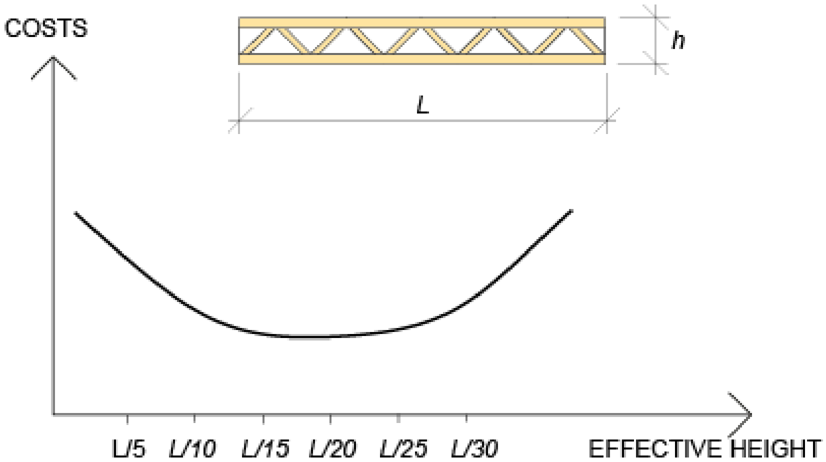


ILLUSTRATION: For roof structures the effective height of between *L*/15 and *L*/20 is often cost effective.

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.

With increased effective height for a structure there is an equivalent decrease in the pressure and tension forces. The product of the pressure forces x effective height = tension forces x effective height = the moment capacity. Special checks should be carried out so that 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.

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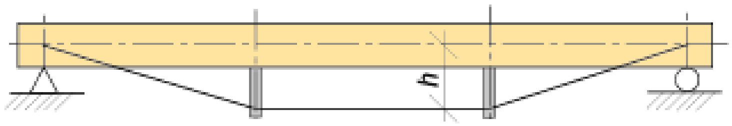


ILLUSTRATION: Examples of under-tensioned beam.

Columns

Columns of glulam normally have good load bearing capacity. A cantilever, which is not supported at the upper end, has a buckling length, which 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.

It is normal that the house design in a natural way creates possibilities to support the column in 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.

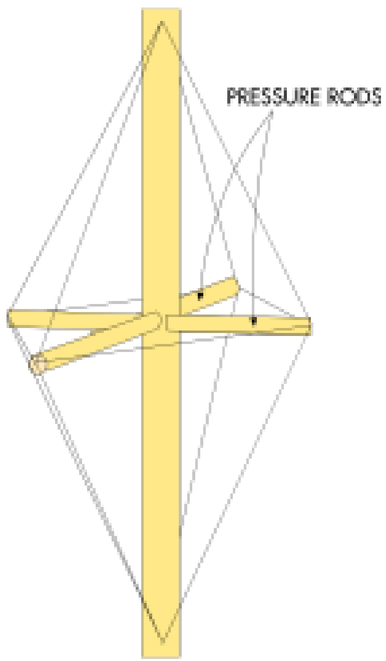


ILLUSTRATION: Principle design of reducing the buckling length and thereby column size is to design free-standing columns with pressure rods.

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.

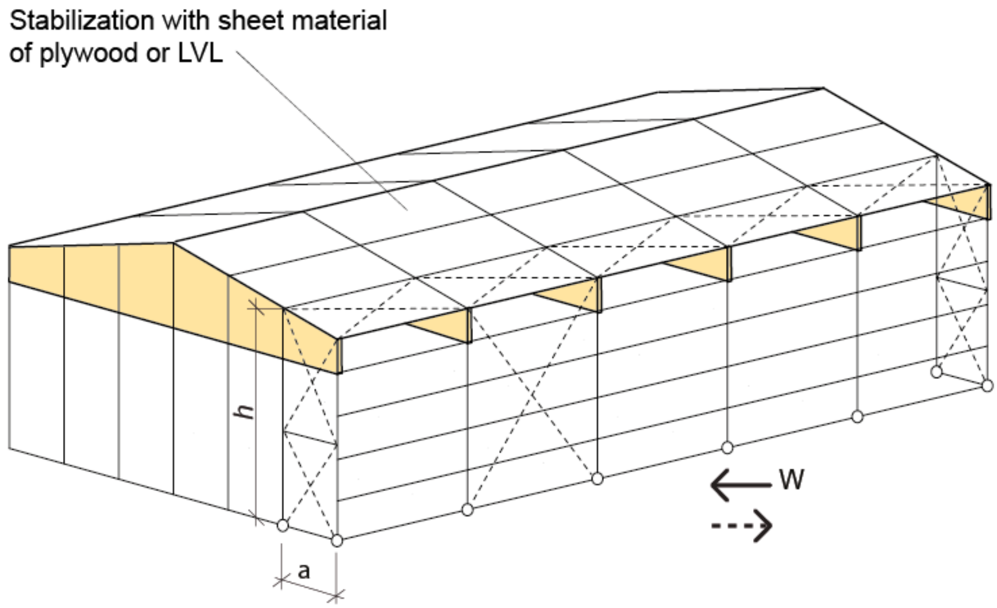


ILLUSTRATION: Example of stabilization of a glulam structure.

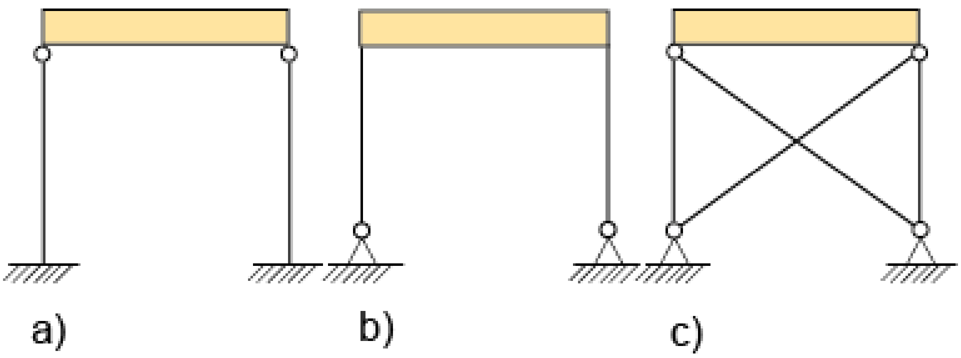


ILLUSTRATION: Examples of structures, which are stable:
a) Rigidly fixed cantilever of column feet; A pinned connection between beam and column.
b) Pinned cantilevering of column feet; Rigidly fixed cantilevering between beam and column.
c) Pinned attachments of column feet and column top; Diagonal braces of steel or timber.

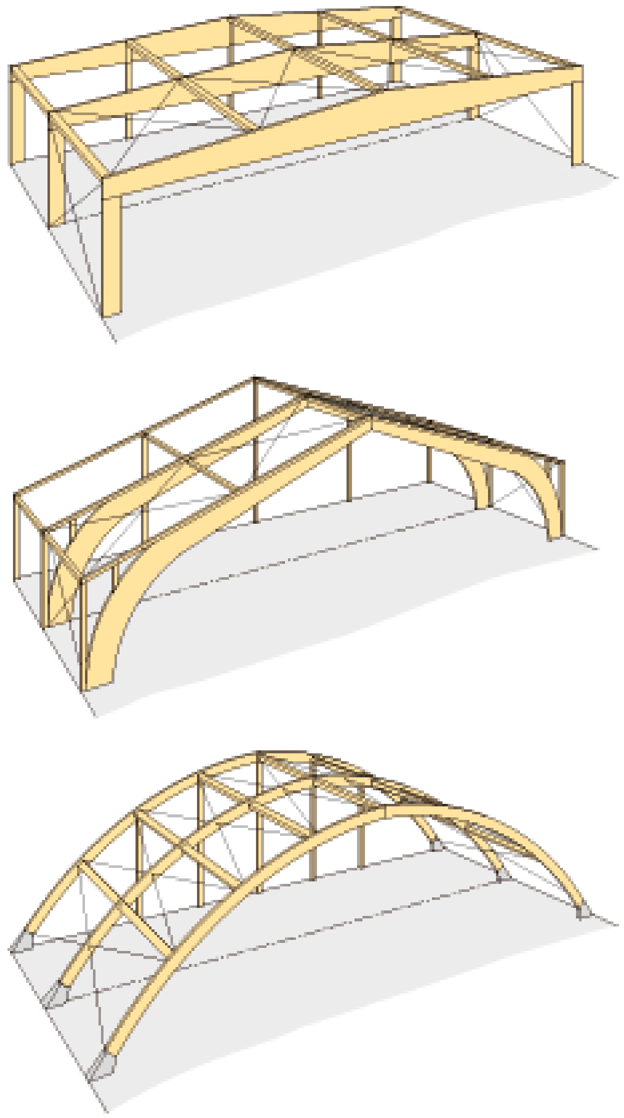


ILLUSTRATION: Examples of devices of wind bracing for portal frame and arch structures. A further description of how the bracing of glulam structures are suitably designed is in the Glulam Handbook Volume 2.

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:

1. Roof covering on rafters and roof beams of glulam.
2. Roof tiles on underlay felt covered timber boards, with or without mineral wool insulation and inward lining. Rafters and ridge beam of glulam.
3. Felt or sheet metal covering on reinforced wood-wool elements.
4. Felt or sheet metal covering on hard mineral wool insulation on load-bearing profiled sheet metal.

5. Roof tiles on underlay felt covered timber boards, with or without mineral wool insulation and inward lining. Roof trusses of glulam.

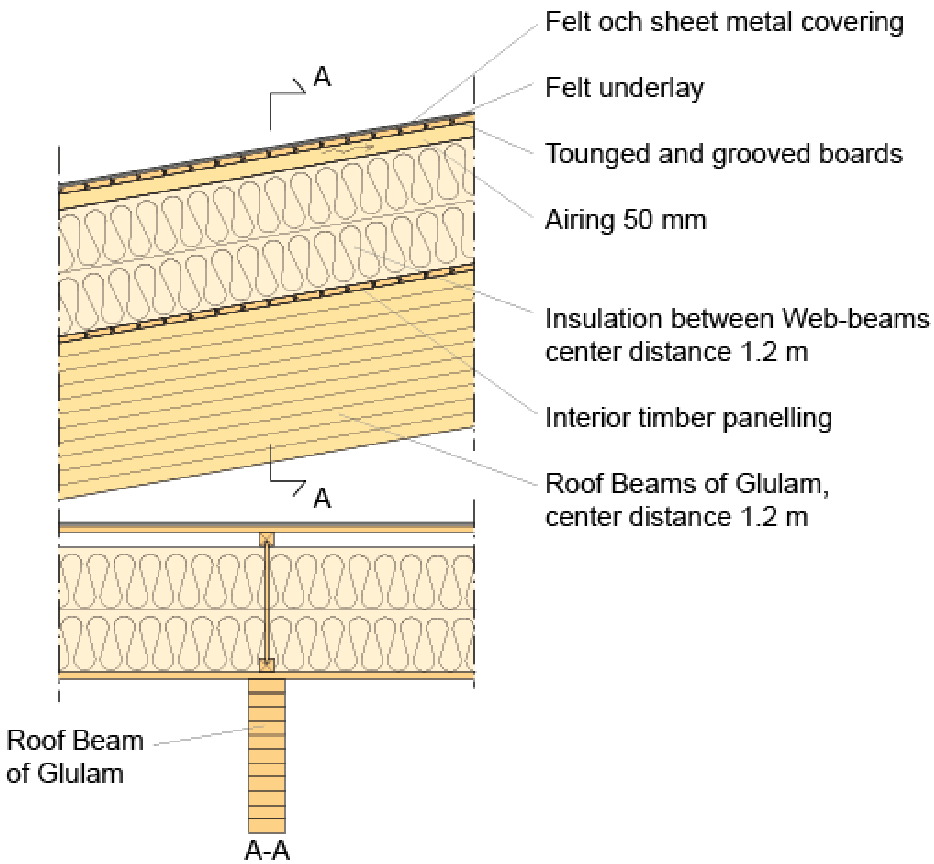


ILLUSTRATION: Principle design of a roof structure with heat insulation between roof beams above visible glulam roof beams. Observe the importance of the correct design of different details, like for example airing.

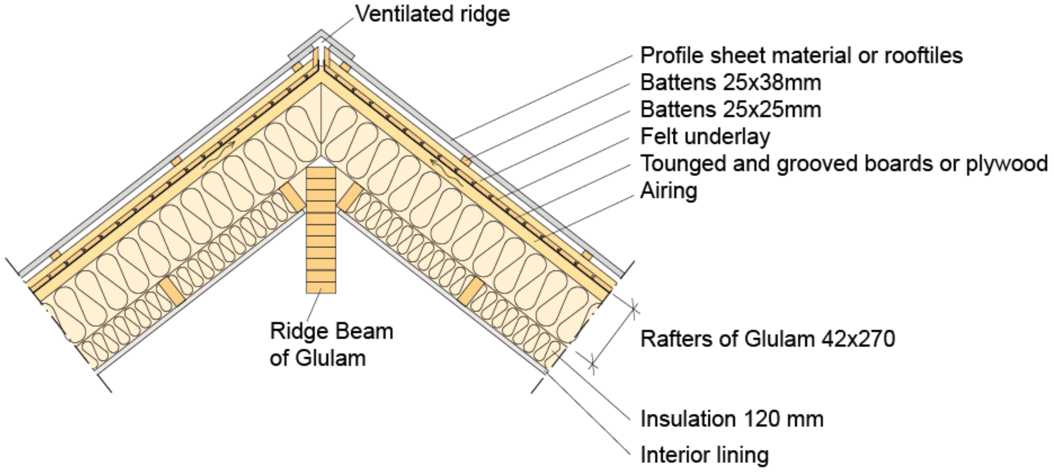


ILLUSTRATION: Principle design of profile sheet material or roof tiles on felt covered tongued and grooved timber boards, insulation, rafters and ridge beam of glulam.

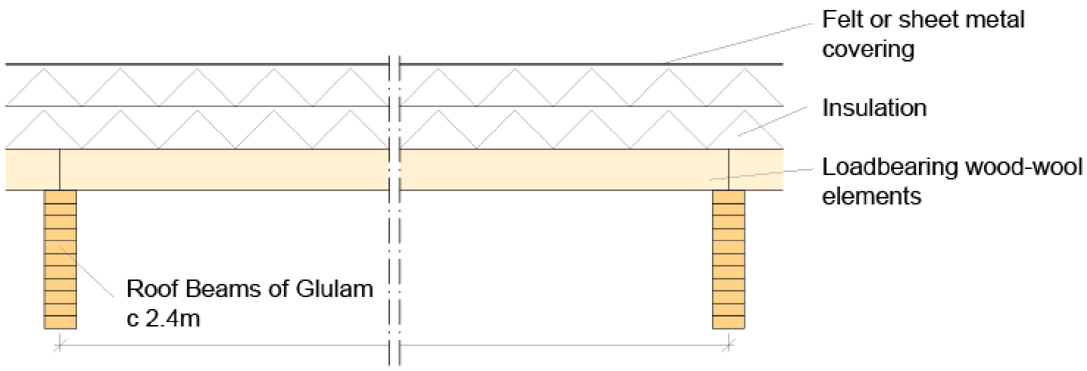


ILLUSTRATION: Principle design of a roof structure with reinforced load-bearing wood-wool elements above glulam beams.

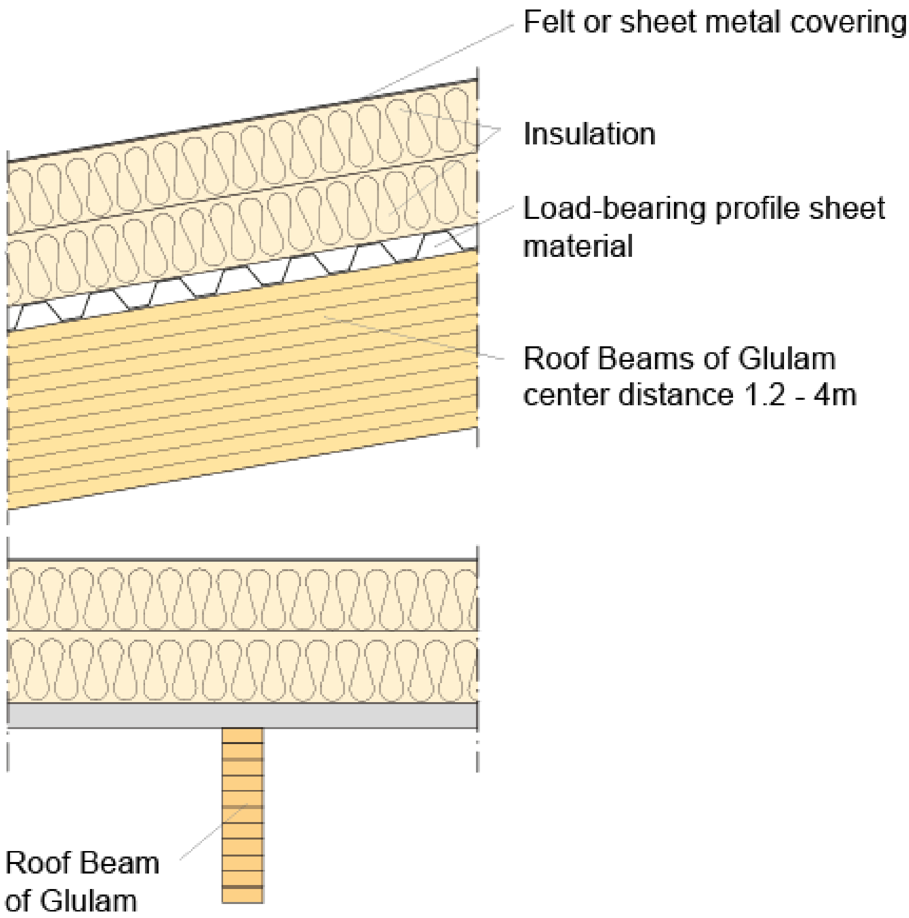


ILLUSTRATION: Principle design of a roof structure with thermal insulation on load bearing profile sheet metal and roof beams of glulam.

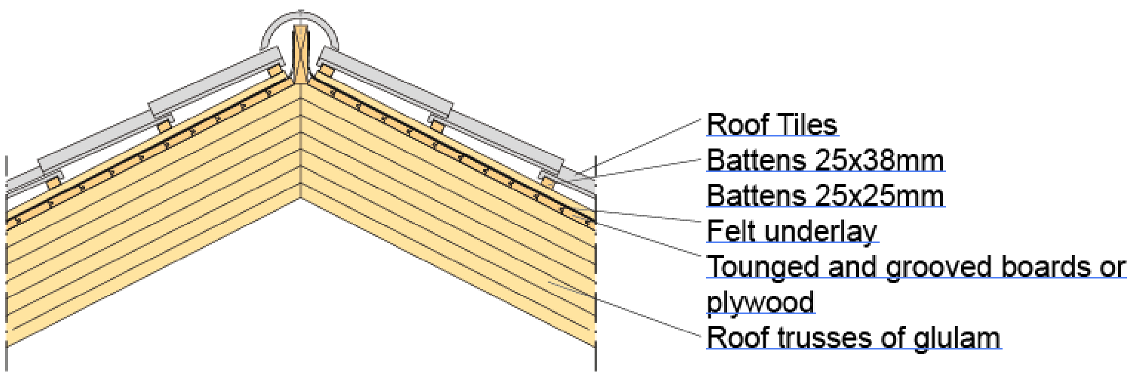
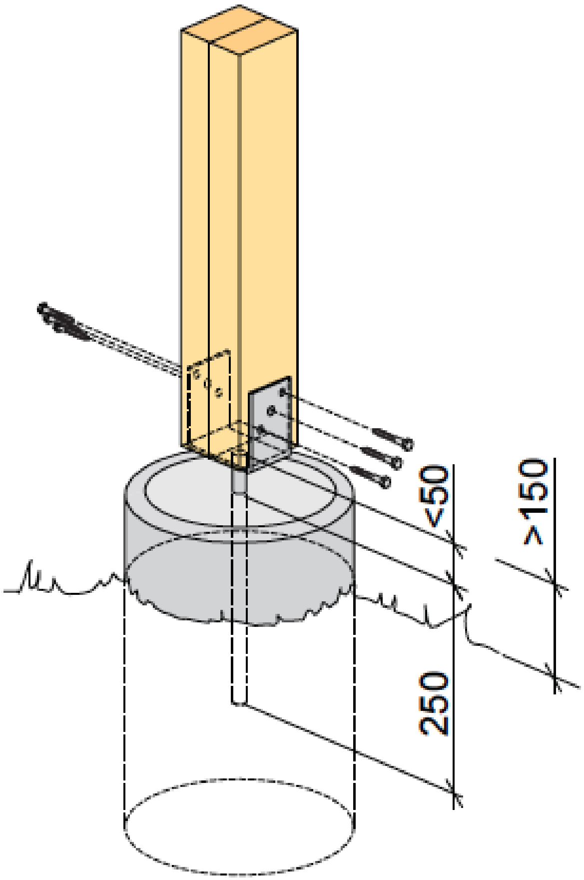


ILLUSTRATION: Principle design of roof trusses of glulam with underlay of felt covered, tounged and grooved timber boards or plywood for roof tiles.

MOISTURE PROTECTION

Glulam should be protected against the long-term affects of damp. Here are shown below some principle examples of moisture protection. See also the section Fixing details, page?



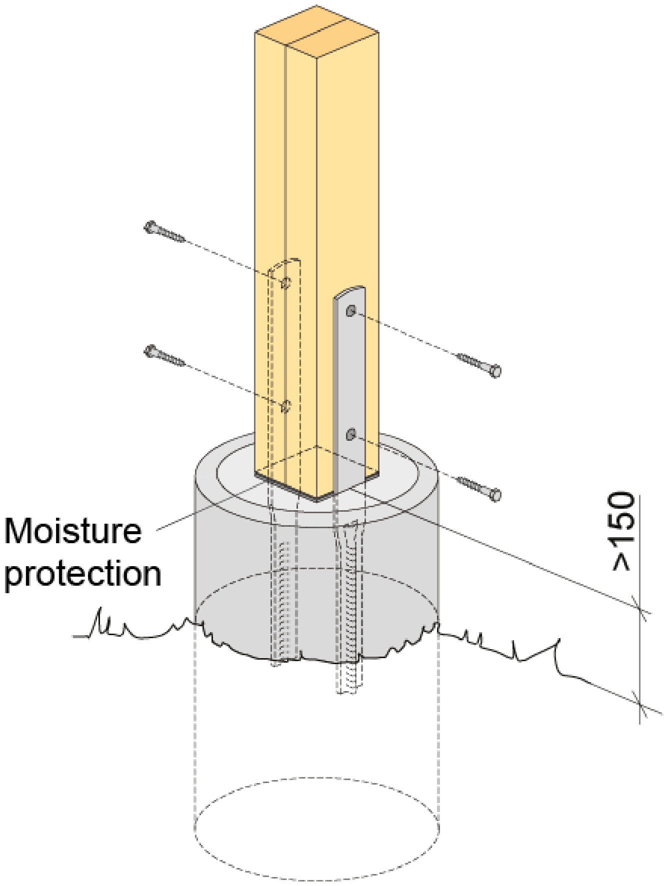


ILLUSTRATION: Two examples of moisture protection of a column foot outdoors. It is important with a moisture protection membrane or airing between the concrete surface and the glulam column.
Upper: Post shoe with possibilities to treat the end grain in order to prevent moisture uptake.
Lower: Sheet metal and moisture protection membran between glulam and concrete.

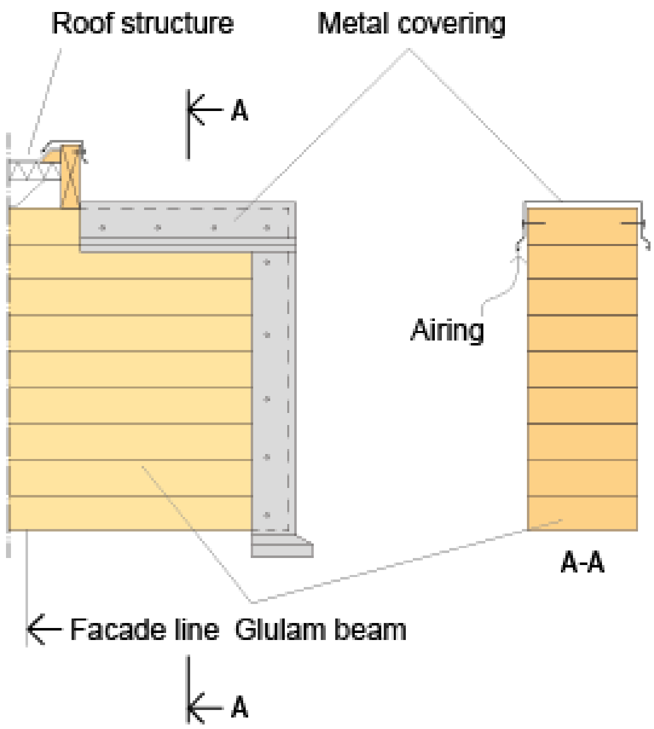


ILLUSTRATION: Moisture protection of an external cantilevering glulam beam. Sheet metal covering on top surface and endgrain. For more information, see Glulam Handbook Volume 2.

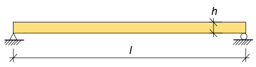
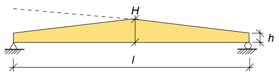
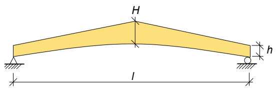
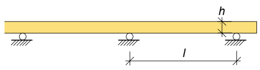
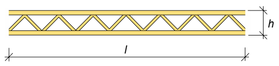
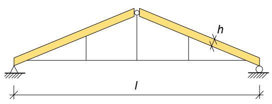
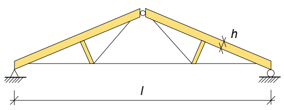
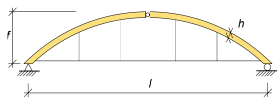
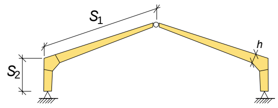
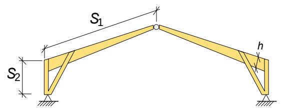
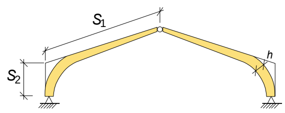
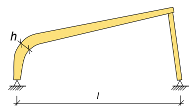
STRUCTURAL SYSTEMS

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.

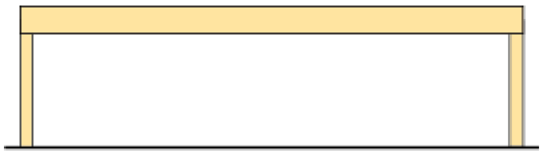
STRUCTURAL SYSTEMS – AN OVERVIEW

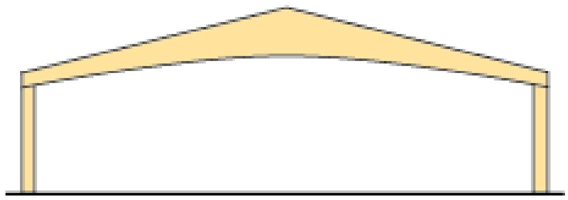
Table. Load bearing structures c-distance approximately 6 m and variable load of ca 3.0 kN/m^2. Suitable span areas *L* and approximate height/depth *h* of the cross-section of the glulam element.

STRUCTURAL SYSTEMS – AN OVERVIEW

System	**Name**	**Roof pitch**	**Span *L***	***h***
	Straight beam on two supports	≥ 3°	< 30 m	*L*/17
	Double pitched beam on two supports; Single pitched beam	3 – 10°	10 – 30 m	*h* ≈ *L*/30 *H* ≈ *H*/16
	Pitched cambered beam on two supports	3 – 15°	10 – 20 m	*h* ≈ *L*/30 *H* ≈ *l*/16
	Continious beam on several supports	≥ 3°	< 25 m	*L*/20
	Truss on two supports	≥ 3°	30 – 85 m	*L*/10
	Three-pin roof truss with or without tie	≥ 14°	15 – 50 m	*L*/30
	Three-pin roof truss with tie and trussed beams	≥ 14°	20 – 100 m	*L*/40
	Three-pin arch with or without tie	f/l ≥ 0,144	20 – 100 m	*L*/50
	Three-pin portal frame with finger jointed haunches	≥ 14°	15 – 25 m	$(s_1 + s_2)/13$
	Knee braced portal frame	≥ 14°	10 – 35 m	$(s_1 + s_2)/15$
	Three-pin portal frame with curved haunches	≥ 14°	15 – 40 m	$(s_1 + s_2)/15$
	Half portal frame with pinned columns	≥ 20°	10 – 25 m	*L*/25

BEAM – 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 those of greater spans it can be economically motivated 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 for esthetic or functional reasons be given a more or less marked curving. 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 in Europe to build timber buildings of more than two storeys for several years. The national regulations can be different. Meanwhile experiences of multi-storey timber buildings, which have been built are up to now good. 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).

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Glulam members can be columns and beams while floor and façade sections can be made of for example panels of cross-laminated timber. There are system solutions for several multi-storey timber buildings with prefabricated components of glulam in the form of for example 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 possible dry building by the outer roof being mounted 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 possible high flexibility in the layout. A glulam structure is mounted with the aid of screw and steel fittings throughout, which makes possible simple disassembly and prospective reassembly in another place. Moreover such a building can be adapted to different needs and to alterred future needs.

Multi-storey timber buildings have good fire protective qualities. One can consider whether to add to the building technological fire protection with a residential sprinkler system. The local fire authorities should be consulted. There are structures, which manage the fire and noise requirements for apartment dividing walls and joists.

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.

Prefabricated buildings with industrially manufactured components is a rational way to build – just in time-deliveries without in between storage on the building site and direct erection gives a shorter erection process.

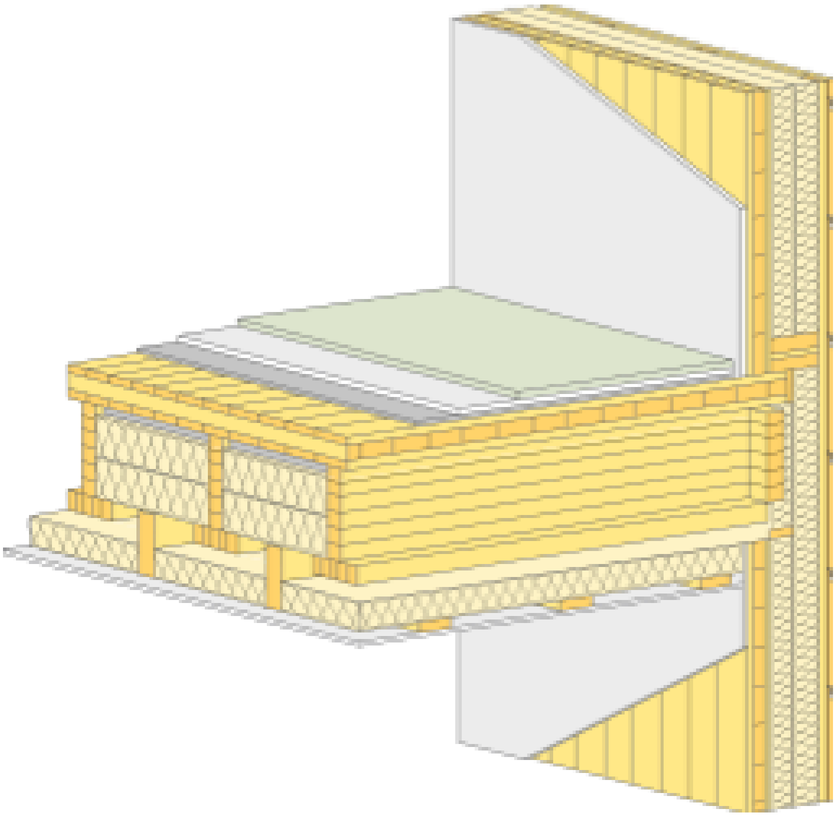
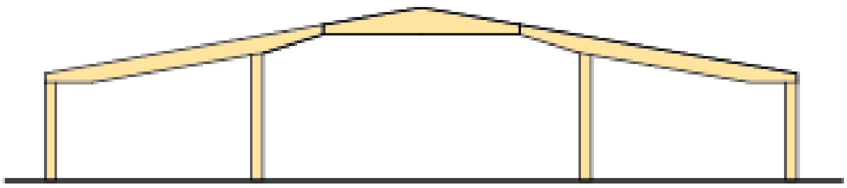


ILLUSTRATION: Principle design of a multi-storey timber building frame. Floor panel with load-bearing glulam beams. This design is approved regarding sound insulation and fire protection..

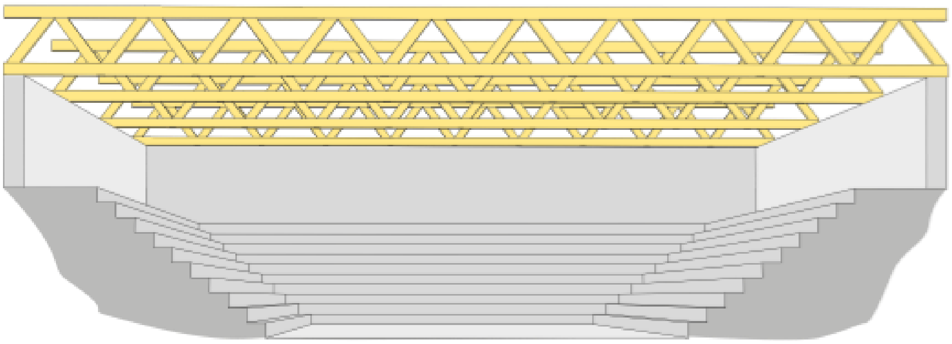
CONTINUOUS BEAMS



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 joins 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).

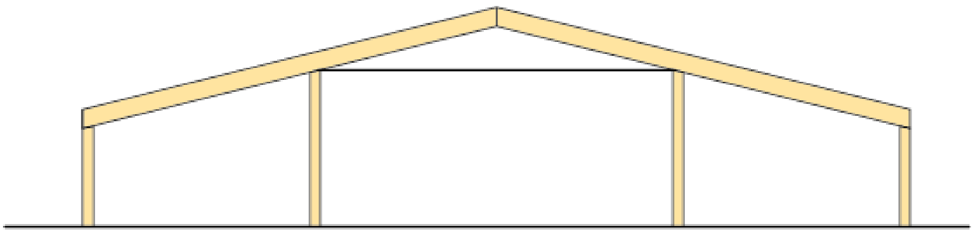
TRUSSES

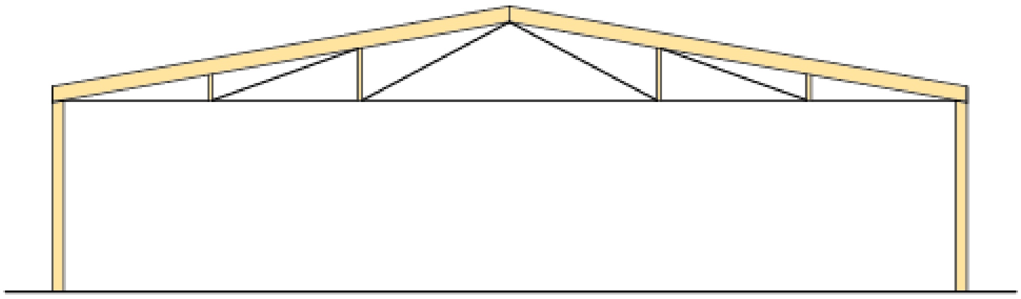


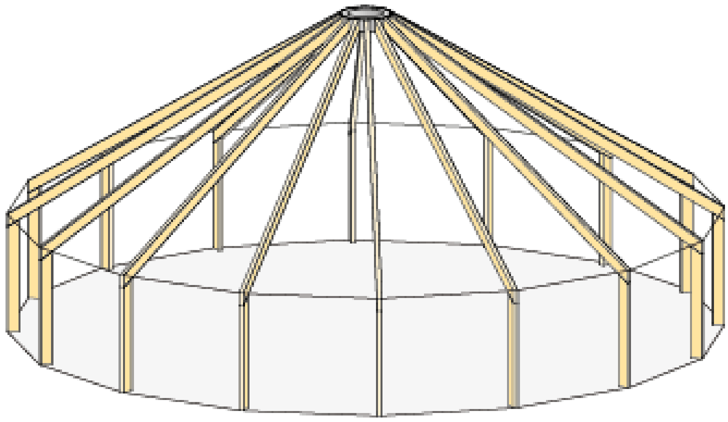
With large spans, when the solid beam tends to be much too unwieldy and material demanding, some types of trusses or tension rods structure can be an effective solution.

The structure of glulam appears above all for the demands of a small roof pitch and where the effective height is not excessively compact.
One advantage of a truss is that it can be manufactured in a factory in suitable transport units, which are mounted 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





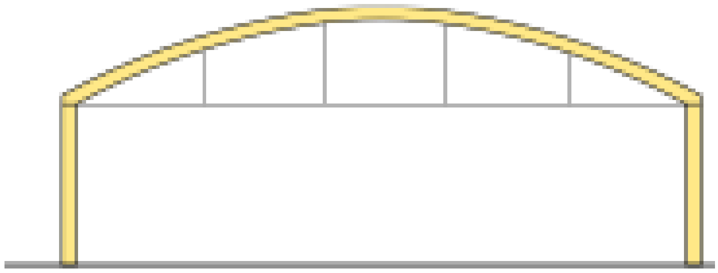


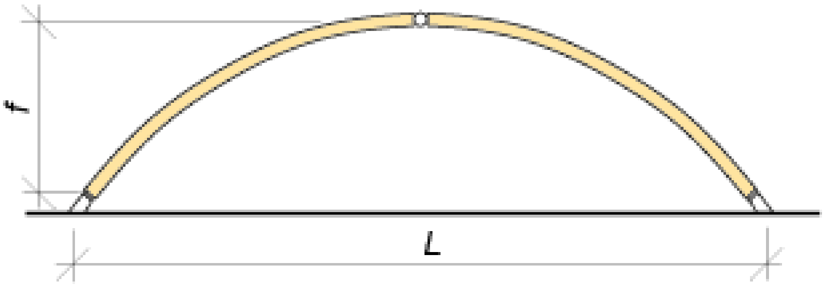
Three-pin roof trusses or trussed beams can be a solution when the demands of the span width rule out solid beams and when arches or portal frames for different reasons are unusable.

Three-pin roof trusses are created in their simplest form from two beams leaning towards each other and 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 equally high but the shape can even here vary. The 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 advantageously 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 illustration beside). Problems often arise with the practical carrying out of erection when more than four sections meet at one point.

THREE-PIN ARCHES





Glulam is an interesting structural material through amongst others the possibility of simply 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).

The design possibilities make, together with the high load bearing capacity, glulam structures especially competitively viable for large spans. Arches with over 100 m free span have been built.

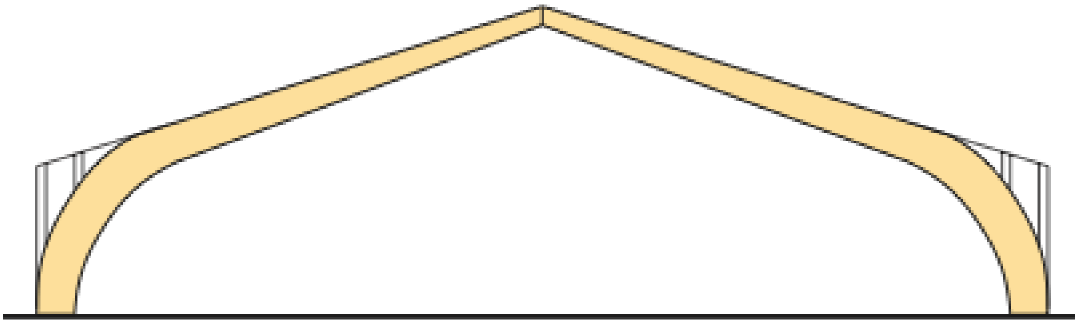
The parabolic arch is the most common form for large span-widths, the circular arch for small. In order to increase the free height close to the supports, the elliptic or other arch form can be preferable. This can also be achieved if the arch is laid on columns. Then the arch in the girder must be provided 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 for transportation reasons. 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, the dome is also a financially attractive solution. In Tacoma, USA, there is an example of a dome building designed in glulam with an over 160 m span.

THREE-PIN PORTAL FRAMES



For functional, aesthetic or other reasons, in many cases another arch shape than the material economically advantageous parabolic arch can be preferred. The demand for a certain free height within the whole building often leads to the, characteristic for glulam, three-pin portal frame with curved frame haunches or, with high demands on the usage of building volume, finger jointed frame haunches.

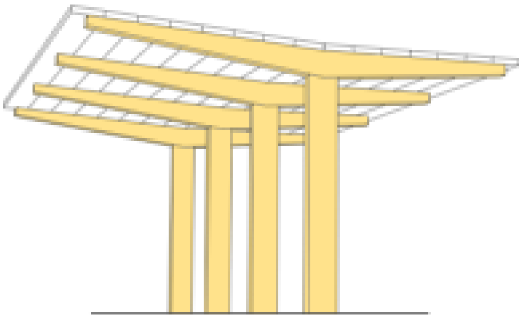
The building’s function is improved in both cases at the expense of a somewhat lower material efficiency. The three-pin portal frame has otherwise the same advantages as a three-pin arch – simple structural design and foundation structure. It is especially unsuitable with a poor foundation-bed as it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

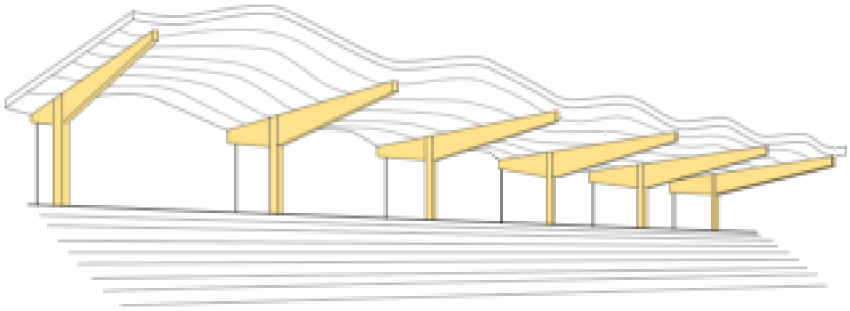
The traditional shape is level symmetrical but other rooms can be achieved by combinations with other structural sections – curved or straight – or through three-dimensional arrangements.

CANTILEVERS

In many contexts the building's function demands that the 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.

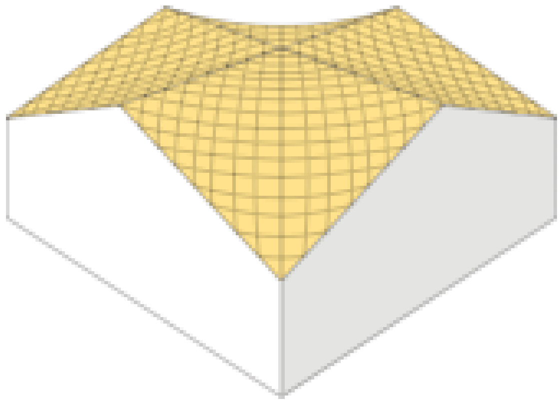
Here the glulam technique offers solutions in the form of cantilever piles, straight beams or curved consoles – half frames. In both cases significant bedding moment must be transferred to connecting structures, which thus must be designed considering this.





SHELL CONSTRUCTIONS

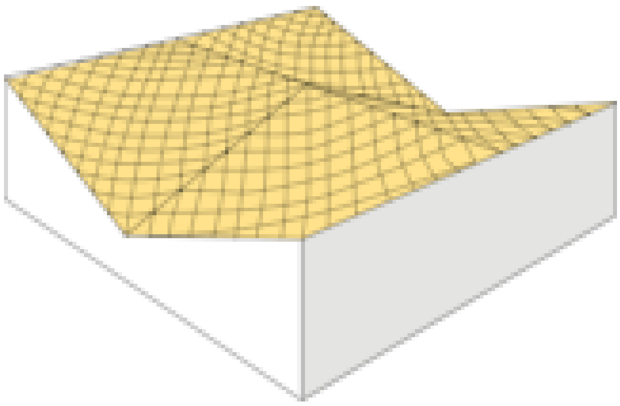
Shell constructions give rich possibilities for advanced design and great spans without supporting columns. By combination of several shell sections many different shapes can be created.

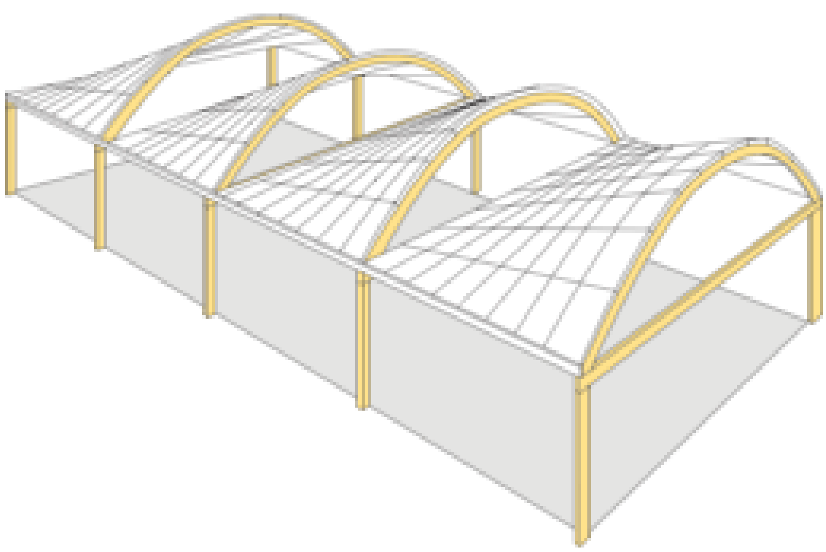


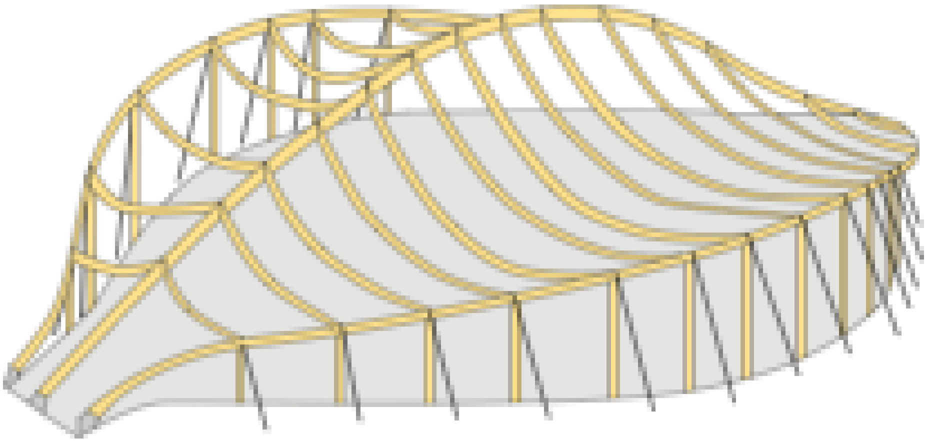
COMPOSITE SYSTEMS

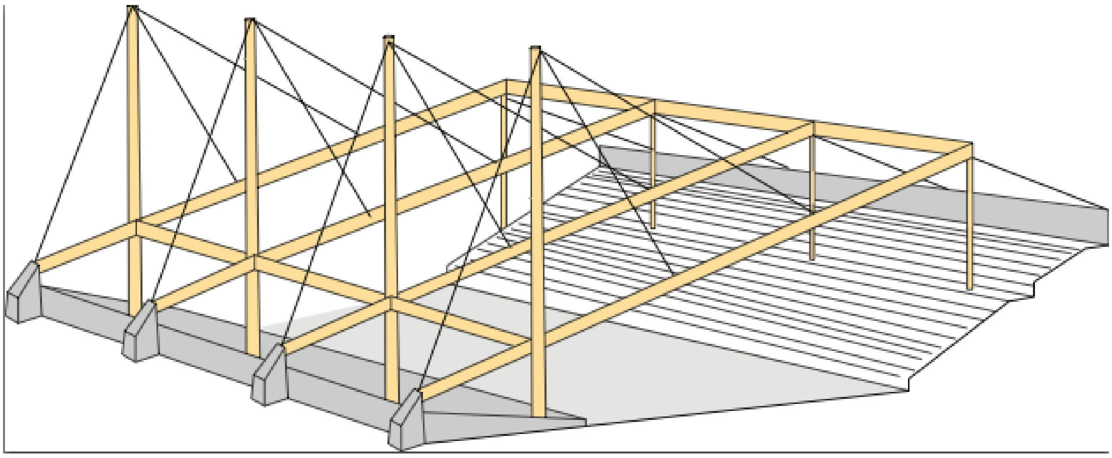
Combinations of different statistical systems often offer excellent solutions. Requests for abundant daylight can be fulfilled with a saw-tooth roof consisting of three-pin roof trusses, which are laid on some continuous trimmers.

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.









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 possible national additional documents.

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 the starting point from timber building design standard Eurocode 5. In addition every country has, for some aspects, their own national agreed parameters to be used.

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

DESIGN LOADS FOR ROOF STRUCTURES

Design loads for a roof beam/rafter depends 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 lock the conditions more than necessary 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 the so-called – snow load on the ground – where the building lies, for example 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. Current snow load expressed in kN/m^2 horizontal roof area is normally given for roofs pitched up to 15 degrees.

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 national annex to Eurocode 1.

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 national annex to Eurocode 1. Examples of self-weight for some normal types of roof are given in the table below. The value shall then be multiplied by the partial coefficient for the action according to Eurocode 5.

5. The load per m of beam is then calculated by multiplying the in that way obtained design load per m^2 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/m^3.

TABLE: The basic value s_k, current snow load and load reduction factors according to the national annex to Eurocode 0. Below is given the value from the Swedish supplement the Swedish National Board of Housing, Building and Planning statute book BFS 2010:28 EKS 8.

BASIC VALUE s_k	SNOW LOAD (kN/m^2)	LOAD REDUCTION FACTOR ψ [1)] [2)]
1.0	0.8	0.6
1.5	1.2	0.7
2.0	1.6	0.7
2.5	2.0	0.7
3.0	2.4	0.8
3.5	2.8	0.8
4.0	3.2	0.8
4.5	3.6	0.8
5.0	4.0	0.8
5.5	4.4	0.8

[1)] In the serviceability limit state (load combination 9) the snow load is multiplied by the load reduction factor ψ

[2)] The snow load's weight shall be decided according to the following formula:
Point of maximum load: snow load · 1,3 + self-weight
Serviceability limit state: snow load · ψ + self-weight

TABLE: Rough values for self-weight for some normal roof structures (exclusive of glulam) kN/m^2.

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

DIMENSION TABLES

STRAIGHT ROOF BEAMS

Table: Strength class GL30c. Resawn beams GL28cs. Adhesive type I. Clean planed, unrepaired surfaces. 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 x the beam's width *b*.
Deflection in serviceability limit state borderline of variable load is at most 1/250 or of the total load at most 1/200 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). Procambered beams are required.

kcr	0,85					
Belastning KN/m	Spännvidd (m)					
	5	6	7	8	9	10
2	42x270	42x315	56x360	56x405	56x450	66x450
3	42x315	56x360	56x405	66x450	66x495	78x495
4	42x360	56x360	56x450	66x450	78x495	78x540
5	56x360	56x405	66x450	78x495	90x495	90x540
6	56x360	56x405	66x450	78x495	90x540	90x585
7	56x360	56x450	66x495	78x540	90x540	90x630
8	56x405	66x450	90x450	90x540	90x585	90x630
9	56x405	66x450	78x495	78x585	90x630	90x675
10	56x450	66x495	78x540	90x540	90x630	115x630
12	66x450	78x495	90x540	90x585	115x630	115x675

Dimensioneringsorsak
Initial deformation
Slutlig deformation
Böjspänning
Skjuvspänning

Belastning KN/m	Spännvidd (m)							
	11	12	13	14	15	16	17	18
6	90x630	115x630	115x720	115x765	140x765	140x810	140x855	140x900
7	115x630	115x675	115x720	115x810	140x810	140x855	140x900	140x945
8	115x675	115x720	115x765	115x810	140x855	140x900	140x945	140x990
9	115x675	115x765	115x810	140x810	140x855	140x900	140x990	140x1035
10	115x720	115x765	115x810	140x855	140x900	140x945	140x990	165x1035
12	115x765	115x810	115x900	140x900	140x945	140x990	165x1035	165x1080
15	115x810	140x810	140x900	140x945	140x1035	165x1035	165x1080	165x1170
18	140x810	140x855	140x945	140x1035	165x1035	165x1080	190x1125	190x1170
20	140x855	140x900	140x990	165x990	165x1080	165x1125	190x1170	190x1215
25	140x945	140x1035	140x1125	165x1080	190x1080	190x1170	190x1260	190x1305
30	140x1035	165x1035	165x1125	190x1125	190x1215	190x1260	215x1260	215x1350

DOUBLE PITCHED BEAMS

Table: Strength class GL30c. Adhesive type I. Clean planed, unrepaired surfaces. 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 most15 x the beam's width.
The deflection in serviceability limit state of variable load, initial deformation, is at most 1/200 or kvasipermanent deformation of the total load at most 1/160 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).
Procambered beams are required.

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.

kcr 0,857

Dimensioneringsorsak
Initial deformation
Slutlig deformation
Böjspänning
Skjuvspänning

Belastning KN/m	Spännvidd (m)												
	12	13	14	15	16	17	18	19	20	21	22	23	24
6	90 365-740	90 404-810	115 353-790	115 381-850	115 410-910	115 429-960	115 458-1020	140 416-1010	140 435-1060	140 454-1110	140 482-1170	140 501-1220	140 520-1270
7	90 415-790	115 374-780	115 402-840	115 431-900	115 460-960	115 489-1020	140 448-1010	140 466-1060	140 495-1120	140 514-1170	140 543-1230	140 561-1280	165 520-1270
8	115 385-760	115 414-820	115 443-880	115 471-940	115 510-1010	140 459-990	140 488-1050	140 516-1110	140 545-1170	140 574-1230	165 523-1210	165 551-1270	165 570-1320
9	115 415-790	115 454-860	115 483-920	115 521-990	140 480-980	140 509-1040	140 538-1100	140 566-1160	140 595-1220	165 554-1210	165 573-1260	165 601-1320	165 630-1380
10	115 445-820	115 484-890	115 523-960	115 561-1030	140 520-1020	140 549-1080	140 577-1140	140 616-1210	140 645-1270	165 594-1250	165 623-1310	165 651-1370	165 680-1430
12	115 515-890	115 554-960	115 593-1030	115 641-1110	140 590-1090	140 629-1160	140 668-1230	165 616-1210	165 655-1280	165 684-1340	165 712-1400	165 751-1470	190 700-1450
15	115 595-970	115 644-1050	140 633-1070	140 651-1120	140 690-1190	140 739-1270	165 688-1250	165 726-1320	165 765-1390	165 804-1460	190 763-1450	190 791-1510	190 830-1580
18	115 675-1050	140 644-1050	140 693-1130	140 741-1210	165 700-1200	165 749-1280	165 788-1350	165 826-1420	190 795-1420	190 834-1490	190 873-1560	190 911-1630	190 950-1700
20	140 635-1010	140 684-1090	140 742-1180	165 711-1180	165 750-1250	165 799-1330	165 847-1410	165 896-1490	190 855-1480	190 894-1550	190 933-1620	190 981-1700	215 940-1690
25	140 735-1110	140 804-1210	140 863-1300	165 821-1290	165 880-1380	165 929-1460	190 898-1460	190 946-1540	190 995-1620	190 1044-1700	215 1003-1690	215 1051-1770	215 1100-1850
30	140 875-1250	140 934-1350	165 873-1310	165 941-1410	165 1000-1500	190 959-1490	190 1018-1580	215 986-1580	215 1035-1660	215 1094-1750	215 1143-1830	215 1191-1910	215 1240-1990

PHOTO: Entrance of Moelven Töreboda AB, Töreboda, Sweden

THREE-PIN ROOF TRUSS WITH STEEL TIES

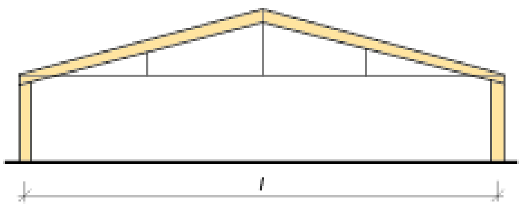


Table: Strength class GL30c. Adhesive type I. Clean planed, unrepaired surfaces. Service class 1.
Uniformly distributed, downward load. The beams are assumed to be braced against tilting. The distance between the bracket points can then be at most 15 x the beam's width. Initial deformation max L/300, max deformation L/240.

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

kcr 0,85

Belastning KN/m	Spännvidd (m) 15	20	25	30	35	40
6	115x450	115x585	140x675	140x765	165x855	165x990
7	115x450	115x585	140x675	165x765	165x900	190x990
8	115x450	115x630	140x720	165x810	165x945	190x1035
9	115x495	140x585	140x765	165x855	190x945	190x1080
10	115x495	140x630	140x765	165x855	190x990	215x1080
12	115x540	140x675	165x765	165x945	190x1035	215x1125
15	140x585	140x765	165x855	190x945	215x1080	215x1215
18	140x630	140x810	165x945	190x1035	215x1125	215x1305
20	140x675	165x810	190x900	215x1035	215x1215	215x1350
25	140x765	165x900	190x1035	215x1170	215x1350	215x1530
30	165x765	165x990	215x1080	215x1260	215x1485	215x1710

Dimensioneringsorsak
Bruksstadium
Brottstadium

THREE-PIN ARCHES WITH STEEL TIES

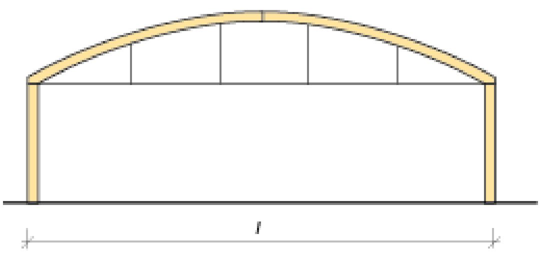


Table. Parabolic arches with height of arch f = 0,144 x the span.
Table: Strength class GL30c. Adhesive type I. Clean planed, unrepaired surfaces. Service class 1.
Downward load. The beams are assumed to be braced against tilting.
The distance between the bracket points can then be at most 15 x the arch's width.

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

Treledsbågar

Belastning [kN/m]	Spännvidd 20	25	30	35	40	45	50
10	115*540	115*630	140*720	165*765	165*900	190*945	190*1035
15	115*630	140*720	140*855	165*945	190*990	215*1080	215*1170
20	140*675	140*810	165*900	190*990	190*1080	215*1215	215*1350
25	140*720	165*810	165*1035	190*1125	215*1125	215*1350	215*1440
30	140*765	165*945	165*1125	190*1215	215*1305	215*1485	215*1665

THREE-PIN PORTAL FRAMES

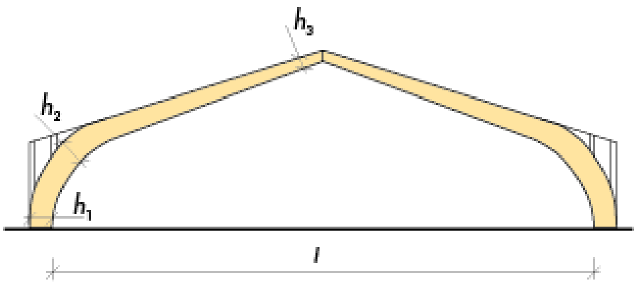


Table. Curved haunches with overriding laminations.
Table: Strength class GL30c. Adhesive type I. Clean planed, unrepaired surfaces. Service class 1.
Downward load. The beams are assumed to be braced against tilting.
The distance between the bracket points can then be at most 15 x the arch's width.

Treledsramar

Förstärkning av tvärdrag förutsätts

Belastning [kN/m]	Vägghöjd [m]	Spännvidd 15	20	25	30	35
		b x h_1-h_2-h_3	b x h_1-h_2-h_3	b x h_1-h_2-h_3	b x h_1-h_2-h_3	b x h_1-h_2-h_3
10	4	140 x 450 - 570 - 300	140 x 600 - 690 - 450	140 x 700 - 810 - 650	165 x 800 - 870 - 750	165 x 900 - 990 - 900
	4,5	140 x 450 - 600 - 300	140 x 600 - 750 - 450	165 x 650 - 810 - 550	165 x 800 - 930 - 700	165 x 900 - 1050 - 850
	5	140 x 450 - 630 - 300	140 x 600 - 780 - 400	165 x 650 - 870 - 500	165 x 800 - 990 - 650	190 x 800 - 1020 - 750
15	4	140 x 550 - 630 - 300	140 x 700 - 780 - 500	165 x 800 - 870 - 600	165 x 900 - 990 - 750	190 x 950 - 1050 - 900
	4,5	140 x 550 - 690 - 300	140 x 700 - 840 - 450	165 x 800 - 930 - 550	165 x 900 - 1050 - 700	190 x 950 - 1110 - 850
	5	140 x 550 - 720 - 300	165 x 600 - 810 - 400	165 x 800 - 990 - 500	190 x 850 - 1050 - 650	190 x 950 - 1170 - 800
20	4	140 x 600 - 660 - 350	140 x 750 - 840 - 500	165 x 900 - 930 - 650	190 x 1000 - 1020 - 750	190 x 1100 - 1170 - 900
	4,5	140 x 600 - 720 - 350	165 x 750 - 840 - 450	165 x 900 - 990 - 600	190 x 1000 - 1050 - 700	215 x 1000 - 1140 - 800
	5	140 x 600 - 780 - 350	165 x 750 - 870 - 400	165 x 900 - 1050 - 550	190 x 1000 - 1140 - 650	215 x 1000 - 1230 - 750
25	4	140 x 650 - 720 - 400	165 x 750 - 840 - 500	190 x 900 - 960 - 650	190 x 1050 - 1140 - 750	215 x 1150 - 1200 - 900
	4,5	140 x 650 - 780 - 400	165 x 750 - 900 - 450	190 x 900 - 1020 - 600	215 x 1050 - 1140 - 650	215 x 1150 - 1290 - 850
	5	140 x 650 - 840 - 400	165 x 750 - 960 - 450	190 x 900 - 1080 - 550	215 x 1050 - 1200 - 650	215 x 1150 - 1350 - 800

ROOF PURLINS

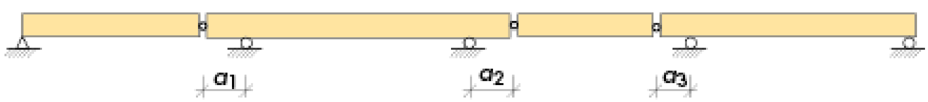


Table. Purlins with a constant cross-sectional height, continuous over two or several intermediate supports.
Moment free joints placed so that support and field moment will be equal in the inner bay, so-called Gerber-system.
Table: Strength class GL30c. Beams with a width ≤ 90 mm GL28cs. Adhesive type I. Clean planed, unrepaired surfaces. 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 1/127 of the span initially and 1/100 of the span kvasipermanent.

kcr	0,85													
Belastning KN/m	Spännvidd (m)													
	4,8		6		7,2		9,6		12		15		18	
	Ytterfack	Innerfack	Ytterfack	Innerfack	Ytterfack	Innerfack	Ytterfack	Innerfack	Ytterfack	Innerfack	Ytterfack	Innerfack	Ytterfack	Innerfack
4	56x225	42x225	66x270	56x270	66x315	56x315	90x360	66x360	90x450	66x450	115x540	78x540	115x630	90x630
5	66x225	56x225	78x270	56x270	90x315	56x315	90x405	66x405	115x450	78x450	140x540	90x540	140x630	90x630
6	56x270	56x270	78x315	56x315	115x315	66x315	115x405	78x405	115x495	78x495	140x585	90x585	165x630	115x630
7	66x270	56x270	90x315	56x315	90x360	66x360	115x450	78x450	140x495	90x495	165x585	115x585	165x675	115x675
8	66x315	56x315	90x315	66x315	115x360	78x360	115x450	78x450	140x540	90x540	165x630	115x630	190x675	115x675
9	66x315	56x315	115x315	78x315	90x405	78x405	140x450	90x450	140x540	115x540	190x585	140x585	190x720	115x720
10	78x315	66x315	78x405	66x405	115x405	78x405	115x495	90x495	140x585	90x585	190x630	140x630	190x765	115x765
12	90x315	78x315	90x405	78x405	115x450	90x450	140x540	90x540	140x630	115x630	190x675	140x675	190x810	140x810
15	78x405	78x405	90x450	90x450	115x495	90x495	165x540	115x540	190x630	140x630	190x765	140x765	215x855	140x855
18	90x405	90x405	90x495	90x495	115x540	115x540	140x630	115x630	190x675	140x675	215x765	165x765	215x945	140x945
a1	0,6		0,75		0,9		1,2		1,5		1,875		2,25	
a2	0,7		0,875		1,05		1,4		1,75		2,19		2,63	

FLOOR BEAMS

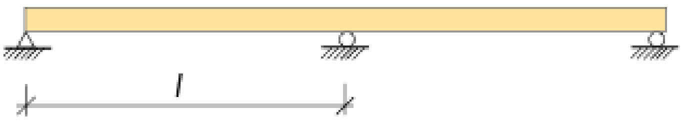


Table. Maximal spans for floor beams on two or three supports.
With beams on three supports the middle support should lie within the area 0.4 and 0.6 of the beam's total length. The beam's centre distance (c- distance) is 600 mm. Flooring of 22 mm glued and screwed flooring grade chipboard.

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, unrepaired surfaces. 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 μ_{fin} has been limited to 20 mm for residential housing, respectively 30 mm for office floor joists. Self-weight = 0.5 kN/m^2.

kcr 0,85

TVÄRSNITTSMÅTT (mm)	BOSTÄDER Spiklimmat undergolv Två stöd	Tre stöd	Spikat undergolv Två stöd	Tre stöd	KONTOR, SKOLOR Spiklimmat undergolv Två stöd	Tre stöd	Spikat undergolv Två stöd	Tre stöd
42x180	3750	3800	2600	2600	3800	3800	2600	2600
42x225	4450	4600	3250	3250	4600	4600	3250	3250
56x225	4800	4900	3600	3600	4900	4900	3600	3600
56x270	5500	5800	4350	4350	5650	5800	4350	4350
66x270	5750	6050	4600	4600	5900	6050	4600	4600
66x315	6450	6950	5350	5350	6650	7000	5350	5350
90x315	7050	7600	6000	6000	7250	7500	6000	6000

Dimensioneringsorsak
Punktlastkriteriet / svikt
Slutlig deformation
Böjspänning
Skjuvspänning

COLUMNS

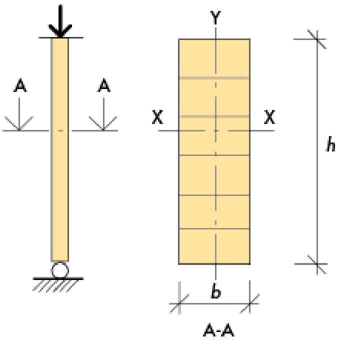


Table: The load bearing capacity in kN for axial-loaded glulam columns with rectangular cross-sections and pinned in both ends (pendular columns). The shortest lasting load types in load combinations are of type *m*, for example snow loads.

Strength class GL30h for columns with the least size ≥ 90 mm. Members with 4 or more laminations: GL30c. Members with less than 4 laminations: GL30h. Adhesive type I. Clean planed, unrepaired surfaces. Service class 0, 1 or 2.

Knäcklängd (m)		2		3		4		5		6		7		8	
Knäckningsaxel		x-x	y-y	x-x	y-y	x-x	y-y	x-x	y-y	x-x	y-y	x-x	y-y	x-x	y-y
Tvärsnitt	Kval														
90x90	CE GL 30h	86	86	41	41	23	23	15	15	11	11	8	8	6	6
90x135	CE GL 30c	172	119	119	58	73	33	48	22	33	15	25	11	19	9
90x180	CE GL 30c	244	159	218	78	159	45	109	29	78	20	58	15	45	11
90x225	CE GL 30c	311	199	296	97	260	56	199	36	147	25	110	19	86	14
90x270	CE GL 30c	377	239	366	116	345	67	301	43	239	30	185	22	145	17
115x115	CE GL 30c	173	173	100	100	58	58	38	38	27	27	20	20	15	15
115x135	CE GL 30c	220	203	453	117	93	69	61	45	43	31	32	23	24	18
115x180	CE GL 30c	311	270	278	156	204	91	139	59	99	42	74	31	57	24
115x225	CE GL 30c	397	338	378	195	332	114	254	74	187	52	141	38	110	30
115x270	CE GL 30c	482	405	467	234	440	137	385	89	305	63	236	46	186	36
115x315	CE GL 30c	566	473	553	273	534	160	499	104	436	73	356	54	286	41
140x135	CE GL 30c	268	268	186	186	113	113	74	74	52	52	39	39	30	30
140x140	CE GL 30c	281	281	203	203	125	125	82	82	58	58	43	43	33	33
140x180	CE GL 30c	379	362	338	262	248	161	170	106	121	74	90	55	69	42
140x225	CE GL 30c	484	452	460	327	404	201	310	132	228	93	172	69	133	53
140x270	CE GL 30c	587	542	569	393	536	242	468	159	372	112	288	83	226	64
140x315	CE GL 30c	689	633	674	458	650	282	608	185	531	130	434	96	348	74
165x180	CE GL 30c	447	442	399	374	292	254	200	170	142	121	106	90	82	69
165x225	CE GL 30c	570	552	542	468	477	317	365	213	269	151	203	112	157	86
165x270	CE GL 30c	691	662	670	561	632	381	552	255	438	181	339	134	266	104
165x315	CE GL 30c	812	773	794	655	767	444	717	298	626	211	511	157	410	121
165x360	CE GL 30c	931	883	916	748	894	508	859	340	798	241	699	179	584	138
190x180	CE GL 30c	515	515	459	459	336	336	230	230	164	164	122	122	94	94
190x225	CE GL 30c	656	647	624	591	549	455	420	317	309	227	233	169	181	131
190x270	CE GL 30c	796	777	772	709	728	546	635	380	504	272	390	203	307	157
190x315	CE GL 30c	935	906	914	827	883	637	825	444	721	317	589	237	472	183
190x360	CE GL 30c	1073	1035	1055	945	1029	728	989	507	919	363	805	271	673	209
215x225	CE GL 30c	743	740	707	699	621	596	476	443	350	323	264	242	205	188
215x270	CE GL 30c	901	888	873	838	823	716	719	531	571	387	442	291	347	225
215x315	CE GL 30c	1058	1036	1035	978	999	835	934	620	815	452	666	339	534	263
215x360	CE GL 30c	1214	1185	1193	1118	1165	954	1119	709	1040	516	911	388	761	301
215x405	CE GL 30c	1365	1333	1351	1258	1326	1074	1291	797	1235	581	1142	436	1006	338

Förutsättningar:
Tryckande normalkraft.
Ingen belastning i tvärledd.

Säkerhetsklass inverkar ej (endast lasten påverkas av ändrad säkerhetsklass)

DESIGN SOFTWARE

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

• Focus Konstruktsjon (2D- and 3D-software for statical 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 modul to RFEM och 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 etcetera

• Lagerbalksprogrammet Moelven – design software in swedish, for beams and columns according to EC5

• StruSoft Ramanalys – 2D-software for columns, beams, portal frames etcetera

• StruSoft FemDesign –3D-software, wich even calculates panels

For further information about softwares, check with the glulam manufacturers.

CONNECTING DETAILS

In this section principle examples of standard solutions for joining points and fittings are reported. The fixing details are shown in the information diagrams below. The material in fittings and attachments should have a rust protection adjusted to service class and corrosivity class – as a rule at least Corrosivity Class C4, equal to hot-galvanized steel with a zink layer

≥ 55 µm according to EN ISO 1461:2009.

The durability of metal connectors shall correspond to corrosivity class according to EN ISO 12944-2. Most of the reported standard fittings meet these demands. They are made of hot-galvanized steel. Some fittings are also available in stainless steel for Corrosivity Class C5. For more information, see Glulam Handbook Volume 2.

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 continuously being developed. Different demands force through new solutions. Built in fittings have many advantages in comparison with surface mounted, for example improved resistance to fire. Timber building screws make the application possible of both more simple and economic connectors.

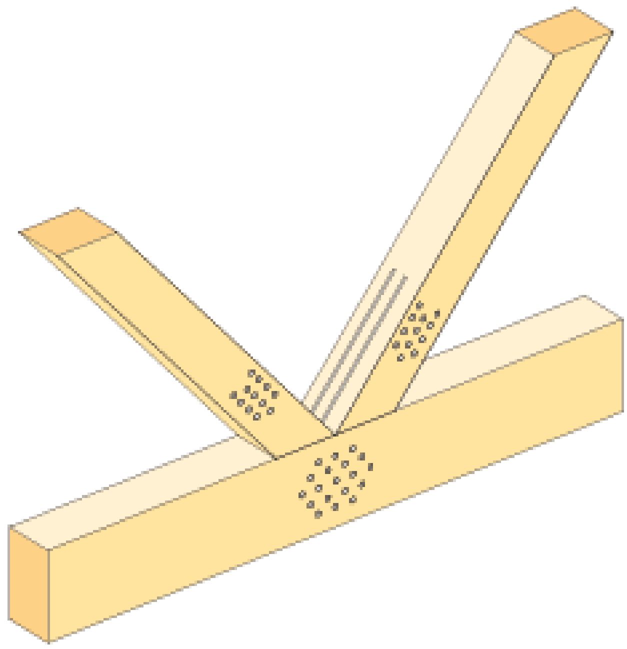


ILLUSTRATION: Connection with slotted-in sheet metals and steel dowels.

FITTINGS FOR ONE FAMILY HOUSES

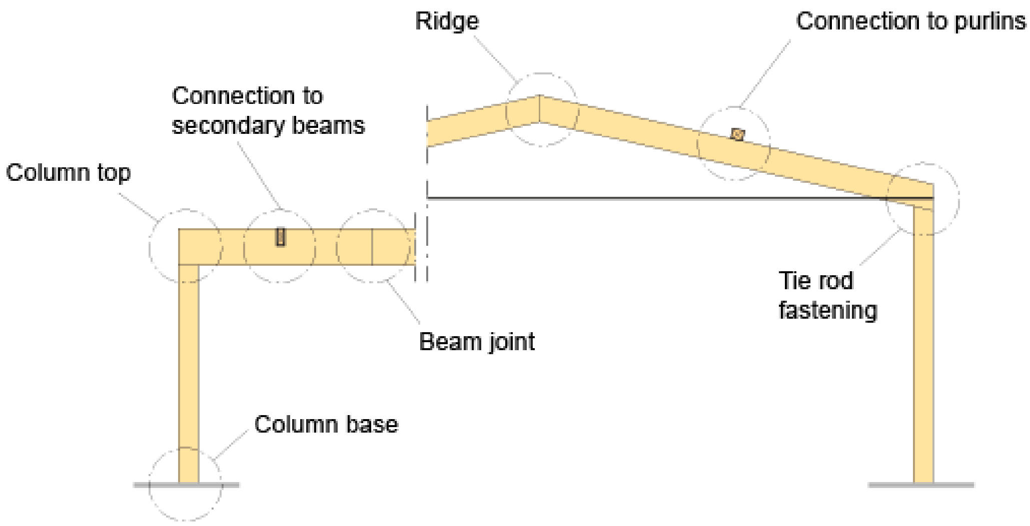


ILLUSTRATION: Fittings for one family houses – information overview.

1. NAILING PLATES (FISH-PLATES)

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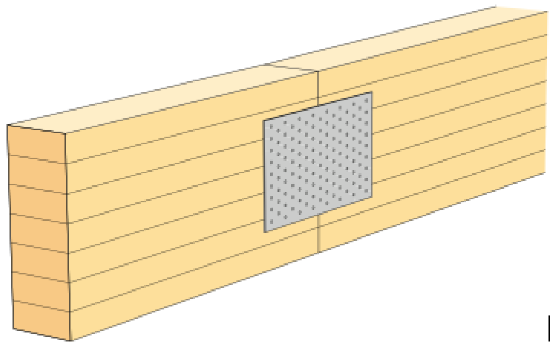
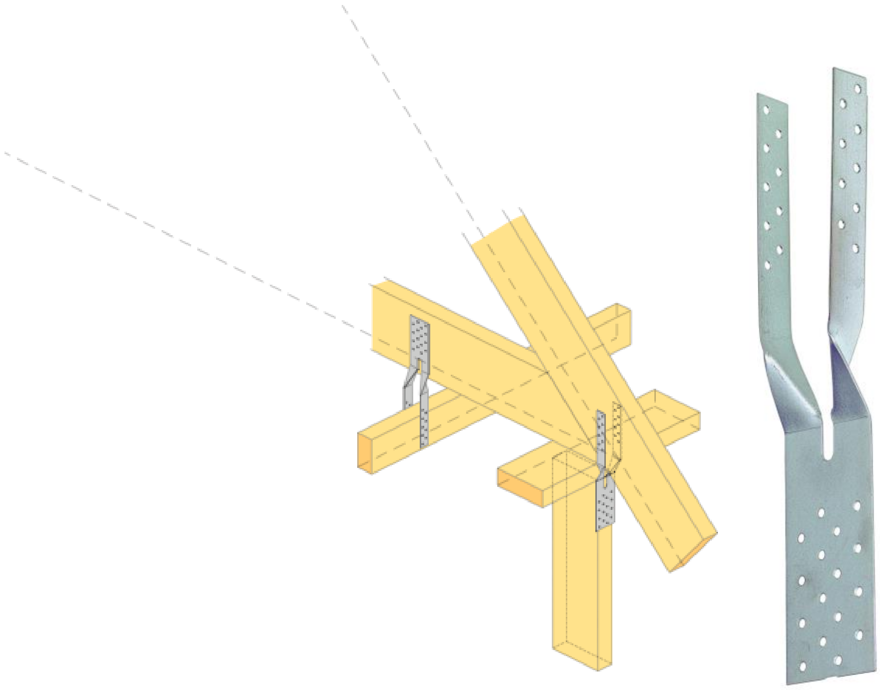


Nailing plates can be used as joints for beam and roof structures of glulam. In order to avoid eccentric loads, two plates per joint should be used (so-called double fittings). The plates are manufactured from hot galvanized steel or stainless acid-proof steel of thicknesses 1,5 and 2,0 mm or even thicker. 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, which 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 models, as left and right fittings, from hot-galvanized steel sheet metal. Hole diameter 5 mm.

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 models from hot galvanized steel sheet metal of thickness 1.5 mm. Hole diameter 5 mm.

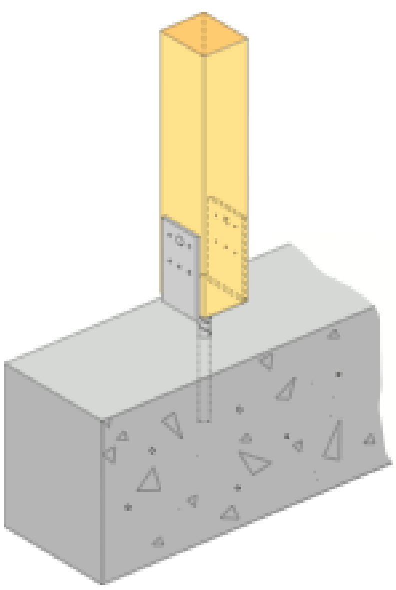
4. METAL STRAPPING

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 4.0 x 40.

5. POST SHOE

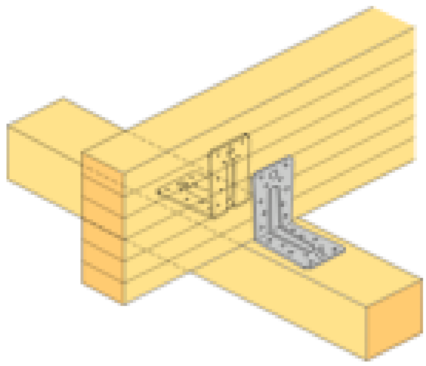
Pole climbers are used for embedding or mounting in concrete for the embedding of glulam posts, for example for fences and verandas. They are manufactured in different models, with or without adjustable design, from galvanized steel sheet metal.

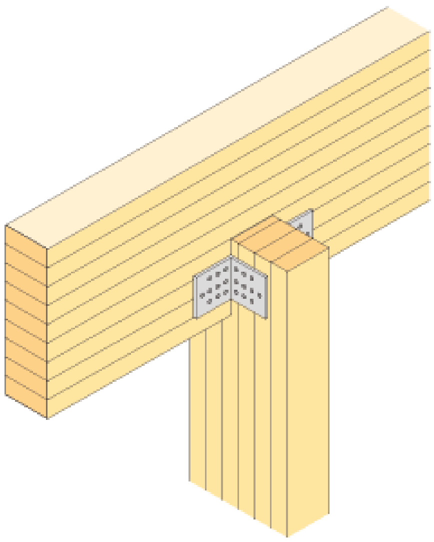
6. ANGLED FITTING



Angled fittings 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 screws, 10 mm for bolts.

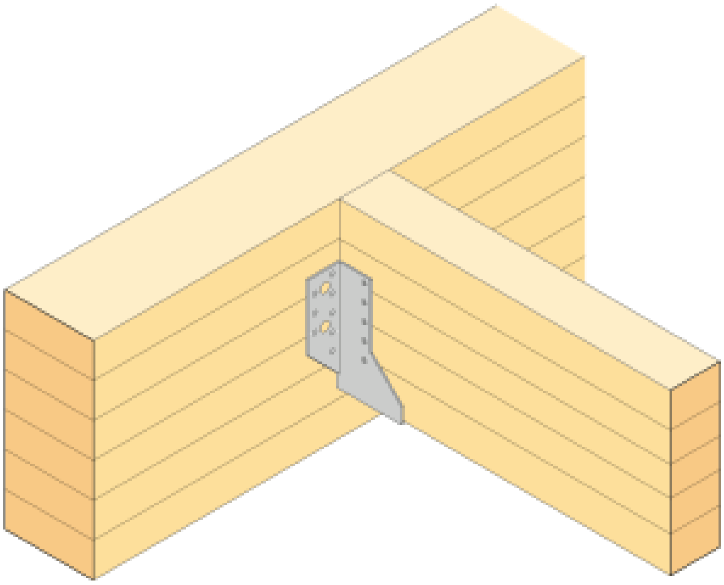
7. NAILING PLATE ANGLE





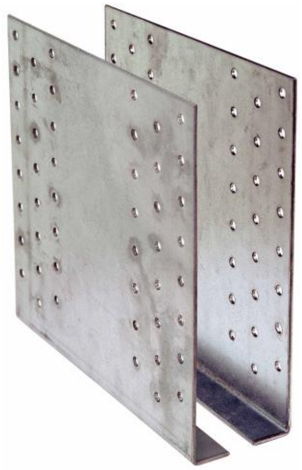
Nailing sheet metal angles can be used for joints between posts and sills or for connections with moderate loads. They are manufactured from hot-galvanized or stainless steel sheet metal of thickness 2 or 4 mm. Hole diameter 5 mm.

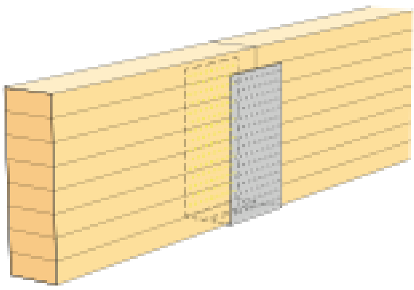
8. BEAM SHOE



Beam shoes 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 beam shoes with edges of different widths. Within each type there are a number of heights. Beams shoes' edges can as shown in the picture be bent both inwards and out. Manufactured from hot-galvanized steel sheet metal with a thickness of 2 mm. Hole diameter 5 mm.

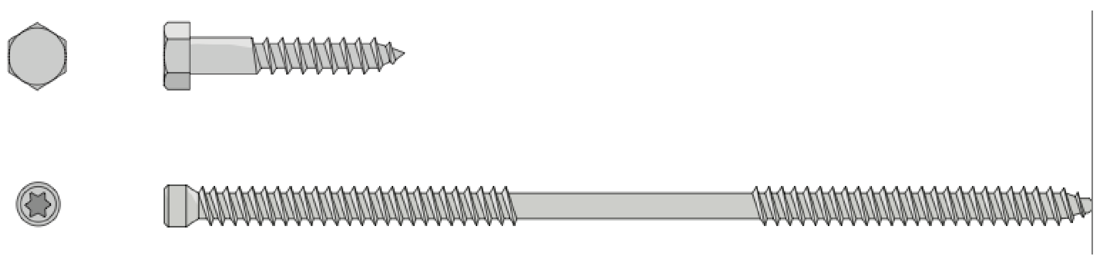
9. GERBER JOINTS



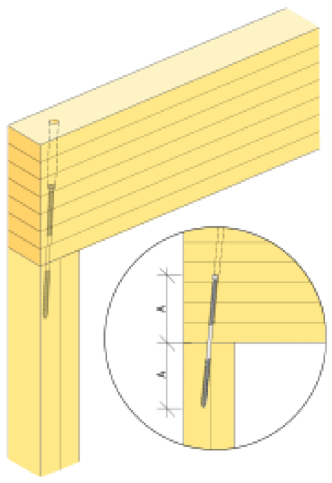


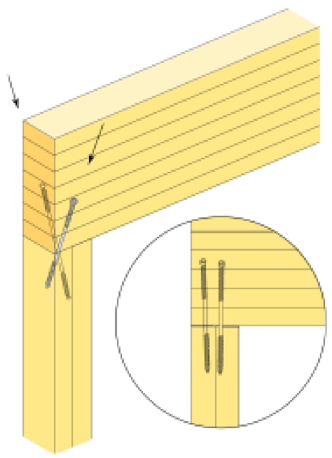
Gerber joints are used for the joining of beams in the same level and for connections between columns and beams. In order to avoid eccentric loads, two fittings per joint should be used (so-called double fittings). They are manufactured from hot-galvanized or stainless steel sheet metal with a thickness of 2 mm. Hole diameter 5 mm.

10. SCREW FASTENING



Above: Coach-screw (hexagon head wood screw)
Below: Axial load-bearing screw





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

CONNECTING DETAILS FOR LARGER BUILDINGS

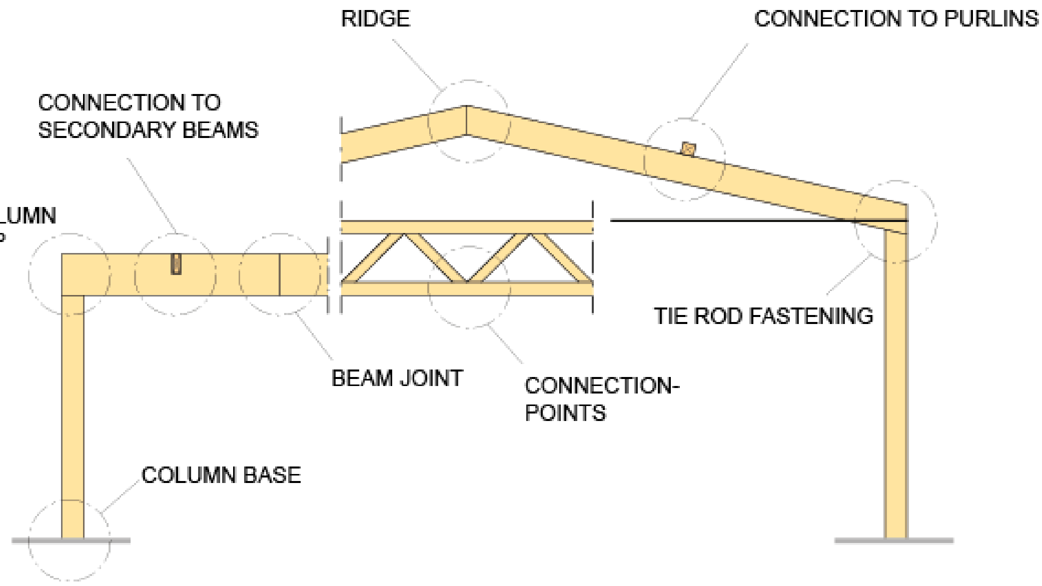


ILLUSTRATION: Information overview of reported connecting details for larger buildings.

COLUMN BASE

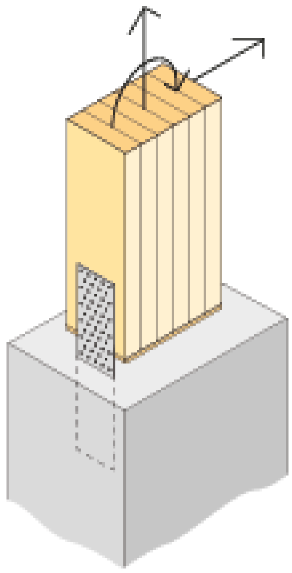
NAILING PLATES

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).

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 molded solidly in concrete structures or welded to an embedded fixed metal sheet. Force transfer occurs with anchor nails or with screws. End grain surfaces should be moisture protected against concrete and other moisture absorbing material and preferably be accessible for vapor protection maintenance, see further the section Moisture protection, page ?

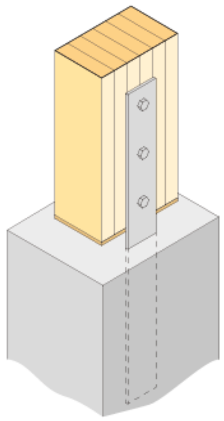
Special measures for fire protection can be required, for example fire protection painting or cladding. See the section Design with regard to fire.



Nailing plates of sheet metal on either side.

FLAT ROLLED STEEL

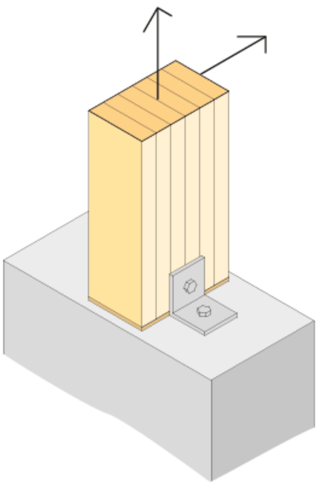
Pinned or clamped attachments of column base with flat rolled steel are equally good alternatives to nailed sheet metals.
With pinned attachments the flat rolled steel is placed in a stud on the column's wide side – with fixed support on the column's narrow sides. The flat rolled steel is moulded into the concrete construction or is welded to an embedded fixed metal sheet. The force transfer is with through going screws (bolts) or some type of so-called timber construction screw or coach screw (hexagon head wood 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 the section Moisture protection, page ?
Special measures for fire protection can be required, for example fire protective painting or cladding.



Flat rolled steel on either side.

ANGLE STEEL FASTENER

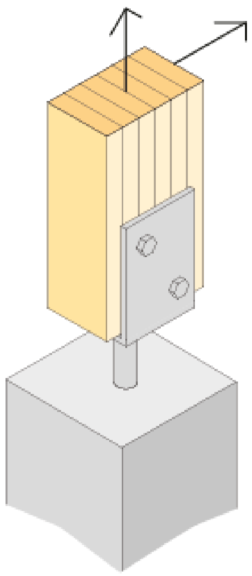
Pinned column base with angled steel which is screwed to the column is a simple solution and suitable for small horizontal and vertical forces (lift). Angular steel is tightly screwed in the concrete construction with expander screws or so-called cramps, which makes possible a thorough measuring and minimizes the risk of wrong placing. Most common is symmetrical angle steel on each side of the column. End grain surfaces shall be vapour protected and preferably be accessible for vapour protection maintenance, see further the section Moisture protection, page ?



Angle steel on either side.

POLE SHOE

For pinned attachments outdoors or in premises where there is running tap water and if the forces are small, the pole climber is a suitable solution as the absorbing of water 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.



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

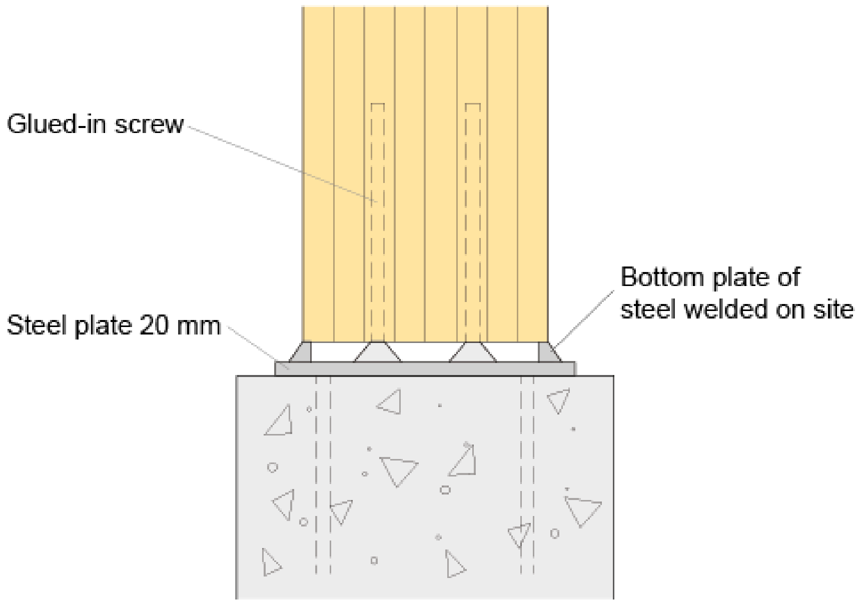
GLUED IN SCREW

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.

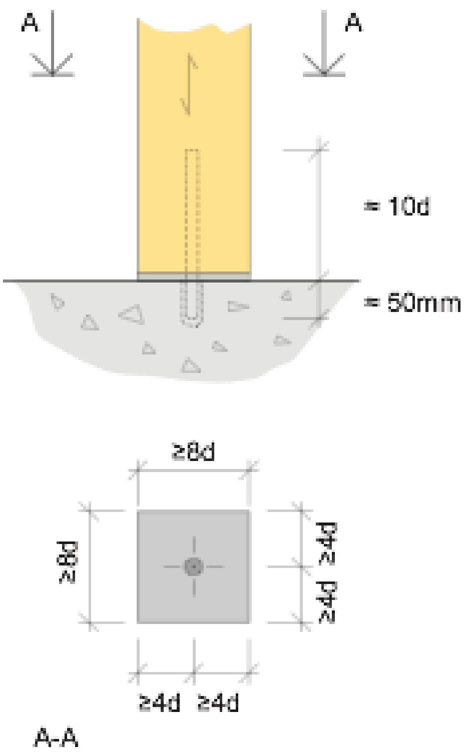
The connection to the ground structure is shaped as a stud with an end metal sheet on the column's end surface. The end metal sheet is threaded on the glued in screw and is welded to an embedded fastening metal sheet in the foundation structure. The column can also be joined with projecting screws, which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

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.

Slotted-in metal sheet and steel dowels. *Still missing.*



Glued in screw (type Peikko or equivalent).

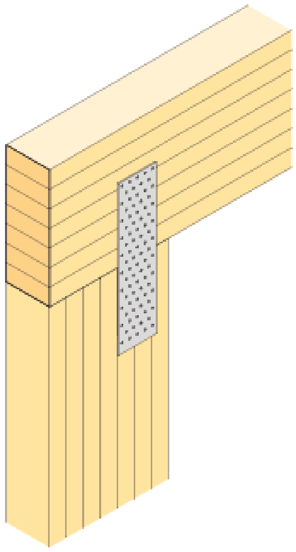


Glued in dowel pin, non-force transferring

COLUMN TOP

NAILING PLATES

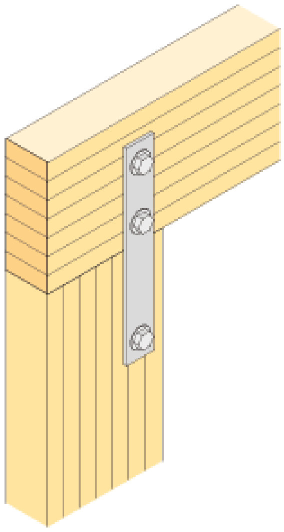
Wired connections with nailed metal sheets on either side of the section are simple and suitable for both small and large loads. The metal sheets, which are found in standard catalogues have thicknesses which limit the usage to moderate loads. The manufacturer’s instructions should be carefully followed.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



Nailed metal sheet on either side of the glulam section.

FLAT ROLLED STEEL

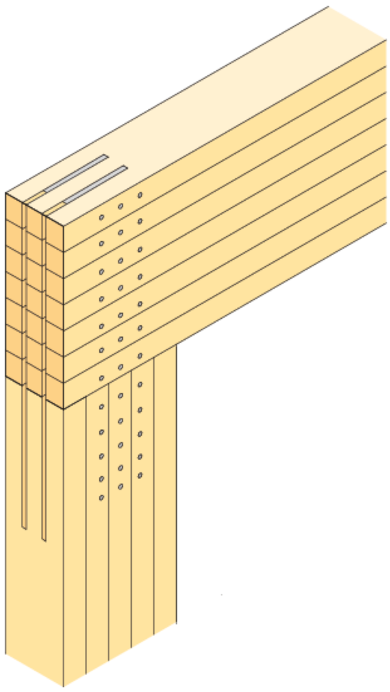
Pinned connections with flat rolled steel on either side of the section are also, similar to nailed metal sheets, simple and effective. Flat rolled steel, type flat rod or universal rod, is suitable for both small and large forces. Material thickness is chosen from the standard series 5, 6, 8, 10, 12, 15 or 20 mm with at least 0,3 x screw-/bolt diameter. The hole for the screw should be 1 mm greater than the screw-/bolt diameter. The upper hole in the beam shall be oval for concideration of moisture movements. Special measures for fire protection can be required, for example protective painting or cladding, see page ?



Flat rolled steel on either side of the section.

SLOTTED IN METAL SHEET

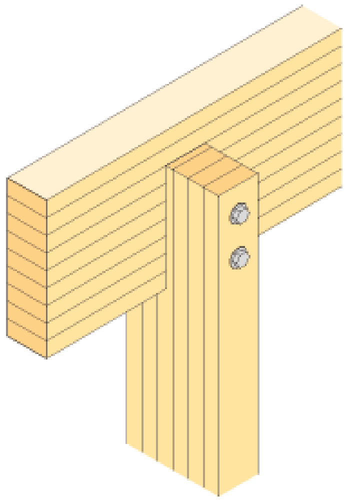
For pinned connections with slotted in steel metal sheet and steel dowels the attachments are completely hidden. The steel dowels can be counter sunk in the beam and covered with wooden plugs. From a fire technological viewpoint a completely hidden fitting provides approved protection.

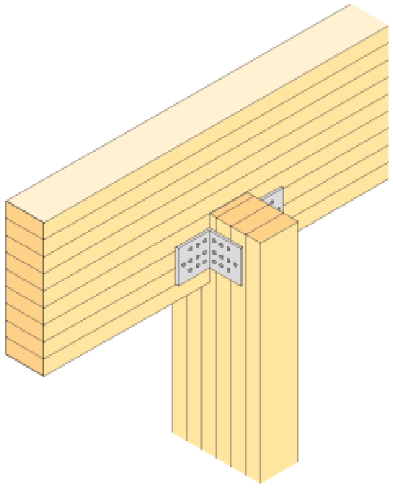


Slotted in metal sheets and steel dowels.

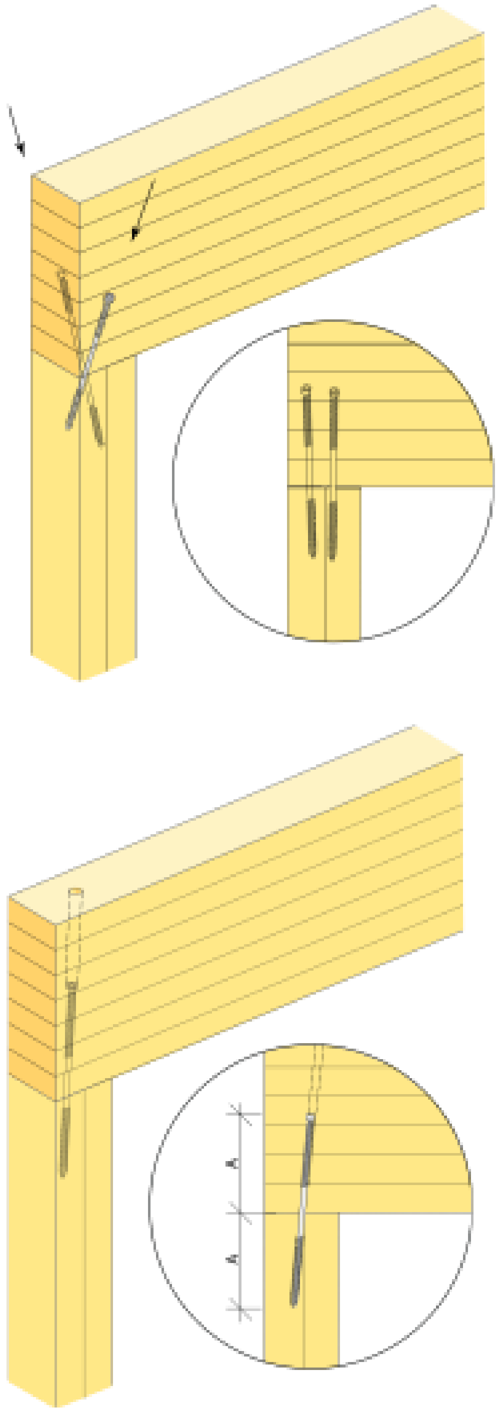
COUNTERSUNK BEAM

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 occurs as a rule with the aid of the through going 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.





Built-in beam and metal sheet angles.



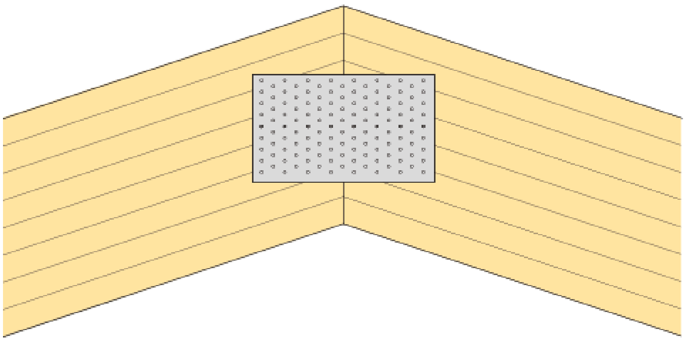
Two examples of column-beam connections with axial-loading screws (small forces). Holes for the screws should be predrilled.

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 which can cause unforeseen damage to the glulam structure.

NAILING PLATES METAL SHEET

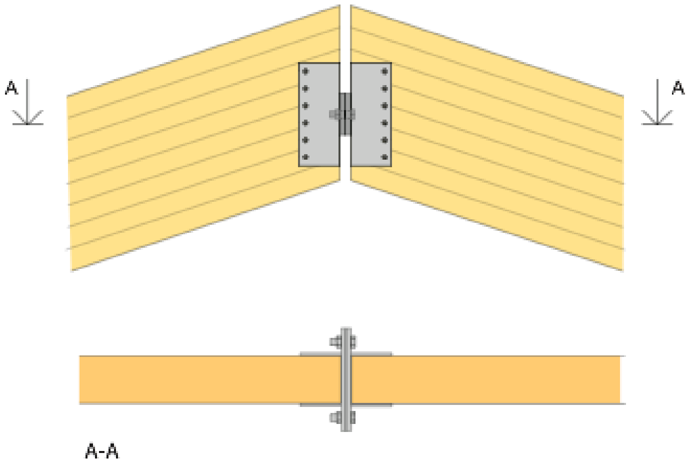
Pinned ridge joints (apex connections) of nailed metal sheets on either side are simple and effective. Nailed covering plates of metal sheet are suitable for both small and large forces. The manufacturer's instructions should be followed carefully. Force transference between nailed metal sheet and glulam occurs with the help of so-called anchor nails or with screws. The metal sheet should be placed as close to the beam's upper 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 x nail-/screw diameter. There are pre-bored nailed metal sheets of hot- galvanized steel metal sheet in stock in different sizes and thicknesses between 1.0 and 5 mm.



Ridge joints, pinned, with nailed metal sheet on either side.

NAILED COVERING PLATES OF METAL SHEET AND TRANSVERSE FORCE TRANSMITTING

When the cross forces are so great that the off-radial moment becomes difficult, the cross forces can instead be transferred with the aid of a joined milled divider (spacer). The divider can be designed in many ways, for example by a piece of welded flat steel bars. The whole of the cross forces are then assumed to have been transferred by the divider and the nailed metal sheet are dimensioned only for horizontal tension forces. In the meantime they contribute to the cross forces being distributed over the beam height and oppose peeling at the divider. Horizontal pressure forces are transferred through contact between the beam-ends and the divider's vertical legs. The structural engineer can give further information.



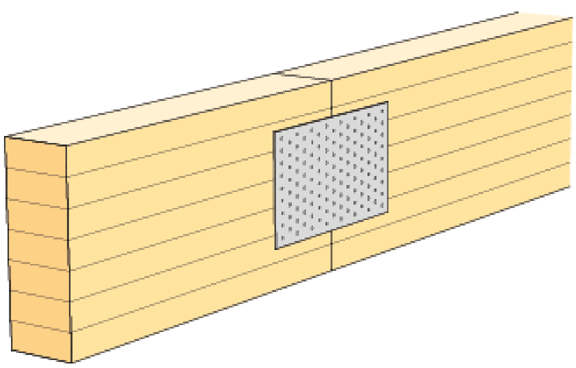
Ridge fixture of steel, developed by the Swedish company Limträteknik i Falun AB (www.limtrateknik.se)

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 which can bring with it unforeseen damage on the glulam structure.

NAILED METAL SHEETS

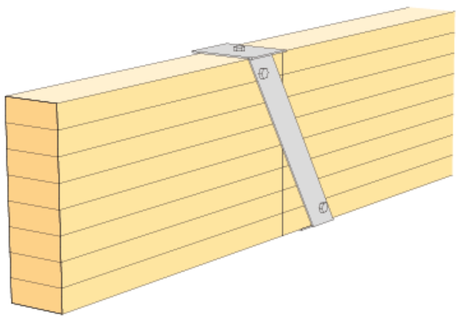
Pinned beam joints with cover plates of metal sheet are simple and effective. They are suitable for small or moderate forces. The manufacturer's instructions should be followed carefully. The metal sheets should be placed centrally with reference to the glulam beam's middle line = system line. The transfer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



Nailed metal sheet on either side of the joint.

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 sheets. The forces are transferred mainly with the aid of anchor nails or screws. 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 sheet as possible. Suitable edge distance is 2 x screw diameter if the screw only transfers horizontal forces and 4 x screw diameter if the screw also transfers vertical forces.

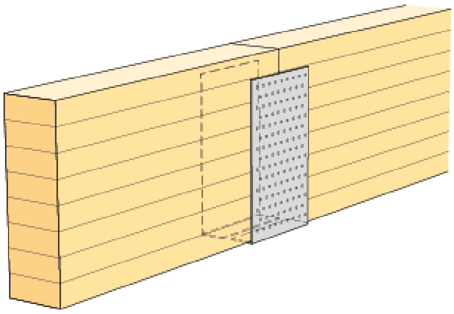


Gerber fastener of flat rolled steel

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 angled fittings, of the type, which are shown here, the risk of flaking must especially be taken into consideration, see Glulam Handbook, Volume 2. A rule of thumb is that the height to the highest nail/screw (h_e) divided by the beam height h should be ≥ 0.7.



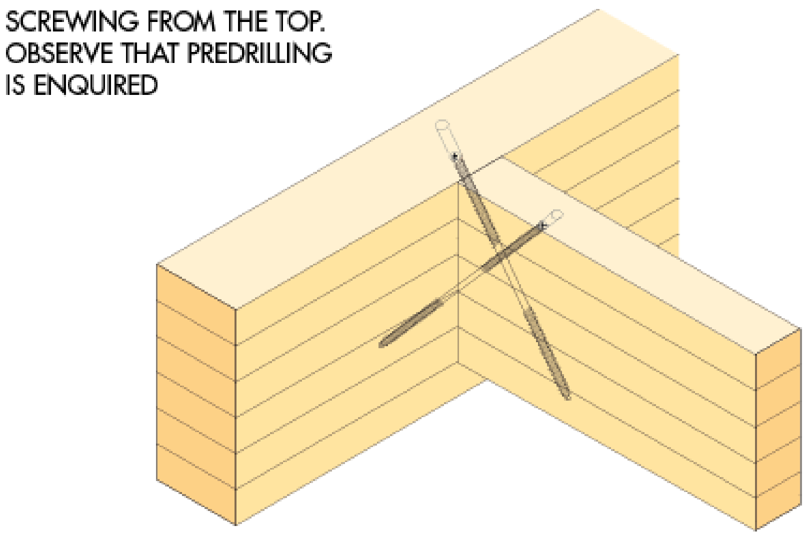
Standard gerber fixtures on both sides of a glulam beam

CONNECTION TO A SECONDARY BEAM

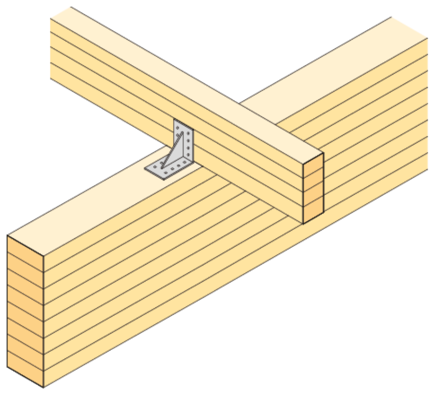
The secondary beam placed on top of the primary beam transfers vertical forces and small horizontal forces in the primary beam's direction. The secondary beam suspended on the primary beam's side also transfers horizontal forces in the secondary beam's direction. If necessary the fitting can be shaped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

SCREW FASTENING

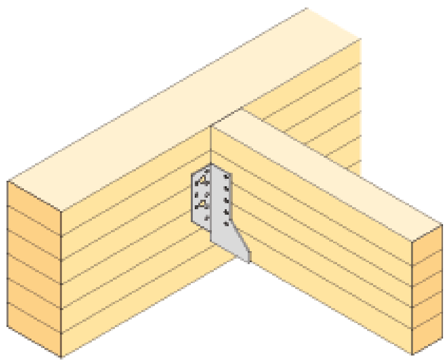
Axial load-bearing screws can be used for small or moderate cross forces. The manufacturer's instructions should be followed carefully.



Screw fastening with axial load-bearing screws.



Angled fittings of hot-galvanized steel metal sheet.



Beam shoe of steel metal sheet or structural steel.

RIDGE FASTENING

Fastening of ridges in the primary beam's upper side is done as a rule with the aid of factory made fittings of cold formed, galvanized steel metal sheet, for example angled fittings according to the illustration. The fittings can be designed with reinforced grooves, or so-called cleat. 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.

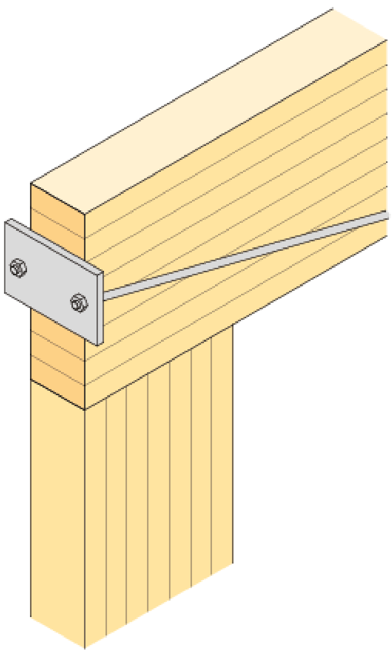
WELDED BEAM BASE

Connecting of 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 as a rule required.

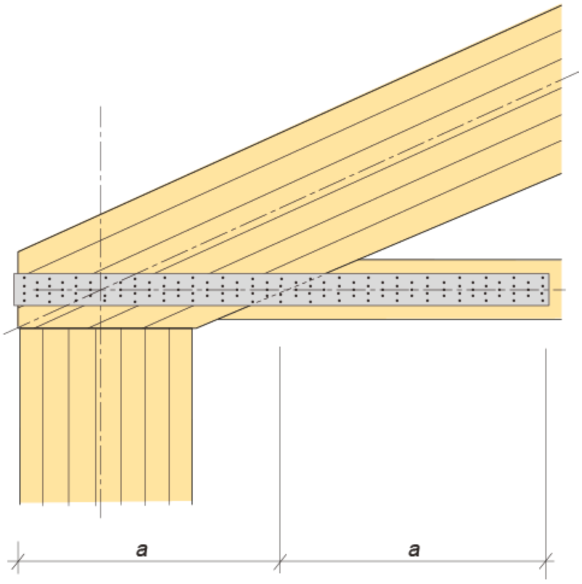
The transfer of forces between the secondary beam and welded beam bases occurs mainly through contact pressure while the transference of force between beam bases and primary beam occurs with the aid of nails, through going screws or some type of timber construction screw. Beam bases can be designed in 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 to the point of intersection between the beam's and column's system lines as possible.



Ties of high quality steel.



Ties of glulam and sheet steel/nailed metal sheet, which go around the beam end.

TIES OF STEEL

Ties of high strength are suitable for both small and large traction. The simplest fastening is obtained with a tie on each side of the beam. For moderate traction 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 traction the two ties on the sides can be supplemented with a third, centrally placed. 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

Ties of glulam are suitable for use with small traction. The fastening of the ties in the beam can be made of flat steel bars which either go around the beam end or which end a short distance from the end of the glulam tie. With small traction the sheet steel can be exchanged for 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.

DESIGN WITH REGARD TO FIRE

Historically several fire catastrophes involving timber buildings have occurred – events which have left a trail in building legislation, among others in the form of different restrictions for the usage 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 the collapsing of glulam structures in fires is extremely rare because the load bearing capacity remain 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. That and increased knowledge on correct structural design for fire protection and the implementation of timber structures has brought with it new possibilities also for such timber structures which meet the demands of reassuring fire safety.
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 which 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 rest 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 adhesive s are used, for example melamine adhesive (MUF). On the contrary other, both old and new adhesives, can lose their strength at, in the context of a fire, low temperatures and cause delaminating, 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. Only at the timber joints is glulam's self-protection often insufficient; here extra fire protection can be needed 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 affects of fire by concealing them with wooden plugs.

The temperature in the unburned parts of a large timber structure remains even during the effects of a long lasting fire in the main unaffected. Only in a small roughly 10 mm deep zone immediately under the carbon layer do temperatures of more than 100°C occur while 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 for secondary damage in for example supports or adjoining walled structures. A glulam structure does not either deform as powerfully 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 among others 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, which govern demands that apply, above all depending on evacuation possibilities 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 Br1. For other buildings fire resistant implementation is required, that is class Br2. For most one-floor buildings however, class Br3 is sufficient, with the lowest requirements.

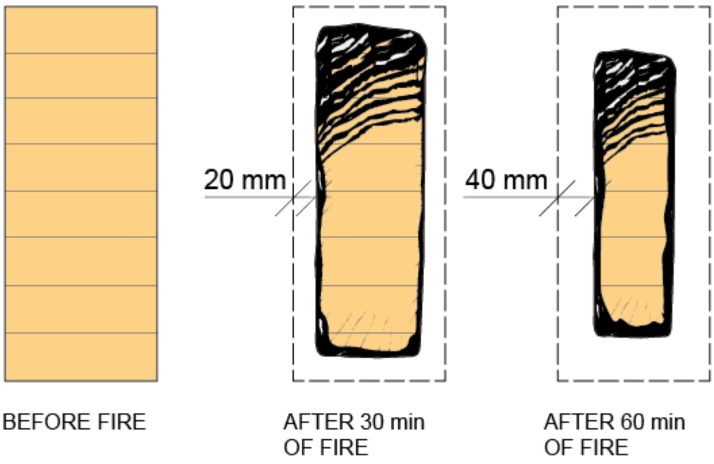


ILLUSTRATION: Glulam retains a significant load bearing capacity even during a fire. The protective carbon layer, which forms on the burnt surface contributes to this. The picture illustrates a glulam cross-section before fire (on the left), after 30 minutes of fire (middle) and after 60 minutes of fire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

Structural sections

Load bearing structures should, according to national directives, be designed and dimensioned so that safety against failure is satisfactory also for the effects of fire. That the requirement is met can be shown by calculating the load bearing capacity for realistic conditions relating to for example 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 the 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 in all types of buildings, also multi-storey buildings, can be made of glulam, on the other hand the requirements on surface layers can in certain areas involve limitations.

Surface layers
Surface layers are defined as the outer part of a building structure which can be exposed in the early stages of fire and indicate the ability to prevent or delay the flash point and smoke emission 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 the table. 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/I is the highest class, which can be obtained for combustible products and class D/III is equivalent to qualities in unprocessed timber paneling.

In the national regulations no detailed demands on surface layers are given apart from those, which apply to emergency exit routes. The advisory text says however, that roof surfaces in fire proof buildings (class Br1) should have surface layers, which are equivalent to class B/I and wall surfaces to class C/II. Fire retardant buildings (class Br2) should have surface layers class C/II in the roof and class D/III on the walls. For roof surfaces in both cases underlay of non-combustible material or ignition protective cladding is recommended, for example plasterboard.

Demands on surface layers of higher class than class D/III (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, which consist of visible glulam.

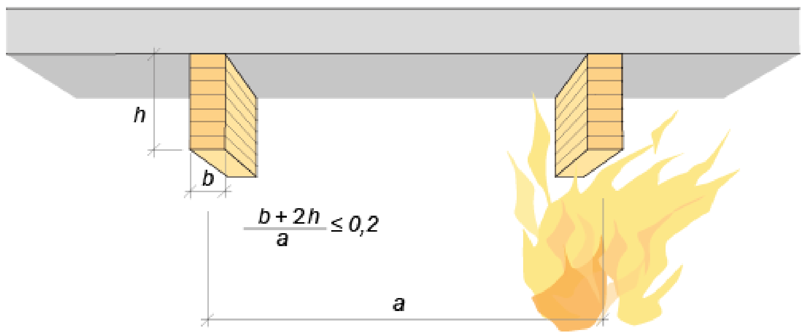


ILLUSTRATION: The glulam beam’s surface can be up to 20 percent of the floor area without demands of treatment in order to achieve a higher surface layer class than European Class D.

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/I or C/II 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/III. 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/I, can be generally acceptable.

The installation of an automatic sprinkler system can make possible so-called technical exchange. 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 example be reduced with the installation of a sprinkler system.

There are also advanced models for design of separate buildings where classification gives far too simplified solutions, for example through so-called fire safety engineering.

Table ? European surface layer classes.

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	–	–	Unclassified	Untested

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

Material	Min. density (kg/m^3)	Min. thickness (mm)	Class
Glulam	380	40	D s2,d0

FIRE RESISTANCE

Regarding fire prone timber structures the national regulations in the Nordic countries are highly restrained when it comes to verifying methods. Calculation models on penetration and strength reduction can be obtained from Eurocode 5 (EN 1995-1-1 or EN 1995-1-2), while safety parameters (partial coefficient, load reduction factors etcetera) must be obtained from every country's national document, adapted to the Eurocode.

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 hereby obtained effective residual cross-section 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 ($\gamma_m = 1.0$). 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 the table? It is possible to have an even higher fire class, but then the required cross-section size must be calculated according to the above.

The table gives the required sizes when the fire attacks from all four sides. If the beam's upper side is protected, for example by the connecting roof construction, only half of the given beam height is required. 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.

If the required design value for bending moment is given, for example by conditions relating to load and structural design, the degree of utilization μ will change for a new cross-section. A straight interpolation between table values is allowed. 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 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 respectively 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. An effective protection of a joint is achieved when it is enclosed with timber or glulam, plywood, plasterboard or rock-wool. A fire protection insulation of wood or plywood should preferably be so thick that it does not burn away during the time the classification refers to. 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, which 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 ? Minimum beam-height in mm for beams with rectangular cross- section. Four-sided fire attack [1)].

		Beam width (mm)					
Fire class	μ	90	115	140	165	190	215
R30	0,50	180	180	180	180	180	180
	0,75	225	180	180	180	180	180
	0,90	360	225	180	180	180	180
	1,00	585	270	225	180	180	180
R60	0,50	–	810	360	270	225	225
	0,75	–	–	765	450	360	315
	0,90	–	–	–	630	450	405
	1,00	–	–	–	900	585	450

1) If the upper side is protected from fire in at least class R30 respectively R60 half the tabled values apply. Degree of utilization □ = the relationship between the load effect for the most dangerous load combination and load bearing capacity for dimensioning in ultimate limit state without consideration of fire.

The table above 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 respectively nailing plate. 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.

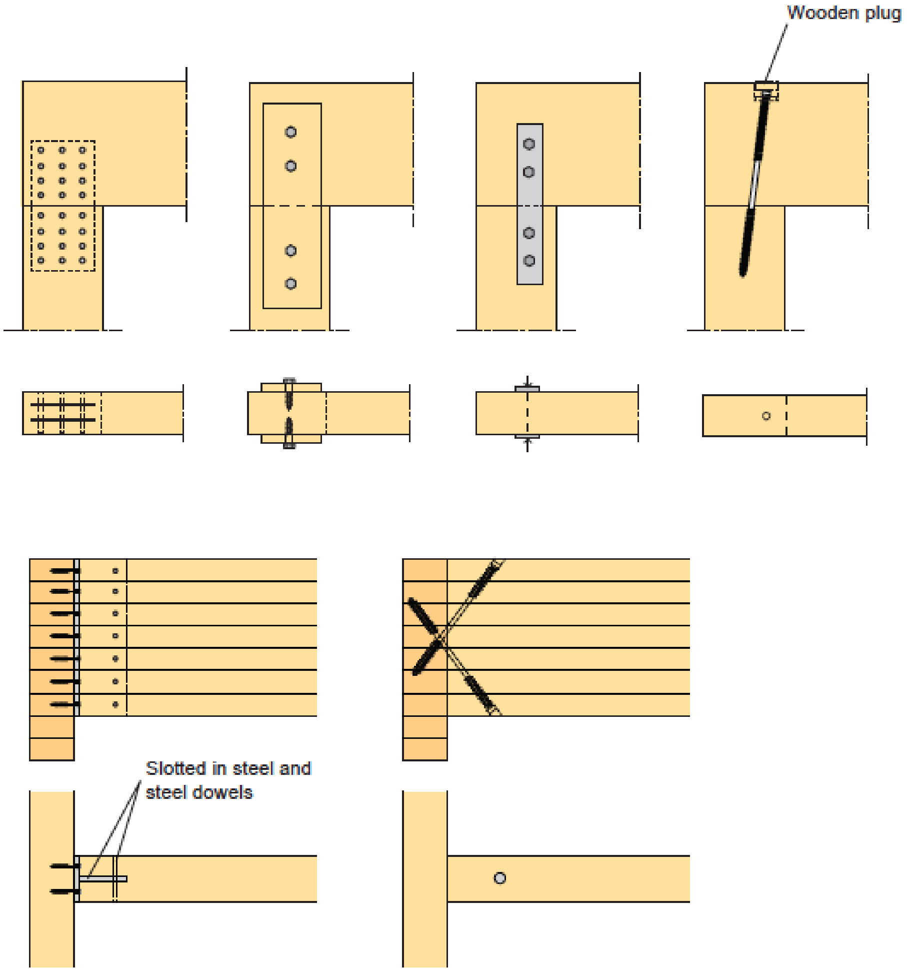


ILLUSTRATION: Different types of column-beam connections.

Table ? Examples of fire protection insulation of different joints. Insulation thicknesses in mm.

Material	Pinned joints		Nail metal sheet, nailing plates, fittings	
	R30	R60	R30	R60
Sheets of stone wool	25	45	45	–
Timber, Glulam, LVL	19	33	27	39
Plywood	20[b]	50[b]	30[b]	60[b]
	2x12[c]	3x12[c]	–	–
Plasterboard, normal	13	3x13[c]	2x13[c]	3x13[c]
Plasterboard, type F[d]	15	2x15[c]	15	2x15[c]

[a] Standard thicknesses can be greater.
[b] Total thicknesses. For several layers of panels each layer should be nailed/screwed.
[c] Nailing/screwing of each layer.
[d] Gyproc Protect F or comparable plasterboard.

NB! There is a table 14.3 in the Swedish Glulam Handbook 2001 (new edition 2008), which differs from this table above. Please compare and comment.

SURFACE TREATMENT AND MAINTENANCE

In order to get a long-term sustainable surface on the glulam surface treatment with associated maintenance must as a rule 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, which appear on glulam surfaces as a rule mean no risk with regards to load bearing capacity. If unsure however, the glulam supplier or a structural engineer should be contacted for an opinion.

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 make clean and it protects the glulam against mechanical damage. There are also special top-coat paints and clear varnishes which counteract flame spreading and smoke emission in a fire, see further under section Planning in consideration of fire, page ?

Generally glulam can be surface treated with substances and methods, which are used for timber. The surface damp ratio must not exceed 16 percent at the time of surface treatment. The technical, economical and aesthetic conditions decide the choice in each individual case. Glulam of treated laminations certainly provides an effective protection against rot but must be surface treated and maintained in the same way as normal glulam.

Glulam indoors

In normally damp premises 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, see further the table ? below.
In damp premises, for example swimming baths and wet rooms or other premises with a risk of condensation, one should be careful with such treatments which 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

Untreated glulam should be avoided outdoors if it is exposed to the weather. Even if it has been surface treated with a non-pigmented treatment (colorless wood oil or clear varnish) the surfaces become 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 damp. Changes between rain and sunshine mean a great 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.

Glulam products, which are designed to be exposed outdoors, e.g. façade boards, can be delivered industrially base treated, to be top-painted after mounting. Such a base treatment should have a layered thickness of at least 60 μm.

Table ? Surface treatment guide for glulam.
The suitable type of surface treatment of glulam is decided by the current conditions.
• = Suitable.

CONDITIONS	TOP-COAT PAINT	STAIN	VARNISH	WOOD OIL
GLULAM INDOORS				
Dry premises	•	•	•	•
Moist premises	–	•	–	•
GLULAM OUTDOORS				
Exposed to precipitation	•	•	–	•
Direct sunlight	•	–	–	–
Mechanical wear and tear	•	–	–	–
TREATED LAMINATIONS	•	•	–	•
PREVIOUSLY SURFACE TREATED				
Top-coat painted	•	–	–	–
Stain finished	•	•	–	–
Clear varnished	–	–	–	–
Oil treated	•	•	•	•

Avoid crack formation

Small cracks, so-called drying cracks, are in general so small and superficial that they do not create any greater nuisance. Larger cracks give water the possibility to quickly cram into the glulam's inner parts. They also create pockets for moisture holding rubbish and dirt, which can speed up the attack of mould or rot.

Especially in horizontal surfaces and in large cracks where the water can remain in long-term, the risk is great for rot. The cracks, which have formed should be filled with suitable material, for example putty for external use, to prevent continued crack formation.

With the aid of at first hand the right building design and building technology, long-term moisturizing can be minimized. Heating from heat induction pipes or hot air blowing in, brings with it the risk for local drying out and crack formation.

Fast moist content changes can be suppressed with a moisture protecting cladding or surface treatment. End-wood absorbs moisture roughly 20 times quicker than other timber surfaces. Glulam elements, which have exposed end-wood surfaces and upper sides must as a rule be protected with a ventilated cladding, of for example metal sheet. See illustration page ? If that is not possible, the exposed surfaces should regularly be treated with moisture protection, for example a penetrating oil, a wood preservative or similar product with equivalent effect.

Prevent destruction by UV-radiation
By using pigmented surface treatment, better protection against UV-radiation is obtained. 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 a certain but limited UV-protection and thereby less durability compared to the top-coat paint system.

Clear varnish and colourless wood oils provide as a rule insufficient protection against UV-radiation and should therefore not be used for outdoor exposed glulam, which is hard to replace, provided that one does not accept the superficial weather greying. 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 qualified context, 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 detoriates.

The purpose of maintenance is to keep up functions and to conserve. Regular yearly inspections of different parts of the building are included in the running maintenance and are necessary in time to discover reduced function or incipient damage and to be able to take suitable maintenance measures.

There are no definite maintenance intervals for different materials and structures. Outside affects can vary so much that it is impossible to generally indicate how often an inspection needs to be made and what maintenance intervals for different measures in an individual case are needed.

MAINTENANCE PLANNING

The maintenance should be planned time-wise and a maintenance plan should contain measures, which are required during the period in question, normally the nearest 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 visual assessment on site. By an experienced surveyor inspecting the building, a good picture of the glulam structure’s maintenance status can be obtained.

With the aid of measuring and sampling one can collect complementary material for a safer judgment. Measuring of the moisture content in the glulam is a normal method for more information on 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, which should be taken and when these measures must be carried out at the latest.

Regarding glulam structures the following should be observed:

- Defects, which can affect load bearing capacity.
- Occurence of rot.
- Occurence of microorganisms, for example mould (can be a sign of rot).
- 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 troublesome sag (floor joists/balconies/verandah floor beam).
- Deformations, for example abnormal deflections or other changes in shape.
- Condition of the fasteners.

Outdoor exposed glulam
Sensitive points where the glulam is included are the eaves with cantilever beams and outdoor columns. End surfaces are especially sensitive for 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 covering 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.

Outer effects vary widely between houses inland and those on the coast. Even the compass points have different effects – a south facing façade is much more exposed to different climatic influences than the other façades. North facing façades lie in colder climates.

Oscillations in air humidity can give essential moisture movements, which in their turn can cause cracks in the timber surface and crackle in the paint layer. The maintenance need 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. This can be done in different ways. 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, which cannot disperse within reasonable time.

The painted surfaces should be regularly checked with regards to the occurrence of discolouring, blister formation and crack formation (crackled paint layer). 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 in connection with maintenance. Slots, which let in the damp and which are impossible to ”paint over”, should not occur in glulam either.

After determining 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, which has rot damage or large cracks. There are always minor cracks – they normally do not cause any problems if treated liberally with penetrating primer oil and primer paint.

During maintenance, glulam, which is damaged or otherwise unsuitable as priming support for paint should be replaced before the painting work can begin. Surfaces, which 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 detoriates even after a few weeks' exposure outdoors and this brings less durability for certain paint types, especially for modern top-coat paint systems. Such glulam should therefore be painted as soon as possible after erection.

It is important to minimize the risk of moisture absorption of 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 has not caused rot. For a far too thick and cracking paint layer, that is to say after a number of maintenance paintings, paint removal should be considered.

When top-coat painting, priming should be used as a first treatment, a substance 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 a modern top-coat painting system the primer treatment is in general a question of 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.

In conclusion: The original surface treatment has from the beginning been chosen with regards to several different factors. Top-coat paint systems give as a rule 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 aesthetically conditional.

GLULAM WITH TREATED LAMINATIONS

Where constructive wood protection design is deemed insufficient and where in case of failure a risk of serious personal injury exists, glulam made of treated laminations should be used.

In certain situations, using glulam, which is manufactured from treated laminations, a long-term and effective rot protection can be obtained. It can however not replace the building technical wood protection design, but should be seen as a complement. Moisture, which is added to 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 and NTR/B, which are suitable for different areas of use. Wood protection classes NTR/M are meant for use in sea-water where there is risk for 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 outer carpentry and is used almost exclusively for impregnating of timber for wooden windows and doors. Treated timber, according to these classes is produced according to common Nordic rules, which have been worked out by the Nordic Wood Preservation Council (NTR) based on European standards. The companies, which produce classified, treated timber are certified according to a set of rules which has also been drawn up by the NTR.

Glulam can be manufactured with laminations from treated timber and the protection effect can be further increased by post-treatment with penetrating primer oil or even pressure impregnated. Please observe that glulam products cannot be NTR classified, only the timber laminations.

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

- In ground contact or fresh water.
- Where personal safety requires that the timber is not weakened.
- When difficult to replace, after being built-in in damp environments.

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

CHECK LIST FOR DESCRIPTION AND ORDERING

DIMENSIONING

A clear, correct and unambiguous dimensioning of a glulam element assists a well-made glulam construction and lessens the risk of errors and delays when completing an item. Example of a correct dimensioning is given in the illustration below. When projecting and creating documents, these facts are given:

All required views must be drawn up and figured. Cut arrows ease comprehension. Meanwhile it is often enough that the beam or column viewed from the side is drawn up. The glulam element is advantageously oriented horizontally or vertically on the finishing work drawing, in order to save on drawing space and simplify the figuring. For measuring one should depart from the unfinished glulam element and include all the sizes in the x- and y-axis, which are required so that oneself should be able to finish the beam. It is advantageous always to start from the same point on the figuring of for example a notch, even if it takes more claims on drawing space. If holes are made at the site, hole diameters and possible notches plus reinforcing are to be set out. If there are for example slits or glued on wooden parts these are dimensioned in a suitable way. Explanatory text can complement the figuring.

Modern 3D- drawing software generate as a rule 2D- drawings, where the figuring however should be checked so that 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.

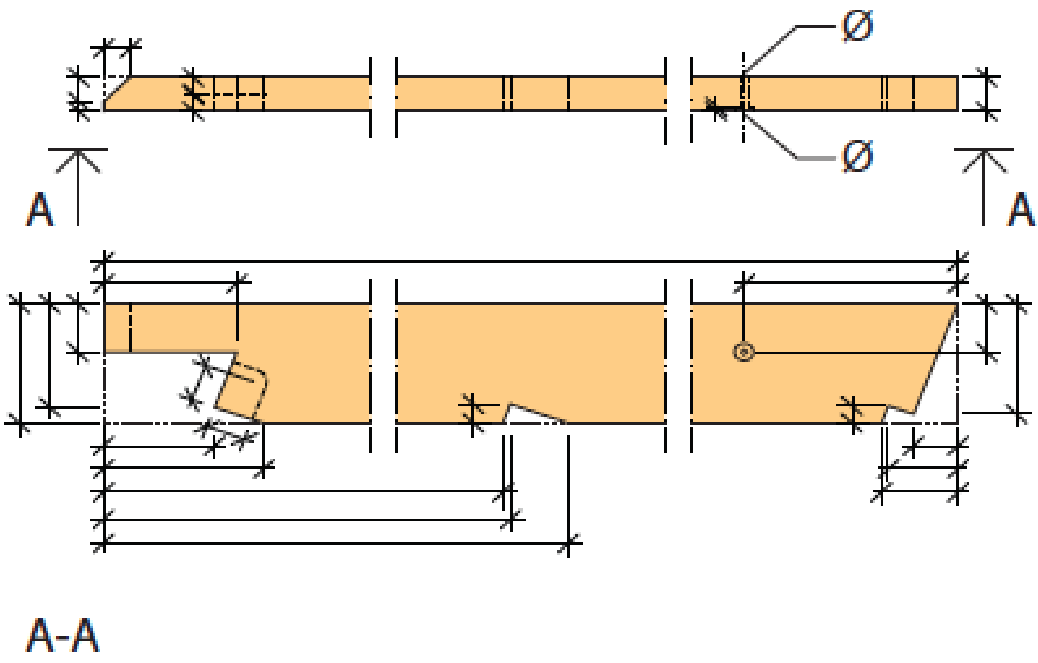


ILLUSTRATION: Examples of clear figuring for manufacture finishing work.

DESCRIPTION

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

• Element labeling for identification.

• Number of units. For different units the number of units for these should be specified, for example 20 columns of length 5400 mm, 10 columns of length 3200 mm and so on. Please observe that a three-pin portal frame or a three-pin arch consists of two elements.

• Type of structural element, for example straight beam, column, double pitched beam or reference for plan.

• Target sizes shall be given. See also section Figuring, page ?

• A glulam beam is set out with width *b*, height *h* and length *L*.

• A glulam column set out with width *b*, depth *h* and height *L*.

• 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 Figuring, page?

• Strength-class, according to the standard EN 14080. Manufacturing standard for beams is normally GL30c.

• Adhesive type. Manufacturing standard is adhesive type I.

• Appearance-grade. Stock standard in the Nordic countries is Clean planed, unrepaired surfaces. Appearance grades according to section Appearance grade, page?

• If Clean planed, repaired surfaces are specified, indicate which surfaces will be exposed to view after assembly.

• If camber is requested, indicate the size for camber in mm.

• If another species of timber than spruce is requested, for example pine. If glulam with treated laminations is requested, indicate timber protection class on the laminations and any surface treatment.

• Special requirements with regards to packaging, for example individual packing, edge protection for crane mounting etc.

• If other size tolerances are required than the standardized, indicate required plus and minus tolerances. See page?

TABLE. EXAMPLE OF SPECIFICATIONS IN CONNECTION WITH AN ORDER

Type of element	Amount	*b*	*h*	*L*	Strength class/ Adhesive	Note
Straight beam	12	90	405	9000	GL30c/type I	Packaging: PE-film
Column	24	90	315	3500	GL30c/ type I	Primer painted 60 ⌠m

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

HANDLING OF GLULAM – CHECK LIST

Handling of glulam demands great care and can in a decisive way 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 lifting equipment is almost always a requirement, as a rule a mobile crane.

For protection against precipitation and dirt during transport, storage and erection glulam elements are as a rule delivered packaged, in a bunch or individually, in plastic film or paper.

ON DELIVERY

- Plan erection in good time before delivery for avoidance of time consuming re-loading.
- Check that the number of glulam elements and fittings corresponds with the order and delivery note.
- Check the packaging, that it is complete.
- Check the delivery, note any visible damage. Tick off strength class and labeling against order and delivery note.
- Label glulam elements and fittings clearly and systematically to ease erection.
- Drain any moisture inside the package by cutting it on the bottom side.
- 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.
- Check that the glulam is free from dirt.

ON STORAGE

- Never put glulam elements directly on the ground.
- Use clean sleeper beams, which are at least 250 mm high and which provide good ventilation.
- 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 above each another.
- 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 tarpaulins reach the ground.
- Long-term storage outdoors on the building site should be avoided.

NB! If the glulam has become damp it must be given the possibility to dry out slowly to prevent the onset of cracks. It is however normal that cracks can occur from the drying out which the glulam is exposed to during the building’s first year. However, small cracks can be found even at delivery.

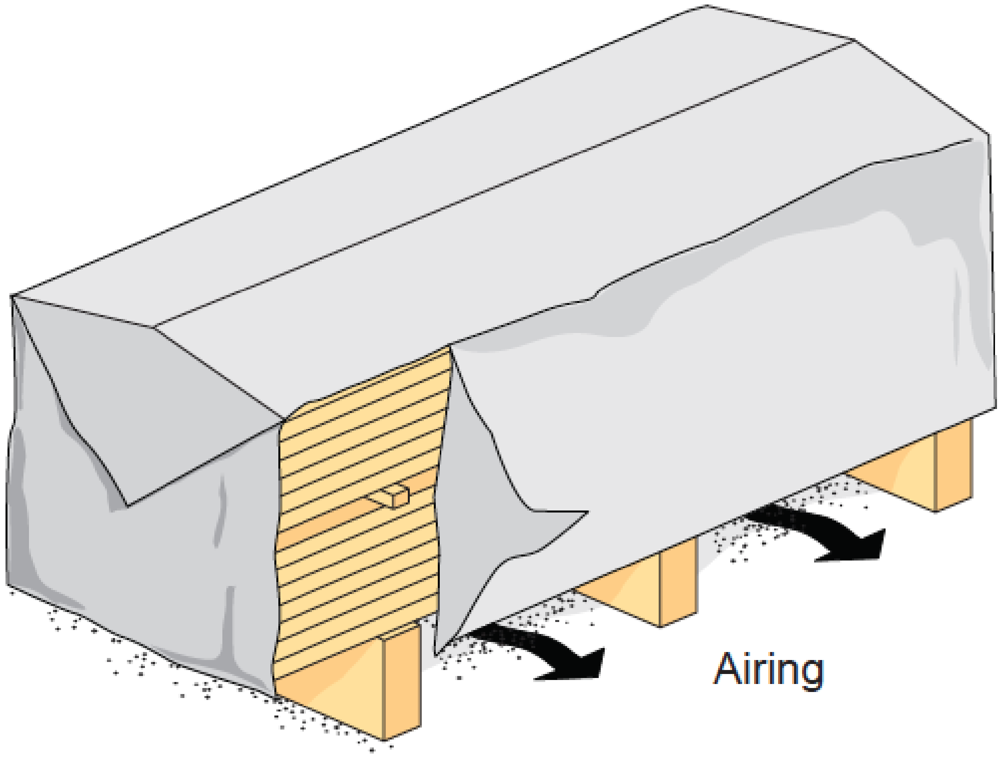


ILLUSTRATION: For shorter outdoor storage the glulam elements must be protected with for example tarpaulins, which are laid on clean studs so that sufficient ventilation is obtained under the tarpaulins. Do not let the tarpaulins reach the ground.

ERECTION

• Use wide 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, which should 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.

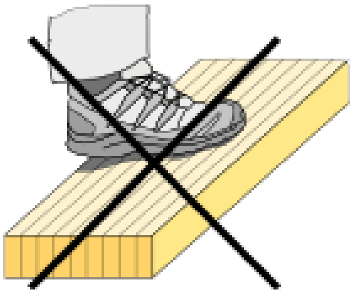


ILLUSTRATION: Do not walk on surfaces, which should be visible after erection.

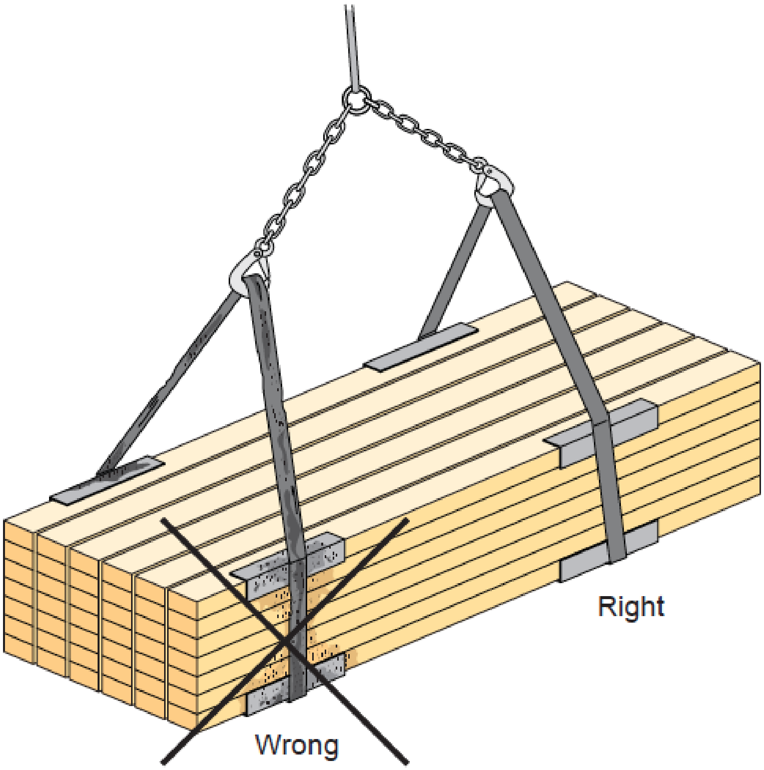


ILLUSTRATION: Use wide straps for crane lifting and protect the glulam element's edges with steel angles or other edge protection, so that no lift marks occur. Make sure that building gloves, straps and other lift equipment are free from dirt.

MISCELLANEOUS

- Running and maintenance instructions can be obtained from the adhesive manufacturer.
- Glulam can be surface treated in the same way as timber, see page?

SUBJECT INDEX

Transport protection
Trusses

Under-tensioned beams

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FOR MORE INFORMATION

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THE PROJECT GLULAM HANDBOOK

This book is included as Volume 1 of the Glulam Handbook, which consists of three volumes. Volume 1 deals with facts on glulam and guidance for planning. Volume 2 contains structural calculations for statical dimensioning of glulam. Volume 3 gives a number of calculated examples of the most common glulam structures.

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ISBN *(Johan Fröbel will fix an ISBN-number)*

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