History of timber structures

STEP lecture E1
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Objectives

To describe the historical development of the use of timber in building and engineering structures and to develop an awareness of the significance of timber as a traditional structural material.

Summary

The lecture traces the history and development of timber building and engineering structures, both small- and large-scale, from their humble beginnings in 'primitive' shelters through to modern long span structures. Some examples of timber structures from throughout the world are reviewed to illustrate this development and present the potential of timber as a structural material.

Introduction

Timber has been available as a constructional material to most societies since the human race first started to build crude shelters at the beginning of civilisation. A diversity of tree species exist and most climatic zones have at least one that has adapted to the prevailing conditions within that area. Thus timber is generally available in most inhabited regions of the world. The history and development of timber structures is an extensive topic. Timber has been used in the construction of buildings, bridges, machinery, war engines, civil engineering works and boats etc. since mankind first learnt to fashion tools. Here it will only be possible to give some examples, generally limited to buildings, bridges and works of civil engineering, to illustrate this development. These examples will not be restricted to the European experience and, where possible, they will be drawn from other continents to demonstrate the adaptability of timber as a structural material, to stimulate study of alternative building forms and to show the engineering and architectural potential of timber structures.

"Primitive" structures

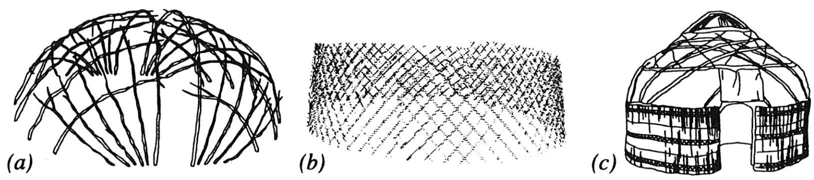


Figure 1 'Primitive' structures (a) withy frame, (b) teepee, (c) yurt.

Probably the earliest shelters constructed by mankind were made from a framework of tree branches covered in leaves or animal hides; one of the simplest, the "withy frame" being a structure formed from saplings inserted in the ground in the form of a rough circle, bent over, woven and tied together with ropes of natural fibres to produce a lightweight dome. The "teepee" of the native North Americans is also an example of a simple structure where timber poles are used to construct a conical framework to provide a hide-covered shelter. Mongol nomadic desert people use a further example, the yurt, which consists of a folding timber lattice or trellis that is expanded and anchored to form a circular wall which then supports a set of thin timber radial roof arches. The skeletal framework is then clad with thick felt material to provide shelter from sand-laden desert winds. These simple timber structures are illustrated in Figure 1.

Traditional Chinese building system

A very sophisticated modular timber building system was developed over 1000 years ago in China and was well established by the time of the Sung Dynasty (960 - 1279) when, in 1103, the Ying-tsao Fa-shih was published. This was a detailed manual of building procedure and practice that, although revised by subsequent dynasties, survived in modified form until the founding of the Chinese Republic in 1912 (Needham, 1971). The basic structure of a traditional Chinese building consists of a grid of timber columns founded on large stone bases which then support floor beams and the heavy roof construction (see Figure 2). Under the modular building system, depending on the importance and physical scale of a building, the structural elements were selected from a standard set of components of prescribed dimensions. The roof structures of the traditional standard Chinese building system appear somewhat alien to the modern western observer as they do not employ any form of roof truss. Main roof beams span between columns and these in turn support a series of simply-supported beams, stacked one upon another, each slightly shorter than the one below. Purlins span between, and perpendicularly to, the ends of the beams in adjacent stacks and short individual rafters span from purlin to purlin to form the classic curved profile of the Chinese roof. Complex timber bracketing is used to support the ends of the lowest beams at each column, the size and complexity of the brackets also being described in detail for each building type in the standard system. Over many centuries the main development in this system was in the complexity and aesthetic appearance of the bracketing whilst the other modular components remained relatively unchanged.

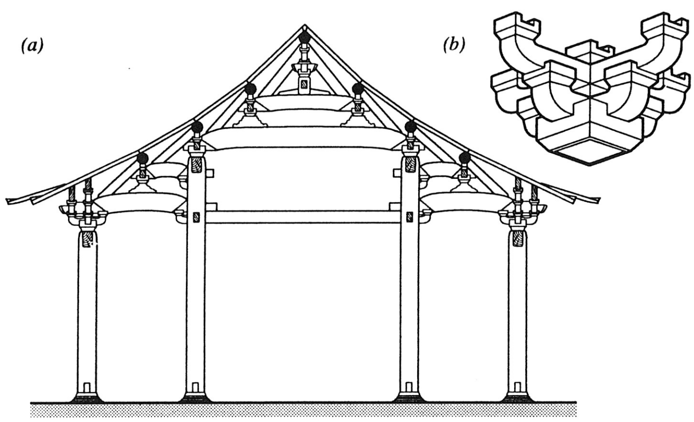
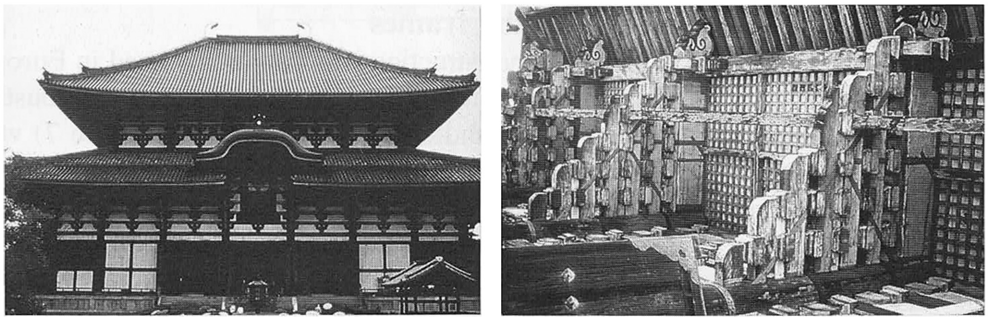


Figure 2 (a) Chinese building system and (b) bracket system.

Historic Japanese structures

In Japan there is also a long tradition of using timber structures and many historic buildings were constructed following the example of the Chinese building system but in a slightly less elaborate form. The largest ancient timber building in the world is the Todaiji temple at Nara in Japan (Figure 3a), which is 57 *m* wide by 50 *m* deep and 47 *m* high and houses the Daibutsu or Great Statue of the Buddha. The current building, which dates from 1708, is only about two-thirds the size of the original which was destroyed by fire. Nearby, there is a pair of elegant timber multi-tiered pagodas, at the Yakushiji Temple, Nara. One of these, the East Tower is original but the other was rebuilt as a copy, in 1981, to replace that destroyed by fire in the 16th century. In the former capital of Kyoto there are many fine examples of timber temples and palaces of great antiquity. Several cities in Japan (e.g. Osaka, Kumamoto) had dramatic timber-framed castles with tiered tiled roofs, however, they were mostly destroyed or severely damaged by fire during times of war and are mainly now reinforced concrete frames cloaked with timber framed roofs and details. In Japan, the quality of traditional timber joinery is high and many complex and inventive joints were used to connect structural elements without using metal fastenings (Sumiyoshi and Matsui, 1991).



(a) (b)

Figure 3 *(a) Todaiji Temple, Nara, Japan - the largest ancient timber building in the world and (b) detail of its extensive cantilever bracketing.*

Norwegian stave churches

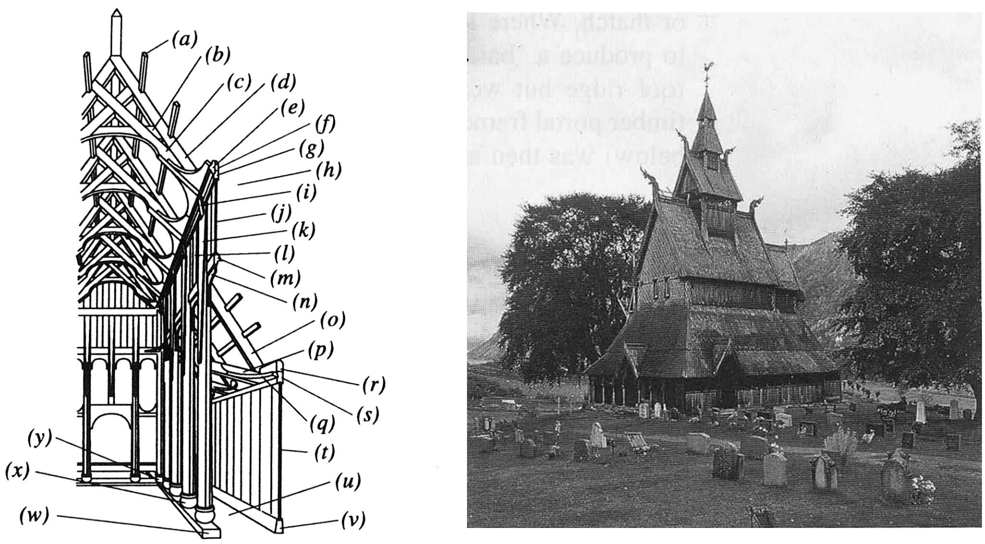


Figure 4 *Left: structural system of Norwegian stave church. (a) Nave purlin, (b) nave collar beam, (c) nave scissor brace, (d) nave rafter, (e) nave roof bearing beam, (f) upper nave wall plate, (g) lower nave wall plate, (h) scissor brace quadrant bracket, (i) applied bracket, (j) nave wall, (k) nave stave splay, (l) port hole, (m) nave bresummer, (n) nave arcading, (o) aisle rafter, (p) aisle strut, (q) quadrant bracket, (r) upper aisle wall plate, (s) lower aisle wall plate, (t) aisle wall, (u) aisle, (v) aisle sill beam, (w) raft beam, (x) nave intermediate stave, (y) nave corner stave. Right: Stave church at Hopperstad, Norway (Photograph by B.R. Lindstad, NIKU).*

Up to the 14th century, between 800 and 1000 stave churches are estimated to have been built in Norway. The name derives from the substantial timber columns, or staves (from 0,3 to 0,4 *m* in diameter) which are a dominant structural element in their construction. That 29 of the churches still survive, some having done so for more than 800 years, is a tribute to the builders' skill in the selection of durable materials, a stable structural system and construction details appropriate for the climate. (Sack and Aune, 1989). An example of one of the surviving buildings is shown in Figure 4.

Medieval timber frames

Timber-framed construction was commonly used in Europe during medieval times for houses, barns etc. In the UK, three methods of construction dominated; cruck frame, box frame and aisled frame (see Figure 5 to 7) with regional variations in the popularity of each form. For cruck frame construction, a series of transverse, laterally-stable, "A" frames were erected at regular intervals along the building on a continuous timber sole plate. In its simplest form, each cruck frame was produced by longitudinally splitting the trunk and main branch of a tree (or an appropriately curved trunk) of sufficient length to span from the sole plate to the roof ridge. The two halves of the trunk then formed a matching pair of slightly curved members (known as cruck "blades") that closely followed the cross-section of the building and could be jointed at the ridge (and connected with a collar beam if required) to make structurally-stable, symmetrical frame. Generally, all joints were made using hardwood dowels. Purlins and wall plates connected the frames longitudinally and lateral stability was achieved in this direction by knee braces inserted between the purlins and cruck frames to resist wind forces. Rafters were added to support tiles or thatch. Where longer clear spans were required, the construction was modified to produce a "base" cruck. In this form, the two cruck blades did not meet at the roof ridge but were connected by a braced cross beam to create a rudimentary timber portal frame. A "crown post" roof (as described in the section on roof trusses below) was then added to the centre section, supported by the cross beam.

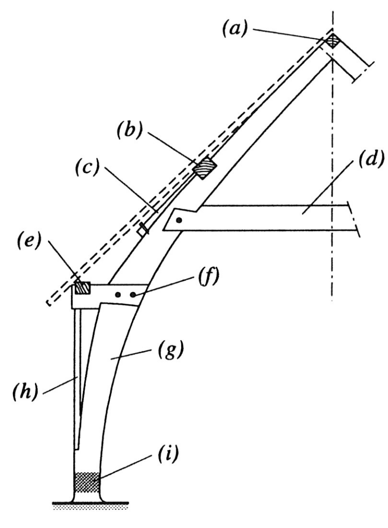


Figure 5 *Cruck frame. (a) Ridge purlin, (b) purlin, (c) wind brace, (d) tie beam, (e) wall plate, (f) cruck spur, (g) cruck blade, (h) wall post, (i) sole plate.*

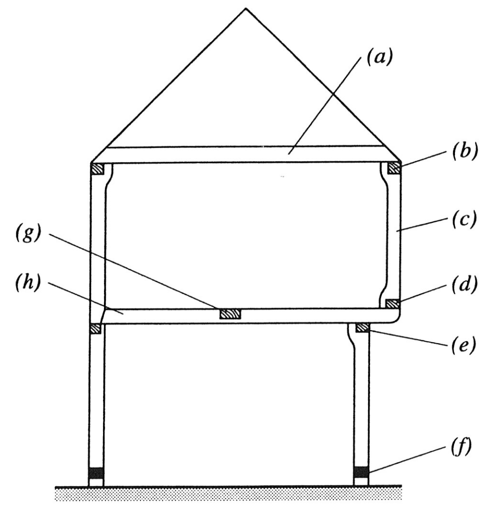


Figure 6 *Box frame. (a) Tie beam, (b) wall plate, (c) wall post, (d) bressummer, (e) storey plate, (f) sole plate or sill, (g) summer, (h) girder.*

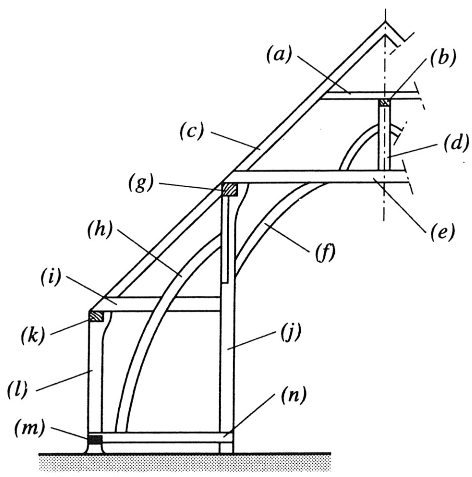


Figure 7 *Aisled frame. (a) Collar, (b) collar plate, (c) rafter, (d) crown post (e) tie beam, (f) arch brace, (g) roof plate, (h) shore, (i) aisle tie, (j) aisle post, (k) aisle plate, (l) wall post, (m) sole plate, (n) post plate.*

Box framing was basically post and beam construction with the addition of diagonal bracing within the wall planes to resist lateral forces. A common feature of this construction was that the upper-storey floor cantilevered a short distance out from the walls of the ground floor. In densely populated medieval cities of Europe this provided additional accommodation over the narrow streets and the continuity of the floor beam cantilever improved the structural efficiency of the beams. In some box-framed buildings only limited diagonal bracing is provided with additional stability deriving from the infilling panels of wattle and daub, or brickwork etc. However, in others the diagonal bracing becomes an architectural feature, in addition to its structural function, with bracing patterns varying from region to region.

As the name suggests, aisled construction, used predominantly for storage barns, has a building cross-section consisting of a main central "nave" and two side aisles, analogous to that of many churches. The central space was defined by two rows of timber columns, the aisle posts, which were usually connected longitudinally at their heads with a continuous timber plate and knee bracing to form two long frames. Tie beams spanned transversely between adjacent columns in the two frames and these were also laterally stiffened with corner bracing. Wall posts were connected with additional framing members to form the side aisles. Usually, diagonal shores were installed, between the aisle posts and the wall sole plate or the post plate, to provide additional lateral stability against wind forces. Above the aisle frame a simple "collar" or "crown post" structure completed the roof. In some ways the cross-section of an aisled barn was a representation, in timber, of that of a typical Gothic cathedral.

Log-houses, balloon and platform frames

In highly forested regions of Eastern Europe a different house building technique developed using the almost unlimited supply of logs (predominantly round) in which they are usually used laid horizontally one upon another to form walls. Structural stability is provided by notching the logs at the corner intersections so that the wall planes interlock. Evidence of the use of this notching technique dates from the Stone Age. However, the earliest evidence of notched log-houses has been found at Buchau, Bodensee, dating from the period 100-800 BC and the earliest in Scandinavian countries from around 1000 AD (Haulgid, 1980). Log-house construction was widespread in regions of Slavonic influence and was not restricted to small building. In Russia, for example there were many instances of tall church buildings constructed using the same technique. In Western regions a more sophisticated variation developed using trimmed logs and dove-tail notches at the corners. A less common alternative utilised halved logs set vertically in the ground to form palisade-like walls. This technique was still used in Europe up to the 11th. century, for example in the churches at Greensted, in England and Lund in Denmark. Of course, the notched log-house was taken to the New World by settlers from Europe. The log cabin was widely used in the forested areas of the USA and Canada where rapid colonisation required the construction of a large quantity of residential accommodation using relatively unskilled labour in a short time.

Figure 8 Farm log building in Norway (Photograph by J.N. Christensen, NIKU).

In North America, as prosperity increased, wood was still used as the prime construction material but using finished timber, produced by mechanised sawmills, in framed construction. The most common methods of timber-framed construction are platform frame, where storey-height wall panels a set on the intermediate floor platforms and balloon frame where two-storey external wall panels are erected first then the intermediate floor is suspended from them.

Development of timber roof structures

Ancient Greek roof construction was based on a beam and post system. Longitudinal ridge beams were supported either on props from massive horizontal main beams up to 13 *m* long or on an internal colonnade. Depending on the roof span rafters then spanned from the ridge beams to the perimeter walls, producing a low pitch. The Romans developed triangulated trusses, with spans up to 30 *m*, for the roofs of their basilicas and these greatly influenced the form of medieval Italian and later European roof structures. The Romanesque roof trusses of St. Paul's Outside the Wall, in Rome, which exceeded 24 *m* span, were repaired in 816 and finally destroyed in a fire in 1823. In Northern Europe the Romanesque truss was built with a steeper pitch, with more internal web framing to improve their structural efficiency.

In the more domestic scale medieval buildings other roof structures were developed. Crown post roofs had braced props supported on transverse collar beams to maintain the longitudinal ridge timbers.

Early timber trusses were often built without much understanding of the structural action involved and often resembled tied arches more than the modern idea of a truss, for example trusses in the roof of Wren's, Sheldonian Theatre, in Oxford (Mark, 1993). The early development of roof trusses is shown in Figure 9 to 12.

The need to support purlins spanning between principal rafters of basic triangular trusses led to the development and widespread use of king post and queen post trusses (Figure 9 and 10). In both cases including "post" in the name of the truss is misleading as it implies that the significant elements are in compression whereas both the central vertical king post and the two vertical queen posts are in fact in tension under downward roof loading. Therefore care must be taken to design the joints at each end of the posts to transfer the tensile force which is present, usually by using metal straps.

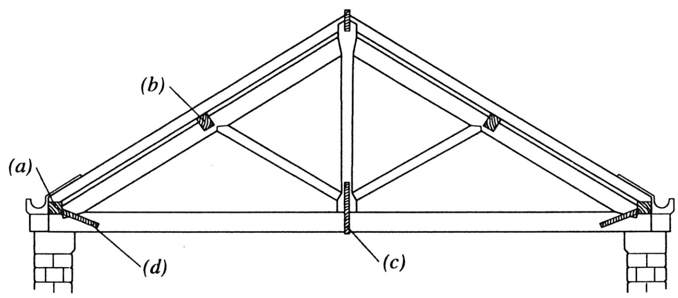


Figure 9 Development of timber roof construction: king post truss.

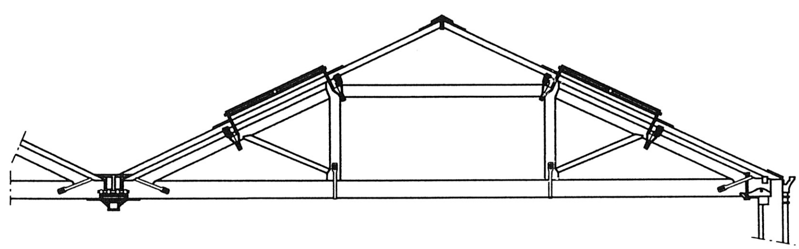


Figure 10 Development of timber roof construction: queen post truss.

Another form of roof construction used mainly for open roofs of halls and churches is that of the hammer beam, Figure 11, one of the best known examples being the

20,7 *m* span roof of Westminster Hall, London, completed in 1394 by Hugh Herland (TRADA, 1985; Mark, 1993).

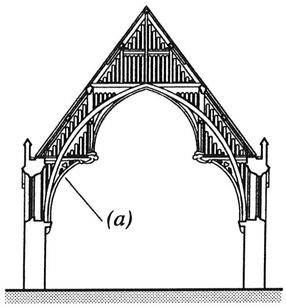


Figure 11 Development of timber roof construction: (a) hammer beam.

The parabolic arch is a very efficient structural form when subjected to uniform vertical loading provided that the supports are fixed in position. To overcome the problems associated with the imposition of lateral and point loads and/or movement of supports, timber bowstring girders emerged for use in spans from about 25 to 55 *m*. These consist of a laminated tied arch with web bracing. A related form is the Belfast truss (see Figure 13), developed in the 19th. century, which has a curved upper chord, a straight lower chord and a dense "criss-cross" pattern of web bracing. This truss form had the distinct advantage that spans up to about 36 *m* could be fabricated from short lengths of timber (TRADA, 1985).

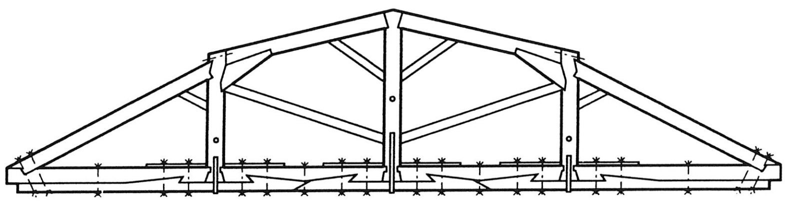


Figure 12 Development of timber roof construction: Wren's Sheldonian theatre roof.

Figure 13 Belfast roof truss for an aircraft hangar at Duxford, England.

Massive timbers were used in roof and spire construction in the great Gothic cathedrals of Europe. For instance at Notre Dame in Paris the timber spire erected over the crossing in the early 13th century survived, though damaged, until its removal in the early 19th century and its replacement, in 1860, by the present spire designed by Viollet-le-Duc (Mark, 1993). Also, after the Norman tower over the main crossing of Ely Cathedral, in the East of England, collapsed in 1322, it was replaced by a timber structure consisting of an octagonal shell base supporting an octagonal lantern. This was completed in 1334. The total weight of the timber structure was approximately 400 tonnes, including the main lantern posts 19,2 *m* long, 508 x 813 *mm* in section, each weighing about 10 tonnes.

Timber bridges

Early timber bridges constructed by the Romans were simple beam structures of hewn tree trunks spanning between timber piled piers. One of the earliest recorded is the Pons Sublicius built during the time of Ancus Marcius (640-616 BC) which survived, with regular repair, until the time of Constantine (306-337 AD) over 900 years later. The bridge known as Caesar's Bridge, across the Rhine, is believed to have been built under the direction of Vitruvius (the Emperor's Chief of Artillery) and, in a later drawing by Palladio, is shown to have longitudinal beams resting on cross-beams supported by inclined piles. An interesting joint was used to connect the piles and cross-beams so that the addition of load to the bridge deck caused the joint to become tighter. In 104 AD Trajan's Bridge, consisting of 20 piers up to 45 *m* high joined by semi-circular timber arches of 52 *m* span, was raised across the Danube River (ASCE, 1976).

In 1570, Andrea Palladio, published an illustration of a 30 *m* span, timber-trussed bridge over the Cismone River, in north-east Italy, constructed around 1550 AD (see Figure 14). The joint details show an appreciation of, and are appropriate for, the forces that are generated by the pedestrian loads on the bridge which are supported on the bottom chord of the truss (Mark, 1993; ASCE 1976).

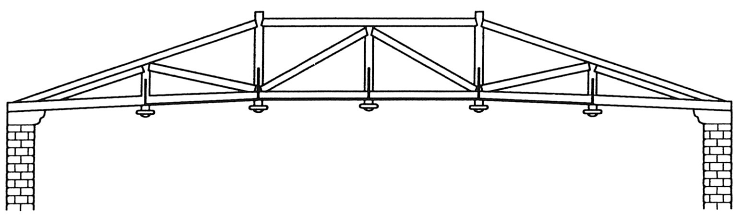


Figure 14   Palladio's design for a 30 m span trussed bridge.

At Queen's College, University of Cambridge, a timber bridge, known as the "mathematical" bridge, designed by William Etheridge, was erected in 1750, to replace an earlier design. (The current bridge has been rebuilt, twice since, to the design of 1750). Although the bridge soffit appears to be an arch, it is in fact formed from straight timbers placed tangentially to the curve. These timbers extend to the level of the parapet handrail and are bolted together at all intersections thus combining to produce a truss (Labrum, 1994).

In France during the 18th century timber bridges were developed which had level decks with low parapets supported on flat profile arches formed from planks clamped together to produce a laminated section. Examples such as the Pont Louis, over the Isar, near Fresingen, had spans up to 45 *m* (ASCE, 1976). Grubenmann also constructed some renowned covered bridges, with spans of up to 120 *m*, in the 18th. century (Stüssi, 1961). For instance, the complex truss/arch at Schaffhausen over the Rhine, built in 1754, and an elegant 60 *m* span arch bridge at Wettingen. His 30 *m* span bridge at Kubel combines arch and suspension principles with the bridge deck effectively tying the arch and the roof structure acting as a strut between the tension elements (see Figure 15). In all of these structures complex scarf joints are used to form long tension members from shorter pieces of timber.

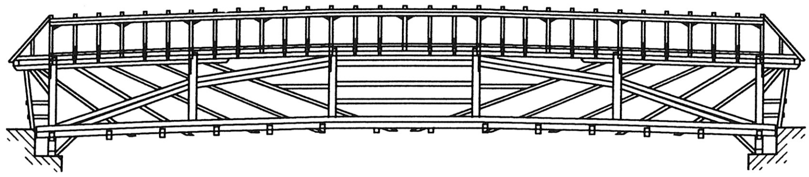


Figure 15 *Grubenmann's bridge at Kubel.*

During the dramatic period of railway expansion in the 19th century many bridges and viaducts were constructed from timber. The renowned engineer Isambard Kingdom Brunel used timber for viaducts and bridges on the South Devon Railway and South Wales Railway. As these structures were quicker and cheaper to construct initially they therefore appealed to the under-funded railway companies. For example, for the Bourne Viaduct of 1842 he used a combination of a "king post" truss and "queen post" truss to span 20 *m* and for the Landore and Usk Viaducts he erected timber, trussed arches of up to 30 *m* span to carry the track-bed. In Cornwall he used a timber modular system for a series of bridges and viaducts. For instance, the St. Pinnock Viaduct had, at the top of each masonry pier, three frames each of four Baltic Pine struts, arranged in a fan shape to support the beams of the track-bed. Initially, the general public were troubled by the slenderness of the bridge components but eventually they came to have full confidence in the skill of the engineer. Brunel had accepted that constructing timber bridges and viaducts would result in a continuing maintenance commitment and had had the timber treated with preservative (kyanised, using a solution of mercuric chloride). Although the timber structures remained serviceable they were replaced by embankments or masonry arches as funds permitted, due to the high cost of upkeep (Vaughan, 1991; Otter, 1994).

In the USA timber has been used extensively in bridge construction as native forest trees of great length and large cross-section were readily available to settlers. The shortage and high cost of other construction materials meant that timber bridge and truss design developed more quickly than in Europe. Early North American timber bridges were of simple beam and pile construction. For example the "Great Bridge" over the Charles River erected in 1660, Samuel Sewall's York River Bridge, in Maine, 82,3 *m* long and having 13 piers, constructed in 1761 and the Charles River Bridge at Boston, 458 *m* long and having 75 piers, built in 1786 also by Sewall. In 1785 Enoch Hale erected what was probably the first bridge in the USA requiring more than simple span beams, the bridge over the Connecticut River at Bellow Falls, Vermont. From 1792, Timothy Palmer constructed innovative trussed arch bridges and, in 1796, patented the idea of fully-enclosing timber bridges with roof and walls to improve their expected life from the accepted 10-12 years to up to 40 years. His works included the "Permanent" Bridge over the Schuylkill River at Philadelphia (1804-6), which had spans of 45,7 / 59,5 / 45,7 *m* acting as a continuous truss over the piers, and a bridge over the Delaware River at Easton (1806-7) which was covered and remained serviceable until its replacement in 1895 when the applied vehicular loads had become excessive.

Lewis Wernwag produced a total of 29 bridges, the most notable being the "Colossus" over the Schuylkill River in Philadelphia (1812). Fletcher and Snow in (ASCE, 1976) said that "This bold design, scientific and architecturally beautiful, probably was never surpassed in America". It was a fully-covered, trussed-arch, timber structure, of 103,7 *m* clear span and 6,1 *m* rise, incorporating 5 parallel trusses having arch-rib lower chords 1,07 *m* deep by 0,33 *m* consisting of 7 layers of timber clamped together. In 1813-14 he also built a timber truss bridge over the Delaware River at Newhope. This bridge had timber parallel top and bottom chords, timber verticals but "X" iron diagonals in each panel, a truss form that anticipated the Pratt Truss.

Theodore Burr patented his bridge truss system (parallel chord truss combined with an arch) in 1817. Burr's truss system was used for many timber bridges throughout the USA, a notable example being the Waterford Bridge (1804) over the Hudson River in New York State. The four spans were between 47 and 54,9 *m* and the covered bridge survived for 105 years until destroyed by fire in 1909.

In 1820 Ithiel Town patented his lattice web truss and, in 1835, the modified form with double webs and secondary chord members. The Town truss was eminently suitable for timber construction as it could be made from standard-sized timbers of relatively small cross-section and length which were assembled using readily available bolts and rods rather than special joint assemblies. If suitably detailed and covered to protect the structural components from decay 60 *m* spans for railway bridges were expected to survive for at least 50 and up to 100 years. The cost of spruce timber bridges of this type and of medium span, in 1890, was approximately half that of an equivalent iron bridge.

The truss patented in 1840 by William Howe had timber web bracing members that ran diagonally between the top and bottom chords over two panels and vertical metal rods connecting adjacent top and bottom chord panel points. This was modified later to have timber "X" diagonals in each panel. The Pratt Truss, patented in 1844, had the timber and metal web elements interchanged, with metal "X" diagonals in each panel and timber verticals. Compression elements were, therefore, shorter than in the Howe Truss and the joints between web and chord members were easier to fabricate.

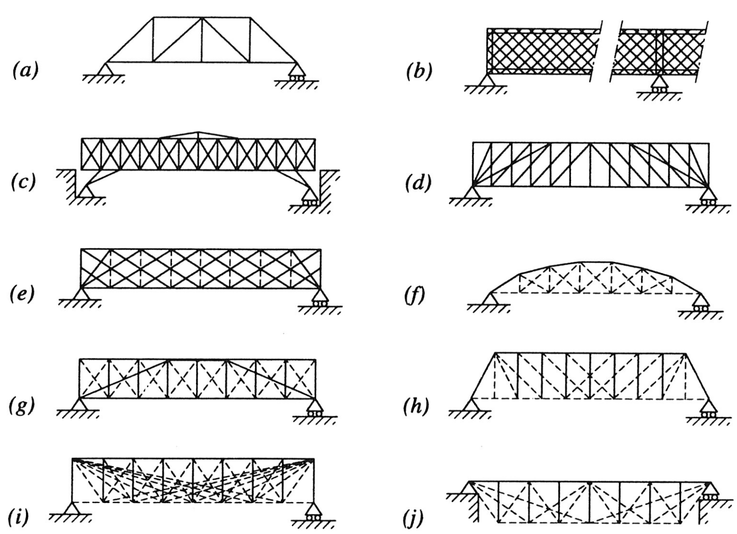


Figure 16 *Development of timber bridge trusses. (a) Androscoggim bridge Brunswick, 1804, (b) Town lattice truss, 1819, (c) Col. Longs brace truss, 1830, (d) Haupt lattice truss, 1839, (e) Howe truss, 1840, (f) Whipple bowstring truss, 1841, (g) Pratt truss, 1846, (h) Whipple double-intersection truss, 1846, (i) Bollman truss, 1852, (j) Fink truss, 1857.*

Laminated timber structures

Although laminated timber was in common use in other countries and had also been used for railway bridge construction in the UK (in particular by Brunel), one of the first major uses in a building was the train-shed roof of Kings Cross Station, in London. The roof was originally constructed using laminated timber arches of 30,5 *m* span. These were formed from boards 38 *mm* thick bolted together to make arch ribs 600 *mm* in depth. Subsequently the laminated arches were replaced by a metal structure due to deterioration of the timber, caused by steam from the locomotives standing at the station platforms. In 1866, arches of a similar form were used for the roof of the German Gymnasium in London (TRADA, 1985).

Early laminated timber structures used mechanical methods, bolts, dowels etc., to connect the individual laminations. However, the development of synthetic resin glues, such as urea-formaldehyde, phenol-formaldehyde and resorcinol enabled joints to be made that were as strong as the timber being joined.

Long span structures (hangars, hypar shells, domes etc.)

Some of the largest clear span timber arch buildings in the world are the non-rigid airship (blimp) hangars constructed for the US Navy, in 1942. A total of 16 hangars (the majority of which still survive) were built from treated Douglas Fir at nine different locations in the USA to house marine patrol craft. To conserve valuable steel and other metal resources the hangars (305 *m* long, 91 *m* wide and a maximum of 52 *m* high) were constructed using timber arch trusses 5,6 *m* deep, spaced at 6,1 *m* centres. The arches were fabricated from various sections, typically double 100 x 300 *mm* chords and 100 x 200 *mm* to 150 x 200 *mm* web bracing, jointed using split-ring and shear-plate connectors. Trussed wood purlins were used to span between the arches and support rafters at 2 *m* centres which in turn carried tongue-and-groove boarding 50 *mm* thick (ASCE, 1989).

Since the late 1950s timber has been used in the construction of shell structures that fully utilise their three-dimensional form to resist applied loads. An elegant example was the 46,6 *m* long by 28,3 *m* wide and 85 *mm* thick, turtle-backed, five-layer, teak shell constructed for the assembly hall of the Rangoon College of Engineering in 1956. Timber is particularly suited to the construction of shells based on hyperbolic paraboloid geometry as this double curved surface can be generated using straight elements. This was demonstrated by the erection of a 35 *m* square roof at Wilton Royal Carpet Company in 1957 (TRADA, 1985).

Timber has also been used both to generate the outer surface of masonry domes (e.g. St. Marks, Venice, St. Pauls Cathedral, London etc.) and in more recent history to generate long span geodesic, lamella and ribbed domes up to 162 *m* plan diameter.

Medieval timber machinery and engineering works

Timber was also used extensively in Europe for agricultural, industrial and military machinery and often as temporary works in the construction of major engineering projects. War engines, such as catapults, were constructed, since the time of the Assyrians and Greeks, for hurling missiles at the walls of cities under siege. In medieval times large timber frames were built to support battering rams used to break down fortifications. Water wheels were used for pumping water for irrigation and for driving corn mills and other machinery (some examples of water wheels at Hama in Syria up to 20 *m* in diameter). Timber post mills utilising wind power were constructed, from medieval times, for grinding corn in areas where water power was scarce. This required the construction of a stable timber frame base for the vertical post about which the mill structure rotates and large wooden rotating sails designed to resist high bending effects from the wind.

Because of its durability in the corrosive marine environment timber was used extensively in the construction of docks, jetties and harbours. Also, until the advent of reinforced concrete and steel as structural materials timber was the only material available for piled foundations to buildings and engineering works on poor ground. Timber was (and still is) used extensively for temporary works in building and engineering, for instance centring to support masonry arches whilst under construction, formwork for casting reinforced concrete etc.

Concluding summary

Representative examples of the development and use of timber in building and engineering structures, through history, have been presented. The significance of timber as a structural material for architectural and engineering structures has been demonstrated. It is hoped that this brief review will stimulate a desire to investigate further the history of timber structures as a way of informing contemporary design philosophy.

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