Wood
and Wood Joints

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Wood and Wood Joints

Building Traditions of Europe, Japan and China

With a Foreword by Valerio Olgiati

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Foreword

After searching for a copy of this book and in the knowledge that the English version was already out of print, we contacted the author and the publisher directly. Not only were we lucky enough to receive one of the last remaining copies but also learned that a new edition was in preparation. This is now available and we are delighted that this wonderful book can once again fascinate new readers.

Illustrated with beautiful photographs and meticulous drawings, the book details the long tradition and development of timber construction in Europe and Asia. Architects and carpenters cultivated a highly developed understanding of this material and the possibilities it offered. The path of forces and the specific properties of the material fundamentally determined the formal appearance of timber constructions and their details.

Timber construction has always related closely to the engineer's way of working and, compared with load-bearing construction, was very highly developed.

The culture of building with wood, its tradition, its regional and climatic particularities, its influences and developments are documented in impressive detail in this book.

In the last few centuries, building with wood has changed dramatically. Adhesives and steel components have changed the character of its construction. In contemporary architecture, wood is used for surface cladding or in construction in the form of resin-soaked materials such as chipboard or sandwich panels. Knowledge and skills of the kind described in this book are rarely seen today.

My own buildings from the past few years have been made primarily of concrete. With concrete one can build houses that are made almost entirely of a single material. Reinforced concrete can sustain tensile and compressive forces, can be used as a slab or a bar and can be assembled on site in phases; the manifestation of an idea to form a larger whole.

All this is possible with wood as well. It is just that we no longer know what this material is capable of and lack the skills to work it. And that is something we can change.

In this respect, this book is a welcome inspiration.

Valerio Olgiati
Flims, December 2010

Introduction to the Second Edition

There are two questions which could be regarded as a thread linking the various sections of this book. Firstly: "What were the conditions which governed the development and form of timber connections?" And secondly: "Can the timber connections of Europe and Japan be compared?" Both questions are interdependent; the second cannot be answered without a detailed consideration of the first.

If all the essential factors which have contributed to the formation of a timber connection are elucidated, i.e. the material itself, the person working the material and the product thereby created, then we come to the conclusion that a juxtaposition of these two cultures of timber construction is indeed possible but that a balanced comparison of the achievements must be regarded as problematic, if we can countenance such a thing at all.

To the sensitive observer, wood joints often allow the train of thought of their creator to be followed. (The carpenter produced the joint; from its form we can deduce what he thought in each case!) The creator's design considerations have taken on a form which we today interpret as a reflection of what was once acknowledged as good. On the other hand, the care shown in the execution, the readiness to produce complex joints, has not always remained the same.

This book describes and explains joints made exclusively from wood, i.e. without adhesives and without metal connectors, together with their origins and evolution. To do this, I have studied the examples found today, examined the scientific literature available and, where information was lacking, carefully supplemented this in order to fill in the gaps. Particular attention is paid to the material as well as to climatic, technical, woodworking and artistic influences. It might appear problematic that in doing so the origins of certain types of joints are discussed in the context of very specific causes. If, for example, the development of splicing joints is dealt with in the chapter covering dependency on the occurrence of wood, then this should not be taken as being more important than any other factor in the creation of such joints; likewise the influence of climatic conditions for the description of board jointing. The reader is referred to the selective nature of the examples given in the chapter on the relationship between timber connections and building tasks.

The classification employed in the chapter on the types of wood joints, which the reader might feel is insufficiently differentiated, is intended to reflect the consideration given to the specific material properties – once decisive in influencing the construction. The characteristics of wood, no two pieces of which are ever identical, have certainly not been accorded adequate attention by every carpenter in the past, but, inevitably, to a much greater extent than is the case today. As long as it was used in its natural form – and that is the theme of this book –, the complexity of the material was accepted for what it was. For today's theoretical approach this means that any classification, if it is to achieve a more detailed distinction, must either set artificial limits and exclude phenomena, or lead to perpetual repetitions. On the whole, the influences described here which helped shape joints in Europe and Japan were able to be readily compared, at least in this selection. In order to make this clear, the aim has been to try to place a Japanese equivalent alongside every example chosen from Europe. This, at the start perhaps confusing, method was the only solution, when seen in the light of the enormous wealth of material, to making the intended comparison easily comprehensible on our journey through thousands of years of timber architecture.

The reader will notice that many dates remain vague or are not even hinted at. There is a good reason for this. The date of the completion of a building can be ascertained. The evolution of a construction form, e.g. the spar roof, can now be traced back further and further thanks to more intensive research work in recent years. Nevertheless, there still remains the fact that there may have been other, even earlier examples which have in the meantime been destroyed and which will always remain an unknown variable. Looked at in this way it is perhaps easy to understand why the regular listing of dates has not even been considered.

A word or two about the constantly recurring Japanese terms is necessary. Generally, no capital letters are employed unless the word is a proper name. The names of people are reproduced in the traditional Japanese form, i.e. the surname before the forename. Temples or shrines are cultural centres of Buddhism or Shintoism. A Japanese person can deduce from the name Todai-ji that the object in question is a ji, i.e. a temple. However, in addition to ji there are a number of other Japanese terms which all mean temple and yet others for shrine, jinja, for instance. In order to avoid tautological constructions like “Todai Temple Temple”, in the case of a conflict we have decided not to distinguish between shrine and temple for the reader from other cultures. The difference can be recognized from various details on or around the structure, and it is irrelevant for the wood joints presented in this book. Those who travel to Japan will quickly discover the, even for visitors from the West, immediately recognizable distinguishing features.

Of all the many messages I received in response to the first edition of this book in 1997, not one took issue with the fact that Europe and Japan were rather unequal partners to compare with one another. For myself, however, this aspect became a matter of increasing concern. So when the publisher approached me with the intention of bringing out a new edition, I felt compelled to put this right and expressed the wish to add a chapter on historical timber construction in China.

There are many fascinating lines of development in timber architecture, but if asked to name the most advanced cultures of building with wood I would, without hesitation, choose the European and East Asian. I have consciously avoided speaking of Western or Far Eastern building traditions. The term “Far East” reflects a eurocentric standpoint that refers back to the era of European Imperialism. In the British Empire, the term “Far East” served to divide the Asian continent from the territories of the Near and Middle East. Today we speak of South Asian, Southeast Asian, and East Asian regions. The variety of timber constructions in Southeast Asia mirrors to a certain extent its geography. One can trace reciprocal influences between the developments in Southeast Asia and those in East Asia. In the border region in particular, it is often not possible to clearly identify the local architecture as specifically Southeast Asian or East Asian.

Nevertheless, when one follows the historical developments, it is possible to trace very clearly the developments of Chinese timber construction. For them, the ruling periods of foreign dynasties were not seen as a break but, on the contrary, as an enrichment (Liao, Yuan) and – depending on one's viewpoint – an endpoint or a culmination (Qing). The Japanese building culture, as previously mentioned, owes its development to a not inconsiderable degree to examples and techniques imported from elsewhere, such as Korea, but above all from the vast Chinese Empire.

In the new chapter I have again followed the principle of a colourful mixture of vernacular buildings and so-called high architecture. There are two main reasons for this. The first is that the organisation of the book is based on criteria that have nothing to do with this distinction. The second can be attributed to a firm belief that singular examples of high architecture "must be seen in relation to, and in the context of, the vernacular matrix, and are in fact incomprehensible outside that context, especially as it existed at the time they were designed and built".[1] That said, this viewpoint should in no way call into question the fact that a whole series of constructional phenomena in vernacular architecture are drawn from examples of high architecture. I do not, however, subscribe to the general opinion that developments in elite architecture, where they are sometimes described as being characteristic of architectural styles, gradually diffuse into vernacular architecture where they then reappear as imitations.

Had I wished to follow the same principle of direct comparison between European and Japanese building technology for the Chinese examples too, I would have had to rewrite the entire book. This was neither in the interest of the publisher nor in mine. I decided instead to append the chapter on Chinese architecture as a self-contained chapter. The reader will have no difficulty in comparing the examples shown with those from Japan or those from Europe. That is not least thanks to the critical and sensitive work of Andreas Müller, who was the editor in charge of both the first edition and this expanded edition.

Amos Rapoport was of the opinion that buildings can be examined in a variety of different ways: "One can look at them chronologically, tracing the development over time either of techniques, forms, and ideas, or of the thoughts of the designer, or one can study them from a specific point of view."[2] The comparison of Europe and Japan mixes both approaches, as does the study of buildings in China, albeit taking a rather different viewpoint. This approach creates a formal connection between the existing section – which has been checked and slightly changed, with some new photographs – and the new chapter. With this addition one can now legitimately speak of a comparison of the developments in Europe and East Asia.

1 Rapoport, 1980, p. 284
2 Rapoport, 1969, p. 15

The Material

The properties of wood

"By applying appropriate tools and techniques to a good piece of timber, a woodworker's imagination is limited only by the nature of his material – a material that often seems to have a life of its own."[1]

Every material is distinguished by characteristics peculiar to itself. Knowledge of these is a necessary prerequisite for processing the material appropriately. Wood lets us know quite definitely and unpleasantly when it is not being treated correctly, whether due to negligence or lack of knowledge. But wood also obstructs us when we try to unravel its mechanical, physical and chemical properties. Many modern textbooks attempt to present the material in a way which justifies this theoretical approach to its use. Twisted fibres, bows and colour discrepancies are only referred to, if at all, as abnormalities to be cut out; beauty, as a non-technical term, is an unknown word. All the properties of wood are interlinked. They interact with each other or are dependent on each other in such a way that this textbook-type of classification is quite simply inadequate if we wish to explain the connection between the characteristics of wood and the culture of woodworking.

The loading capacities of timber in tension (Fig. 1) and compression (Figs 2 & 3), in bending (Fig. 4) and shear, i. e. the mechanical properties, need to be considered directly and visually, as apprentices once did on their long way to becoming masters. The practical reappraisal of what had been seen in active work and daily routine was in any case only achieved competently by very few. The size of the cross-section is of fundamental significance for the loading capacity. The oversized members often encountered in older elements, possibly not unaffected by considerations of proportion, i. e. partly determined by aesthetics, undeniably contributed to the preservation of the material. Other authors dispute such oversizing and prove "that the timber constructions investigated from the period between 1000 and 1800 are often loaded to the limit of their capacity."[2] According to David Gilly in 1797: "For example, the machine master Reuss from Dresden cut the heavy truss posts in the town's opera house to suit the machinery in such a way that a narrow opening was created through both truss posts. He was very well aware that the truss posts would remain capable of taking any load likely to be put on them."[3] Examples of oversizing are the (sometimes) original columns of Norway's stave churches,[4] Switzerland's wooden bridges, which are capable of carrying today's heavy road traffic,[5] or Japanese temples and shrines. The fire in the Horyu-ji in 1949 can be regarded as an example of just what stresses wood can withstand even after 1200 years. The colossal dimensions of the columns, each 1.5 m in diameter, are certainly to thank for the fact that sufficient undamaged timber remained to guarantee the survival of a large part of the structure intact.[6] In total contrast to this are the sometimes "stupidity prescribed standardized sizes for all posts which would have been heavier in places if the construction had been logically worked out."[7]

1 The joints of the diagonal bracing members on this bridge between Appenzell and Schlatt in Switzerland are so tightly restrained that settlement at the corner in the left foreground has caused the wood to split.

2 In technical terms the loading capacity parallel to the grain is greatest. However, in a structure, as compressive forces increase so does the susceptibility to buckling. – Cowshed on a farm in Zaunhof, Tyrol, Austria.

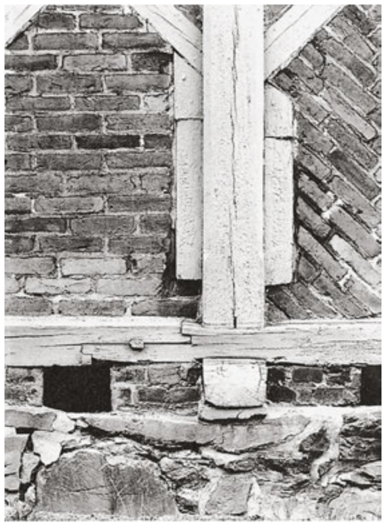
4 The pliability of wood can be exploited in very simple ways. – Zuberec, Slovakia.

And yet wood itself is relatively light, as the one time normal transportation of houses and churches indicates quite clearly. The village of Kiscsány in Hungary supplies a rather curious example of this. When in 1764 the local church threatened to sink into the marshy ground, strong wooden axles were laid beneath the sill beams of the building and then fitted with wheels. Oxen, helped by the whole community, then proceeded to pull the church 1,500 m to safety.[8] Even today, we take advantage of this fact which once shaped the term “goods and chattels”. In Switzerland old storehouses are, literally, led to a new lease of life as holiday homes![9] In Japan too, there is some evidence to suggest that shrines were built as movable objects. Even today there are customs which require shrines to be carried around on certain festive occasions.[10]

When still usable wood was no longer needed to fulfil its original function, there were sufficient reasons to recycle it. (Fig. 5) It saved its user a great deal of work and, above all, had already proved its worth. Numerous instances of reused timber have been found even in buildings which, even when subjected to closer scrutiny, did not appear to make use of such savings. During repair work, non-original members, carefully removed from other places, have been discovered again and again in the so-called “hidden roofs” (see p. 193ff.) of Japanese temples.[11] Spectacular examples of this procedure are provided by a barn in Jordans, Buckinghamshire, England, built from the wood of the *Mayflower*,[12] or the use of beams and spars from St Mary’s Church in Munich, Germany, to make violins.[13]

“Out of all the natural materials wood has the most balanced characteristics and can be relatively easily worked.”[14] This is probably one of the reasons why timber has been used for building even in Iceland, which has no trees.

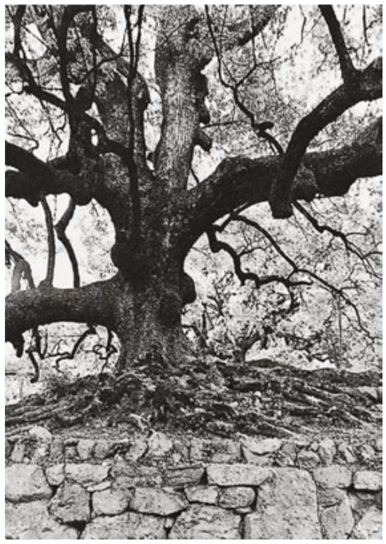
Humans were at least at one time convinced that each tree had a soul. In Japan the view is held even today that such a soul can also be bestowed on pieces of wood. On the surface this soul materializes in the beauty of the wood. The close bond with the material is revealed not least in the fact that it remains almost totally untreated.[15] Only if you walk barefoot or in socks across a wooden floor will you appreciate its texture, learn the difference between a few wide planks and many narrow ones. They are chosen for the beauty of their grain, and that depends



3 As a rule, horizontal timbers subjected to compressive loads cannot buckle; instead they are crushed. Therefore, the growth rings of rift-sawn wood are placed opposing the compression whenever possible. – Sill of a timber-framed building in Oslo, Norway.

5 The corner column of this barn in Zaunhof, Tyrol, Austria, is made from two older columns. This can be recognized from the lap-joint housings and nail holes of former bracing members.

to a large extent on the conversion of a trunk. The deep admiration, indeed almost religious worship which trees are assigned in Japan is expressed in one word: *kodama*, the spirit of the tree.[16]
If we look for positive characteristics in wood, then one of the first that comes to mind is its warmth. And this can be actually depicted. The average wall thickness of the houses in Goms, a valley some 1,500 m up in the Swiss mountains, is only 140 to 150 mm.[17] However, this definition would not correspond to our modern concept of warmth; a constant room temperature according to our tastes would very quickly kill off traditional timber construction.
Looking at a tree we might be able to glean how the forces of nature act on it and within it. (Fig. 6) The older the tree, the more it might have to tell us – what chaos it has had to face, how it overcame this, how it regained its balance again and again, defying the force of gravity. It demonstrates a diversity of forms which we only have to copy in order to employ them properly. It is not so very long since we knew how to use the tree as nature gave it to us. For those for whom the tree was too short to span the required width, they had to accept intermediate posts, those "tyrants of the floor layout". (Figs 7 & 8) It was only the development of the truss post (see p. 186 ff.) which allowed unsupported spans to be gradually increased. (Fig. 9)
The bond between the woodworker and the wood itself had already begun back in the forest. The location and appearance of a tree were decisive criteria for its later use. The master builder himself selected it. The farmer, in the capacity of master builder, observed the forest, whether it was his or not, and so knew about just a few more details which could be significant



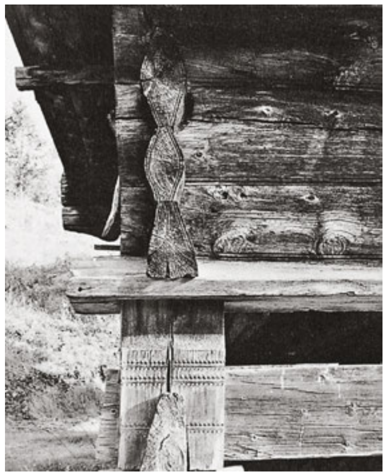
6 Camphor tree in front of the Shoren-in in Kyoto, Japan.

8 The roof in the Senyo-kaku in Miyajima, Hiroshima, Japan, is supported by columns arranged on a grid.

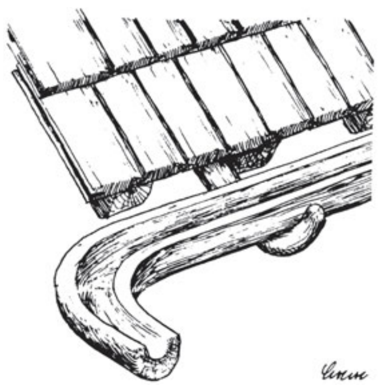
9 Two-part truss posts carry the tie beams in Schloß Thürntal, NE Austria.

7 Granary beam supported on columns.
– Primmersdorf, NE Austria.

for its use. *Schindelbaum* (literally "shingle tree" – a tree whose timber was particularly apt for shingles; it has nothing to do with shingle tree, *Doona zeylanica*) is just one of many names which owe their existence to such knowledge.
The individual character of all nature's products does not only lead to the individual appearance of every house in a village. It is also found in the uniqueness of every single tree, every post and every beam. It is the Norwegians who express this best. In a very discreet way the two-dimensionality of the perfectly sealed wall is broken down in the horizontal direction by way of grooves in its individual members, the wall thus separated into its components so that their uniqueness may be appreciated. (Fig. 10)
Knot-free, straight wood only grows in dense, regular forests. A style of building which will probably never be revived, revealed in many listed timber structures, demonstrates most conspicuously, particularly in the use of wood as nature provides it, how extreme economic constraints and the standard of living we demand have impoverished our use of form. For example, many timber-framed buildings are in fact characterized by bowed timbers. The original economic requirement to also make use of timber which was not straight enjoyed such a wide acceptance that in later times bowed timber was produced artificially.[18] People were so familiar with the mainly irregular elements of the tree – in fact, an irregularity governed by natural laws – that certain shapes seemed predestined for certain applications. (Figs 11 & 12)
In Japan this tradition has not been so thoroughly wiped out as it has been in western Europe and a large part of eastern Europe. Influenced by the Sukiya philosophy, which found expression in the tea-house style,[19] the Japanese have developed a very special feeling for timbers which have grown unusually. (Fig. 13) Indeed, they look for growth abnormalities. (Fig. 14) Just like in the West, demand outstrips supply. The result is industrially produced growth abnormalities. Examples of this are the *Kitayama sugi*, a cedar, the growth of which is influenced artificially, and the *Sugi kashira*, another cedar, which has pieces



10 Very light grooves decorate not only the ends of the logs, they emphasize the individual wall elements of this *loft* in Åmotsdal, Telemark, Norway.



11 The form of this natural curve is exploited to discharge water from the gutter. (source: Loewe, 1969, p. 132)

12 These bowed timbers enable a design clear of the ground in the virtually always damp Salzkammergut region. – Gössl, Steiermark, Austria.

13 Beams in Sakuta House, Chiba, Japan, in the Nihon minka en.

14 The owner of this *minka* in Shirakawa-mura, Gifu, Japan, does not conceal his enthusiasm for unusually shaped pieces of timber.

of hard plastic placed around its trunk which, for at least one year, force the tree to produce an extremely erratic surface.
Today, it is rare for the location of a tree to be taken into account when deciding its future usability. But it is precisely this aspect that can either bring about a rude awakening or a purposeful application. Single, exposed trees must constantly resist the actions of wind and weather. The result is that their heartwood is displaced northwards, giving rise to unequal densities on the north and south sides. Upon drying, the softer southern side shrinks more than the harder northern side. Acknowledgement of this property and knowledge of the wood allow the carpenter to exploit this characteristic. Used horizontally, the carpenter will place the timber north side uppermost, thereby building in the tree "pretensioned". Vertical applications of this irregularity are also possible.[20]
Spruce is not simply spruce! Trees which grow in a dense group are subjected to less favourable growing conditions and, hence, produce denser timber. This is normally regarded as more valuable.[21] Especially well liked are northern timbers because both the duration and severity of the winter forces a particularly slow rate of growth. Another highly valued property in woodworking is that coniferous trees growing under such extreme conditions form fewer branches, or at least no large branches.[22]
However, growing in a dense, regular forest in no way guarantees uniform material. It is not without reason that Japanese carpenters are reported to say you should not buy a piece of wood but rather the whole mountain![23] The master carpenter Nishioka Tsunekazu, who died only recently, is said to have proceeded with the rebuilding of the Yakushi-ji – a temple in Nara originally built in an age when the town was a political and cultural centre (710–94) – in such a way that the wood was used according to where it was felled, i. e. timber from southern slopes on the south side …[24] To Europeans, such a consistent approach to the material may appear, at best, exaggerated. However, it is known "that for longhouses [residence and stable positioned adjacent each other under one ridge] in the Tegernsee valley in Germany, single, slow-growing trunks from northward-facing slopes … were specifically selected."[25]
A property which can often be seen from the outside is the orientation of the fibres: straight or twisted. Timber with a twist to the right is generally considered to be usable. However, you are urgently warned against so-called "with-the-sun" or "after-the-sun" timber (wood which grows in the direction of the rising sun – midday – setting sun, i. e. like a left-hand screw thread).[26] The effect is supposed to be exactly the opposite for wood destined for shingling. The shinglemaker preferred left-hand timber because, apparently, it could be split more easily.[27] Everywhere you go these days, you notice how this property of wood is not taken into consideration. (Fig. 15) Nevertheless, examples of old timber architecture can also provide evidence of past negligence. (Fig. 16)
On the other hand, the careful observer gets the impression that the study of considerate or prudent handling of the material is virtually only possible using old examples. If coincidence can be ruled out as a design factor and an outdated "ornate artistry" seems hardly credible, then we must ask ourselves

15 Even sophisticated timber joints would not have been able to prevent this timber from twisting. – Wooden bridge in Umhausen, Tyrol, Austria.

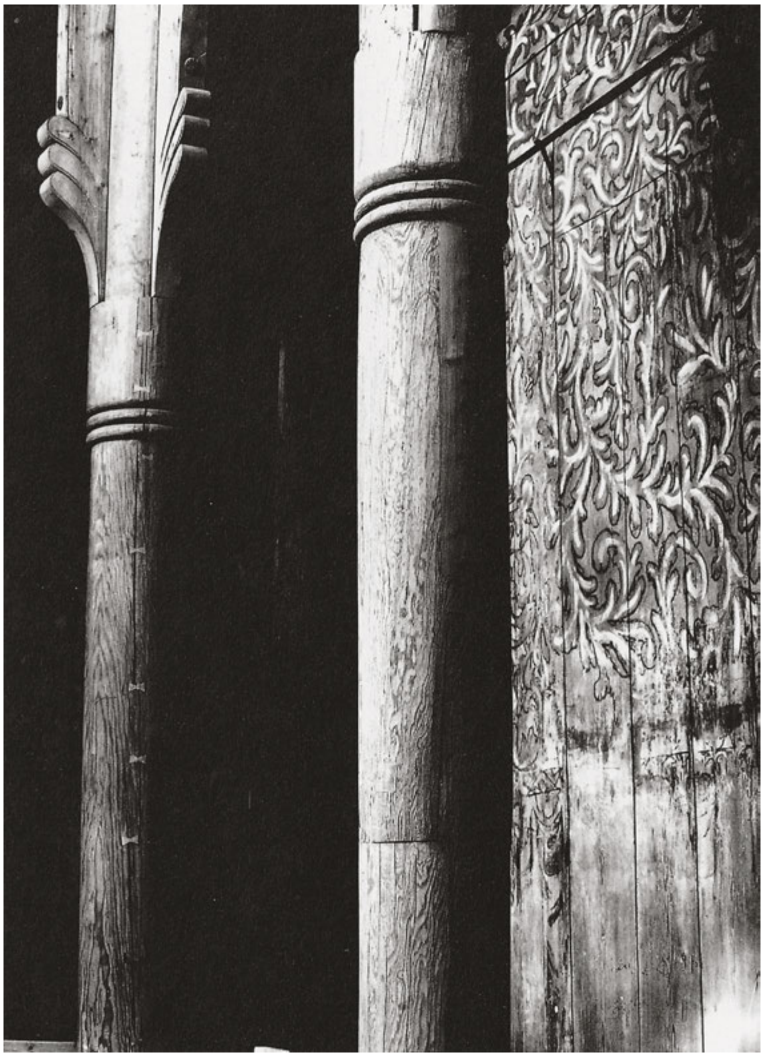
16 The thrust of the corner column of this bell tower in Malé Ozorovce, Slovakia, exacerbates the rotational movement of the twisted-fibre sill beam. As the halved-and-tabled joint prevents it from deflecting, it has to split.

whether such old examples, like the Japanese temples, might not be an occasion to reflect on the best of pre-industrial craftsmanship. (Fig. 17) Those who cut their wood themselves are fully aware of its qualities and can put this knowledge to best use in selecting planks or posts for certain tasks. Those who do not cut their own timber, but at least look at it, can gather some information about its characteristics from the pieces lying before them. However, those who rely totally on today's customary working procedures must work hard to develop a "timber" matching their ideas.

Diverse methods have been ventured in order to counter the reduction in value of the total quantity of felled timber during the drying process. One really successful method was girdling. It is said that this is how the selected pines for the stave church in Heddal, Norway, were polled when they had reached the necessary height. A small piece of bark was removed from the base of the tree. Further upward growth was thus hindered and afterwards the tree only grew very much more slowly. It became extremely hard and produced close growth rings. At the same time, the pine impregnated itself with its own resin. The tree was then felled only 20 to 30 years later; and prior to being worked it was still allowed to dry for many years.[28] (Fig. 18)

We can be relatively sure that it was not just the girdling which produced the desired success. A multitude of sayings conveying the knowledge of skilled woodworkers are evidence of how

17 On this bracket complex in the Yakushi-ji eastern pagoda, Nara, Japan, the direction of the wood is altered from block to block in order to compensate for possible twisting as far as possible.

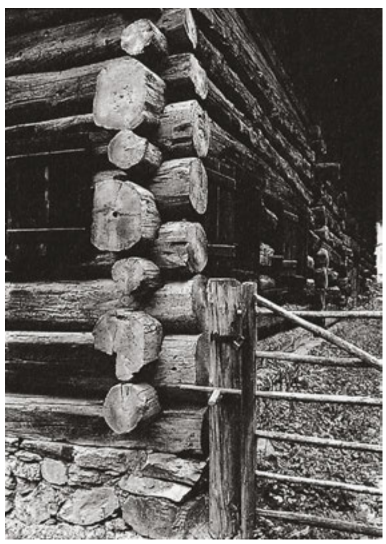


18 The new columns of the stave church in Heddal, Telemark, Norway, erected during its reconstruction in 1952, can be recognized by the up to 20-mm-wide crevices, next to which the fine cracks of the old columns remain almost invisible.

important the "right" time to fell was considered to be. The famous Schaffhausen bridge (1755–57) built by Grubenmann had to be renovated only 28 years after its completion "because timber felled at an inopportune moment" had been used.[29] In any case, in establishing the correct time to fell, economic considerations were just as important then as they are now. In earlier times no building work took place during the winter months, so workers were available for low wages. In the mountains in winter, felled trees could be relatively easily brought down into the valleys. In winter wood is more resistant to fungal attack – and timber infected by blue stain fungus would have been no easier to sell in the past than it is today. Furthermore, wood has been built in "green" for a long time and of course should not become infected by fungus in the built condition either. And finally, freshly felled timber is much easier to chop or work with an axe than dry timber.[30]

Many of the maxims which became forgotten during the industrial revolution – e. g. "Timber felled on Christmas Day will hold your house come what may!" – have been unearthed again in recent decades. A reactionary movement questioned all commercial practices which contradicted the old rules. Today, the discussion is superfluous as to whether those who swear by the old custom of felling timber in winter are right just because this was based on centuries of experience. Researchers have come to the conclusion that the differences be-

19 The different cross-sections of root end and crown end must be taken into account if you wish to remain level! – Longhouse from Murau, Steiermark, Austria, Stübing Open-air Museum.

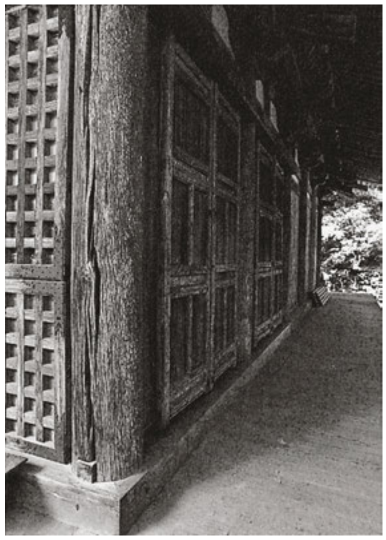


tween timber felled in summer and timber felled in winter are evened out after one year of air-dry storage.[31]
Trees grow in a pyramid shape; therefore, root end and crown end have different diameters. (Fig. 19) Once again it is the considerate Norwegians who have expressed this aspect most aesthetically. The tree "reaching for the sky" has been wonderfully imitated in the stave churches of Norway. With your head tipped right back you could almost believe you were looking up at a treetop in the forest. (Fig. 20)
Furthermore, root end and crown end exhibit different strengths.[32] In Japan there are separate names for the different possible variations for joining root end and crown end.[33] Besides the aesthetic aspect, the well-founded practical argument appears to be perfectly clear when we try to copy one or other of the highly complex joints.
There is another property which characterizes the structure of a tree; heartwood and sapwood possess very different properties due to their distinct, different functions within the tree. The variety of colouring sometimes found is a visible difference. However, others are more important for the use of wood as a building material. The main problem with sapwood is its susceptibility to fungal attack. (Fig. 21) The simplest solution would be to cut away the sapwood. However, many log buildings bear

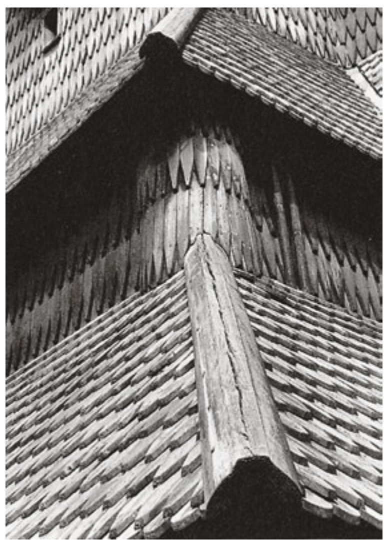
20 As they rise, the tapering of the staves or columns in Torpo, Hallingdal, Norway, is emphasized most effectively by the carved shape of a head at the top.

witness to the fact that this is not strictly necessary. Again it is the Norwegians who have found an ingenious solution to utilizing the properties of the material to best effect. The underside of the log is provided with a V-shaped groove; due to the weight of the logs placed on top, the softer sapwood of the log underneath in each case is pressed into the groove above, thereby sealing the joint. Apart from that, this method presents a very effective method of preventing the logs from rotating out of position.
The effect of the drying process on the heartwood side of the halved tree is similar to that on the north side of the whole tree (or south side and sapwood side respectively). The denser heartwood loses less volume through drying than the sapwood. As it is favoured during its growth, the wood from the southern side of a tree undergoes a more severe change to its shape after felling than the northern side. In solid wood the sapwood tends to split. (Fig. 22) The carpenter Tanaka Fumio had to replace the columns of a temple twice because they had split, although they had been air-dried for 20 years (artificial drying is not yet technically feasible for such large cross-sections).[34]
An essentially more pragmatic procedure is used in the reconstruction of the Ise-jingu, the most important Shinto shrine, which is carried out every 20 years. Here, as in many other structures built from solid wood, a groove is cut in the timbers down to the heartwood as a precautionary measure; this is done at a point not normally exposed so that cracks in exposed parts are avoided.[35]
Japan once allowed itself the luxury of fabricating the columns for temples, gateways, etc. from half-round timbers in order to minimize the risk of splitting. This raises the problem of where to obtain such enormous trees when restoration work is undertaken nowadays. And even with half-round timbers, the wood splits away from the pith on the heartwood side. (Figs 23 & 24) Only “the old masters understood how to handle the wood in such a way that even worked half-round timbers, in which the face of a cut passed through the pith, remained free from larger cracks.”[36] (Fig. 25)
Timber should be dried before it is worked. But whether timber should be dried with its bark on or off is not irrelevant. This mainly depends on the species of wood, but the differentiation goes even further. Larch wood intended for use as shingles is allowed to dry with its bark left on. For air-drying, the recommendations vary between two and three years.[37] These days, artificial drying is the norm, and it is generally accepted that only timber in which the moisture content has been reduced to a certain figure should be used for building work. This was not always the case. Right up until late Gothic times wood was worked green.[38] It is not known when it became customary to dry building timber before working it.[39]
Every farmer knew how to sensibly exploit the properties of green timber. “The fabrication of wooden hay and crop forks depends on the combination of green and dried ash wood. The sharp-edged, dried nails are driven through the round holes of the still flexible prongs of the fork; the prongs shrink during drying and pull the whole assembly together so that it can no longer be separated.”[40] It is precisely this principle that is employed in joints made with wooden nails (cf. p. 122 ff.).

21 There is not a single log on this barn in Solvorn, Sogn, Norway, which is not severely damaged.

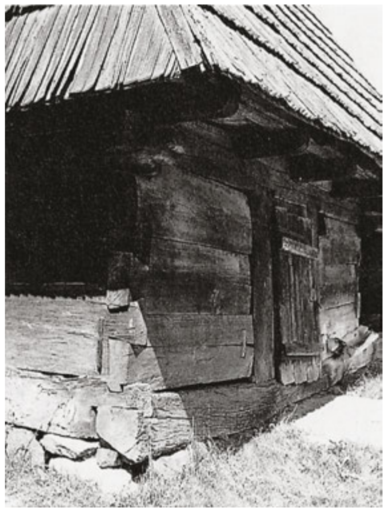


22 Due to the stress, the sapwood has had to give way in this corner column of the Muro-ji hondo at Muro mura, Nara, Japan.



23 The ridge covering on the stave church in Heddal, Telemark, Norway, will not fulfil its function for very long.

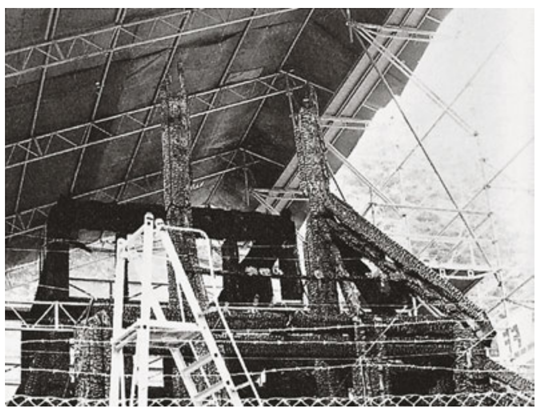
In Japan, in contrast to Europe, timber is normally stored and dried vertically (with the crown end downwards). This must be advantageous, at least until the fibre saturation point has been reached, because this method is also recommended in Europe for colour-sensitive woods, e. g. maple.
Timber is not dried so that it burns better! And despite this, mankind has painfully been forced to realize again and again that wooden buildings are combustible. Bruno Taut was advised by the Japanese to shout "Fire!" on discovering a burglar – only that would ensure getting help from others![41] In times of war, this property of wood has been exploited so consistently that hardly a conversation on timber structures passes without this "negative" characteristic surfacing. Besides the species of wood and the nature of the surface, the ratio of surface area to volume is the decisive factor for behaviour in fire. However, the oversizing of members, normal in the past, together with modern methods of fire-fighting, cannot prevent the further decimation of monuments to cultural achievements. (Fig. 26)



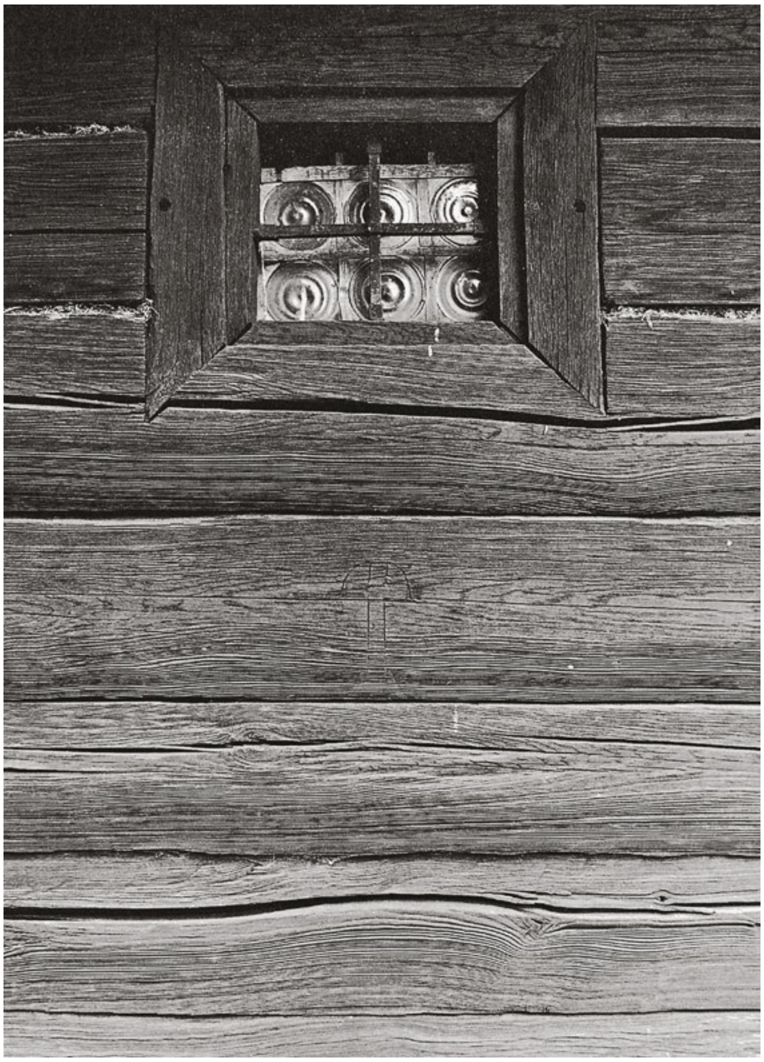
24 The butterfly spline is intended to prevent the log splitting away further from the pith. The concern of the owner was probably mainly aimed at the door post which in the end has also deformed in sympathy. – Sighetu Marmaţiei/ Maramureş, Romania.

25 Even in planks, the nature of the cracks reveals how wood dries. – Entrance area of the Zuisen-ji hondo in Inami machi, Toyama, Japan.

26 The stave church in Fantoft near Bergen, Hordaland, Norway, was destroyed by fire in 1992.



Mankind has known for thousands of years how to use the positive effects of fire on wood. Even today, posts which are to be buried are charred beforehand; likewise in Japan, wooden claddings to protect them from termite attack.
Even more pronounced is the ambivalence of wood and water. When timber is felled, its vital supply lines are destroyed. Its structure means constant loss of water from this moment onwards until equilibrium with the surrounding air humidity is attained. Linked with this is a decrease in the volume of the timber. The cell structure of the sapwood, which releases more water, undergoes a more severe change than that of the heartwood cells lying nearer the pith. The shrinkage of the timber in the radial direction is also different from that in the vertical.
In log buildings this property is particularly significant. Despite a two-year drying period, the log wall was left for at least one summer, in order to ensure that it had settled properly, before installing doors and windows.[42] (Fig. 27) However, the openings in the log wall were not the only problem. The logs settle within the wall more than at the joints, i. e. settlement

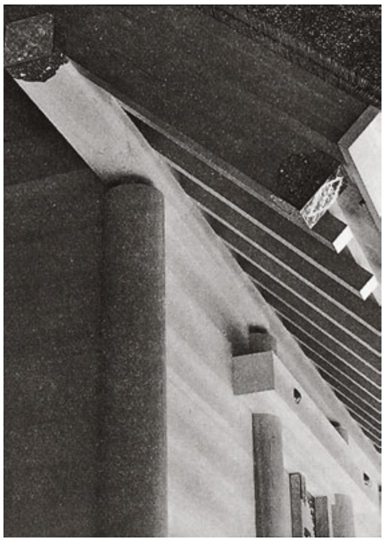


27 This window in the church in Ruská Bystrá, Slovakia, is mitred dispensing with the need for a cladding protruding from the line of the wall.

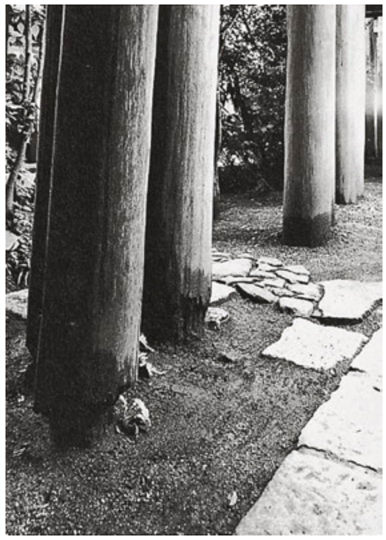
gaps must be incorporated. These weaken the assembly at the most awkward position. In Russia log cabins were built from green wood and then subjected to the drying action of the air for a certain period to allow the rings of logs to settle. The cabin was then dismantled and fitted together again, this time packing the gaps with moss.[43] Norwegian carpenters became so experienced that they were able to combine stave and log-cabin forms – an enviable achievement when the different rates of shrinkage of vertical and horizontal timbers is considered.[44]

As a result of many centuries of observation, mankind has succeeded in acquiring the knowledge of the regularity of this property. Only now was our builder in the position to install door and window frames at the same time as the wall itself. The precautions taken for this purpose can of course be extrapolated to encompass the entire building. (Fig. 28) The central column of many Japanese pagodas does not rest on the ground but instead is carried by the surrounding construction.[45] In his reconstruction of the second pagoda of the Yakushi-ji, Nishioka Tsunekazu resorted to the older system in which the central column is in contact with the ground. In order to prevent the column from damaging the supporting structure as it slowly settles over the years, the master carpenter had to calculate very accurately how high the column had to be wedged up during its erection.[46]

28 Directly after the erection of this building from the Ise-jingu complex, Mie, Japan, the settlement gap for the head beam can still be clearly seen. The perfectly sealed walls will settle over the years, taking the header beam with them.

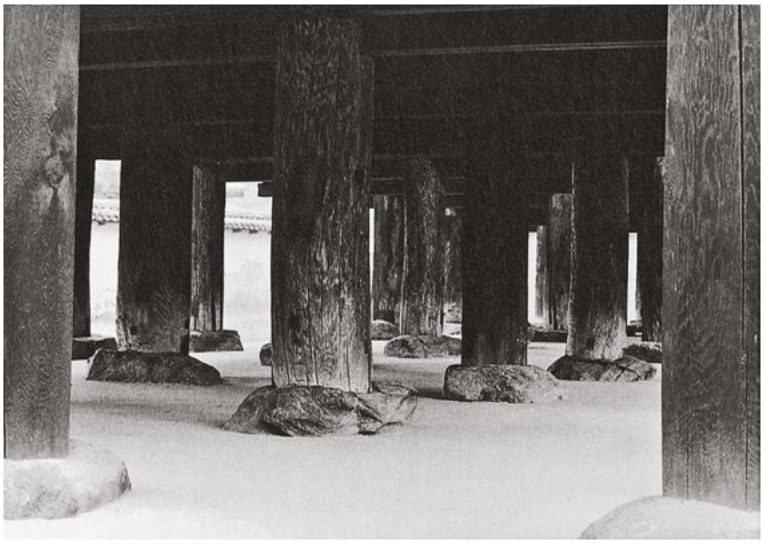


Wood does not just release water into its surroundings, it absorbs moisture from the atmosphere too. The climate fluctuations in Japan mean that the Japanese are far more acutely aware of this fact than the Europeans. For a long time it has been believed that the reason why the treasures in the Shoso-in (Todai-ji, Nara) have remained intact to this day is because of their storage in a log building erected in the 8th century, particularly as measurements of the atmospheric humidity inside the building have revealed that it remains practically constant throughout the whole year.[47]
This property of wood presents the woodworker with enormous problems which must be considered in advance. On the other hand, it is precisely this property which leads the architect Seike Kiyoshi to favour wood above all other materials.[48] Many other Japanese architects live in timber houses even though they do not use wood in any of their designs. Even Jules Fletcher, England's ambassador to Russia in the second half of the 17th century, came to the conclusion that wooden buildings were far more appropriate for the Russians than those made from stone or brick because inside it was much warmer and drier.[49]
Humidity, splashing water and driving rain can destroy wood under certain conditions. If wood becomes wet, then it must be ensured that it can dry out again as rapidly as possible, like after felling. Only in water, or rather under exclusion of air, are many species of wood immune to attack by fungi and insects. In 1877 in Austria, the corner of a log construction from the 6th century BC was uncovered by a landslide; it revealed just how durable timber is under ideal conditions. In rafting, which greatly eases the transportation of large quantities of timber, this fact has been put to good use.
Buried timbers or those erected directly on the ground are obviously at the mercy of decay. (Fig. 29) Nevertheless, the posts of the Ise-jingu were buried again after its reconstruction, probably to emphasize the nurturing of tradition. The soil excavated to form the holes for the posts was mixed with gypsum, this mixture being subsequently used to ram down the posts. (Fig. 30) Although it might seem unconventional to use, of all things, gypsum, which attracts water,[50] there are other interesting, not easily understood examples of timber protection which must be the outcome of many years of experience. In Romania timbers were laid across oak sill beams. Weaker boards were then laid over these and perpendicular to them. To prevent these boards from rotting, the space in between was packed with lichen and sand – not left empty, for example, in order to let air circulate.[51]
A solution to the problem was achieved by erecting the columns on padstones. (Fig. 31) In the case of huge columns with sometimes incredible diameters the problem was complicated by the fact that the base of the column had to be very carefully matched to the stone underneath if the long-familiar stability was to be maintained. (Fig. 32) As dressed stones became more common for these foundations, builders at the same time had to ensure that the column base was well ventilated, for water collected on the flat stone and was then absorbed by the end grain of the column.[52] (Fig. 33)
At most risk is end grain, every face of a cut revealed when a piece of wood is divided perpendicular to the direction of growth.

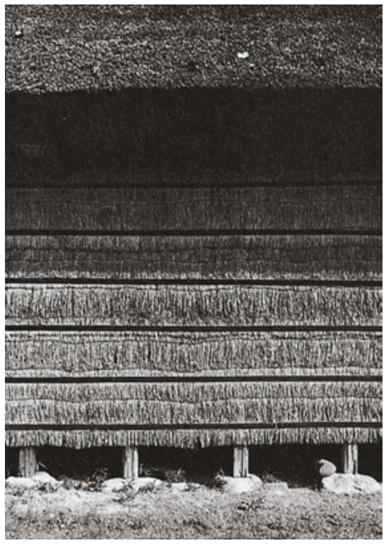


29 Wood suffers most damage at the air-ground transition, as shown by these *torii* in the Zeniarai benten in Kamakura, Kanagawa, Japan.

30 The columns of the Ise-jingu are somewhat protected from the moisture of the soil by means of copper sheathing.



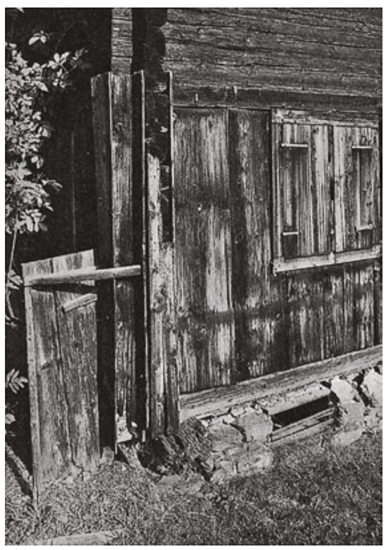
32 The forest of columns under the Horyu-ji daihozoden, Nara, Japan.



31 Every single column of this *Kabuki* stage from Sodoshima, Kagawa, Japan, is placed on a padstone. – Shikoku minzoku haku butsukan Open-air Museum

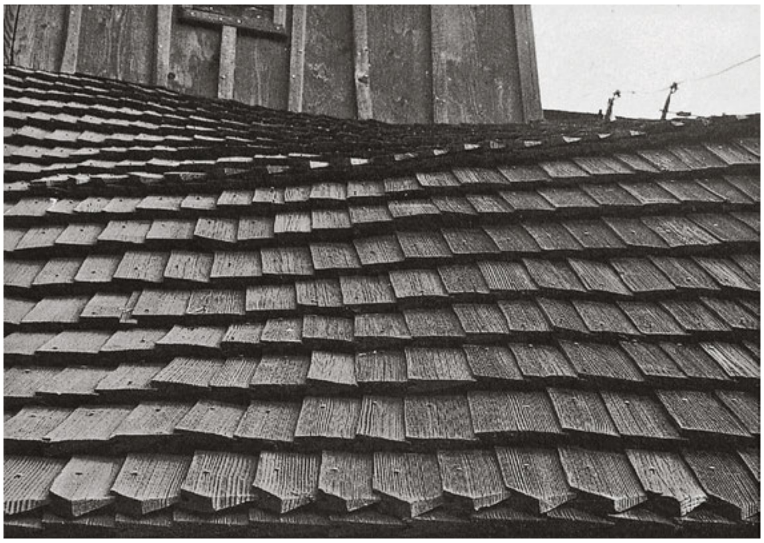
33 The bases of the columns of the To-ji kodo, Kyoto, Japan, all have ventilation slots.

34 The rafters of this barn in Galgenuel, Vorarlberg, Austria, demonstrate quite clearly wood's weakest point.



35 The projecting ends of logs were often cladded for protection. – Farmhouse in Gaschurn, Vorarlberg, Austria.

36 On the To-ji kondo, Kyoto, Japan, the sill, rail and header are all covered in such a way that no end grain remains exposed to the weather.



37 Left: The cleft shingles laid at a relatively flat pitch on the roof of the church in Inovce, Slovakia, will probably last considerably longer than the sawn vertical planks.

38 Above: The pieces of timber which succumb most rapidly are those in which the cell structure runs least parallel to the face of the cut and have been sawn without mercy. – Town house in Hagi, Yamaguchi, Japan.

(Fig. 34) All sorts of ideas have been tried out to protect the wood. (Fig. 35) In Japan they set about eliminating such end grain from risk zones (i. e. exposed areas). (Fig. 36)
Even if the ventilation functions, it must be accepted that those cells of the wood which have been cut open will absorb water like a sponge. Whenever a length of timber has to be cut there is no avoiding it. Working along the fibres exposes the conflict between economic pressures and woodworking ideals. The plain fact is that a saw rips open the cells of the wood and thus prevents water from draining via the shortest route as in wood which has been chopped. (Fig. 37) If we use sawn wood, then we should check it even more thoroughly. The saw disregards the direction of the fibres and so exposes end-grained wood to water where we least expect it (Fig. 38) Timber worked with hatchet or axe, likewise hand-planed, cannot be equated with machine-planed timber. Although wood worked by hand will only in exceptional cases convey the impression of having a smoother surface, it actually leaves the cells intact. Nishioka had all the timbers for the Yakushi-ji finish-planed by hand where the final surface was important. In the snow-covered, mountainous areas of north-eastern Austria closures, so-called "Schließen" (wall plates) as supporting timbers for *Dippelbäume*[53] were still hewn in the 20th century because they were stronger and more durable than sawn versions. The difference between the surface characteristics of sawn and hewn timbers really can be felt.
A multitude of solutions have been tried out to promote the real need to allow timber to dry out quickly in buildings. They begin with detail solutions, such as very simple covering boards (Fig. 39), and can lead to quite complicated solutions like the drainage holes in the sill beams of Norwegian stave churches (Fig. 40), or to useful ones like the drainage channels in the window sills of Silesian *Umgebindehäuser*.[54] The grooves in Japanese storm doors *(amado)* also required a means of draining off water. In Russia the roofing boards were placed in the gutter which was drained at its lowest point by means of a hole.[55] Numerous methods were employed which, to us today, seem unreasonable. At least in the past the long lifetime only achieved through careful working practices justified the use of complicated procedures. (Figs 41 & 42)

39 Covering boards protect the projecting ends of the tie beams of the column-and-beam construction of the Kiyomizu-dera in Kyoto, Japan.

40 Drainage holes can be clearly seen in the sill of the *svalgang* around the stave church in Urnes, Sogn, Norway.

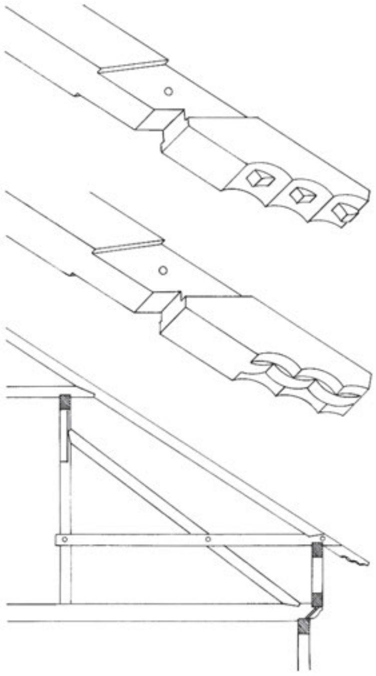
41 Miniature roofs protect the sill and all horizontal rails of the church in Hronsek, Slovakia.

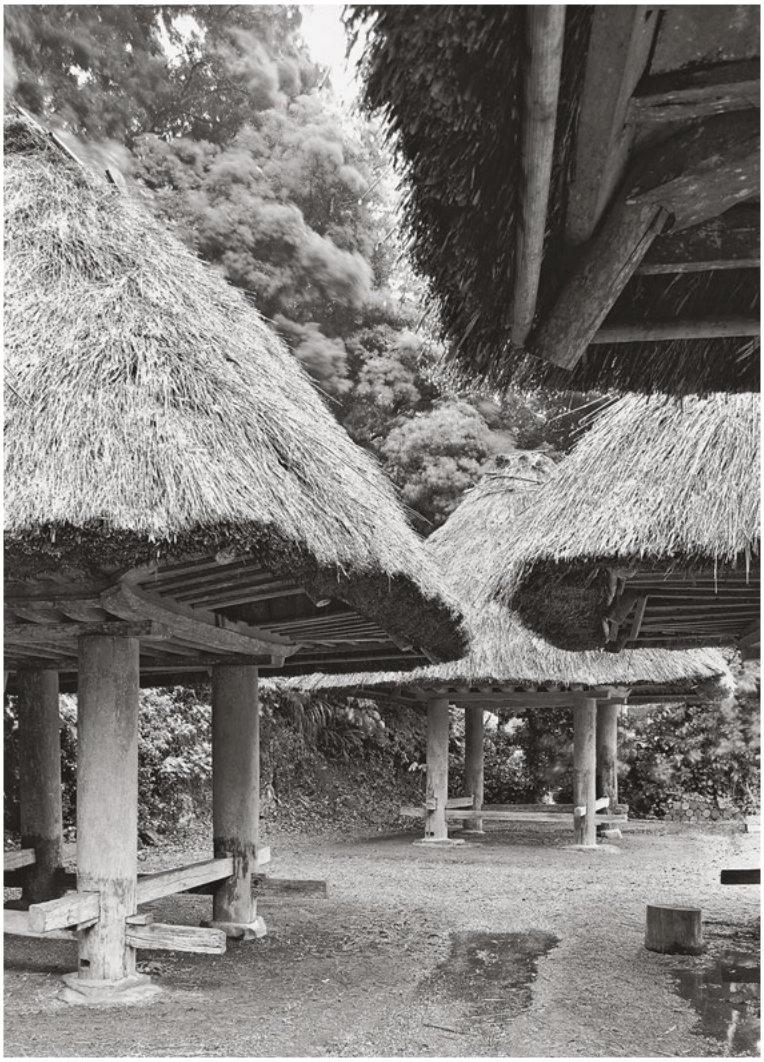
Shapes which are often only regarded as ornamental or a feature of the style were introduced, at least historically, for no other reason than to drain off rainwater.[56] (Fig. 43) Many times we come across shapes which are both useful and discreet. Roofs featuring large overhanging eaves (Fig. 44) or roofs reaching far down the building, supplementary canopies above windows (Fig. 45), verandas and porches are obvious precautionary measures. With their diverse forms, roofs as protection from the elements have contributed not inconsiderably to the appearance of buildings. The object of the Russian *poval*, a roof construction formally continuing and closing the log cabin towards the top, was to discharge rainwater as far as possible from the wall of the building.[57]
Mankind was for a long time unable to do without the help of the as yet unbroken natural resistance of the tree. As protection from the weather it was often planted in front of the wall which was most severly subjected to wind and weather.
In the form of wall and roof claddings, wood itself takes on the protective function. (Fig. 46) Used vertically, corresponding to the material, (Fig. 47) or horizontally for aesthetic reasons (Fig. 48), this sheathing often conceals the construction behind. As walls were given planks and roofs shingles, so the opposite was also done, i. e. walls given shingles and planks laid on roofs, (Fig. 49) primarily according to local traditions. Shingles were also eminently suitable for enclosing every conceivable shape. (Figs 50 & 51) However, the shingles on onion towers needed a

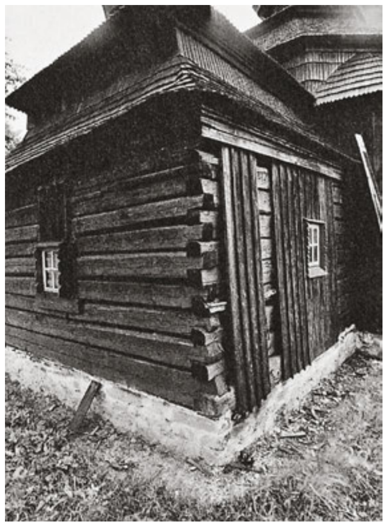
42 The wall of the church in Bogdan Vodă, Maramureş, Romania, is so high that a monopitch roof has been incorporated halfway up to protect against driving rain.

43 Rainwater drips on the ends of rafters (source: Opderbecke, 1909, Fig. 269)

44 Only the wide overhanging roofs protect the post-and-beam construction of the takakura and the produce stored within from the raging typhoons of the East China Sea. – Amami Oshima/Okinawa, Japan.

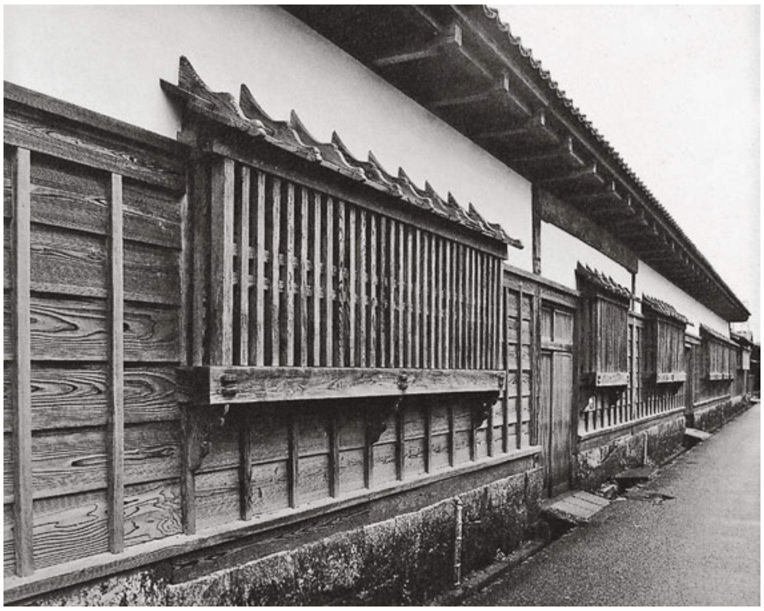




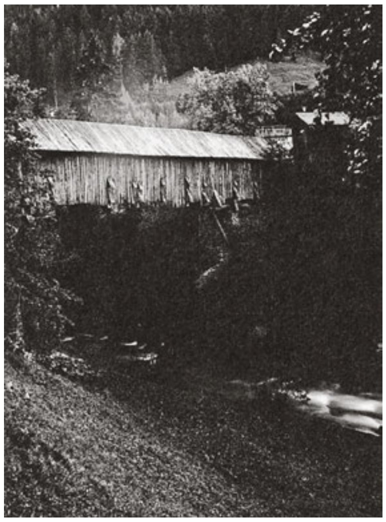


47 Like so many log churches, this one in Ladomirová, Slovakia, is clad with vertical planks.

45 Protective cladding for wall and openings in Hundwil, Appenzell, Switzerland.



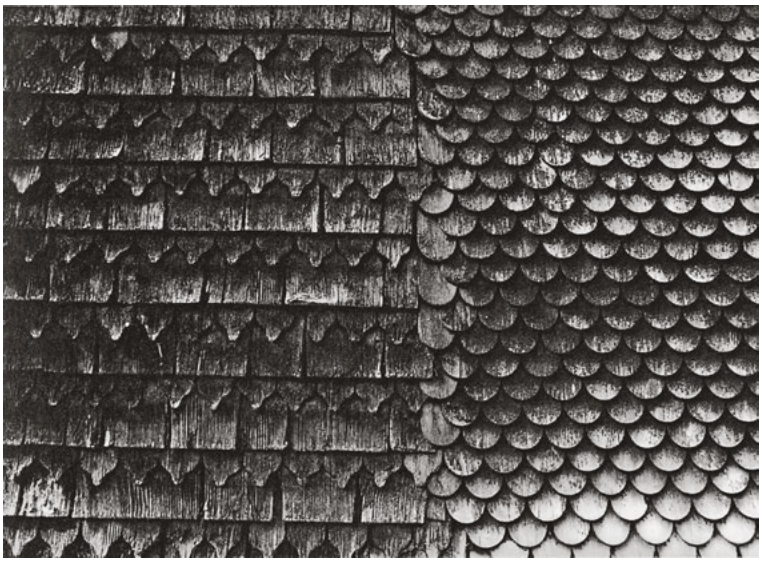
48 Wall cladding in Hagi, Yamaguchi, Japan.



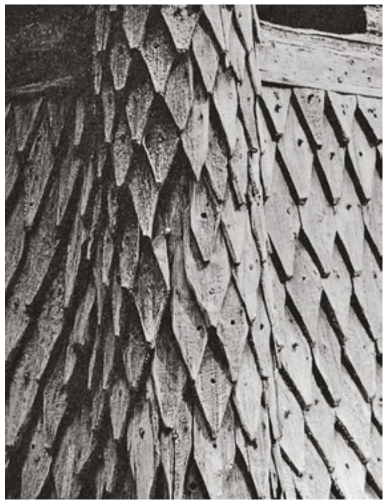
46 On this wooden bridge in Strengen, Tyrol, Austria, the whole of the side facing the prevailing wind is covered with planks.

50 Shingles on a roof hip in Potoky, Slovakia.

49 Such frivolous and decorative shingling as was carried out in the past is no longer fashionable today. Detail of partly renewed wall cladding in Schwende, Vorarlberg, Austria.



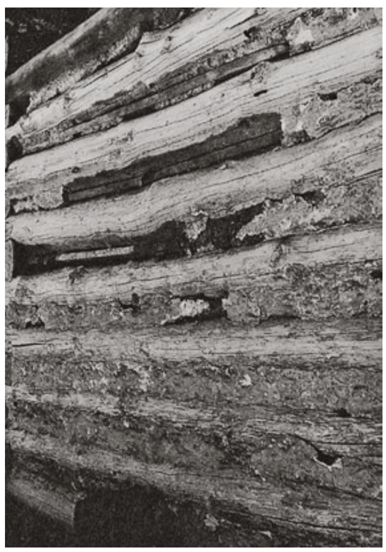
little help: curved shingles were produced in order to create a dense, enclosing envelope.[58]
Substantial claddings attached in front of the structure to be protected can take on a more architectural than a protective role. (Fig. 52)
Wood's susceptibility to moisture demonstrates the importance of adequate ventilation. However, for most people, timbers "laid dry" are too inhospitable for living spaces. Utility buildings represented the main applications. (Fig. 53) The advantage for the structure itself was coupled with the chance of finally drying the hay stored within, for instance. Another bonus was the lower weight. Even the woodwork in sacred buildings was built with ventilation in mind. This is why Russian summer churches were more generously fitted out, while the winter or warm churches, with their sealed gaps, (Fig. 54) had to pay the price of the long Russian winter that much more quickly.[59] In Switzerland there were storehouses with two doors, one behind the other: the outer, air-permeable, summer door and the solid inner door.[60]
In Japan the need for ventilation plays such an important role that it has become a foregone conclusion. Only a stranger notices that all structures are raised clear of the ground. (Fig. 55)
The fact that many people today have no connection with the materials of their houses is not a new phenomenon. (Fig. 56)
In the Baroque period it was usual to plaster over the façades of timber-framed buildings – their owners did not want to lag behind the stone buildings of the Church and the aristocracy.[61]



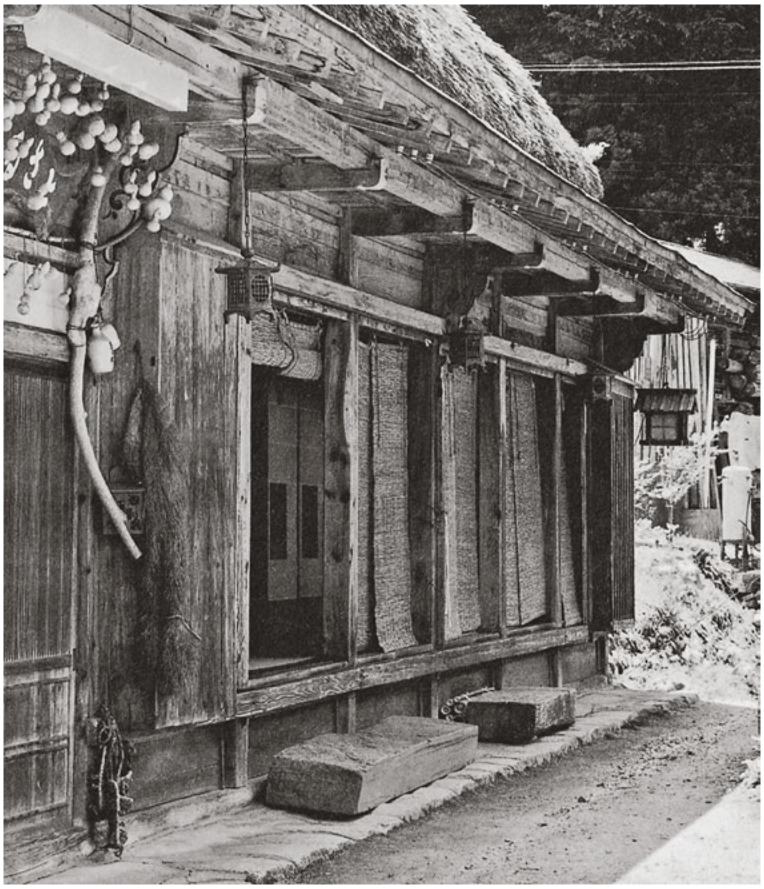
51 The columns of the *svalgang* around the stave church in Eidsborg, Telemark, Norway, are also clad with shingles.

52 A timber wall protects the daub shell of the storehouse of the Chiba House in Iwate Futsukamachi, Iwate, Japan.

53 "Airy" timberwork on a barn in Köfels, Tyrol, Austria.

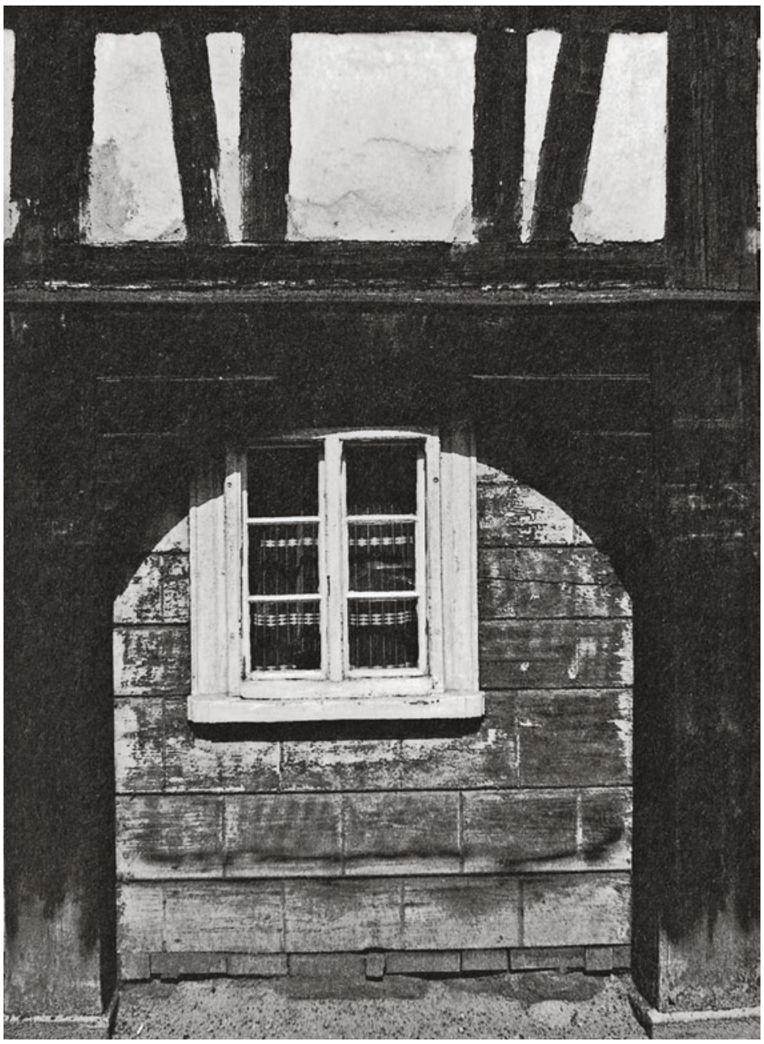


54 The variously filled gaps between the logs were subsequently coated with daub. – Log building in Šumiak, Slovakia.



56 An *Umgebindehaus* in Obercunnersdorf, Saxony, Germany, renovated at low cost with YTONG® (lightweight mineral) blocks.

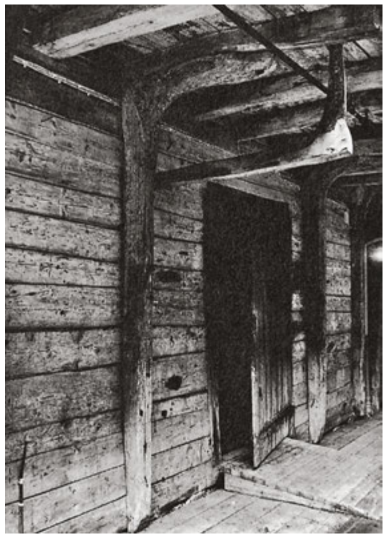
55 A *minka* in Shirakawa mura, Gifu, Japan.



58 Vertical grooves in the logs of this *Umgebinde* in Hirschfelde, Saxony, Germany, are intended to imitate squared stone masonry.

57 This plastered false wall concealing the timber-framed wall in Berga, Thuringia, Germany, allows water to collect exactly where the ends of the beams of the jettied upper floor are supported.

Many examples are still visible today. (Fig. 57) Often, less damage was done to timber structures when, owing to lack of funds, cheap versions had to fulfil the desire to match more wealthy specimens. (Fig. 58)
Quite understandably there are hardly any confirmed figures concerning the durability of timber buildings. (Fig. 59) To the many properties of timber already mentioned, which, added together, determine how long a building shall survive, we must also add the arbitrariness of humans. As users it is mainly up to us whether to apply means of preservation or not, to live with wood or to fight against it.
We know today that attack by pests, whether of the animal or the plant variety, is not possible provided there is no basis for their existence.[62] Many species of wood are protected by their own constituents. Many of these are known to us but some remain to be discovered.[63] Why have termites destroyed virtually all older timber structures in the South Pacific but not in Japan?[64]
It is an irony of fate that among the wooden structures of Buddhism, in which the transitoriness of all things is a major theme, the largest (Todai-ji) and the oldest (Horyu-ji, 7th century) are still in existence. Lord Bacon said that by obeying nature we overcome her. Only the old Japanese really overcame her. After every death they built a new house. In accepting the transitoriness of their mortality they were now ready to accept the transitoriness of their building material. They could find no adequate reason to erect a stable home.[65]



59 Root and branch beginnings like on these columns in Bryggen in Bergen, Hordaland, Norway, contribute considerably to their durability and perhaps also to their aesthetic appeal.

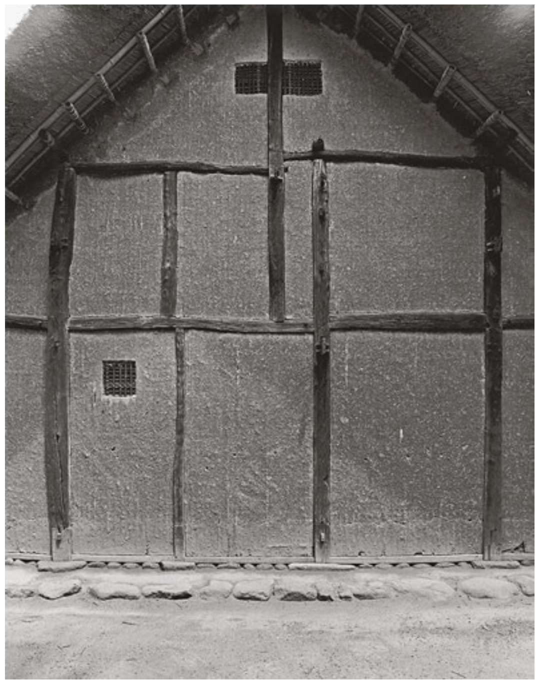
SPECIES OF WOOD

Many types of timber have their own peculiar odour. Oak smells acidic, fir quite unpleasant. Only very few of these odours can be expressed in words, not to mention the fact that the feelings they trigger are perceived subjectively. However, the interesting distinguishing criteria in this context are two others: firstly, their different appearances, and secondly, their suitability for particular purposes. "Trees which are preferred for building … nevertheless possess very divergent, disparate properties; for the oak is not suitable for the same uses as the fir, the cypress not for those of the elm … Every one of them is different from the rest because they are made up of certain components; therefore, due to their individual, unique qualities, some are suitable for one sort of use, others preferred for different applications."[66]
The suitability of a particular species of wood in turn depends on its ease of working,[67] its structure, its durability, its availability and its stability, i. e. its resistance to deformation with regard to the effects of the weather. The Romans once remarked when erecting their fortifications how essential it was to remain flexible with respect to the use of established materials. However, they in no way wished to alter the designs and methods of construction. In England they soon had to make do without oak, which was in short supply, in favour of pine and the not particularly durable alder.[68]
The species of wood available may be the primary criteria for selection.[69] Better knowledge of the properties of special types of timber increasingly steers the choice towards specific var-

ieties of them. And the joints between timbers must take into account the type of wood and the method of construction. Using hardwood in lieu of softwood enables other joints to be incorporated. The sometimes unbelievably slender timbers which were worked in the Shoin and Sukiya style[70], and used for building in the Edo period (1603–1868) for aesthetic reasons, which sometimes even leave the trained eye puzzling to explain the construction, necessitate other types of joints than metre-thick sill beams. Short, crooked timbers (Fig. 60) compel a different assembly and hence other jointing techniques than do long straight pieces. (Fig. 61)

Generally, softwoods, hardwoods and tropical woods are distinguished according to their structure. In Europe it was almost exclusively the first two groups which were used, whereas in Japan both indigenous species as well as the third group have been used for a long time. Under "favourable" growing conditions the long-fibred conifers supply long, straight, sometimes resinous wood which on average exhibits a lower strength than deciduous wood. Put very simply, tropical wood can be distinguished from the other two types by the lack of visible growth zones, which appear as annual rings in the others.

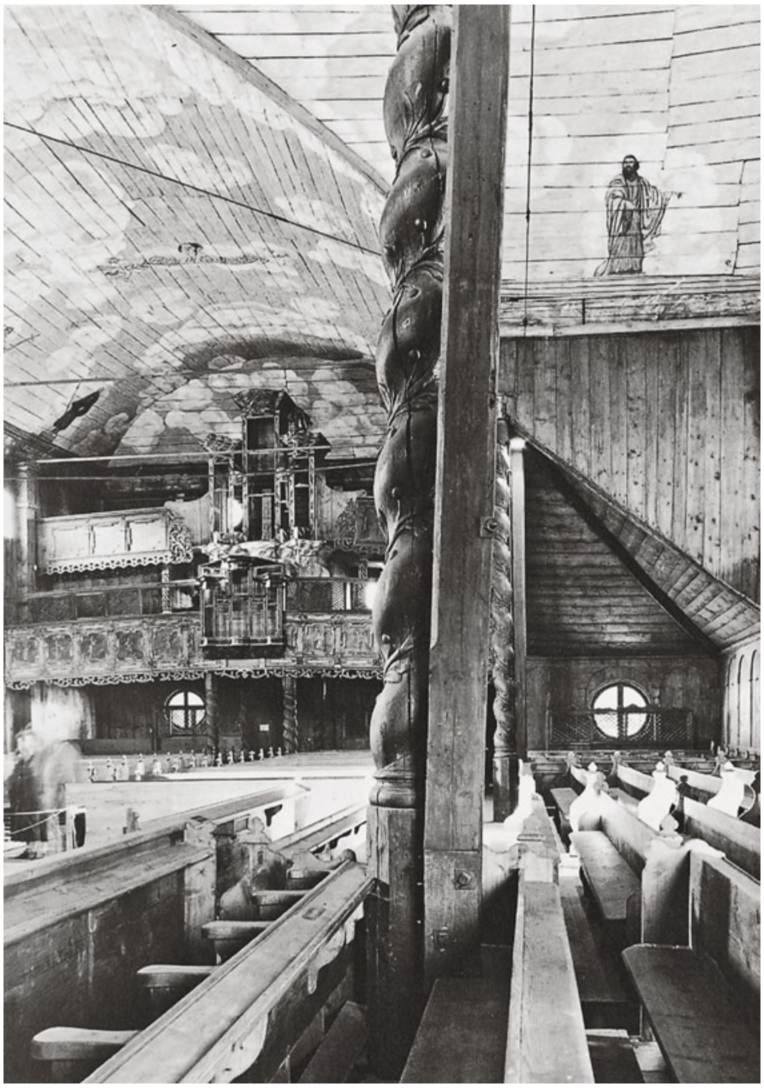
Concerning conifers it should first be mentioned that the modern custom of equating the wood of the fir and the spruce[71] is not an old one. However, their equal bending strengths has already ensured their mixed use in timber-frame construction. It is for this reason that they were preferred to the oak – stronger in tension and compression – and also the pine, which due to its resin content was more "weatherproof" but comparatively brittle.[72]



60 It seems that every piece of wood was welcome when the Hirose family house was built. Nihon minka en open air museum in Kawasaki shi, Japan.

61 In 1199 as Todai-ji nandaimon, Nara, Japan, was rebuilt after its destruction by a typhoon, there was still sufficient timber available for selecting the almost 20-m-high columns.

So, although equal in terms of building physics, the appearance, smell and resin content of fir and spruce, and above all their possible lifespans, distinguishes them significantly. The fir lives for over 400 years, the spruce barely 120.[73] The durability of fir wood should match the comparatively long lifespan of the tree itself.[74] It cannot be just coincidence (and also no mistake) that Grubenmann's invoice for the bridge in Wettingen, Switzerland, only refers to oak and fir.[75] The Romanians too were convinced of its qualities. It was used in the north of the country for all building projects, which also meant its use as the exclusive timber for churches, a particularly Romanian feature, "because in Romania, churches, on the whole, harmonize with the type of housing of the region concerned." Fir was favoured for sill members in the whole of Romania,[76] but in the region between Sibiu and Braşov it was the spruce.[77] In Finland the branches of the fir were used as wooden nails.[78] Fir was only second choice in Russia and Poland.[79] In England on the other hand, the Riga, Memel and Danzig firs were very highly esteemed, having been imported as early as the 13th century.[80] To only be regarded as second best was the fate of the spruce.[81]
Pine and larch are the two other types of coniferous trees widely found in Europe. The pine *(matsu)*, also indigenous to Japan, was also always regarded as second choice.[82] However, it is still used extensively today for roof trusses.[83] No matter how short and crooked the trees are, they can still be incorporated. A Japanese carpenter working on a *minka* (house for ordinary people) would certainly regard it as a challenge if conditions were made more difficult because of the material. "The beamwork [of the roof] became the part of the house where the carpenter could best show his prowess."[84]
Although pine tends to twist and, like the larch, still warps severely after decades, it had its fans in the North. The Norwegians used it for all loadbearing members and stave walls.[85] In Sweden, where it was generally used green,[86] and in Finland and in Lapland it had been the most important building timber,[87] besides birch, since the Stone Age.[88] Nearer the Baltic Sea and North Sea, pine was the only adequate timber as oak stocks became depleted.[89] In Poland it was so valuable that it was only used for sills.[90] And in Russia its heartwood was employed on an equal footing with spruce and larch.[91]
In Karelia unsquared pine trunks were the usual material for log construction.[92] Nevertheless, the expert Klöckner insists: "The most suitable wood for log construction" is the larch.[93] Examples of this can be seen in southern Poland[94] as well as in many Slovakian churches and the houses in Goms or in Val d'Herens, Switzerland. Today, we judge larch according to its machineability: indeed highly resistant but cross-grained and frequently exhibiting sickle-shaped growth.[95]
In keeping with its low occurrence in volume terms, juniper was only used for wooden nails and dowels.[6] The yew was quite simply too rare in order to be utilized in a way which corresponded with its properties. A special case is the church in Hervatov, Slovakia, the majority of which is made from yew; in Tročany and Kežmarok, Slovakia, this is only true for parts of the churches.[97]
Just how important it is to select the right timber is shown by one convincing example. The larch columns of the church in

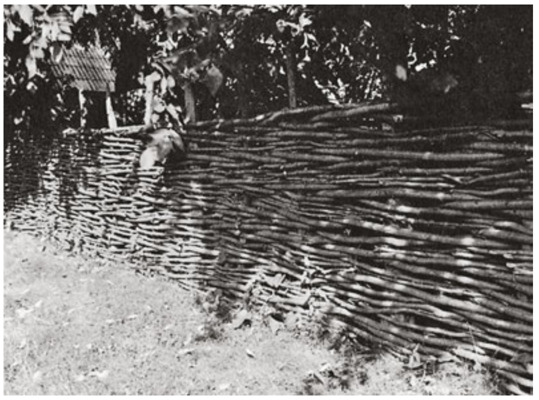


62 **The supplementary supports added to relieve the old, carved columns in the church at Kežmarok, Slovakia, have already had to be refurbished again in the meantime.**

Kežmarok were in such need of repair 100 years ago that it was decided not to remove them but instead to supplement them with ones made from pine. In the meantime, the relieving columns, severely impaired through fungal attack, had transferred their function back to the original larch columns, which were still fulfilling their task, until the damaged parts were replaced. We may assume that the lack of care shown in the selection, drying and possibly also in the installation too contributed to the rapid decay of an otherwise well-tried-and-tested wood. (Fig. 62)

Fir and spruce are not indigenous to Japan. Instead, it has many varieties of pine as well as larch *(aka matsu)*, *sugi* and *hinoki*, cedar and cypress. Its conspicuous texture has made cedar very popular for interior works. It is comparatively soft and, like cypress, easy to work. This characteristic clearly distinguishes it from the conifers we use. This was a primary condition for the fact that coniferous wood was able to take on such a superior role in Japan's building industry. Even today, the beautiful colour and the timber connections so wonderfully matched to the properties of the wood secure first place for the cypress on the popularity scale. Its level of natural resistance is so high that even Japan's current building regulations do not require cypress wood to be impregnated.[98] The high prices which cypress commands have only served to increase its esteem.

Vitruv was aware of the outstanding properties of cedar and cypress, in particular their natural resistances, and wrote about them.[99] The wood of the cypress was still highly prized in later times – popes were buried in coffins made from cypress.[100]
The reconstruction of the shrine complex of Ise-jingu every 20 years is only possible because the enormous quantities of cypress wood required can be met by the shrine's private forest. Master carpenter Nishioka lists six species of cypress: three American, one less important Japanese, the Taiwanese, which he used to reconstruct the Yakushi-ji, and *ma-ki*, the "true wood", which is absolutely unique.[101] In Japan this wood was so coveted that its use in the Edo period was reserved by decree exclusively for prescribed applications by the highest representatives of the Samurai class.
In Europe deciduous wood became at least as important as coniferous. During the long period in which mankind was not forced to inhabit permanent accommodation, people had the opportunity to gather impressions and experiences about the suitability of the various species of wood available. At first, mankind used what was near to hand. Archaeological findings report a variegated mix of many different types of building timbers next to each other, trees and shrubs of all kinds. A discovery from the Neolithic Age records 13 different types of timber used in building one collection of huts! The most common species were willow, alder and hazelnut.[102] Owing to their flexibility they were the most suitable types for wattlework. (Fig. 63) This way of joining wood was already very familiar to the people of the Neolithic Age; we are able to tell that they selected their materials very specifically. It is interesting to make a comparison at this stage. At the Japanese archaeological site at Toro near Shizuoka the discoveries indicate that over 90 % of the wood used was cedar.[103] In terms of history, this site corresponds roughly to the European Iron Age.
It could not have taken very long before oak was discovered to be the ideal timber for building. Its outstanding properties have been sufficiently proved through the ubiquitous use of its wood. (Fig. 64) Even in places where it was never available in sufficient quantities, builders have always tried to use it for those parts subjected to the greatest stresses, e. g. sills, corners of buildings, structural members.
According to some sources the elm was more highly valued than the oak,[104] but a use corresponding to its qualities is out of the question; it is too rare and does not grow tall enough. One prominent example of its use is for parts of the stave church in Urnes, Norway.[105]
A similar importance must be attached to the sweet chestnut, which in Great Britain replaced the oak following its clearance,[106] but which also found favour in France, Italy and Spain.[107] Even today, all wooden parts of buildings on Mount Athos in Greece are made from this wood. In Japan too, the kuri wood was highly prized.
The view taken of deciduous timbers in Japan was very different from that in Europe. Although in Japan the special properties of a particular timber were important for its selection, the texture has played and still does play a far more significant role in the selection procedure than is the case in Europe. However, this



63 Wattle fencing in Sat Şugatag, Maramureş, Romania.

64 In regions where oak was used for log buildings requiring really solid walls, very dense, old oak or mixed oak woods needed to be available, for instance, in Topola, Slovakia, in the Carpathian Mountains.

approach considering the beauty of the material for its own sake is not unknown to Europeans, e. g. the interior panelling in the region around Lake Constance (Germany) or in Carinthia (Austria), especially in arolla pine. In many places in Europe wood is painted or carved (Fig. 65) for the purpose of ornamentation, and only then does the structure stand out aesthetically from the mass of insignificant buildings. Keyaki *(Zelkova serrata)*, Japan's most frequently used hardwood, is popular not only because of its properties, which are similar to oak, but above all because of its "wild" grain. This wood is employed for all exposed construction elements and for interior works. In the Nikko Tosho-gu, an exceedingly opulently decorated shrine, keyaki is the only native wood alongside seven imported tropical varieties. Now and then, keyaki columns can remind the observer of marble pillars (Fig. 66), door panels of the best examples of European cabinetmaking.

Bamboo, the use of which is unknown in Europe, characterized above all the architecture of Kyushus, the most southerly island of the Japanese archipelago,[108] but was ranked equal with wood everywhere in Japan. (Fig. 67) Bamboo is unrivalled as a material expressing a building at one with nature, its curved form being difficult to conceal. (Fig. 68) Owing to its uniqueness, it plays a very special role in the tea-house style.[109] Bamboo is used today, as in former times, in conjunction with the very ancient jointing technique of tying the members together. A wattle of split bamboo sticks laid in a criss-cross pattern can be used to fill the spaces between structural and bracing members. (Fig. 69) Applying daub to both sides creates the lightest possible skeleton for a wall.

When we speak of species of wood and the importance of choosing the right ones, we should not forget to mention shingles. If they are to fulfil their function, they must be made properly[110] and, even though they may appear unremarkable, should not be produced from waste timber.[111] The best is just about good enough! This is proved by the case of stubborn farmers in the Carpathian Mountains of Romania who made their shingles from spruce, which was urgently required by the aircraft industry at the beginning of World War 2[112] The unique quality of this wood was highly regarded in many European countries as a resonant spruce in the making of instruments. Especially dense, low in resin, even-growing and almost without branches, at that time it came from practically untouched ancient forests. When one considers how much wood is required to cover a roof, it becomes clear why so many different types of wood have been used for shingles: fir and spruce, larch, oak, sweet chestnut. "In order to achieve tight joints when laying, the shingles are best laid in rows next to each other in the same order as they were cut. They thus nestle against each other in a most natural manner despite the roughness which is always a feature of chopped wood."[113] In Scandinavia and Russia birch and poplar were also used to a significant degree for making shingles – two species whose properties do not normally include resistance to the weather![114]

Faced with the pressures of local availability, people were forced to really investigate the properties of each of the species of wood they found. Indeed, in examining the different types, astonishing facts were discovered, like the incredible swelling

65 Richly carved and painted brackets and sill beams characterize the appearance of those timber-framed buildings in Brunswick, Lower Saxony, Germany, which have survived intact.

66 The column and floorboards of the Zuisen-ji in Inami machi, Toyama, Japan, illustrate the impressive grain of keyaki wood.

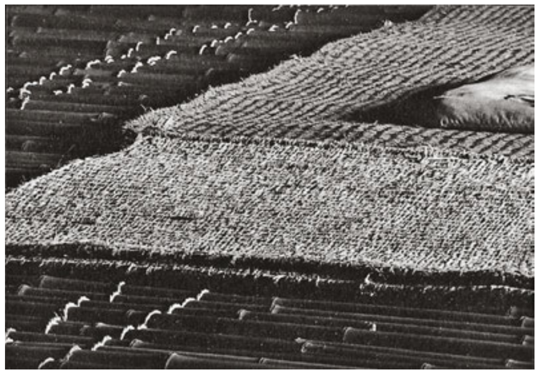
67 Pyramid-type roof over the circular plan of an oil-press house from Sakaide shi, Kagawa, Japan. – Shikoku minzoku hakubutsukan Open-air Museum

70 Cypress bark cladding on the wall of the Tomatsu House from Nagoya, Aichi, Japan, in the Meiji mura.

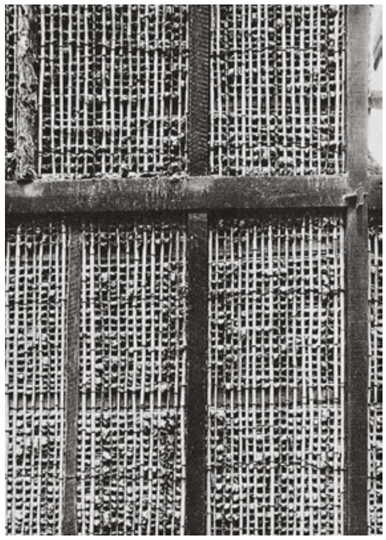
capacity of the wood of the paulownia[115] or the imperviousness of cypress and birch bark. (Figs 70 & 71) In summer bark from the larch was satisfactory, (Fig. 72) but in winter it had to be from the birch.[116]

The fundamental difference between Europe and Japan with respect to species of wood is that the Europeans as a rule restricted themselves to just a few different types, arguing that different timbers shrink at different rates. Japanese carpenters on the other hand seem to know of no restrictions in this respect. One reason for this might be that the construction and the interior works of a building in Japan are entrusted to one person to a far greater extent. If the aesthetic feeling for the texture of wood is highly developed, it is not surprising that craftsmen transfer the materials from the interior to the exterior, provided this is sensible and feasible.

Another reason might be found in the tradition of timber construction which lasted until the end of World War 2. Nishioka explains that different forces act on every structure, forces which can be held in equilibrium with the help of various trees according to an ideal image. A mountain to the north, a river to the east, a pond or lake to the south, and a straight road to the west – the Horyu-ji (the oldest timber structure in existence) is fenced in by these ideal surroundings, and it is still standing. Deficiencies in the site could be compensated for by planting special trees: willows should compensate for the river, plum trees for the road … [117] Such thinking was no stranger to western European cultures: it was no coincidence that the useful elder stood adjacent every farmhouse. And the restriction to one or two species of wood throughout the entire European timber construction industry does not hold true everywhere. For example, Petrescu specifically draws attention to the "originality" of Romanian structures which, owing to the use of various timbers, he compares with the "relative monotony of the timber buildings of the North."[118]



68 Bamboo floor of a *minka* in Shikoku minzoku hakubutsukan.



69 Bamboo lattice forming a backing for plaster in a new building in the traditional style in Iwakuni, Yamaguchi, Japan.

72 Spruce bark protects this small shed in Grundlsee, Steiermark, Austria, against rain.

71 Birch bark forming the insulation layer beneath the sods of grass on the roof. – Maihaugen Open-air Museum in Lillehammer, Oppland, Norway.

1 Holan, 1990, p. 147
2 Deinhard, 1962, p. 47
3 Gilly, 1797, p. 30
4 Holan, ibid., p. 179
5 Graubner, 1986, p. 94
6 Seike, 1981, p. 13
7 Taut, 1958, p. 217
8 Gunda, 1986, p. 79
9 Gschwend, 1988, p. 46. Großmann refutes this interpretation of the term. He regards goods and chattels as movable objects as distinct from immovables such as land. (Großmann, 1992, p. 96)
10 Nishi, Hozumi, 1985, p. 40
11 Parent, 1985
12 Bramwell, 1979, p. 75
13 Phleps, 1951, p. 3
14 Binding, 1989, p. 7
15 Harada, 1936, p. 46
16 Seike, ibid., p. 12 f.
17 Geschwend, ibid., p. 277
18 Phleps, 1951, p. 4; Gerner, 1979, p. 31
19 cf. note 70
20 Bresson, ibid., p. 25
21 Gerner, ibid., p. 52
22 cf. Hadert, 1938, p. 9 f.
23 Coaldrake, 1990, p. 25 f.
24 Brown, 1989, p. 29
25 Clausnitzer, ibid., p. 74
26 Rosenfeld, 1956, p. 152 f.
27 Carstensen, 1937, p. 37; Verband deutscher Arch.- und Ing.-Vereine, 1906, p. 171
28 Various authors describe this process in modified form and not only with respect to Norway: Ahrens, 1981, p. 166; Phleps, 1942, p. 34; Holan, ibid., p. 179; Clausnitzer, ibid., p. 248; Bugge, Norberg-Schulz, 1969, p. 7
29 Killer, 1941, pp. 24, 30
30 Clausnitzer, ibid., p. 30 f.
31 Ibid., p. 247
32 Bresson, 1991, p. 25; Phleps, ibid., p. 50
33 cf. p. 94
34 Information given personally by the carpenter.
35 Harada, 1936, p. 49
36 Phleps, ibid., p. 50
37 Holan, ibid., p. 148; Bresson, ibid., p. 25; Phleps, ibid., p. 40; Brown, ibid., p. 59
38 Gerner, 1979, p. 52
39 Clausnitzer, ibid., p. 66 f.
40 Haiding, 1975, p. 4
41 Taut, 1958, p. 234
42 Phleps, ibid., p. 191
43 Lissenko, 1989, pp. 53, 56
44 The *Umgebindehaus* log construction was combined with timber-frame construction in most cases, but quite intentionally, in order to exploit the different rates of shrinkage to relieve the wall construction from the weight of the roof. (cf. note 54)
45 *kenchiku gakai*, 1992, p. 50. The central columns of the oldest pagodas were set up buried deep in the ground on a padstone. For religiously motivated, traditional reasons, the padstone (*shinso seki*, i. e. “heart stone”) remained in those pagodas in which the central column was lifted clear of the ground during restoration work. (Parent, 1977/5, pp. 77, 82)
46 Brown, ibid., p. 42; Nishioka et al., 1990
47 Torao, 1959, p. 71
48 Seike, ibid., p. 14
49 Lissenko, ibid., p. 35 f.
50 Cement had been used in the past. (Parent, 1977, p. 78)
51 Petruscu-Burloiu, 1967/68, p. 84 f., Fig. 12/1
52 Today, columns in Japan up to 210 mm diameter are not provided with ventilation slots, while those with a diameter of over 300 mm are provided with them on all sides apart from the exposed side (information given personally by Tanaka Fumio).
53 *Dippelbäume* in the form of ceiling joists close off the top of a storey from above. These halved trunks are laid side by side, with the heartwood facing downwards, in order to carry the filling material.
54 Gruner, ibid., p. 39; Verband deutscher Arch.- und Ing.-Vereine, 1906, Fig. 44.
The *Umgebindehaus* (in Czech: *obwas* and *podstavka*; in Polish: *przysłupowy*) developed in the border area between log construction and column- and-beam construction and combines the two building systems. A frame, usually consisting of supports, header beams and braces erected around a one-storey nucleus in log construction, carried only the roof or a second storey plus the roof. The second storey could be built in log or column-and-beam construction.
55 Lissenko, ibid., Fig. 4.25.a,b; Alexandrowa et al., 1964 p. 301
56 Clausnitzer, ibid., p. 250
57 Faensen, Iwanow, 1972, p. 504
58 Lissenko, ibid., Fig. 3.20.
59 Mayer, ibid., pp. 39, 106
60 Gschwend, 1988, p. 50
61 Gerner, 1979, p. 18
62 Clausnitzer, ibid., p. 7
63 Ibid., p. 69; Graubner, ibid., p. 22
64 Seike attributes this to the natural resistances of indigenous species of wood. (Seike, ibid., p. 12)
65 Taut, ibid., p. 218 f.
66 Vitruv, 2nd book, chap. IX
67 Petrescu, 1974, p. 43
68 Johnson, 1990, p. 119 f.
69 Schulz, 1964, p. 7
70 *Shoin* = writing hall or alcove; the characteristics of this style established in the Muromachi period (1392–1573) are the provision of *tatamis* (rice-straw mats), *shoji* (transparent, sliding paper screens), *fusuma* (opaque, sliding paper screens), columns with a square cross-section and a room with *tokonoma* (alcoves), *chigaidana* (shelving system) and *tsukeshoin* (built-in table). The most famous example is the Katsura rikyu in Kyoto. The Sukiya style (*Sukiya* = tea-house) evolved out of the Shoin style under the influence of the tea ceremony. New characteristics which have been adopted are naturalness, irregularity, understatement and the most exquisite materials.
71 Geschwend, 1968/8, p. 3
72 Binding et al., 1984, p. 68; Blaser, 1982, p. 38
73 Gerner, 1979, p. 52
74 Dendrochronological investigations have dated fir wood in Roman buildings in Trier, Germany, as being 1,900 years old. (Clausnitzer, 1989, p. 77)
75 Killer, 1941, p. 41. Fir was better suited for special parts than oak. As for large structures, such as bridges, there was an inadequate supply of mature timber in the necessary arched shape, such timbers had to be manufactured. Fir has the most suitable properties for such purposes. (Blaser, 1982, p. 42)
76 Petrescu, ibid., pp. 20, 43, 52
77 Petrescu-Burloiu, 1967/68, p. 85
78 Sirelius, 1909, p. 76
79 Lissenko, 1989, p. 34; Strzygowski, 1927, p. 23
80 Brunskill, 1985, p. 28
81 Keim, 1976, p. 63; Phleps, 1942, p. 52; Erixon, 1937, p. 37
82 Coaldrake, 1990, p. 22
83 Graubner, ibid., p. 23
84 Kawashima, 1990, p. 83
85 Holan, 1990, p. 179. Dietrichson and Munthe contradict this statement: “The material of stave churches mainly comprised the mighty fir trees

which grew so extensively in the Norwegian forests in medieval times." (Dietrichson, Munthe, 1893, p. 6) And Ahrens rounds off the picture of disagreement. He notes that the stave churches have been built with spruce. (Ahrens, 1981, p. 165)

86 Erixon, 1937, p. 37

87 Sirelius, 1906, p. 135; Erixon, 1937, p. 14

88 Florin, 1937, p. 29

89 Saeftel, 1931, p. 59

90 Grisebach, 1917, Pl. 1, Fig. 2

91 Lissenko, ibid., p. 52

92 Blomstedt, 1902, p. 123

93 Klöckner, 1982, p. 11

94 Strzygowski, ibid., p. 23

95 Graubner, ibid., p. 23

96 Holan, 1990, p. 179; Sirelius, 1909, p. 76; Berg, 1981, p. 357

97 Mayer, 1986, p. 106

98 Graubner, ibid., p. 23

99 Vitruv, ibid.

100 Laris, 1910, p. 44

101Brown, 1989, p. 28

102 Ahrens, 1990, p. 74; Reinerth, 1929, pp. 63, 90 f.

103 Muramatsu, 1992, p. 21

104 Klöckner, 1982, p. 11

105 Dietrichson, Munthe, 1893, pp. 6, 46

106 Brunskill, ibid., p. 27

107 Clausnitzer, ibid., p. 81; Castellano, ibid., p. 83

108 Itoh, 1982, p. 118

109 Morse, ibid., p. 58; cf. note 5

110 Ast, 1990, p. 30 ff.

111 In Japan it appears to be different. It is precisely this which Kawashima claims, at least for mountainous regions. (Kawashima, 1986, p. 12)

112 Hadert, 1938, pp. 164–91

113 Phleps, 1942, p. 96

114 It would seem that a reappraisal is becoming established. (Clausnitzer, ibid., p. 77)

115 Seike, ibid., p. 12; Taut, 1958, p. 214

116 Sirelius, 1907, p. 56

117 Brown, ibid., p. 55 f.

118 Petrescu, ibid., pp. 10, 20

Working with Wood

Uses

The uses to which a material is put are primarily determined by its availability. The need for shelter encouraged our ancestors to look around them for building materials which they were able to work. Wherever wood was available in sufficient quantities it presented itself as the ideal choice owing to its ease of working. As experience in handling wood grew, this led to an ever more specific selection of not only the species but also the pieces of wood.

Nature offered plenty of assistance at all times and served as a model for the observer and the searcher. The more dependent mankind was on nature, the more intensively mankind had to strive for compatibility with her. Not only did the routines of life have to be greatly adapted to nature, housing too had to be exactly in harmony with her. What for us today has become an advertising slogan promising rich rewards was once a necessity for survival: building in accordance with nature – a form of construction which sought and found its orientation in the natural environment. Nothing stood in the way of utilizing roots, forked branches and other pieces of wood which are all boycotted by modern building codes.

The traditional style of building with wood is based on a linear or planar concept. This corresponds to the structure of wood itself. In Japan we find only very few exceptions, like the Kintai bridge in Iwakuni, the Soribashi in Itsukushima- jinja and a number of other old wooden bridges. (Fig. 73) In Europe arched bridges were built as long ago as the days of the Roman Empire; in doing so the Romans discovered and exploited the fact that beams laid on top of each other and fastened together could carry loads many times greater than if multiple beams were left unconnected. Furthermore, if they were curved while being assembled, they then maintained this curved shaped after as-

73 The Soribashi in the Itsukushima- jinja, Yamaguchi, Japan.

74 The Eiho-ji kannondo, Gifu, Japan, is one of the very few temples with planking to the eaves.

sembly. Although arched forms of construction were developed to a great extent in Europe, above all in churches[1] or bridges, flat surfaces still remained normal for the outer envelope. Even buildings erected over polygonal layouts usually have a flat periphery, although they are popularly designated as round.[2] Only in the details, e. g. ogee turrets, did the exception become the rule at times.
In contrast to this, the roofs of Japanese temples and shrines are characteristic precisely because of their curved shape. The curved surfaces and lines here were not attained by bending the wood. Both the rafters, which support the roof covering, and the purlins consist almost entirely of straight pieces of timber. Their depths are graded step by step in such a way that in the end the typical bent-up shape of the Japanese roof ensues. Only in the zenshuyo (which reached Japan at the end of the 12th century) was the upward curve of the raised corners of the edges of the eaves even more strongly emphasized through the additional, delicate working of the rafters to a curved shape.[3] (Fig. 74)
As towns emerged and populations increased, it became necessary to construct more and larger structures. At the same time, the demand grew for more uniform wood with the best properties. A tree which was straighter, longer, thicker and had less branches was easier to work. Carpenters no longer took the trouble to look for the most suitable piece of timber for each task (and had they done so, remuneration for their efforts would not have been forthcoming). The more a piece was like its neighbour, the more versatile it was in terms of application, and the more quickly it could be put to use in a building. The development of towns in medieval Europe brought with it an enormous increase in building activities. The plundering of the forests which went hand in hand with this decimated resources not only for prestige buildings. And in addition there were the even more devastating effects of wars and fires. The larger the town had become, the more the effects of such calamities were felt. Besides the fact that the productive energies of the victims were not available for the rebuilding work, the acute demand for timber led to serious economic consequences. The response was to restrict, even forbid, the use of timber in building.[4]
In those regions where wood continued to be used for construc-

75 As column-and-beam construction was unknown in this region, even such totally unsuitable timbers as these were pressed into service for log construction, like for this cowshed in Stará Halič, Slovakia.

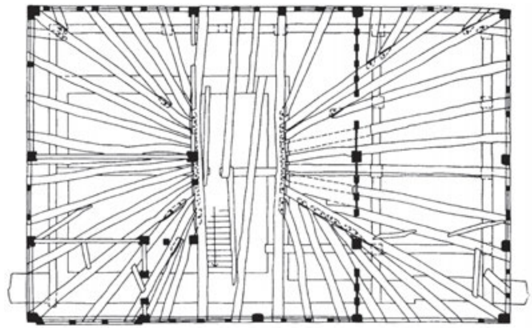
76 A simple utility building near Hola, Nordaland, Norway, the low-quality materials of which do not appear to any observer to be a disadvantage.

tion work, the population was forced to be content with ever "poorer", i. e. less uniform, material. (Figs 75 & 76) However, before builders were ready to swap tried-and-tested species, they tried out every conceivable trick. In northern Germany the use of oak ceased in the 17th and 18th centuries as even crooked pieces of oak became scarce; in fact whole, unworked pieces of oak were used just to maintain the required cross-section, i. e. to guarantee the thickness of the member.[5] Often only a look inside, at non-exposed places, revealed that savings had been made. (Fig. 77) If high quality was not the prime requirement, for instance, in the case of roofing battens or wind bracing, then our builder did not spend too long pondering over joints, but simply used bent branches and lashed them together. The carpenter at work in the towns also appears to have been influenced by such ideas. (Fig. 78)

Another possibility was to offset dwindling material resources by increasing the amount of work put into a piece. At least in the Japanese roof there seemed to be incredible chances to make savings, looked at from the point of view of the Western observer. The Japanese carpenter built with the conviction that the enormous weight of the roof was the best guarantee of safety in an earthquake.[6]

Johann Jacob Schübler reveals how even back in the 18th century one could avoid declaring deficiencies for what they actually were and instead present, totally pragmatically, that which appeared as a plight to the French,[7] a virtue to the Germans: "The readily available timbers with the naturally grown curves" would indeed "bring more benefits" than "could be obtained with straight and precious timbers".[8] Who would have thought that the values would reverse at some time in the future? The "bowed" wood was obviously in such great demand (Fig. 79) that with time it became sought-after decoration. (Fig. 80) The observer occasionally obtains a very similar impression in Japan when *ryokans* (simple hotels) wish to sell not only comfort but the flair of old architectural styles to an audience which is only too willing to pay. (Figs. 81 & 82) In Poland one was forced to appreciate the value of curved spars as long ago as the end of the 16th century. (Fig. 83) As wood is a transitory material, we

77 **Spar roof construction of a *minka* exposed to decay. – Ayaori, Iwate, Japan.**



78 **Floor joist layout of the *Schoberhaus* in Pfullendorf, Germany. (drawing by Ossenberg, Kahnt, Mechmann; source: Binding et al., 1989, Fig. Z 66c)**

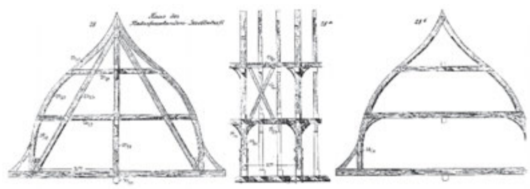
79 **A naturally bowed brace on a timber-framed building in Marthalen, Zürich, Switzerland.**

84 **A mature, common beech hedge is denser than many man-made fences.**

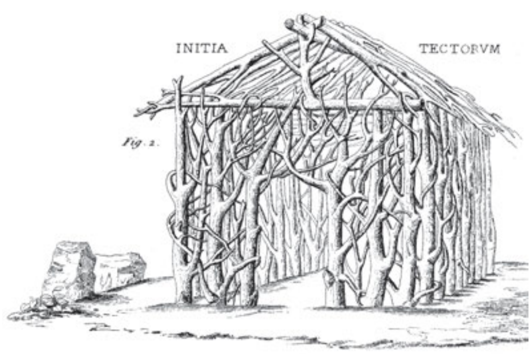
81 Attic storey of the Koyama House in Kurashiki, Okayama, Japan, prior to its conversion … (photo: Kawashima Chuji)

80 Quite obviously, this façade in Marthalen does not reflect the thrifty use of a timber available to the majority of the populace!

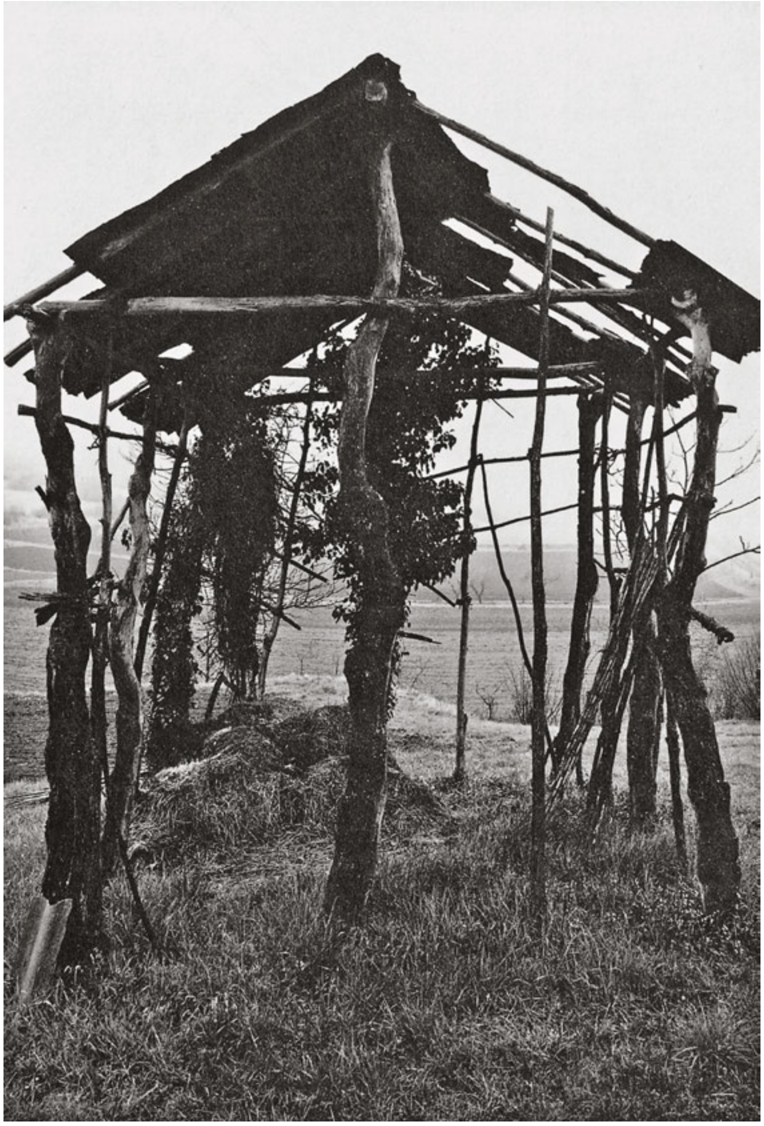
82 … and after its conversion to a *ryokan*, a simple hotel.



83 The roof to the premises of the Society for the Natural Sciences in Gdaňsk, Poland: principal truss, longitudinal section and common truss. The spars, each divided into three parts, are mortised into the collars! Their primary function is to create a specific silhoutte. (source: Heyn, 1913, Fig. 28)



85 Rondelet's interpretation of Vitruv's description of the beginnings of timber construction. (source: Rondelet, 1833, Pl. LXXI, Fig. 2)



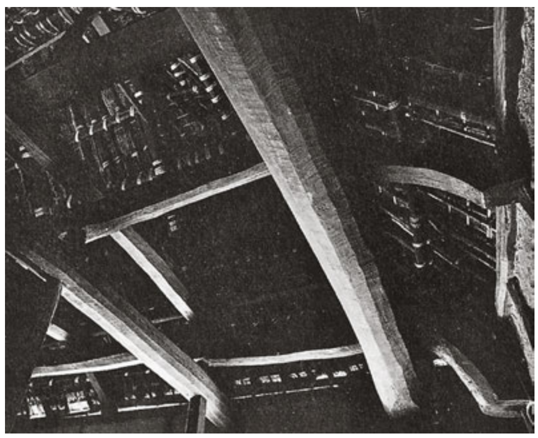
86 A very primitive construction made from pieces of wood simply gathered from the forest which clearly illustrates the principle of column-and-beam construction. – Near Ferenci, Slovenia

87 The fixing of a gate to a wooden fence. – Stübing Open-air Museum, Austria

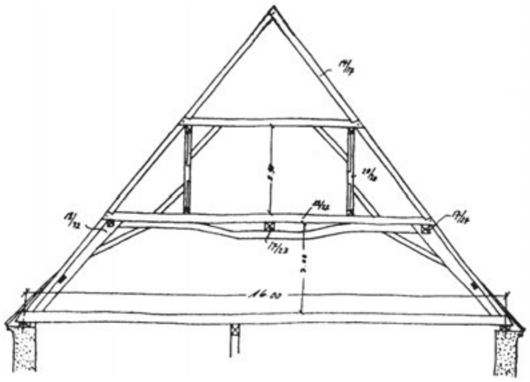
can in some cases only surmise the archetypal effect of nature. (Figs 84 & 85) For example, the use of the fork of a branch in its most primitive form as a support for a member laid in the fork appears so suggestive at first sight that its importance cannot be overestimated. (Fig. 86)

Those for whom it was always necessary to exploit every single piece of wood not only hit upon ingenious engineering solutions but also created works of art which draw their aesthetic appeal from the perceptible bond with nature. (Fig. 87) Whether our builder now "looked for purpose-made solutions in the branches or root collar", where "nature had already contributed to preforming the required part of the structure" and "now only needed a minimum of working with tools"[9] (Fig. 88), or whether he left the timber more or less unworked and only searched very carefully (Figs 89 & 90), again and again every single example is evidence of the knowledge of the worked material and free fantasizing with nature. (Fig. 91)

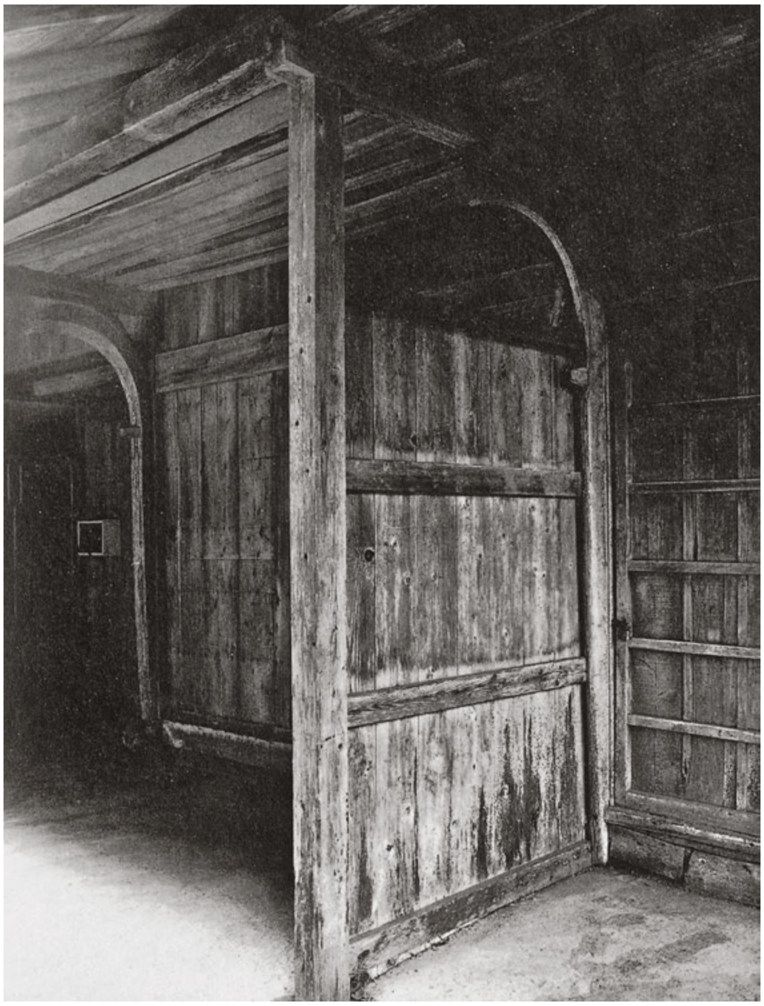
Timber free from branches and exhibiting uniform growth is not always the most suitable. When supports for an elevated storehouse were needed, trunks which had grown under unfavourable conditions and had produced many branches were selected because these were supposed to be particularly long-lasting.[10]



88 The crossbeam position in the roof construction is chosen so that its end grain meets the end grain of the columns. Hence, the roof loads are transferred to the columns in a visually intuitive and comprehensible manner. – Roof structure of the Shimoki ke no jutaku in Itchusonkijiya, Tokushima, Japan, in the Shikoku minzoku haku butsukan.

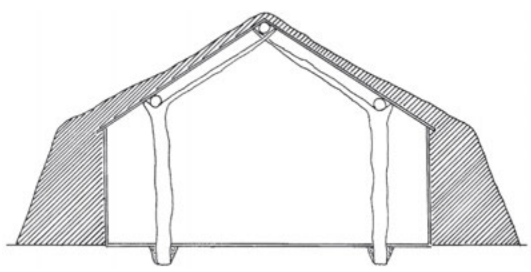


89 The Reutlinger House in Überlingen, Baden-Württemberg, Germany, could manage without columns in the first attic storey because an appropriately selected, bowed straining beam carried, in its bowed section, the collar purlin which supported the collar as well providing longitudinal stability. (source: Gruber, 1926, Fig. 38c)



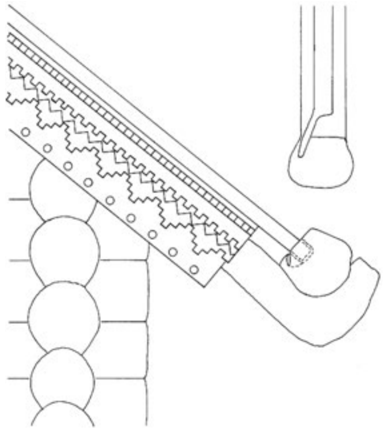
95 Bowed columns support the wide overhanging eaves of this *minka* near Keihoku cho, Kyoto, Japan.

90 Extravagant design around the entrance to an eel business in Kawagoe, Saitama, Japan.



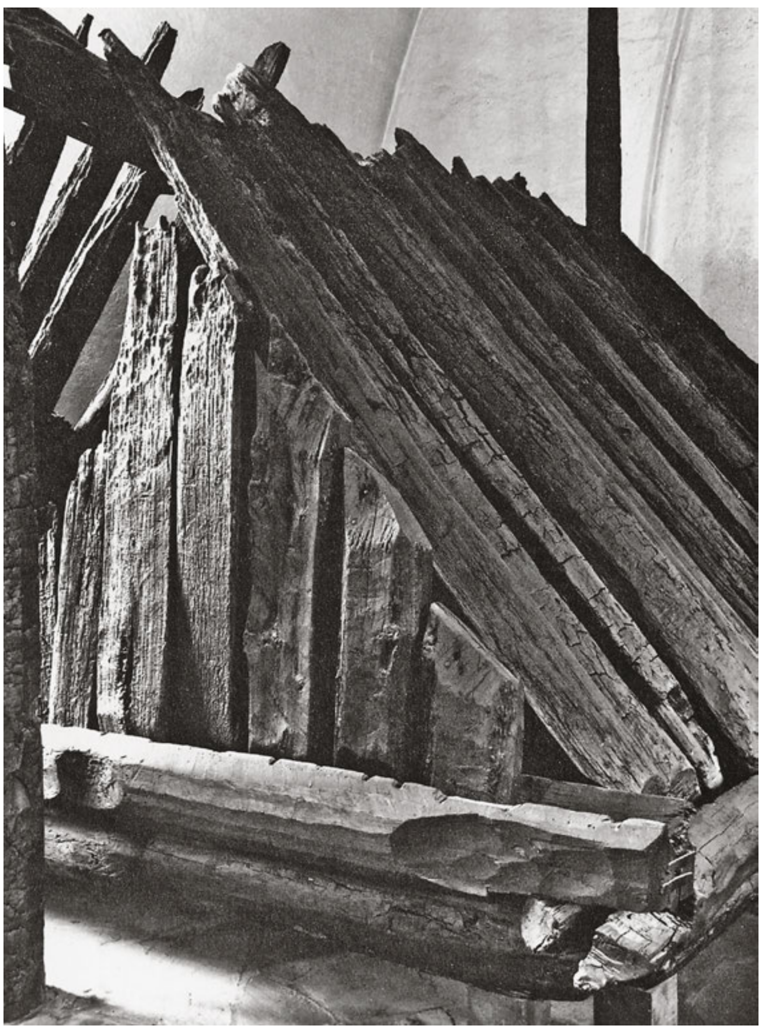
91 Reconstruction of a purlin roof structure with reminiscences of a cruck roof structure. The drawing (here simplified) reflects a free train of thought rather than a credible design. (according to: Brønsted; taken from: Funkenberg, 1937, Vol. I, p. 87)

From time to time even wooden nails represented a selected piece of wood. A "projecting head prevented the hole from soaking up water, the nail from drying up and rotting in the hole; after shrinking it could be easily removed and replaced."[11]
Some solutions were so firmly anchored in tradition that even serious disadvantages did not lead to their being modified. In Russia root collars were employed as eaves brackets. As the extensive resources did not require rejection of the traditional methods of construction, the old, proven solution persisted even though the use of tools had long since created other methods. Although the principle of draining the eaves member is basically identical to that of the Norwegian stave churches, the type of construction and the exposed nature of the arrangement leads us to assume that the base of the roofing boards very quickly rotted and, therefore, had to be replaced frequently. (Figs 92, 93 & 94)
How widespread the use of crooked timbers was because of their benefits can be learned from numerous examples which were not hidden, like the spars in Polish roofs already cited or the beams in the *Schoberhaus*. Mankind could have studied the living tree to discover what colossal forces were contained in timber as it grew in a curved shape. These forces protected the tree against collapse or breakage despite the laws of the force of gravity. In the East as in the West mankind has left behind traces which bear witness to its ability not only to exploit this characteristic and to take pleasure in its aura, but to be aware

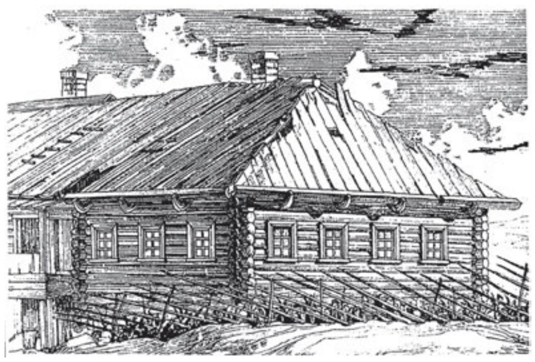


92 Naturally grown hooks carry the roof gutter (shown simplified). (source: Lissenko, 198, Fig. 4.25)

96 The brackets of the stave church in Torpo, Hallingdal, Norway, are an example of very specially selected timber.

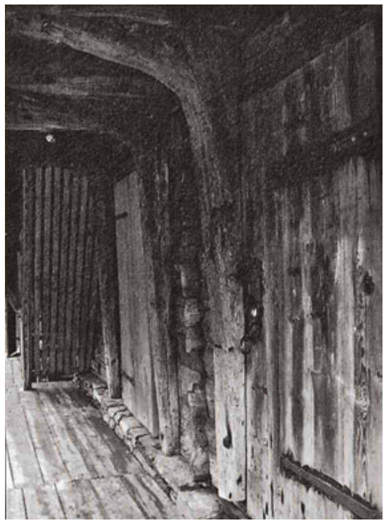


93 Just like in the burial chamber of a Viking ship (this specimen is in the Viking Ship Museum, Oslo, Norway), in which the sloping roof members rest in a groove in the inferior purlin, …



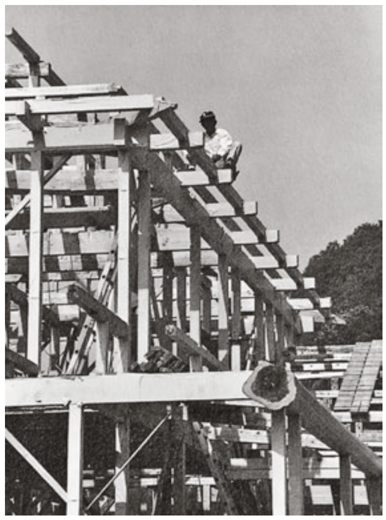
94 … so does the roof covering of Russian dwellings of the 18th and 19th centuries. (source: Lissenko, 1989, Fig. 3.5)

97 **During the refurbishment of the stave church in Heddal, Telemark, Norway, no further attention was paid to selecting naturally bowed timbers.**

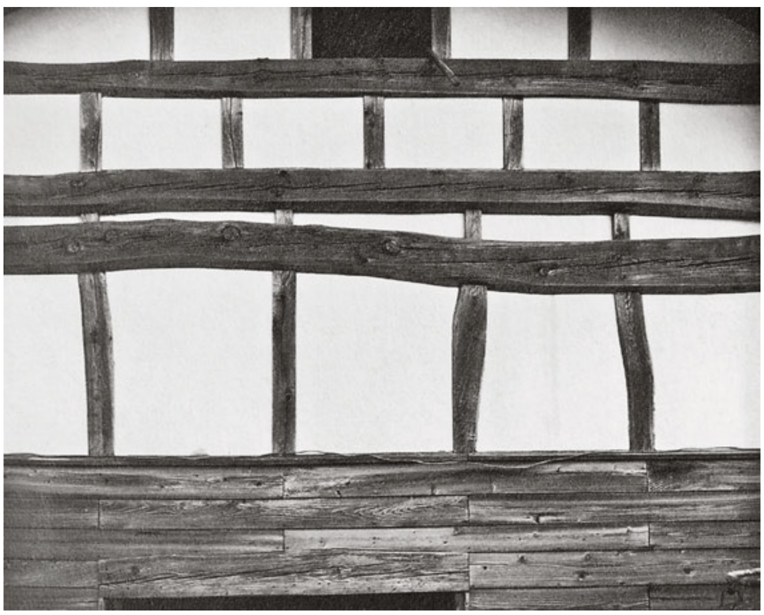


98 **Supports, as nature had formed them, carry a jettied storey in Bryggen in Bergen, Hordaland, Norway.**

of the tree as a form. (Fig. 95) The quadrant brackets which firmly join the individual members in Norwegian stave churches are a major feature in the appearance of the interior. (Fig. 96) Sometimes comparisons are needed to open our eyes, to show us how much power of expression has passed us by: (Fig. 97) in the course of refurbishment work, copies are often necessary which are then happily treated as faithful reconstructions.
No less impressive is the example of the L-shaped supports of many of the houses in Bryggen in Bergen, Norway. (Fig. 98) They do not just remind us of ribs from the shipbuilding industry – some of the supports are actually ribs which once saw service inside a ship![12] In the southern part of Hungary it was until quite recently possible to find *ambar*, small grain stores whose sill beam ring was fixed to two ski-like, bent-up timbers. The purpose of this design was to make it possible to move the vital stores to a safe place quickly and without any great effort in the case of fire or flood.[13]
How sensible or ridiculous, how up to date or out of date we may judge such examples to be, attempts to link them to tradition are not easy. Set pieces can easily be misunderstood as the subjective expression of the architect. (Fig. 99)



99 **The construction of a new building in Kibitsu, Okayama, Japan, making use of traditional construction. The timbers remain wrapped in protective paper for as long as possible.**



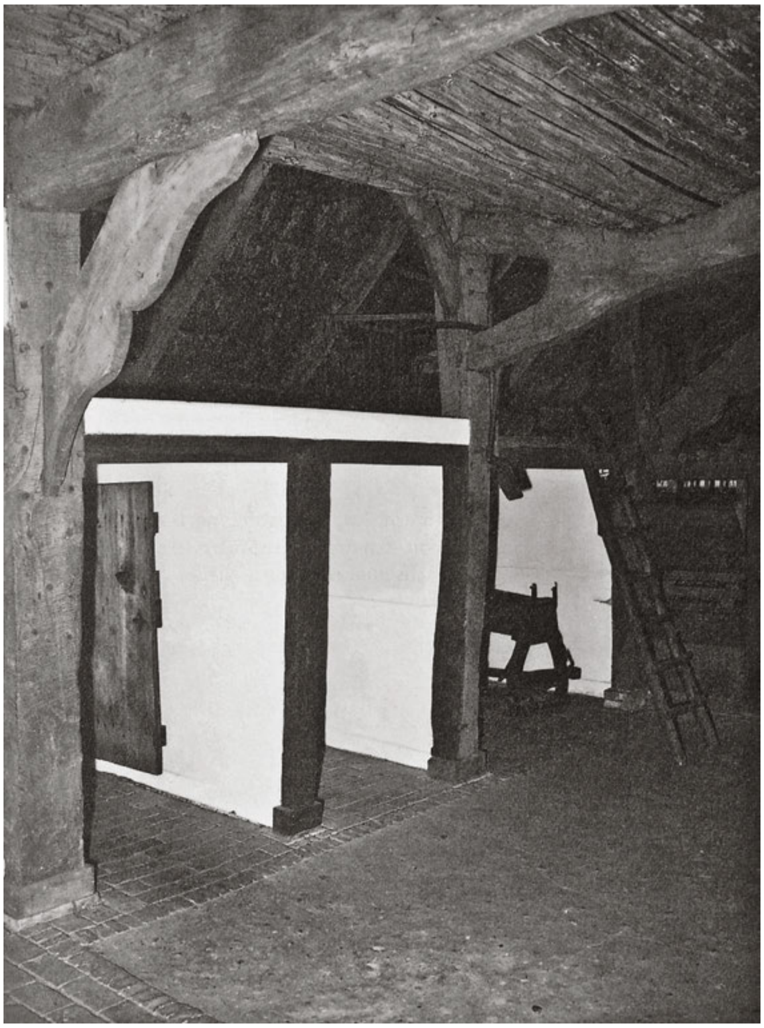
100 **The appeal of this gable in Aozawa, Iwate, Japan, lies in its skilled use of non-standardized timber.**

103 The amount of work required to build in the forked columns in the former Foeth House in Menslage, Lower Saxony, Germany, may well have been less than for conventional up braces. Apart from this, these columns create an unmistakable appearance. – Cloppenburg Open-air Museum, Lower Saxony

101 To the economically minded, such a repair as this one to a fence in front of the Honmon-ji in Tokyo, Japan, appears utterly unfathomable.

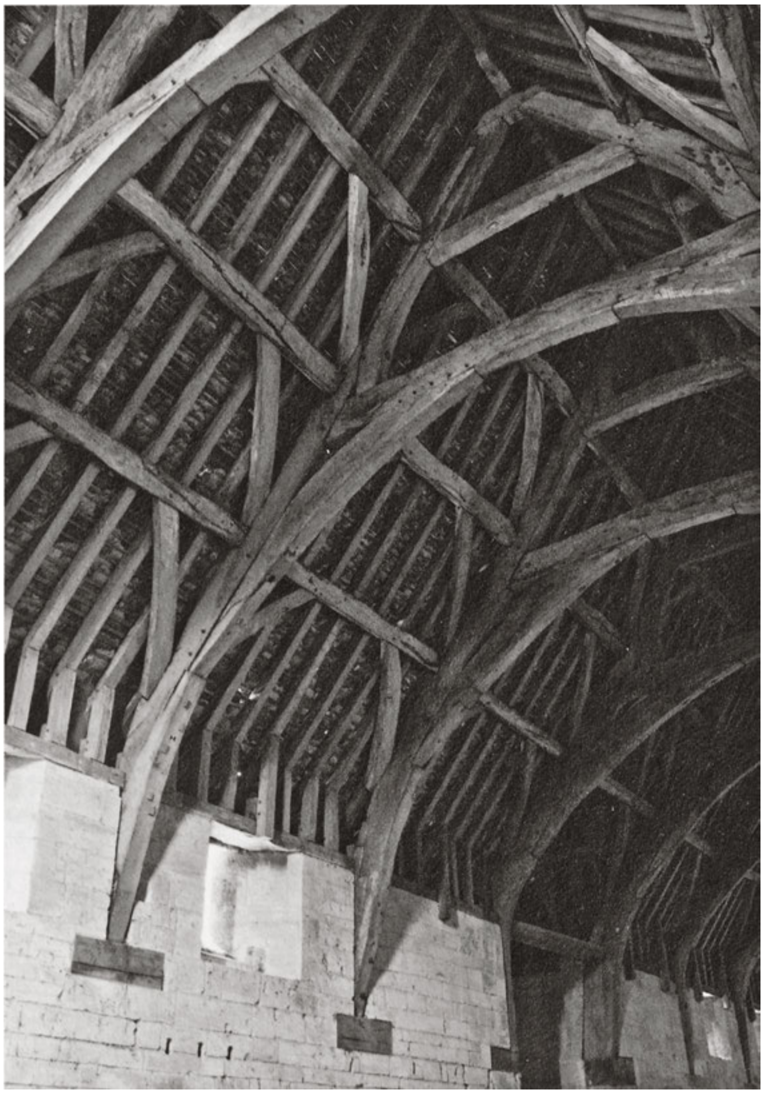
However, there are also counterexamples (Figs 100 & 101) and in Japanese woodyards we can relearn today just what wood of the very best quality really means.[14] Among the best examples for the use of natural forms of growth are forked timbers. (Fig. 102) In northern Germany they were used widely in column and beam construction. (Fig. 103) It was also known how to exploit their functional form in the horizontal direction. Forked timbers can not only replace bracing exactly, they are, understandably, more stable than any other conceivable connection. (Fig. 104) Bent, curved timbers have not only influenced the appearance of parts of buildings. Without them one very special type of structure would not be feasible. Their characteristic feature is the joint-free transition between roof slope and wall, and hence the direct transmission into the ground of the forces acting on the roof. Although without actual walls, they nevertheless provide the room otherwise enclosed by these. Primitive specimens of this type are virtually non-existent today because owing to their most simple usage (Fig. 105) they were never worth preserving. On the other hand, due to the special form of the material they were more resistant than structures built from sawn timber in the conventional manner. This form was particularly widespread in England where it was known as "cruck" construction. However, it is evident or at least suspected in almost all regions of Western Europe.[15] One of the real strengths of this construction could only be realized in lar-

102 The idea of the draw well is for most people in Central Europe linked with the forked branch. – near Böhönye, Hungary

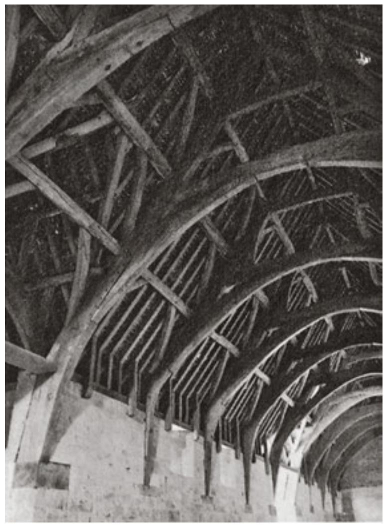


104 Forked columns are not only equivalent substitutes for up braces, they are understandably more stable than any conceivable connection. – Transition between living/cooking area and hallway in the former Deddens farmhouse from Hallenermoor, Lower Saxony, Germany, in Cloppenburg Open-air Museum .

105 Covered firewood store in Cloppenburg Open-air Museum utilizing the cruck or A-frame type of construction.



106 The cruck construction over the tithe barn on Barton Farm at Bradford on Avon, Wiltshire, England, in which nearly every truss is built differently. One variation: the roof slope timber runs through to the connecting piece below the ridge.



107 Another variation: at the fixing point of the lower collar beam the two roof slope timbers are pieced together in such a way that only a very detailed inspection reveals the join.

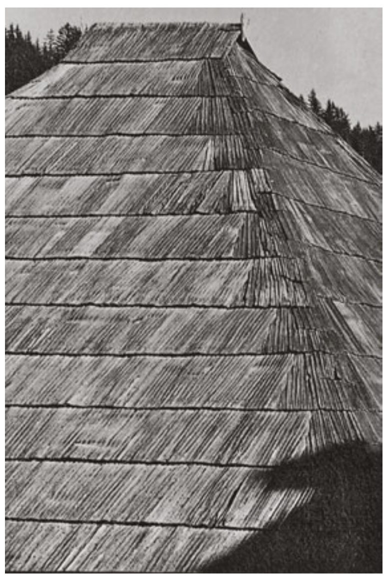
ger buildings. Almost every bit of crooked timber above a certain diameter was suitable for building purposes. (Figs 106, 107 & 108)

England's lack of sufficiently long building timber bestowed it with the development of another extraordinarily extravagant form of construction. The hammer beam roof spanned large distances with short pieces of timber. (Fig. 109) Irrespective of whether straight or curved wood was used, in every case it had to be worked at least at the point where it was to be joined to another piece. In order to be able to work the wood more easily it was prepared, even in prehistoric times, with cutting and chopping tools, later with the saw as well. The saw ignores the run of the fibres. Therefore, it can happen that the wood tapers[16] due to the incision at the very point where the join is to be made. In contrast, the older method of working had the enormous advantage that it left the newly created surface of the timber undamaged. Therefore, even after sawn timber had long since become the norm, all those who could afford it incorporated hewn timber for particularly heavily stressed parts.[17] The great disadvantage of hewn timber lies in the enormous wastage.[18] (Fig. 110) To shorten a tree trunk the saw produces waste equivalent to the width of its set. (In order to prevent a saw becoming jammed its teeth are bent outwards alternately left and right. Therefore, the sawcut is wider than the sawblade

108 A third variation: a very short extension of the spar joins to the upper collar beam.

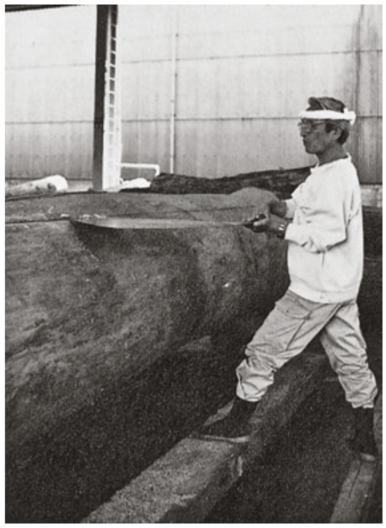
109 The hammer beam roof to the church in Woolpit, Suffolk, England.

itself.) In contrast, the axe needs to be worked into the trunk in a tapered cut, with the amount of waste depending on the diameter of the trunk. The thicker, and hence in most cases the more valuable a tree is, the greater the amount of wood which has to be sacrificed upon hewing it. Nevertheless, even thick trunks were felled only with axes in the 19th century, and even in the 20th in exceptional cases. The skilled worker had fewer problems with the axe than with the thick, poorly hammered saws of the 18th and 19th centuries. Trunks which had to be brought down from mountainous districts into the valleys suffered immense damage to the straight faces of the cuts. The tapered end of the trunk formed by working with the axe was much better suited to being transported down into the valley.[19] If the tree was divided lengthwise, it normally provided no more than two halves or, after further working, two planks. An impressive exception are the planks in the floor of a Gothic mortuary; they were formed by splitting a circular trunk five times.[20] Thanks to this (later forgotten) masterly performance, three times more material was available than usual. In Russia split planks were produced up until the 18th century,[21] in remote districts in Norway and Switzerland even in the 19th century.[22]
Despite their far higher price, due to the laborious and inefficient method of production, cleft planks were able to assert



110 With cleft shingles there is absolutely no waste because they are not even given a groove. When laid properly, every branch inclusion, every bow can be followed in the surface of the roof. – Greschitz, Carinthia, Austria

themselves against the competition of sawn timber for some time. This was probably due to the much better quality of the split planks. Such timbers are more flexible, exhibit a higher breaking resistance, warp less and swell up less under the effects of moisture.[23] Even in the 20th century some forest tenants were still able to use their ability to hew round timber into squared timber during the bleak winter months in order to improve their incomes. Prepared lengths up to 30 m enabled really economical treatment of the semi-finished goods.
Anachronisms will live on as long as a high quality is demanded which exceeds the scale of values of most people. In Tokyo five manual sawyers are still employed. (Fig. 111) They still have a sufficient number of customers who really appreciate the difference – perhaps only in order to own prestige objects. The abilities of such workers are legendary in Japan. Manual sawyers cut planks as thin as 3.5 mm! Wood had become so precious in Japan that the best board sawyers took pride in being able to slice up to 12 planks of equal thickness from one post. A less-skilled operative might only manage 10! The relevance of such a comparison is made comprehensible when it is born in mind that the better sawyer cut the customer enough ceiling panels for an eight-*tatami* room[24] from one piece of wood, the other only enough for a six-*tatami* room. However, if the latter's planks were also destined for an eight-*tatami* room, then the client had to pay for a second log![25]



111 One of Tokyo's last sawyers.

The Carpenter

Longer than any other group, it was farmers who retained the custom of building their own house. To be able to carry out any changes or rebuilding work necessary at any time was worth the effort required. Adapted to local circumstances, the great diversity of farmhouses, an unbelievably rich variety signifying different individual needs and visible both in terms of the exterior as well as the interior, reflects the accumulation of experience in Europe and Japan alike.
The majority of farmers would not have been in a position to appoint somebody else to build their house. Relying on the materials available, the use of which was sometimes still subject to severe limitations, and the assistance of family and friends, optimum designs evolved which today give rise to yearning and transfiguration.
Until recently, particularly in areas where plenty of timber was available, one could still obtain an impression of this ability, which was absolutely and solely derived from knowledge handed down as well as a tremendously strong bond between farmers and their own houses. In Russia the ability to build your own house was regarded as so matter-of-fact that travelling merchants always took with them axes, saws and hammers in order to be able to build their own branch offices![26] Whether in the Carpathian Mountains,[27] the Alps[28] or in Japan,[29] farmers built their own houses until into the present century, as long as this was not impossible due to reasons of size.[30] Functionality, coupled with a uniqueness which comes about through using natural materials, determines the appeal of these apparently very simple and modest structures. The acceptance of a manageable size is a distinctive feature of Norwegian farmhouses. When

a building became too small, nobody thought of enlarging it – a new building was erected alongside![31] In some cases farmers put their capabilities to the test by building churches.[32] The wooden churches of Finland in the 18th century were of such a quality that it was believed they were the work of Swedish architects; however, especially talented Finnish farmers proved to be responsible.[33] Building work in Norway relied upon the directions of a carpenter.[9]

Serfs or tenant farmers drew their knowledge from their socage on the ruling court or manor.[35] Hence, they enjoyed the dubious advantage of plenty of practice and experience which the construction of or repairs to such buildings, large and small, brought with them.

This store of traditional knowledge and the farmer's deep bond with his own farmstead accounts for the extraordinary ability to reconstruct even simple buildings true to the original. Kruke Farm in Norway has been completely destroyed by fire on three occasions, but each time it has been rebuilt identically.[36] That a log construction settles and to a certain extent, that the columns of the huge north German barns had to be set up at a certain angle,[37] was not knowledge based on intuition but, on the contrary, on experience gained over hundreds of years.

The just four, six or eight columns of these north German barns support purlin-type members in the longitudinal direction. These must carry the weight of the entire roof which, due to the thatching and the extreme steepness – to cope with the heavy rainfall –, exerts a colossal pressure on these head beams. In the raised header assembly (see Ill. 349, p. 161) the transverse bracing was attached well below the joint between column and header. Therefore, the headers tilted readily under the pressure. The risk was that the head beams would be ripped apart due to the columns mortised into them, or that the columns would split or the teazle tenons on top of the columns would break off. (Fig. 112) This danger suddenly came to light as the lack of oak necessitated its replacement with pine. However, setting up the columns at an angle alleviated this problem.

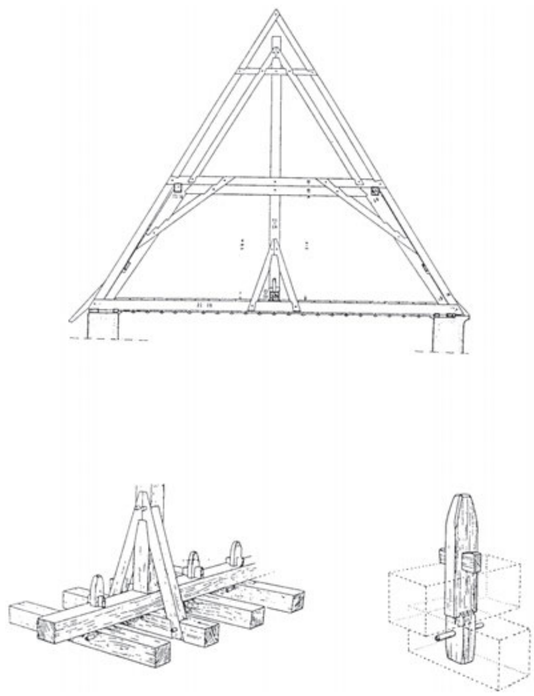
If in a log building one wanted to incorporate door and window frames while setting up the walls, one had to know the degree of future shrinkage of the logs very accurately. In a way this knowledge is no less impressive than that required by the rebuilders of the Ise-jingu who could work to an accuracy of a tenth of a millimetre. In that special case, detailed records kept over many generations of reconstruction replaced the personal imparting and handing-down of the knowledge.

As towns evolved it became increasingly clear that the specialization of especially talented people was indeed sensible and could be gainfully employed. One example of this is the desire to free the roof space or spaces of a building from the columns (king and queen posts) by supporting the purlins or the roof trusses with vertical queen struts carrying the collar beams. The invention of the lying frame with inclined queen struts provided the solution. However, inclined queen struts place considerably greater demands on the builder than upright queen struts. The citizens were willing to bring in experienced carpenters from far afield in order to build such elements[38] – and for building churches, too. In fact, no less than three master carpenters were

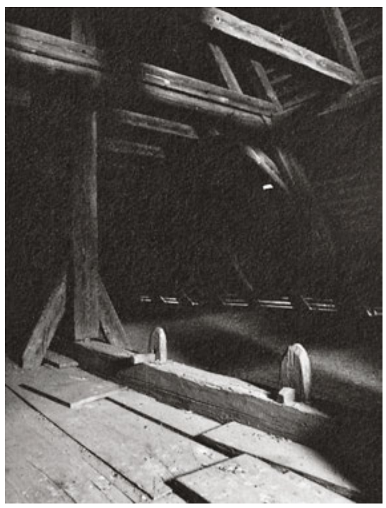
112 Iron straps prevent the worst in this barn in Frindsbury, Kent, England. The thrust of the roof has split open the columns via the tenons fitted into the header beam and against the tension of the tenons fitted into the tie beam.

113 The truss-post construction of the bell-tower in Malé Ozorovce, Slovakia, demonstrates which types of construction were dared even in the countryside.

fetched from different places for the church in Slavonov, Czech Republic.[39] Under the guidance of these three experts, the local carpenters and farmers constructed the church and at the same time had the chance to further their own knowledge. Consequently, structures which outwardly might lead one to suspect unskilled labour, can also turn out to be very sophisticated upon closer inspection. (Fig. 113) When there was no more work to be found in a place, the carpenter moved on.[40]
Even the use of the word "carpenter" is anything other than clear. Sometimes the carpenter was treated as the equal of the master builder.[41] Elsewhere it is stressed that up until the Baroque period the carpenter and the architect were one and the same person; conception, design, sizing and execution all lay in his hands. As the age of the Baroque dawned, a development took place which was to change the whole nature of building. Designing and planning, the creative act, hitherto the result of practical experience, was to be theorized by and for more and more specialists.[42] Thinking in terms of wood had to give way to "forms devised by pencils on paper."[43]
Such developments are always determined by several factors. An understanding of the material, which cannot be taught in schools, had enabled incredible structures to be erected. Nevertheless, although helped by the fact that iron was quite simply too expensive for everyday applications, for devising unusual and original solutions, a period of inertia set in in timber construction at some stage, influenced by the solutions which the blacksmith had created. The proud carpenter wanted nothing to do with iron, but on the other hand, new developments in carpentry were not forthcoming. Easily copied forms led to shapes which could not conceal their spiritual ancestry. A characteristic example of this can be seen in the roof truss of the St Cyriak church in Sulzburg, Bavaria, Germany. (Figs 114 & 115) The construction employed is an eloquent witness to the speechlessness of carpenters in the search for words from their own store of forms. The first step to adopting items made from other materials had been taken.
But there are also examples in which any feeling for the material is missing to such a degree that we initially believe it must be a mistake by the draughtsman. (Fig. 116) This cannot be insinuated in the case of Ostendorf, one of the most profound experts on roof construction. When the cross-section of a truss post is reduced to one-sixth of its size exactly at the point where it is suspended, the question must be asked as to what safety factor carpenters incorporated in those days!
In some respects similar, but also very varied, was the situation in Japan. The Japanese carpenter was always a joiner as well.[44] Every European who has seen a timber joint made by a Japanese craftsman cannot help but think of a joiner, irrespective of the type or complexity of the joint. The nature of the construction of a Japanese building does not permit any physical separation between the interior and the exterior. A similar idea can also be found in Europe – the partition walls of log buildings can usually be seen on the external walls. Wooden ceilings – from the simplest planks with carved joists to vaulted, Gothic plank-and-beam ceilings and coffered ceilings – these are the showpieces of the carpenter's art. Europeans can only gaze in amazement at the incomparably finer work of Japan.



114 Details of the roof structure of St Cyriak in Sulzburg, Baden-Württemberg, Germany. (source: Binding, 1991, Fig. 249)



115 Truss posts carried the tie beam in the closed truss via lap-jointed down braces. A longitudinal beam is supported by these and this in turn had to carry the tie beams in the open trusses. It did this by means of highly "idiosyncratically" (Ostendorf) formed tenons, i. e. imitations of wrought iron ones. They are fixed above the longitudinal beam by wedges and suspend the tie beams below on a wooden nail.

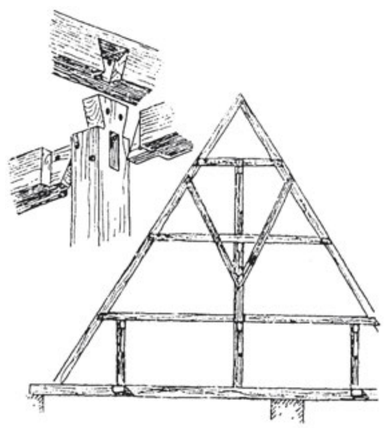
Historical restrictions might have played a part here. In the Middle Ages carpenters in Germany were only permitted to make chests and cupboards in the rudimentary slab stile, while joiners produced them with dovetails.[45] However, they may have been other, far more decisive reasons: other timbers, different tools, aesthetic aspirations differing significantly from those of us Europeans – all these aspects are dealt with elsewhere in this book.

Just as the Japanese carpenter has, to this day, remained responsible for the interior works, so he also, to this day, at least shares responsibility for the architectural design. *Daiku*, the Japanese word for carpenter, consists of the elements "dai" and "ku", the literal translation of which would be "great artisan" or "chief builder", corresponding exactly to the Greek roots "arkhi" and "tekton" from which the English word "architect" is derived. This derivation may sound highly pretentious for the beginnings of timber construction.[46] However, we are concerned here with the continuity of the process of creating a structure. The Europeans have interrupted this continuity radically and permanently. In contrast, as craftsman and artist, architect and master builder, the Japanese carpenter is just as responsible for the intellectual input as for its practical implementation. His knowledge and responsibility have secured the Japanese carpenter an astonishing status. The carpenter was the person who determined the appearance of palaces. The more important a structure was, the more weight the carpenter's word carried in its design.[47] Great temples and shrines even went so far as to house their carpenters nearby, and these carpenters were allowed to bequeath their positions.[48] This authority was based on the carpenter's knowledge of the laws of proportion handed down over generations. However, this authority was putative because even the carpenter had to abide by the laws of *kiwari* and *ma*.

Kiwari, literally "wood dividing", is a law of proportions. The diameter of the main columns is the decisive dimension for all variables connected with the construction. The ratio of the diameter of a support to its height, one support to the next, is also specified by *kiwari*; likewise the extremely complex division of the cantilever bracket carrying the roof, the bracket in turn determining the rafter spacings.

Ma designates the "in between", in architecture the space defined by the walls, the space between loadbearing columns. *Magusa* (door lintel) is *gusa* (material) which is used in *ma*. *Mado* (window) is the door which is set up in *ma*. A quote from Hugo Kükelhaus serves to explain: "Owing to their spaced-out succession, the columns [of a row of columns, K. Z.] create a sort of form like a sequence of notes through the rests in a pattern of sounds, a melody … Only in relation to that which does not exist, will that which does exist become reality."[49] In contrast to that which Kükelhaus calls non-existent, this "in between" really does exist for the Japanese, namely *ma*. In European thinking that which exists is defined by that which does not. In traditional Japanese thinking that which "is" can only be described by including that which lies "in between".

Almost all structures in Japan were made from wood. Consequently, the carpenter was the most important craftsman. For major projects the number of workers was so great that the



116 Perhaps Ostendorf's drawing of the truss-post suspension detail above the town hall in Marienburg, Germany, owes its existence to the astonishment of what is possible. (source: Ostendorf, 1908, Figs 54, 54b)

overall control, organization and handling of the construction could only be guaranteed by means of a hierarchical, strictly organized pyramid of responsibilities. A six-level ranking system did not even include the ordinary carpenter.[50] A breakdown was necessary and advisable in the horizontal plane too. The *miya-daiku* (shrine carpenter) and the *tera-daiku* (temple carpenter)[51] of course had to fulfil very different tasks from those of the *sukiya-daiku*, "the magician with materials and interior finish",[52] who had become specialized in the architecture of the tea-house style for the aristocracy, rich merchants and warriors.
An example might serve to throw some light on how very different the expectations of the majority of people are these days regarding the work of a craftsman from the self-conception of a *sukiya-daiku*. Asked to build a S*ukiya* house the carpenter regretfully declined, giving as a reason the fact that he had lost his tools during World War 2; without these he would not be in a position to work satisfactorily.[53] Although such an idea can hardly be comprehended by anyone nowadays, it does show a remarkable attitude to work – which is only accepted when it can be absolutely guaranteed that it can be performed to the carpenter's complete satisfaction.
When the term "carpenter" actually became a specific job title is lost in the mists of time. Firstly, because of the extreme regional deviations, and secondly, because a sensible definition distinguishing it from the layperson is hardly imaginable. Which ability to produce which joint or which construction at which date in the development should be used to define a carpenter? In the Bible translation by Bishop Wulfila we can read that the Goths employed professional carpenters as long ago as AD 350. On the other hand, there were districts in Austria in which the term *Zimmermann* (carpenter) was still unknown in the latter half of the 19th century.[54] And no date can be established for Russian carpenters, for when these were defined "first by way of the increasing number of their tools, the increasing technical content … as greater and greater specialists."[55] This seems especially curious when we think of the 10th-century St Sophia's Cathedral in Novgorod, "an immense timber structure with 15 towers."[56] That the ability to erect such a building cannot be gained in months or years is obvious.

117 A carpenter's mark as an aid to assembly in the roof truss of the monastery church in Neuberg an der Mürz, Steiermark, Austria.

The presence of carpenters' marks can certainly serve as a good starting point. (Fig. 117) They are normally to be found in important structures involving technically advanced construction. Incidentally, they are of no use in determining the date of a building. In the majority of the more important buildings in Japan, information concerning the structure can be found on a wooden plaque. This plaque *(munafuda)* is attached to the ridge purlin.[57] (Fig.118) On such a plaque in the Itsukushima-jinja, Hiroshima, Japan, we can read that in 1577 a plane was employed here for the first time.[58]
Like so many other trades, the carpenters formed themselves into a group. Their main objective in doing so was to attain greater independence from the authorities. The craft guilds evolved during the 12th and 13th centuries out of the religious brotherhoods of the 11th century, and coupled with the flourishing of the towns.[59] The importance of this movement is shown by the example of Norway, there, were craft guilds did not emerge until the 17th century.[60] However, the towns were in

118 *Fudomado* in the roof of the Kencho-ji sanmon in Kamakura, Kanagawa, Japan, on which the disaster of 1923 is recorded: “On 12 September in the 12th year of the Taisho era, there occurred the most terrible earthquake in Kanto that ever was. This temple was badly damaged. Although the sanmon was not totally destroyed, the roof suffered serious damage …”

turn dependent on the influx of carpenters to such a degree that these were guaranteed freedom and citizenship after only one year in the town.[61] Although there were many positive sides to the guild system, for those who held opposing views things could become extremely unpleasant. Today, we marvel at the works of the Swiss family of master builders, Grubenmann.[62] But they were not allowed to be called carpenters and so they became entangled in a conflict with the guilds as, thanks to their superior carpentry skills, they were awarded a contract by the town of Lindau to rebuild two palaces destroyed by fires. According to the ideas of the guild members, such financially lucrative projects should not be given to people who had not even completed the course of training laid down by the guilds.[63] The guilds had become the storehouse for the wealth of experience gained thus far. They monitored training and the acquisition of knowledge. A cleverly thought-out system regulated the distribution of work. From the middle of the 15th century the travels of the journeyman became mandatory. This custom was fostered not only because the experienced wardens of the guilds were convinced that the journeyman must further his experience among strangers. As Gerner writes: “By sending the journeyman off on his travels he was delayed in becoming a master, and the time in which he could practise as a master was shortened. Hence, the pressure of competition was somewhat alleviated.”[64] Negotiations between the guilds staked out the allotted territories. But in all other respects the guilds were hermetically sealed and nurtured no contact with each other.[65] The knowledge was not to be allowed to leak out. All the power of the craft guilds was based on this concept. This mysteriousness characterized both the European and Japanese institutions.[66] Another example from the realm of the *sukiya-daiku* serves to illustrate the mythical status attributed to their work. In breaks between working, when eating or resting, they covered parts of their work with towels to ensure that no outsiders could copy anything![67]

Experience was the principle determining all the work and the success of the carpenter, and such experience could only be acquired through working with the material every day, solving certain problems under the expert guidance of a master. The knowledge concerning the necessary cross-sections is as much the outcome of this experience as is that dealing with the overall construction. The designs of Hans Ulrich Grubenmann are well known. He devised such bold structures that he had to lead clients and users into believing supports which were not actually there in order to circumvent their fearful mistrust and be able to realize his projects. He hung column capitals, which were never supported by columns, under the 18 m clear span of the eastern gallery of the church in Wädenswil, Switzerland.[68]

Wilhelm Coxe wrote in 1792 that the Schaffhausen bridge did not really rest on the central pier which Grubenmann had to erect at the behest of the client.[69] His self-confidence equalled his ability. Dissatisfied with the councillors of Schaffhausen, who wished to discuss the building of the bridge with him, Grubenmann went home having accomplished nothing: "The fools only ever talked about how they wanted it and never asked how I wanted to build it."[70]

Experience made careful working easier but made its necessity understandable. Those who have to rely on the careful work of others, themselves go about their work carefully so that when the work is handed over to the next trade, smooth progress is assured. It was expected of every Japanese carpenter that not only should he pick the right piece of wood every time, but that he should choose the single, most appropriate joint to suit the task. For when the construction work was begun after cutting all the joints, there was absolutely no more leeway for changes.[71] Accurate work can be seen in roof trusses and perfectly sealed log walls alike. It begins with the choice of timber and continues with the forming of the joints. (Fig. 119) Even complex joints must be as precise as any other, if the structure is not to suffer any disadvantage. (Fig. 120)

At a time when engineering drawings were not made and, for reasons of secrecy, no written records were circulated, our experienced carpenter went about the work uniquely and alone on the given layout. The positioning of the main columns of a Japanese building fixes its fundamental layout for the whole time during which the building should stand – it cannot be changed; the diameter of the columns determines their spacing and height, and vice versa. Based on this was a law, the *kiwari jutsu*, which permitted all further sizes to be deduced, right down to the *tatami* mats.[72] This explains how it is possible that experienced carpenters only need a careful look at a building in order to be able to reproduce it. The obvious proportions only permit modifications at unimportant places which depend on the perception and analytical powers of the carpenter.[73] Not dissimilar to this was the approach in Russia. Work was performed for a long time without any written documentation but the so-called "letters of hire" (*rjadnaja sapis*) which appeared between the 16th and 18th centuries are proof of the overwhelming priority given to experience.[74] These letters specify little more between client and contractor than how many rings of logs a building should have, i. e. how high it should be. The ideas of the client with respect to the extent of the works was explained in the "layout". In addition, the appearance of churches was determined by the shape and height of their towers. Further details in the project specification concerned only the quality of the workmanship, the material and the locations for felling. It was only the considerably more detailed specification of the interior design which then fixed, indirectly, the number and size of the windows, for instance. Something very similar had

119 When a dovetail is cut so accurately as here in this suspended interrupted tie-beam on the Kubel bridge, Appenzell, Switzerland, its form also fulfils sober expectations.

120 Corner of a log building in double *Klingschrot*. – Hasleiten, NE Austria.

been practised in northern Germany. One of the few, important dimensions was the the distance between head beam and anchor beam, the *Vertiefung*, in the raised header assembly. This dimension was discussed and specified in the building contract.[75]

Today, we shake our heads in incredulation when we see the complexity of structures such as the Church of the Transfiguration in Kishi, the Church of the Assumption of the Virgin in Kondopoga or the Cathedral of the Resurrection in Kola in relation to the building documentation. In Russia drawings only started to appear at the end of the 17th century.[76] When working drawings eventually started to be used, these were frequently the work of artists whose familiarity with engineering sometimes left much to be desired![77] (Fig. 121)

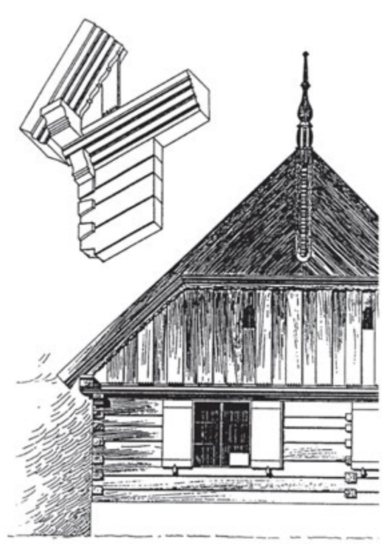
There are very graphic examples which help us to recognize the experience of a master, examples which distinguish that particular master from a host of other good ones. For instance, if a large block is to be mounted on the tie beam above a column in a Japanese temple, immediately after assembly the block must exhibit a couple of millimetres play. (Fig. 122) The tie beam shrinks and the weight of the roof forces the large block down onto the column. The block, secured by means of a dowel, is intended to distribute the roof load equally onto column and tie beam. Needless to say, the chance of choosing the wrong settlement gap, too large or too small, is very great; only one dimension is correct. Despite the colossal dimensions of temples, millimetres are crucial at such points. In these situations it is only the master carpenter who knows the correct dimension. Another example is provided by the bargeboards: only those who really know right from the outset how to estimate the settlement of the gable under the action of the roof load are in the position to produce a mitre without a gap. (Fig. 123)

There have been similarly magnificent examples in Europe. If you have the chance to dismantle an old Norwegian storehouse, you will discover that the timbers which define the ground floor have deeper notches than those of the jettied timbers which form the support for the upper storey. (Fig. 124)

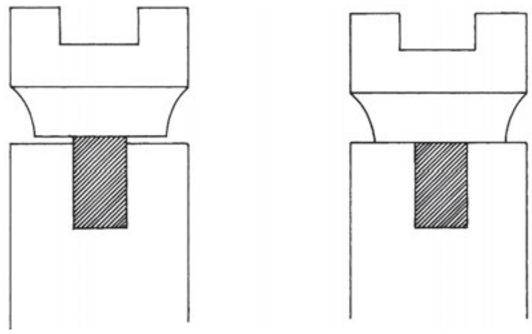
Like with every piece of wood, every component in a construction must take account of the shrinkage process. "The Norwegians treated this 'enemy' as an 'ally' in their joint work."[78] They laid the logs on top of each other, just as in any other log structure, with the characteristic addition of a groove formed on the underside of each member. The pressure acting on the timbers caused greater settlement along the wall than at the jointed corners. In order to take this into account, the carpenter left gaps in the joints. The drier the wood became, the more it shrunk and the tighter the joints became, and each log was pressed more firmly into the groove of its neighbour above. The same principle was known in Russia.[79]

Part and parcel of such carpentry work are intuition and a thorough understanding such that besides all the obvious, more important tasks and decisions, there still remains time to consider all manner of "little things". This and the ability to create the new while respecting the old are the hallmarks of real proficiency.[80]

There is another essential criterion signifying this proficiency, difficult to comprehend and not really definable. It is certainly



121 Gable of a Mazurian farmhouse (source: Neumeister, Häberle, 1894, Pl. 62). The dovetailed ends of the logs are drawn the wrong way round in both the elevation and the detail axonometric view!

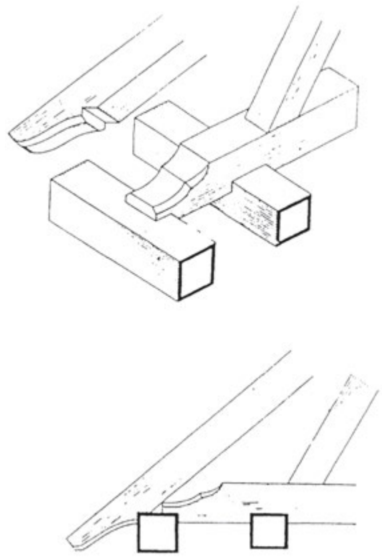


122 At the time of assembly the block must be provided with a settlement gap so that it sits in the correct position after the horizontal beam has shrunk. (according to: Brown, 1989, Fig. 37)

123 The bargeboards converging in the centre of the gable meet almost perfectly. – Rinshun kaku, Wakayama, in the Sankei-en, Yokohama, Japan.

124 These rainwater drips on the jettied timbers of this *loft* in Øverbø, Telemark, Norway, are so beautifully decorated that it is easy to overlook their real function.

125 Detail from the fortified church in Bithälm, Siebenbürgen, Romania: "The pleasure in the work also led to the decoration of such parts which were to be covered by other items." (source: Phleps, 1942, Fig. 41.3)

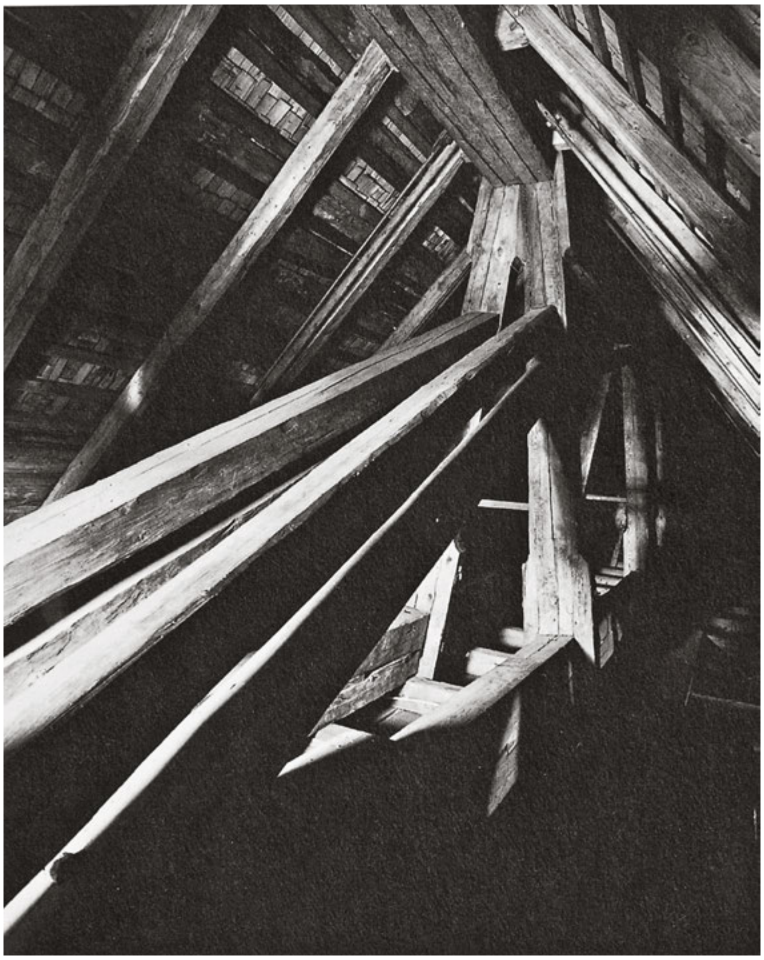


no coincidence that this is pointed out by a woman, Jerri Holan: "the *love* of making things".[81] (Fig. 125) In addition, there is the love for the material itself, which first makes it possible to select the right piece of timber, and for every single piece held in the hands, to allocate this to the right purpose and work it appropriately.

For how many years must a capable carpenter learn, watch, gather experience, in order to acquire this knowledge? What information can tables convey, tables from which our budding carpenter could read how much shrinkage takes place for which species of wood under which temperature, weather, regional and other conditions and over what period of time? What can tables tell the carpenter if after reading and learning them he is tested on them but cannot implement them in practice? Thirty years according to one man who has tried to follow in the footsteps of Japanese temple carpenters.[82] Whatever timescale is set for the trainee, one characteristic of the best masters in particular is the neverending analysis of the works created, their own and those of others, and the readiness to examine in detail, to uncover errors or areas for improvement, and to implement what they have learned in practice at the next opportunity.

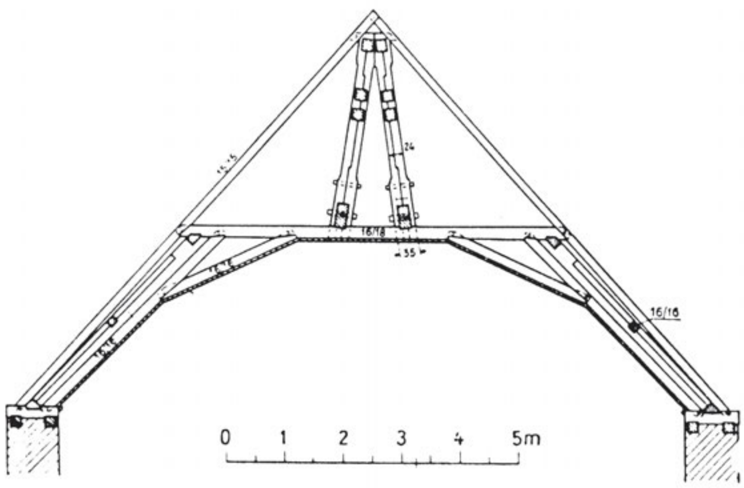
The outstanding talents of Hans Ulrich Grubenmann were not just handed to him on a plate. Graubner is of the opinion that Hans Ulrich, unlike his brother Johannes (Fig. 126), took up the Roman idea of indented beams[83] and adapted it for his bridges. (Fig. 127) However, we do not have to look so far to find an example of indented bridge beams; there was a bridge over the Sitter from Gossau to St Gallen (Switzerland) built around the end of the 15th century. A model can still be seen in the town hall in St Gallen.[84] Later, as Hans Ulrich Grubenmann also took on contracts for churches, he demonstrated again and again the engineering skills of his bridge-building. His arch construction – like a strut frame –, which was developed as longitudinal wind bracing for the Reformed Church in Ebnat, Switzerland, gradually evolved into the composite truss frame supporting the upper part of the roof truss in the church in Grub, Switzerland, (Figs 128 & 129) and later into orthogonally interlaced composite truss frames for the Reformed Church in Wädens-

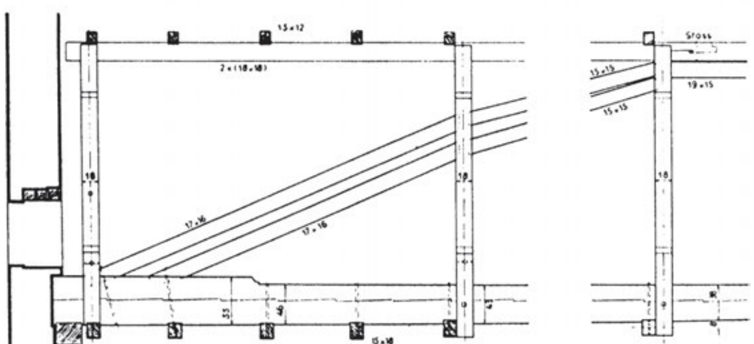
126 Johannes Grubenmann used indented beams to strengthen the girder members of the strutted frame abutting every truss post on the Rümlang bridge near Oberglatt, Zürich, Switzerland.



127 Shortly before his death, Hans Ulrich Grubenmann built the Kubel bridge near Herisau, Appenzell, Switzerland, without the help of iron nails or ties. The upper chord, which simultaneously serves as the inferior purlin for the roof, is strengthened by an indented beam exactly at the point where the straining beams of the girder join the chord.

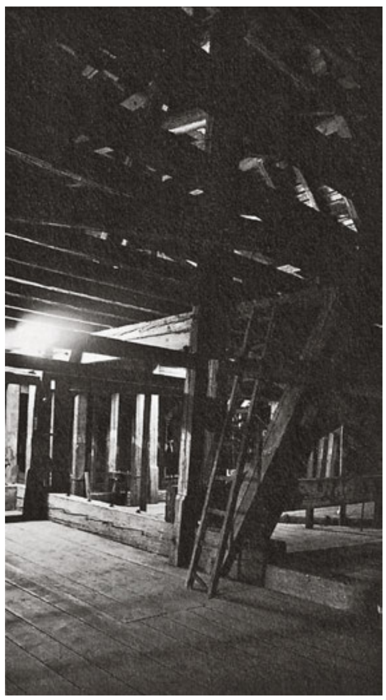
128 No other roof truss of Hans Ulrich Grubenmann demonstrates so clearly as this one in Grub, Appenzell, Switzerland, that he had learned his trade in bridge-building.



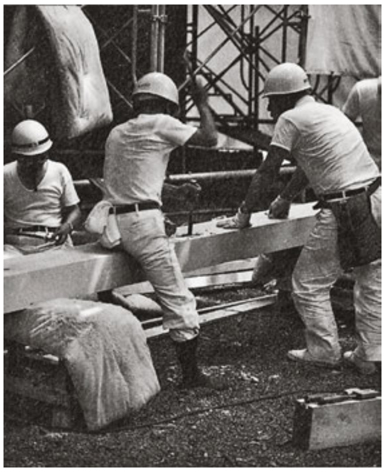


129 A ridge beam carries the load of the upper section of the roof, as well as the suspended coffered ceiling, and transfers it to the gable masonry of the church in Grub. (source: Killer, 1985, Figs 75, 77)

130 Indented longitudinal tie beam in the roof of the Reformed Church in Wädenswil, Zürich, Switzerland.

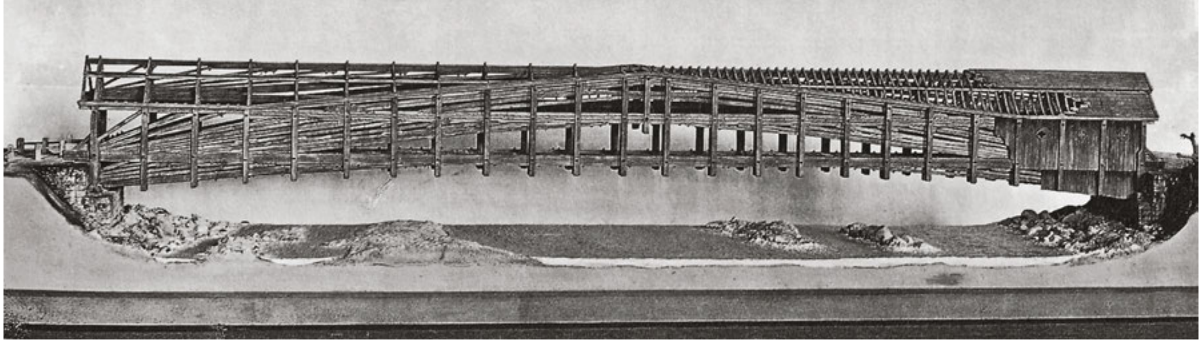


wil, Switzerland.[85] (Fig. 130) His designs became structurally better and clearer as he proceeded from each church roof truss to the next.[86]
It is surely an indescribable feeling to realize that all that totally theoretical knowledge about the material, which is so difficult to compile today, has been incorporated in one single building complex. Nishioka Tsunekazu says that he gained this experience with the reconstruction of the Horyu-ji.[87]
With the coming of the textbook, tradition as the regulator was slowly ousted.[88] In Japan the first handbooks appeared during the Edo period.[89] They did not demand slave-like obedience to the examples shown but instead presented them more like recommendations. As building at that time was still very much based on tradition and organizational restrictions carried such weight that major changes were not even dared, serious new ideas were limited to *tokonoma* and *chigaidana*.[90]
Likewise in Europe, the first textbooks were published in the 17th century.[91] However, they should be regarded more as self-portrayals and advertisements of a craft in dire need after the horrors of the Thirty Years' War.[92] Russian carpenters had to wait until the middle of the 19th century for their first textbooks.[93]
However, missing from these early handbooks are details, rules perhaps for fabricating joints. This knowledge was so taken for granted that nobody thought of producing drawings, let alone with dimensions!
More important than drawings were models. For a long time they took the place of structural calculations. And they were not just produced for the client – the carpenter made use of them too for studying problematic details. (Fig. 131)
As the traditional handing-down of the knowledge disappeared at different rates of rapidity, so did the traditional knowledge itself. It is interesting to note that this fact is only acknowledged by authors describing Japanese carpentry although in Japan the traditional method of building is far more alive (Fig. 132) than in Europe where it seems to be difficult these days to find anybody who still knows how to handle a hand tool.
In hardly 100 years the knowledge accumulated over some 1,300 years, constantly extended, refined and adapted to new tasks, has been allowed to seep away, as the Japanese carpenter Nishioka states with regret. What he was able to pass on was only a small fraction of the former wisdom.[94] The restorers of the Todai-ji in the Tokugawa era (corresponding to the Edo period) could acquire the knowledge from their grandfathers. At the end of the 18th century much time had been lost since the construction of castles, palaces and religious buildings at the beginning of the Tokugawa reign, but there was still a



132 Carpenters fabricating a sill for a building in the Ise-jingu complex, Mie, Japan.

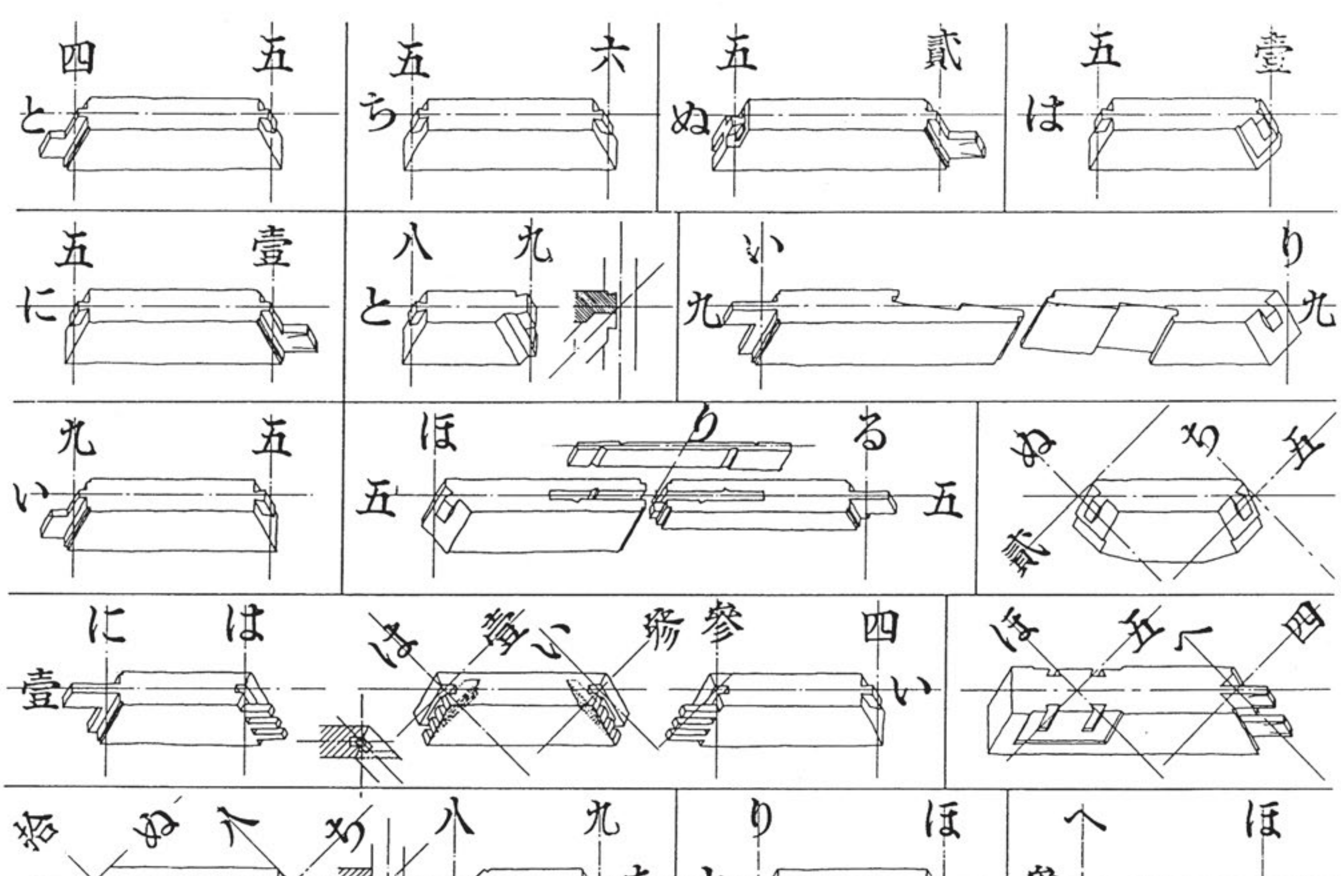
131 This model of a bridge copied from drawings and made in 1913 shows the unapproved first design for the 119-m-long Schaffhausen bridge. Grubenmann was forced to introduce a central pier in the bridge that was actually built. (photo: Deutsches Museum, Munich)



chance that the knowledge would not be lost for ever.[95] By the start of this century, during the Meiji era (1868–1912), it was too late. The special problems which buildings of this order of magnitude throw up were now being solved with the help of modern technology.[96]
The Europeans have already bid farewell to the traditions of timber building so unequivocally that a discussion, like the one started by the architect Seike in Japan, is simply no longer relevant. He too regrets the lack of experience shown by modern carpenters, but in the new materials and associated technologies does not see any danger for the few who campaign for the preservation of traditional methods of working.[97] The progression away from the comparatively complex traditional method of timber construction can no longer be stopped, even in Japan. However, it seems there are still individual carpenters tucked away proving their worth, handing down their cultural heritage. (Fig. 133) The carpenter Tanaka Fumio designs many wooden joints himself, following on in the old traditions.[98] (Fig. 134)

133 Traditional timber construction is easily discernible on the newly built Kyuhonjin kinenkan in Hirata, Shimane, Japan.

134 Design sketches for wooden joints by Tanaka Fumio for a house built by him. (source: *Kenchiku bunka*, Vol. 38, No. 439, 1983/5, p. 129)



In most instances tools which fulfil the same or a similar purpose look very much the same no matter where they come from.[99] But only at first sight. When we look more closely we see that the very great differences in the way the Japanese use woodworking tools, in comparison with the Europeans, has led to their tools taking on a totally different form.

It is worth comparing a description of Japanese tools by an American, who we shall take here as representing the Western viewpoint, and a description of European tools by a Japanese. Edward Sylvester Morse was an ethnologist who spent several years in Japan in the second half of the 19th century. He mentions one of the most conspicuous distinctions at the beginning of his less than flattering comparison: "When I look at our heavy toolboxes made from shiny wood, with their costly marquetry, and see how they are crammed full with tools worth hundreds of dollars – flawless tools produced by expensive machines –, and when I think of the work which is performed with those tools, where it moves but should be fixed, where it is fixed but should move, where much has to be done twice, everything which highlights the shortcomings – and when I then think of the Japanese carpenters with their ridiculously light toolboxes which only contain the simplest and barest essentials – when I compare the carpentry of these two cultures I come to the conclusion that civilization and modern technology are worthless if they are not accompanied by a decent portion of competence and a pinch of taste and wit."[100] Muramatsu Teijiro also begins his comparison with a description of the impressive appearance of the European toolbox: thick, robust, massive and strong – these terms "symbolize the sweat and blood of those who work with them." In complete contrast, the light tools of the Japanese carpenter, with their small, narrow and extremely sharp blades, "bear witness to an almost insatiable, ascetic passion for the craft."[101]

Bruno Taut was reminded of a mechanic when he saw the Japanese carpenter's tools spread out; it was not the many different tools but rather the many different gradations of the same tool which suggested this image to him.[102] A study carried out in 1943–44 brought to light the fact that our Japanese carpenter needed at least 179 tools. The credibility of this figure becomes more believable when we break it down: 49 chisels, 40 planes, 26 gimlets, 17 assorted tools for measuring and marking, 12 saws, 9 pairs of pincers, 6 hammers and mallets – but just 2 different axes. At the same time, this list shows us just what capital a carpenter was prepared to invest in tools. The importance of caring for the tools is also clearly revealed: 6 whetstones and 5 files complete our list.[103]

That European and Japanese tools developed along different lines can be attributed to three main factors. The European tool was designed to deal with hardwood, the Japanese for softwood. This leads to the blade of the European tool appearing thick and blunt to the Japanese.[104] Such a tool damages the surface of the wood to such a degree that a good finish meeting the extremely high demands of the Japanese – their surfaces are usually left untreated – is impossible. Softwood, i. e. wood of lower density, requires a razor-sharp tool with a blade as thin as possible if it is to be worked cleanly. This affects chisels and planes in particular. The methods and skills of the sword-cutler were exploited here. The fusing of a comparatively soft core with an extremely hard steel as an outer shell led to the legendary cutting ability of the Japanese Samurai sword. As in 1876, following the period of Tokugawa rule, the making of Samurai swords was forbidden, the sword-cutlers were forced to channel all their secret formulas into the production of tools. Never before had craftsmen possessed such fantastic implements.[105]

The European manner of using tools is mainly characterized by a thrusting action away from the body, the Japanese by a drawing action towards the body. This technique shifts the emphasis of the work away from one of strength to one of more sensitivity.[106] In the case of most European tools their size and weight alone indicate that they are designed to exploit the physical strength of their user.

The second main difference is that Japanese carpenters hardly ever need a drill, at least not in a form which their European counterparts would understand. The drilling of starter-holes to ease the subsequent chiselling-out does not belong to the Japanese carpenter's repertoire of techniques.[107] While timber joints in Europe would have been unthinkable without wooden nails – and every single scarf or tenon joint was secured with wooden nails, precisely because this technique suited the use of hardwood –, Japanese carpenters devised joints bearing in mind that they must work long-fibred and hence comparatively pressure-sensitive softwood. It is not necessary to drill holes in order to secure joints with wedges and dowels. The only drill known in Japan was a sort of gimlet which was rotated back and forth between the palms of the hands. Its main use was in forming the holes through which ropes could be passed. Tied together in this way, the felled timbers were floated downriver.[108] In Europe on the other hand, a multitude of corkscrew-like drills were produced. Such a form, which, incidentally, later led to the development of the screw thread, was totally unknown in Japan.[109]

The third difference is the attitude of the user to his tools. For the European they are a necessary collection of implements which are intended to ease the work as far as possible. However, even today the Japanese carpenter speaks not simply of tools but of *dogu*, "the instruments of the Way of Carpentry",[110] and this despite much altered working practices in some respects and despite the use of all the machines which are also customary here. This testifies to an extraordinary esteem, an almost religious respect and subjugation which was considered to be the very foundation for really competent work. If an apprentice simply stepped over a tool, then it was for the apprentice understandable and for the master a matter of fact that such disrespect would be punished with a clip round the ear.[111] For many years an apprentice was not allowed to handle the tools. A psychological calculation lay behind this rule: apprentices were to be forced to watch the master and journeymen using their tools until they were overcome with an unquenchable desire to try out for themselves what they had observed and learnt through watching throughout that long period. Only the very simplest basics were taught directly. All the rest the trainee gleaned from *nusumi-geiko*, "stolen lessons" – watching. Total immersion in the working environment and real motivation underpinned the development process of youngsters at a highly sensitive and impressionable age as an anonymous master. The learning process of the apprentice was inextricably linked with the maturing process of the adolescent. The result was that both daily routines and the majority of solutions to the problems which arose were no longer analysed. The master had come this way too.[112] This mental attitude with all its pros and cons has in the meantime been lost.

Western perceptions favoured the development of tools which, directed towards better handling and a constant easing of the work, pathed the way for the development of machines and factory production. Japanese thinking on the other hand, until the turning-point during the Meiji era, was trapped in a feudal structure, a way of life which was opposed to changes and characterized by striving to get every last ounce out of craftsmanship.[113]

The outcome of these different conditions is reflected in the differently shaped tools. The European implements stand for efficiency and practicality. They were designed to serve "like domesticated animals".[114] Carpenters went to great lengths to adapt tools to meet their personal needs. The great variability in the toolbox was constantly increased by the segregation and specification of various woodworking trades. European carpenters expressed their relationship with their tools by way of artistic designs.

The tools of the Japanese carpenter must be seen more in the sense of a tyrant to its user. In the 6th century the tools of China and Korea, based on the same principles as those of Europe, reached Japan as the peoples of those countries made their knowledge available to the group of islands off their coasts. Tools requiring a thrusting action were still used in the building of the Horyu-ji (AD 607).[115] Even more astounding is the development which modern Japanese tools have undergone, a development for which we have to make suppositions in our attempt to uncover the reasons. The more difficult a tool is to use, the less comfortable it is to hold and the more attentive the user has to be. The handle of a Japanese saw in no way embodies good ergonomic design; it is nothing more than a straight piece of wood forming an extension of the sawblade and roughly as long as it. However, the concept of cutting on the backstroke, along the line of the stick-like handle, enables a totally different control over the work from that of the European saw. For the movement towards the user, leading automatically to the centre of the body, means that, basically, a saw cutting on the backstroke is much easier to guide in a straight line.[116] Apart from that, the strength of the arm is adequate for pulling Japanese saws with their much narrower set. In contrast, the guiding of the European saw is designed to be backed up with the force of the whole body.

The plane introduced by the Chinese was a wooden block with handles left and right. It complemented the *yariganna*, a tool unknown in Europe. (Fig. 135) This cutting tool, sharpened both sides, bent up slightly towards the tip and held in both hands by means of a long handle, was used for finishing planks and columns which had been hewn out. It did not take long for the

Chinese plane to be turned around, robbed of its handles and then pulled towards the body.[117] Therefore, Japanese carpenters quite intentionally rejected something which, from the point of view of the movements involved, had eased the work. As there are absolutely no records of why this was done, we can only speculate about the reasons. When using a saw, the eye of the Japanese carpenter follows the surface of the wood which has been sawn and not that which is to be sawn. When planing the opposite is true. The drawing motion enables the user to guide the plane over any length without having to lift it off the workpiece at all. Specially shaped handles do ease the work but, in the end, redirect the force. With direct guiding of the plane block, the bond between hand and wood is felt most intensely.

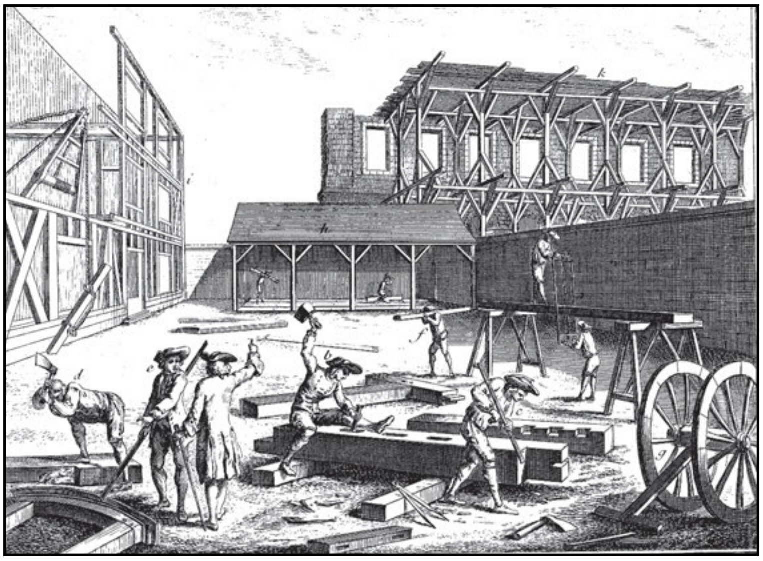
The small Japanese plane in the hand of an experienced and skilful user is an indication of the quality of the surface; it is through the plane and not visually that the competent user feels the texture of the surface to be worked. Plane shavings many metres in length but only a few hundredths of a millimetre thick are apparently only possible with such a tool. They are not simply an indication of a carpenter's skill but instead are necessary to meet the demands placed on the quality of the work influenced by aesthetic values.

Further different designs are encountered in chisels as well as axes and hatchets. In Japan tools that can only be used in one direction are nothing out of the ordinary. Knives employed for boring holes or finishing curved internal surfaces come in pairs, used depending on the direction of the grain. Likewise the shoulder plane, which has to be built for one corner or the other, depending on its intended use. The Japanese carpenter has always painstakingly made sure to cut in the right direction, and

135 Carpenters building a shrine. (source: *Matsuzaki tenjin engi emaki*, Roll 4, 1311) Up until the introduction of the plane during the Muromachi period (1392–1573), it was the *yariganna* (2nd row from bottom) which gave wood in temples and shrines its noticeably characteristic surface finish. Like the *chona* (bottom row), an axe with transverse blade and related in function and appearance to the European adze, it had long since lost its significance. Both tools were again employed in the reconstruction of the Ise-jingu. By using them extensively in the Yakushi-ji reconstruction, Nishioka helped them regain their high regard among the initiated.

never to tear open the fibres; for subsequent corrective measures, which should remove no more material than was planned, would of course be impossible. It is for precisely this reason that the Japanese are so amazed that in Europe it is only the hatchet which has a single-sided alignment. Accustomed to always working with one eye on the direction of the grain, they suspect that the one-sided, curved design really conceals a desire to also be able to work against the grain.[118] Actually, the differing curves of the hatchet came about in order to take account of left-hand and right-hand use![119]

The range of tools used in Europe did not alter substantially from the time of the Roman Empire to the end of the 19th century.[120] (Fig. 136) The journeyman had to buy his most important tools himself: a try-square for marking out or checking right-angles; a carpenter's axe, firstly for the very rough work such as cutting a beam from the trunk, and secondly as a true universal tool for striking, likewise cutting and chopping; a chisel and mallet; an adze to remove large amounts of material but also, like the *yariganna*, to smooth the surface. All other tools were



136 Contemporary print (source: Diderot, 1763, Pl. 1)

provided by the master for whom the journeyman worked: various saws, axes and hatchets, assorted drills, spirit level, plumb-line, dividers, snap-line with spool and inkpot.[121] The *sumitsubo*, the Japanese equivalent of the marking line, was the only tool which appeared in countless variations covered in artistic carving. (Fig. 137) However, this, for Japan, unusual decoration of a tool did not appear until the end of the 19th century.[122]

The average Japanese carpenter uses no more than 80 tools today, including power tools. Only a first-class craftsman possesses perhaps 200, but only needs 120 of these. During the Asuka period (552–645), as the first temples were built, the carpenters had no tools other than chisels, axes, *chona* (the Japanese equivalent of the adze) and *yariganna*.[123]

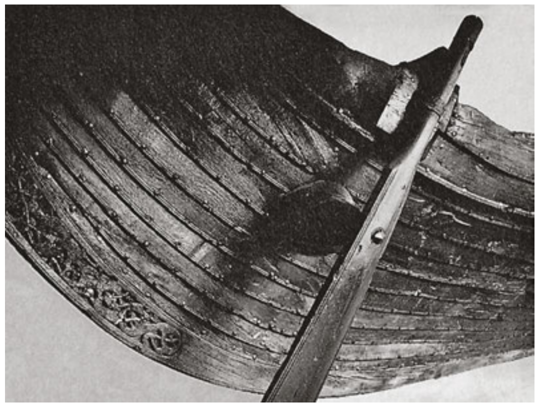
A properly maintained tool is a prerequisite for allowing the imagination to run free. There is no joint which cannot be made. That is why there appears to be such an unbelievably large number of tools to our way of thinking. If every corner, every groove, every tenon, every hole really is to be executed exactly as it was designed to be, then not even the very slightest concessions, no "cutting corners", can be permitted in the execution.

137 A horizontal plane is established with the aid of a try-square and a *sumitsubo* acting as a plumb-line. (source: Suzuki, Masaharu, 1847)

For the Japanese an immaculately smooth wood surface is an aesthetic quality which the carpenter must take into account through the artistic employment of the plane. The Europeans have different tastes. To satisfy the European client, the European carpenter must be able to handle a carving tool. Whether just the use of a *geitsfuss* (Fig. 138) or more advanced ornamentation right up to three-dimensional figures (Figs 139 & 140) is in the end merely a reflection of contemporary tastes. However, there are indeed examples of artistic Japanese carvings which should not be absent from any history of art, whether they be in the Nikko Toshogu, Nijo-jo or Nishi Hongan-ji in Kyoto. (Fig. 141)

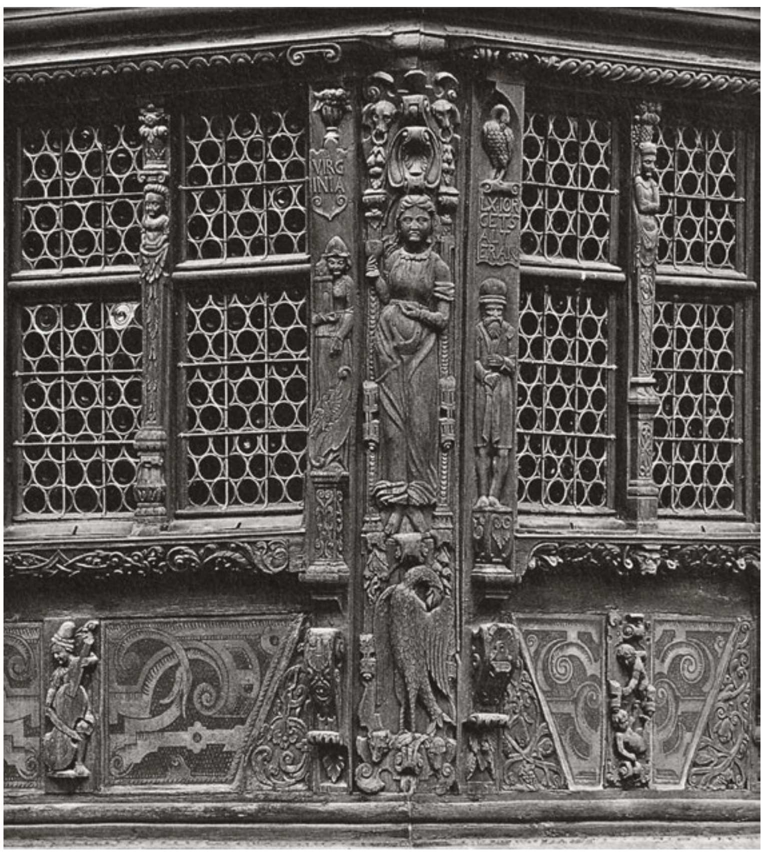
How the different species of wood were taken into account during the work can be demonstrated by means of the chisel, a tool which neither the Japanese nor the European carpenter could do without.[124] The chisel has played a much more prominent role in Japanese architecture than in European.[125] To obtain the necessary sharpness, a steel considerably harder than is known in European tool production was forged on using the method mentioned earlier.[126] Without appropriate experience and practice, enjoyment of the super tool will be short-lived. The harder the steel, the more easily it will break and the less it will tolerate in incompetent hands. Comparative tests have shown that hand-forged Japanese chisels have a lifetime up to six times that of those which stem from Western mass production. Japanese carpenters who were proud of their abilities never drilled a hole because even the smallest destroys the fibres which it touches. That represents a significant difference to the European approach. In Europe, every slot, every hole for a joint was first drilled out as far as possible so that only the sides of the joint needed to be cleaned up with a firmer chisel. If a Japanese carpenter had to produce a hole, then he had specially shaped chisels which tapered towards the tip and with which a square hole could be formed.[127]

Among the carpenter's tools, the saw occupies a particularly headstrong position. Its most conspicuous feature across many parts of Europe is its misuse. The readily quoted comment of Phleps concerning the saw: "The tool which violates wood the



138 Every plank on the stern of the Oseberg ship has been decorated using a *geitsfuss* in exactly the same way as many log buildings. – Viking Ship Museum, Oslo, Norway

141 The Zuisen-ji in Inami machi, Toyama, Japan, is among the less well known temples. However, the richly carved brackets of the Zuisen-ji taishido prove that gifted carvers were not unknown in the region.



139 Corner column in the second storey of the Kammerzell House in Strasbourg, Alsace, France.

140 Detail of the faithful reproduction of the carved portal on the stave church in Urnes, Sogn, Norway.

142 Fulfilment of the wish for ornamental creations without having to be an artist helped the saw become widely established much more easily than statutory rules and regulations could ever have done. – Ciucea, Cluj, Romania

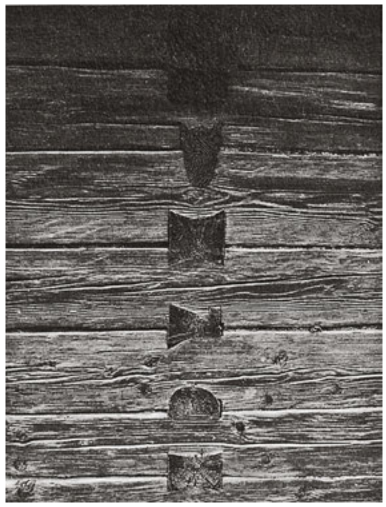
most",[128] was not solely responsible for this. Convinced that using that "most awful of tools"[129] would signal the end of traditional timber construction, his angry words sound like those of a man who was painfully aware of his inescapable defeat at the hands of economic progress. "The dangerous and damaging opponent in artistic terms"[130] becomes highly stylized as a personal enemy. Resigned to the fact, Phleps still continues to grumble years later: "Although it [the saw] simplified woodworking, through its contemptuous division of the structure of the fibres it became the tool for the inconsiderate destruction of the characteristics of wood."[131] What it was that gave Phleps the opportunity to curse and swear about such a tool in the 20th century was the inertia of those who did not want to make use of saws to which they were not accustomed. Of course, Phleps' comments provide us with food for thought. Therefore, in the light of pronounced jig-saw architecture some may ask whether such results were worth the development of the saw. (Fig. 142) However, it would be a misrepresentation of the facts if we were to say that it was solely the undeniable economic advantage of the saw which led to its acceptance. The fact is that the saw, as we know it today, has been around since the Bronze Age. As it had no set, hence tended to jam in the cut, and was made from soft material, it was pulled, i. e. it cut on the backstroke. The Romans provided the saw with a set, thereby enabling deeper cuts. However, really viable saws did not appear until humans were able to work steel – from the 15th century.[132] In Europe it is only since the end of the 19th century that the entire sawblade has been made from steel; formerly, only the front end was steel.[133] Perhaps Phleps would have revised his opinion if he had had the chance to watch Japanese carpenters at work. Many interesting joints, like those of the *isuka-tsugi* group,[134] have evolved, notionally, out of the proper use of the saw.

Looking closely at a Japanese saw, one will get an idea of how much experience, over generations, has contributed to the saw's present form. The first main feature is the shape of the teeth. For cutting with the grain they correspond more or less to those of our handsaws. In contrast, the teeth for cutting across the grain look very different. These two basic types are then further subdivided into saws for cutting hardwood and saws for cutting softwood. The idea behind this diversification is the opinion that it is the teeth which should do the cutting and not the force used. As the teeth of a saw are not equally loaded, this observation has also been incorporated in their design. Both the angle and the size of the teeth varies. It is really amazing to see how specialized the range of circular-saw blades in Europe has become, while for manual work the same European saw must cut both hardwood and softwood, both with and across the grain.

In Japan too, the importance of saws alongside the other tools is not the same everywhere. In building a *minka*, saws only came into use during the Edo period.[135] However, the cross-cut saw was already the favourite tool of Japanese lumberjacks as long ago as the 18th century.[136] Their use was prescribed for European lumberjacks even earlier – in the 17th century – but in some exceptional cases could still not be enforced even in the 20th century.[137]

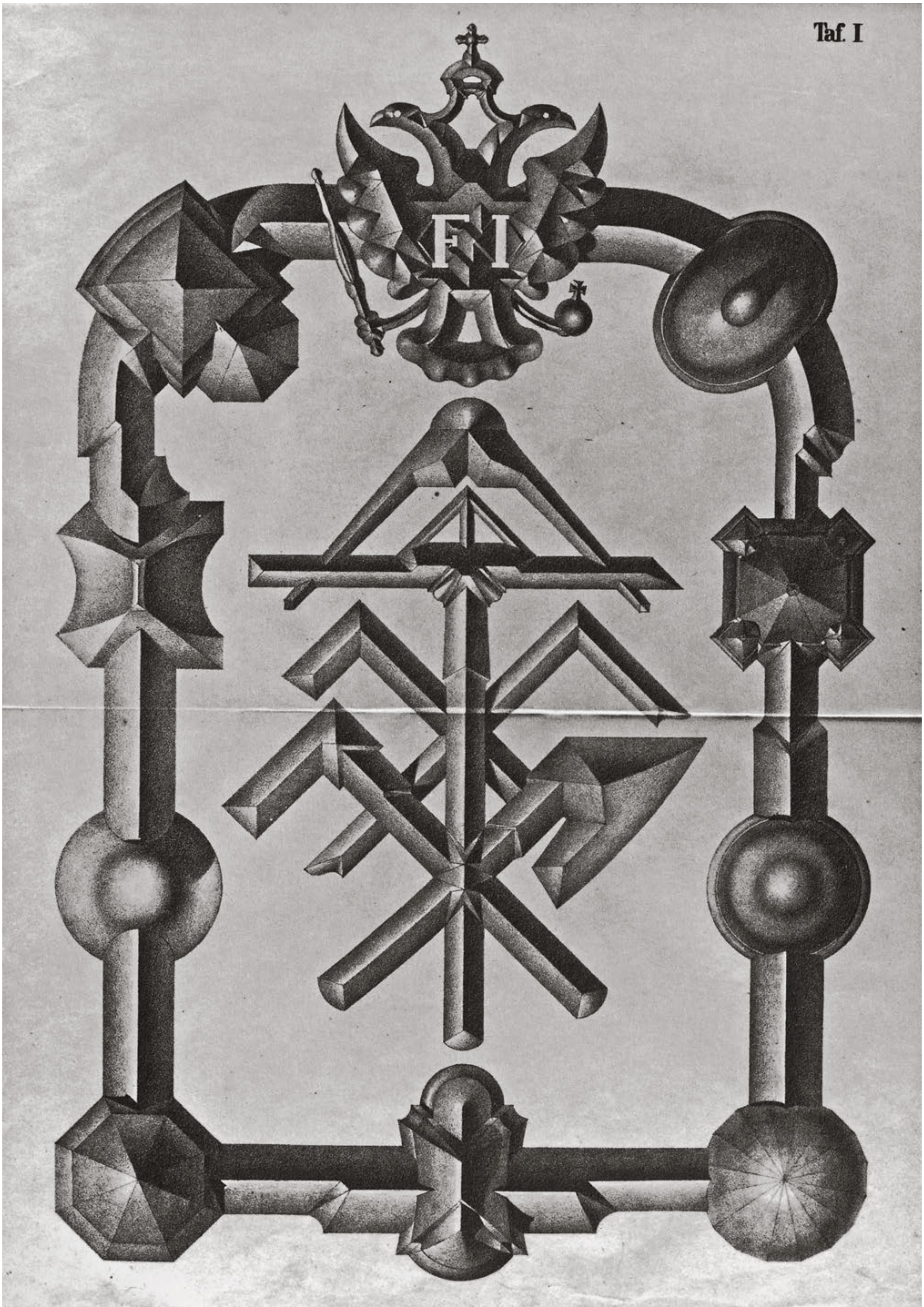
I started this description with the very different value placed on tools by European carpenters in comparison with their Japanese colleagues. This regard for their tools was not only expressed in their diverse forms. The same playful streak which drove the carpenter to decorate his tools now inspired him to experiment with the form of the material to be worked. What could have been more obvious than to play with his tools?[138] (Figs 143 & 144)

Whether our carpenter relies on the power of his internal composure, as is expressed in a certain way in the ascetic tool, or finds his impetus in the effusive, relishing, earthbound nature, which in turn characterizes the appearance of the tools,[139] "what matters above all is the level of precision of the work and the beauty and finish of the result. What the craftsman ultimately serves through union with the tools he uses lies beyond function and efficiency; it is beauty."[140]



143 The pictorial representation of an axe in an integral partition wall in Laufen, Bavaria, Germany, is an indication of the specifically European regard for the tool used.

144 The tool of the carpenter, incorporated graphically in a presentation of what it was used for: the creation of a roofscape. (source: Gierth, 1840, Pl. 1)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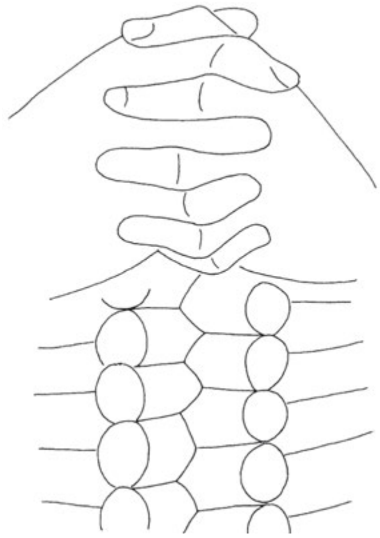
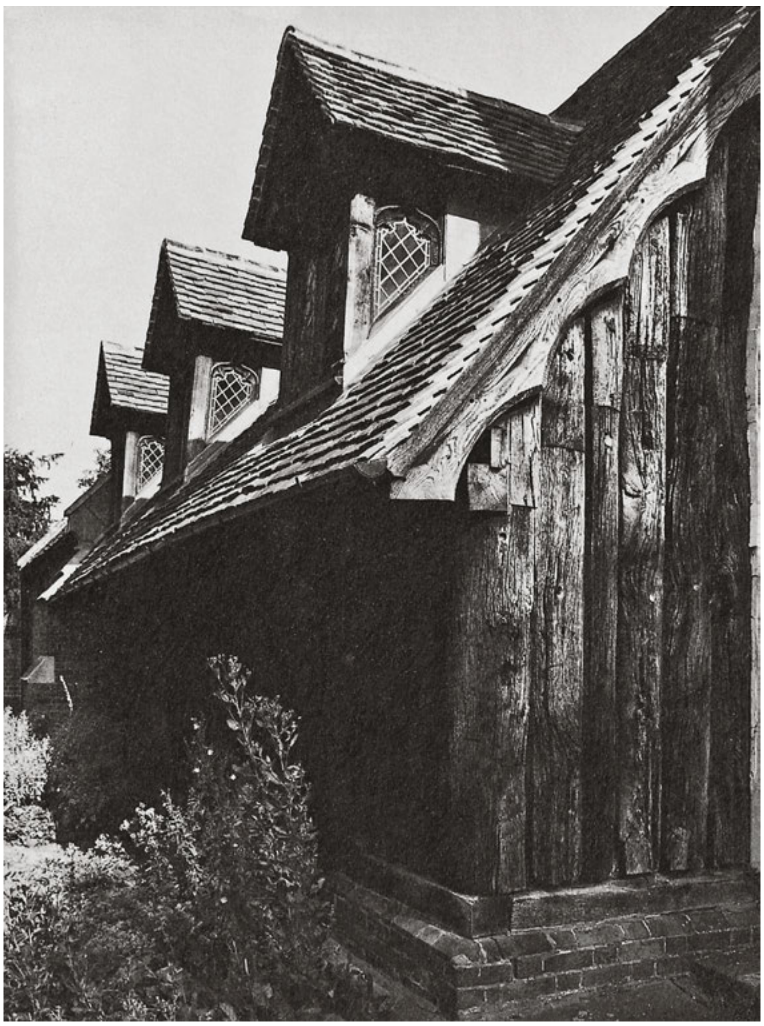
Traditional timber construction can be divided into two categories: log construction and the considerably older skeleton construction.
The literature on wood is still peppered with the wrong ideas concerning the supposed primitiveness of log construction, which then gives rise to false conclusions. Its peculiarity stems from the fact that the building of a wall, a two-dimensional element, is only possible in three dimensions. Therefore, a log wall can only be produced in conjunction with at least one adjoining wall. On the other hand, it is irrelevant whether these walls are built as flat or curved surfaces. This consideration alone should make it clear that the transition from windbreak – often regarded as the first type of protection erected by mankind – to log construction cannot be considered without at least taking into account other facts. (Fig. 145) There are of course serious ideas about the formal relationship between wattlework and log construction, particularly in terms of the jointing methods,[141] but to designate log construction as "the simplest form of construction", as "the archetypal woodworking technique which then later developed to become column-and-beam construction" is quite simply wrong.[142] Some authors do not make it any easier when they note that in some countries the reverse may have been true, but in Poland log construction is older. The reasoning alone places this claim in a poor light:

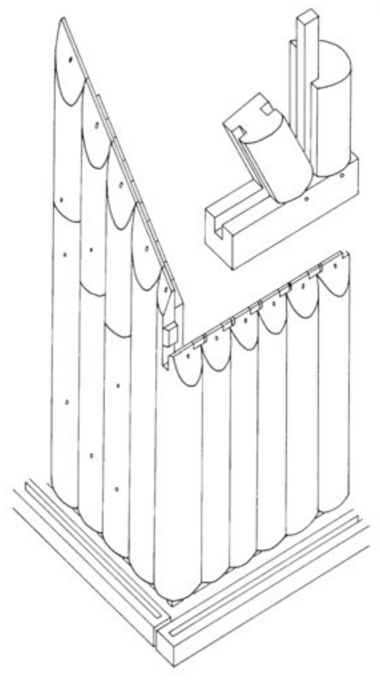


145 The likeness between interlocking fingers and log construction does indeed point to simplicity, but it also demonstrates the creation and separation of interior and exterior. (source: Kükelhaus, 1988, p. 28)

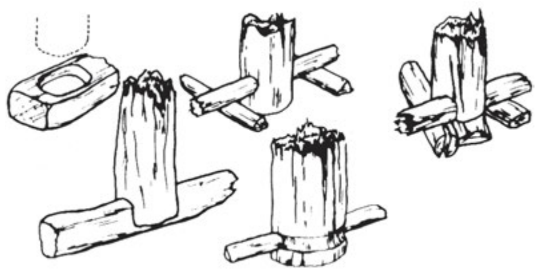


146 The oldest surviving church made from halved oak trunks originally had a earthfast wall. – Greensted-juxta-Ongar, Essex, England

"Log construction only requires a relatively superficial processing ... Columns call for artistic mortises where they should be mortised into horizontal wooden elements."[143]
The appearance of log construction is characterized exclusively by the horizontal arrangement of its timbers. In skeleton construction it is the vertical members which take on the load-bearing function. And to hold them in their vertical position they have to be placed in the ground; they are then called posts, whereas those erected above ground level are called columns. There were two possible alternatives for forming the walls. Wood-to-wood, whether unworked trunks, half-timbers or planks, placed in the ground produce a palisade or stave wall. The corners could be simple here but could equally as well take on an architectural identity.[144] On the church at Greensted-juxta-Ongar, England, one can still discern how the half-timbers were able to be taken round the corners without the need for joints. (Figs. 146 & 147) The other possibility was to drive the posts into the ground at a certain spacing and to fill in the intermediate spaces by means of a wall.
Changes took place in two areas simultaneously. One concerned the filling between the vertical elements, the other concerned the evolution from post-and-beam to column-and-beam construction. If we begin with the latter, it must be remembered that a uniform and generally valid line of development cannot be drawn, neither in regional nor in chronological terms. Post construction caused various problems. A piece of wood standing in the earth is not only at risk at the point where it leaves the ground, although that is the point most in danger. The post could also sink in, which then became very awkward if a head beam was placed on top of the row of posts afterwards. To prevent this sinking, the base of each post was mortised into a horizontal beam which itself could be supported on pieces of timber laid perpendicular to it.[145] (Fig. 148)
The next step was probably laying out the bracing to the posts on the ground.[146] This simplified the integration of the individual bracing timbers. When lying on the ground they could be seen and exchanged if necessary. It was then only a small step to connecting the separate bracings because, in the end, the desired effect was multiplied when two posts were linked together. Every vertical member which was mortised into this horizontal beam fixed into two posts became a column, even though tradition dictated that its tenons still be buried as deep as 2 m in the ground. The horizontal timber had thus become a sill beam.[147] For the 500 years before the birth of Christ, such sill beams had this load-distributing function. So, in the first instance, the evolution of the sill beam had nothing to do with protecting the structure from moisture. Indeed, as long as the sill beam remained directly on the ground, its use for such a purpose would have been strictly limited.
The further evolution to column-and-beam construction was by no means a continuous process, no matter which way you care to look at it. In German timber-framed buildings, sill beams lap-jointed to the front face of the individual columns are met with again towards the end of the Middle Ages. The lap-jointed sill was replaced by mortised interrupted sill beams which were in turn ousted by the continuous sill running between corner columns.[148] What this really achieved was increased flexibility

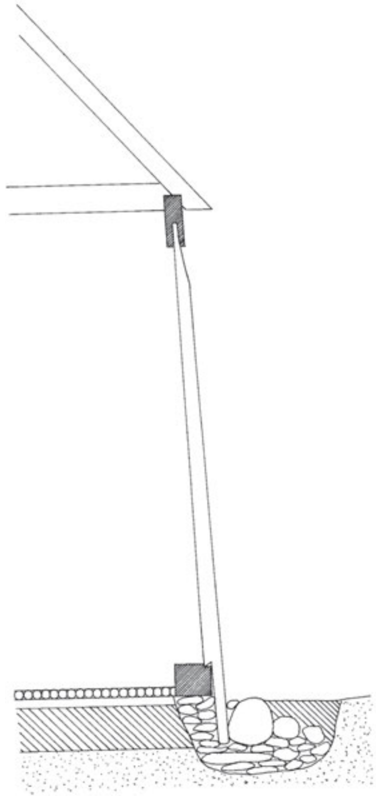


147 The internal quarter of each corner post was cut away along the whole length of the post. The right-angled notch lay exactly at the junction of the internal wall surfaces. – Illustrated here simplified (according to: Hewett, 1980, Figs 3,4)

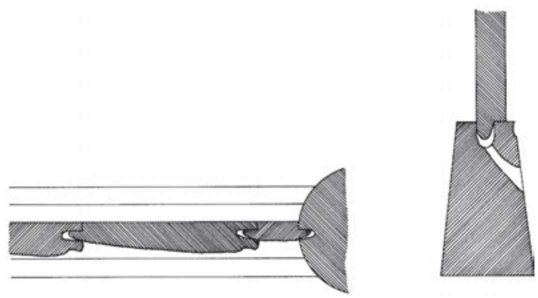


148 Various methods have been tried out to prevent the posts from sinking under load. (source: *Tsugi shiguchi kenchiku no kakusareta*, 1984, p. 24)

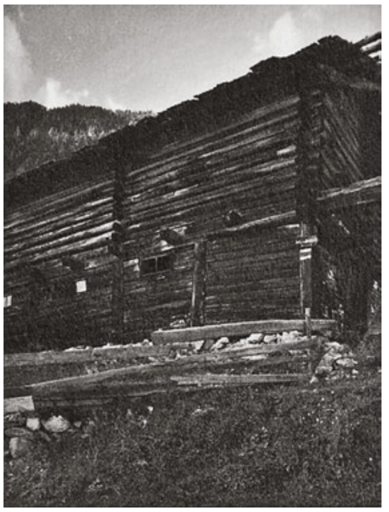
in construction: the positions of the columns could now be determined relatively freely, and hence the window divisions.
In early Nordic stave church building, a sill was slipped under the vertical wall planks from inside. (Fig. 149) In this detail, barefaced, quasi undersquinted notches in the planks engaged with a corresponding groove in the sill, just like "standing" rafters engage with the inferior purlin. (These standing rafters are leaned against the ridge purlin in contrast to rafters hanging from the ridge purlin. They need no joining to the inferior purlins.) In this case, protection against moisture was almost certainly at least as important a consideration.
The practicability and success of the water drainage system developed here is brought to light by the excavations at the stave church in Silte, Sweden. The church's timber predecessor was discovered beneath the 13th-century church. The remaining wall planks were able to be detached undamaged from their connection with the sill beams. As the wall planks were not nailed on at all, no moisture could pass through to the sill laid on a dry masonry wall. The wall itself was wedged with stones into a brilliantly well-thought-out drainage channel in such a way that it required no further means of fixing.[149] This system of protecting the wood appears to have worked at least as well as that of the much better known Norwegian stave churches still standing today. (Fig. 150)
The question of how long post-and-beam construction remained in use despite the problems it caused, or when column-and-beam construction took over and the different set of problems that caused were accepted, has never been satisfactorily answered.[150] Some claim the end of the first millennium marked the end for the former,[151] others maintain it was still in use in the 16th century.[152] In the case of barns – subordinated utility buildings – the loadbearing elements were still being placed in the ground during the 17th century in parts of Germany.[153] In Japan it was towards the end of the 18th century before a sill beam was able to be introduced under a *minka*.[154] While in Scandinavia the transition for churches can be given as the 12th century – in contrast to secular buildings, which waited another two hundred years –,[155] the influence of the Roman sill-and-column construction could not be proved for early medieval timber church architecture in German towns.[156]
The developments in skeleton construction taking place parallel with the transition from post-and-beam to column-and-beam construction had an effect on wall infills. The choice was between a purely timber filling and the plaster-covered filling known from timber-framed buildings. If the planks were incorporated horizontally, they had to be set into grooves in the columns or posts left and right. (Fig. 151) If they were arranged vertically – reminding us of the palisade wall –, they had to be mortised into the header beam or, if a sill beam was present, into sill and header. This then formed a stave construction.[157] (Fig. 152)
However, the stave wall as a wall infill is also tongued-and-grooved at the sides, into the framing members. This distinguishes it not insubstantially from the column-and-beam construction with horizontal plank infills. The filling of horizontal planks makes clever use of gravity by allowing the horizontal planks, guided in the slots at the sides, to slide down as they shrink. In stave construction the carpenter must actively take



149 In early Nordic stave church building, a perfect system was developed to protect the sill against moisture. (Detail based on reconstruction drawing for Silte, Gotland, Sweden, by Trotzig in: Ahrens, 1981, p. 291)



150 The wall planks were mortised into sill beams which contained grooves deepened to form inclined drain channels; these threatened to become blocked by leaves or moss growths. – Detail of external wall of stave church in Kaupanger, Sogn, Norway. (based on: Ahrens, 1981, p. 175)



151 Column-and-beam construction combined with log construction above in Köfels, Tyrol, Austria. The walls between the columns are filled with horizontal planks tongued-and-grooved into these.

153 A wedging plank driven in from outside restrains the flooring of the upper floor supported on stilts in this log building in Reckingen, Wallis, Switzerland.

152 Column-and-beam construction with vertical plank filling in Goricko, Slovenia.

154 **The stave wall of the church in Urnes, Sogn, Norway, is restrained by means of a wedging plank.**

155 **In the timber-frame construction of the towns, the wattle-and-daub filling was gradually replaced by stone and brick. This example from Michelstadt, Hessen, Germany, suggests that shingles were at one time cheaper than plaster.**

account of this property of wood. For this purpose, the same principle of the wedging plank in log construction, serving to press together the floorboards, was imitated here. (Fig. 153) Like in every case, here a wedge-shaped member is driven into a wall assembly provided with tongue-and-groove joints in order to ensure its imperviousness. (Fig. 154)
To save wood, there was an initial transition in the towns to filling the panels with practically free timber, i. e. poles, thin branches and canes, formed into a wattlework, and to then spread a daub mixture on this in order to seal it. As time passed, this wattle-and-daub filling was replaced more and more by brick. (Fig. 155) Just like a drawer, which despite the best joints only becomes rigid when the bottom is added, wall infills of wooden planks or boards acted like bracing. (Fig. 156) Wattlework alone was not in the position to do this. Therefore, rails and braces, either as passing braces[158] or up- and foot-braces, had to be incorporated to stiffen the framework.[159]

156 **The panels between the column-and-beam skeleton of this barn in Shirakawa mura, Gifu, Japan, are filled with boards.**

1 Ostendorf, 1908
2 The situation was different so long as timber was only an aid, a temporary support, for wattling. In wattlework the nature of the construction meant no sharp corners. Indeed, wattle walls were often really no longer flat.
3 Parent, 1986, p. 80
4 It is interesting to compare the reverse of this prohibition, i. e. building with stone. In their efforts to prevent the proletariat from seizing the chance to erect more massive strongholds for defence purposes, the rulers as it were forced those under pressure to develop an outstanding culture of timber buildings. This was the case for the Romanians under the Angevin kings of Hungary (Petrescu, 1974, p. 51) and likewise the Norwegians under Swedish rule. (Graubner, 1986, p. 128)
5 Saeftel, 1931, p. 21 f.
6 Coaldrake, 1990, p. 28
7 Gilly, 1797, p. 11
8 Schübler, 1736, p. 82
9 Phleps, 1942, p. 30; Rosenfeld, 1956, p. 159
10 Keim, 1976, p. 63
11 Hanftmann, 1907, p. 188
12 Sjovold, 1985, p. 32 f.
13 Gunda, 1986, p. 79
14 This has to be seen to be believed! Out of the bole of a larch, 1.6 m diameter, of which only the 150-mm-thick outer annulus still exists (the core of this old tree has long since been eaten away), the valuable wood is cut out manually. (Tokyo Meiboku)
15 Smith, 1964, p. 150
16 The pyramid-shaped structure means, in principle, that all pieces of wood should be tapered. To the woodworker this means that a cut timber presents the run of its grain clearly oblique to the direction of the incision. That creates problems, on the one hand during the processing, above all if the taper is not uniform, and on the other, and especially then, if the front face is involved. This affects our study of joints in that a connection may not be cut in a sensible manner in such a piece of wood. The course of the fibres can be so unfavourable that, for example, a tenon would break off under the slightest load because its grain simply does not run parallel with the edge of the wood.
17 Keim, 1976, p. 63
18 The situation was different in the production of shingles. Apart from one groove, there is absolutely no waste in a grooved shingle roof. Only the finishing of the shingle and providing chamfers gives rise to a little waste. However, this wastage is more than made up for by the increased service life of the shingle. (Ast, 1990. p. 30 ff.; Phleps, 1942, p. 95 ff.) Further, those cleft timbers used in primitive forms of timber construction for the post walls (Ahrens, 1990, p. 153) were, like the grooved shingle, split out radially from the wood.
19 Rosenfeld, 1956, p. 154 f.
20 Phleps, 1939, p. 400
21 Lissenko, 1989, p. 52
22 Phleps, ibid., p. 401
23 Lissenko, ibid., p. 52
24 The dimensions of a *tatami* mat have changed very slightly over the years; regional variations were also known. However, 1800 x 900 mm can be taken as a guideline.
25 Coaldrake, 1990, p. 145
26 Schulz, 1964, p. 8
27 Magocsi, Zapletal, 1982, p. 26
28 Ast, 1979, p. 31
29 Taut, 1958, p. 193
30 For example, the *Hochstudhaus* (a type of building found in central Switzerland, the ridge pole of which is carried by enormously high supports originally standing on the floor) was the work of professional carpenters. (Gschwend, 1988, p. 34) Similarly, the farmsteads influenced by upper-class urban buildings, e. g. the Low German *Hallenhäuser* of the 17th and 18th centuries which were managed by big farmers and certainly no longer built by them. (Klöckner, 1978, p. 29; Kaiser, Ottenjann, 1988)
31 Bresson, 1981, p. 124; Hauglid, 1989, p. 10
32 Foltyn, 1960, p. 32; Strzygowski, 1927, p. 26
33 Strzygowski, 1940, p. 38
34 Dietrichson, Munthe, 1893, p. 60
35 Schulz, 1964, p. 11; Österr. Ingenieur- und Architektenverein, 1906, p. 90 f.
36 Holan, 1990, p. 9
37 Saeftel, 1931, pp. 28, 55
38 Schier, 1966, p. 44
39 Mayer, 1986, p. 107, note 92
40 Coaldrake, 1990, p. 19; exhibition catalogue *Holzbaukunst in Vorarlberg*, 1990, p. 7
41 Killer, 1985, p. 112
42 Gerner, 1986, p. 33
43 Phleps, 1942, p. 28
44 Taut, 1958, pp. 34, 197
45 Saeftel, 1939, p. 35
46 Seike, ibid., p. 7
47 Hirai, 1980, p. 119
48 Coaldrake, ibid., p. 16; Okawa, ibid., p. 117
49 Kükelhaus, 1988, p. 32
50 Okawa, ibid., p. 116
51 Only towards the end of the 13th century did the distinction between *miya-daiku* and *tera-daiku* disappear with the dependence on a certain shrine or temple. (Masuda, 1969, p. 120)
52 Coaldrake, ibid., p. 18
53 Itoh, 1972, p. 95
54 Haiding, 1980, p. 146
55 Schulz, 1964, p. 20
56 Ibid., p. 8
57 Coaldrake, 1990, p. 14; Masuda, 1969, p. 120
58 Itoh, 1972, p. 21
59 Gerner, 1986, p. 10; Weiß, no year, p. 24; Coaldrake, 1990, p. 7
60 Holan, 1990, p. 163
61 Binding et al., 1989, p. 12
62 The Grubenmann family of master builders was active over three generations. Ulrich Grubenmann (1668–1736) had three sons: Jakob (1694–1758), Johannes (1707–71) and Hans Ulrich (1709–83). Jakob and Johannes each had two sons themselves. Johannes built a number of important buildings but the really famous and outstanding achievements were those of Hans Ulrich Grubenmann. (Killer, 1985)
63 Killer, 1941, p. 165 f.
64 Gerner, 1986, p. 16
65 Itoh, 1982, p. 117 ff.
66 Ibid., p. 117 f.; Lissenko, 1989, pp. 41, 50; Weiß, no year, p. 66
67 Itoh, 1972, p. 95
68 Killer, 1985, p. 125 ff.
69 Killer, 1941, p. 29 f.
70 Ibid., p. 23
71 Coaldrake, ibid., p. 33
72 Itoh, 1982, p. 42 ff.; Okawa, ibid., p. 114; Coaldrake, ibid., p. 37
73 Brown, 1989, p. 45
74 Lissenko, ibid., p. 41 ff.; Schulz, 1964, p. 13; letters of hire (*rjadnaja sapis*, literally: document on the agreed cost)
75 cf. p. 160 ff.
76 Schulz, ibid., p. 13
77 Ibid., p. 42

78 Holan, ibid., p. 155
79 Opolownikow, 1986, Fig. 364
80 Brown, ibid., p. 66 f.; Lissenko, ibid., p. 49
81 Holan, ibid., p. 143
82 Len Brackett in Nakahara, 1990, p. 7
83 Graubner, 1986, p. 9
84 Killer, 1941, p. 40
85 Killer, 1985, pp. 91 ff., 112 ff., 122 ff.
86 Killer, 1941, p. 183
87 Brown, ibid., p. 27 f.
88 Holan, ibid., p. 139 ff.
89 *Shomei*, the oldest work of this kind still in existence, appeared in 1608. Divided into five volumes, each section deals with a specific topic: palaces and residences, gateways, shrines, temples, towers. (Hirai, 1980, p. 103)
90 cf. p. 41, note 70
91 Johann Wilhelm, *Beschreibung und Vor-Reissung der vornehmsten Dachwerke*, 1649; Johann Wilhelm, *Architectura civilis*, 1668; Johann Jacob Schübler, *Zimmermannskunst*, 1736, and another volume in 1749.
92 Blaser, 1982, p. 18 ff.
93 Schulz, ibid., p. 17
94 Brown, ibid., p. 30
95 Omori, 1966/4 & 1966/5
96 Coaldrake, ibid., p. 156
97 Seike, ibid., p. 17 f.
98 Graubner's book shows Tanaka's intensive analysis of the inheritance of his ancestors.
99 Graubner, 1986, p. 40
100 Morse, 1983, p. 13
101 Muramatsu, 1992, p. 20
102 Taut, 1958, p. 197
103 Coaldrake, 1990, p. 30
104 Ibid., p. 21
105 Ibid., p. 158
106 Seike, 1981, p. 9
107 Coaldrake, 1990, p. 78
108 Ibid., p. 112; *Nihon kenchiku gakai*, 1992, p. 62, Fig. 1
109 Muramatsu, 1992, p. 22
110 Seike, ibid., p. 18
111 Muramatsu, ibid.; Seike, ibid.
112 Coaldrake, ibid., p. 8
113 Muramatsu, ibid., p. 24
114 Muramatsu, ibid., p. 23
115 Coaldrake, ibid., p. 103 ff.
116 We can try this out ourselves. When we pick up a saw we automatically begin the cut with a drawing motion. The wide set of our saws first needs a guiding slot before we can exert the powerful thrusting action. If we were to begin a cut with a thrusting movement, against the resistance of the wood, then irreparable damage to the surface would be the inevitable consequence.
117 Muramatsu, 1992, p. 23
118 Muramatsu, ibid., p. 24 f.
119 Schadwinkel et al., 1986, p. 81
120 Binding et al., 1989, p. 8
121 Ibid., p. 12
122 Coaldrake, 1990, p. 44
123 Brown, 1989, p. 69
124 Norway is an exception. There, the chisel was not used, just *geitsfuss* and drawknife. (Holan, 1990; Bergenhus, 1991)
125 Schadwinkel et al., ibid., p. 214 f.
126 cf. p. 68
127 Coaldrake, 1990, p. 48 ff.
128 Phleps, 1942, p. 15
129 Ibid., p. 43
130 Phleps, 1951, p. 4
131 Ibid.
132 Schadwinkel et al., ibid., p. 136 ff.
133 Ibid., p. 214
134 *Isuka* means "halved rabbeted oblique scarf" (Nakahara, 1990, p. 26). (cf. p. 92) (cf. p. 251 f. for *isuka-tsugi*)
135 Kawashima, ibid., p. 76
136 Coaldrake, ibid., pp. 130 f., 145 f.
137 Schadwinkel et al., ibid., p. 138 ff.
138 Werner, 1978, p. 204 ff.; Pöttler, 1984, p. 48; Gebhard, 1975, Fig. 134
139 Muramatsu, 1992, pp. 91, 116, 117
140 Muramatsu, ibid., p. 23
141 cf. p. 140
142 Swoboda, 1967, p. 1
143 Grisebach, 1917, p. 54; Schier, 1966, p. 106
144 Ahrens, 1981, p. 145 f.
145 Coaldrake, 1990, p. 112 f.; Ahrens, 1990, p. 97
146 Zippelius, 1954, p. 21
147 Ibid., pp. 16, 22
148 Gerner, 1979, p. 29. However, interrupted sill-beam construction continued to be used parallel to this into the 18th and 19th centuries. (Bedal, K., 1983, p. 408)
149 Trotzig, 1981, p. 284 ff.
150 cf. p. 153
151 Zippelius, 1954, p. 49
152 Klöckner, 1978, pp. 16, 27; Olrik, 1937, p. 71
153 Baumgarten, 1961, p. 53
154 Itoh, 1982, p. 144; Kawashima, 1990, p. 74
155 Ahrens, 1981, p. 124 f.
156 Binding, 1981, p. 267; Vitruv, 2nd Book, chap. VIII
157 Ahrens has provided the urgently needed clarification of the vocabulary. There were stave churches, like the one in Silte described above, whose walls consisted of planks placed vertically adjacent each other. To distinguish them Ahrens proposes the name "stave wall church". The outstanding Norwegian achievements in timber construction which we normally associate with the term stave churches owe their name to their freestanding columns (Norwegian: *stav*). He proposes calling these "stave column churches". (Ahrens, ibid., p. 138)
158 Passing braces were formed by diagonal braces lap-jointed to the horizontal members of a storey – on older buildings also over the whole height of the wall – both on the eaves and gable sides. It is only such diagonal members which create the triangulation necessary to guarantee the stability of a structure.
159 The very different method of bracing in Japan is described on pp. 155 ff. and 192 ff.

Types and Functions of Wood Joints

Typology

Firstly, let no-one tell you there is a good reason for defining wood joints in a particular way. The sole reason behind any system of definitions should be the purpose for which said classification is intended.

Therefore, in principle, nothing stands in the way of dividing up wood joints into movable and fixed. So long as iron remained very expensive, such tasks had to be accomplished exclusively in wood, the problems this raised often leaving us today totally perplexed. Whether a door mounted on pivots (Fig. 157) or its wooden latch, a sliding gate which closed a small window, or a pivoted horizontal cut-out in a log wall which could have served to admit light and air. (Fig. 158) Climatic conditions in Japan have led to a development which we have not witnessed here in Europe. In order to really open up the entire building in extreme situations – and conversely too, to seal it completely –, the Japanese developed doors which could be slid around corners! (Figs 159, 160 & 161)

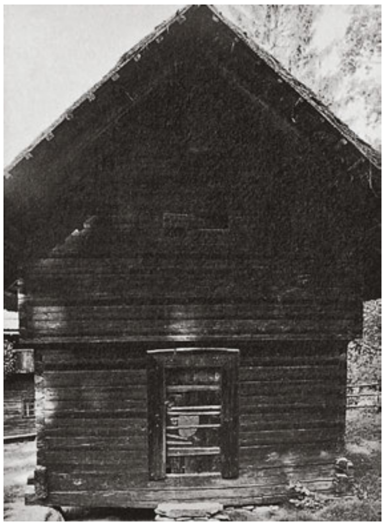
Wood joints of this type are hardly ever covered by definitions. However, their contribution to the informative value of this classification is actually very limited.

Another possibility would be to subdivide joints into detachable and permanent. Think for a moment of the importance which was at one time attached to the detachability of a connection and the value of such a classification becomes apparent.

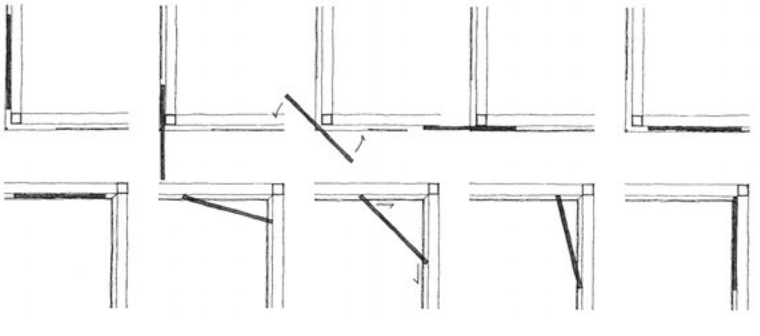
The first use which comes to mind is probably the easy replacement of defective parts of a structure.[1] Other considerations are normally too obscure for our modern minds. The Norwegian *loft*, "purely a system of joints" was a customary part of a bride's dowry,[2] a tradition also known in northern Germany.[3] Some buildings even today show evidence of having been moved. (Fig. 162) The sequential numbering of logs, usually clearly visible on the exterior, is an unmistakable sign for a building having been taken down and re-erected at some time.[4] Numbering was provided to ensure that, if necessary, the building could be put together again by people other than those who had dismantled it. This is not the case with complicated church roof trusses in which the individual components had to be numbered for organizational reasons.

In a similar vein, in Hungary the terms "Slovakian chamber" or "Romanian chamber" were known, pointing to the fact that these were fabricated in a totally different place from where

157 Door mounted on pivots with wooden latch in the Muzeul Satului in Sighetu Marmaţiei, Maramureş, Romania.



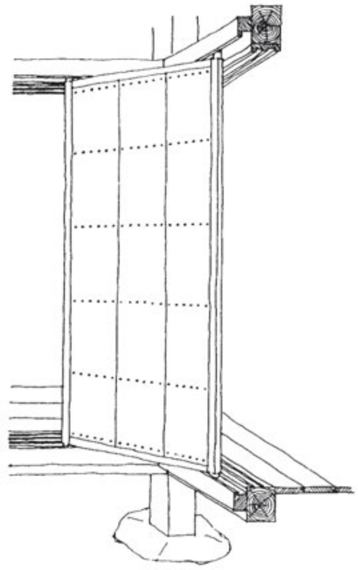
158 This grain store from Eggen am Kraigerberg, Carinthia, Austria, only has tiny window openings, the door and the movable beam as optional opening. – Maria Saal Open-air Museum, Carinthia, Austria.

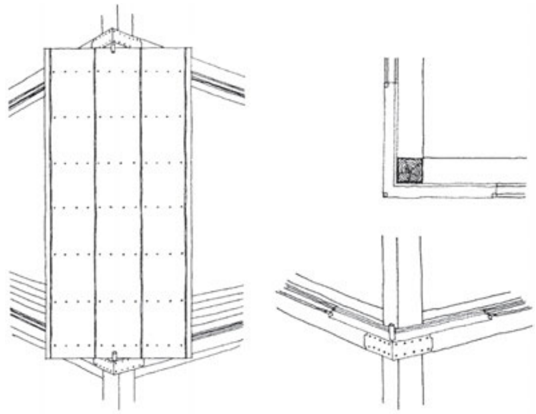


159 *Mawari amado* (= pivoting storm/rain door) on the corner of a building. (source: Ando et al., 1995, p. 20)

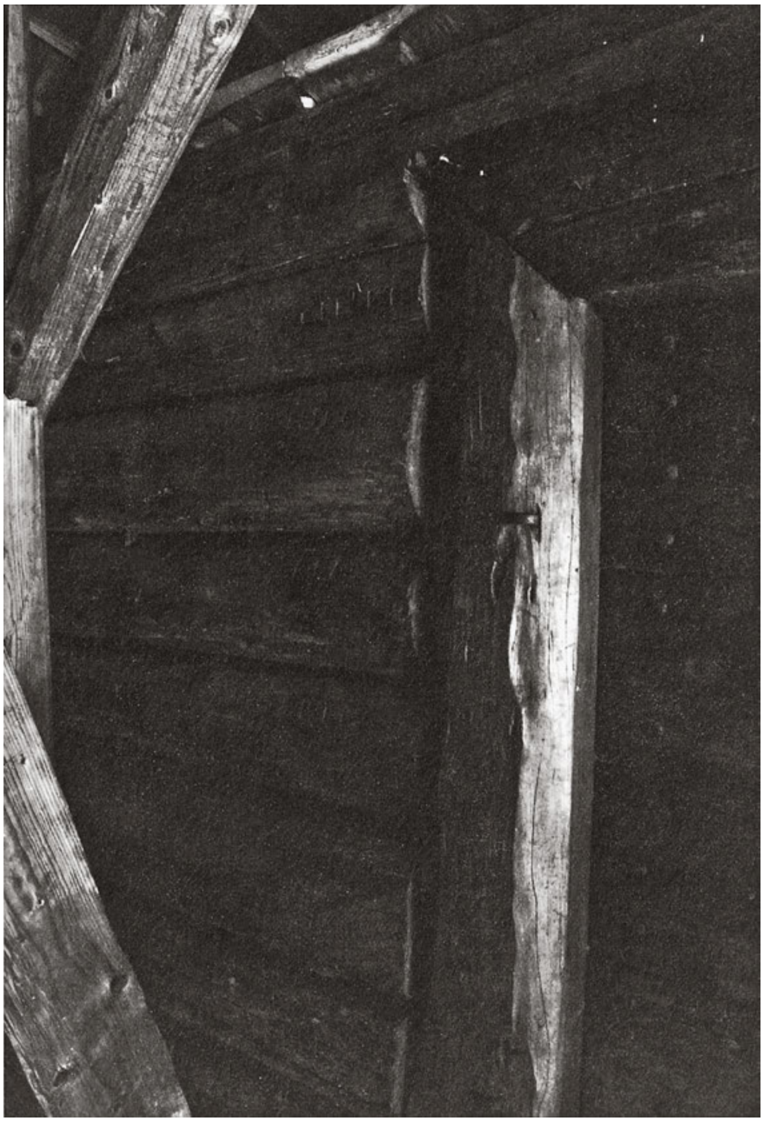
they were used.[5] Precisely because timber houses were classified as goods and chattels, there was nothing to stop the tax collector from confiscating the house and carting it off as payment for outstanding debts![6] Whole settlements were robbed,[7] churches sent "on a trip"[8] or saved prior to demolition by moving them.[9] If somebody wanted to take account of his increased prestige and built a stone house, he did not necessarily have to forego the accustomed benefits of his old timber dwelling – it was simply dismantled and integrated in the new building.[10] A very widespread procedure was certainly the addition of extra storeys at a later date.[11] Such cases are easily recognized by means of variously arranged projections. (Fig. 163) And in the case of inheritances being split, moving timber houses more than once was no rarity.[12]
A system of flexibility and movability would be just as useful in Japan as it would be in Europe. It was not only the shrines and temples which were taken by the rulers when it was decided to move the capital,[13] but in fact all the more important build-

160 The door jamb strips are extended top and bottom to enable the door to be guided around the corner in the grooves. (source: Ando, ibid.)



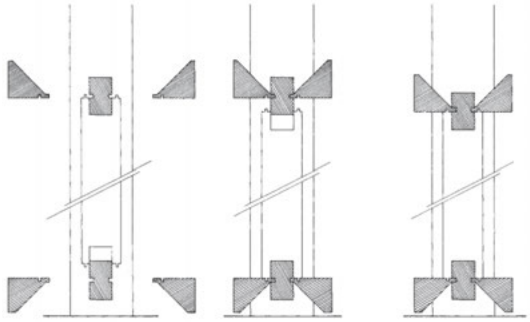


161 In this case the door is turned from one groove into the other behind a tenon on the corner column. (source: ibid.)



162 The logs of the Kosmas and Damian Church in Lukov-Venecia, Slovakia, are numbered successively, starting at the bottom.
163 Log construction with extra storey inserted. – Evolène, Wallis, Switzerland

ings; however, only so long as simple joints permitted successful transportation.[14] In these cases as well, dismantling and reerection would have been inconceivable without the individual elements first having been identified and marked.[15] The sill beams of temples are an example of a part which has to be replaced regularly. Thanks to large overhanging eaves they are normally protected from driving rain, and from splashing water by being raised clear of the ground, but not from the wear caused by the feet of countless thousands of visitors. (Fig. 164) Another obvious example for the important role played by permanently detachable joints is the European hay-barrack, with four, five or six poles, the clever feature of which was the roof which could be adjusted to the desired height. (Fig. 165)
The opposite of the detachable joint is the joint which, after assembly, cannot be dismantled without damaging it. Among these are all tenons which are clamped with hidden foxtail wedges. Such joints cannot be taken apart. They were used where aesthetic considerations demanded it or where extremely strong joints were required. Lumberjacks needed them for constructing the chutes used to send felled tree trunks down into the valley.[16]
The categories utilized up to this point suffer from the fact that they only select according to a specific criterion and do not really permit a comprehensive and generally applicable classification of timber joints.
At this point it is practical to briefly describe the terms which occur again and again, and suggest a possible classification. This



164 Developed over centuries, this method of building the sill into the door frame enables the sill member to be easily replaced. (according to: Brown, 1989, Fig. 40)

165 Thanks to its ingenious simplicity, the haybarrack with an adjustable roof has survived to this day in Jurici, Istrien, Croatia.

is not intended to be systematic nor exhaustive; the objective is to introduce the specialist vocabulary of the carpentry trade. There are various ways in which two pieces of wood can be joined together:
They may be butt-jointed (Fig. 166); this is simply two pieces of wood laid against each other – no real interlocking joint is formed.
The halved-and-lapped joints represent a very large group. (Fig. 167) Some basic forms are the edge-halved scarf (Fig. 167a) and the stop-splayed scarf. (Fig. 167b) The longitudinal bevelled halved is another form of splayed scarf (Fig. 167c); the main difference between this and the former type is its ability to withstand a limited degree of tension. Another scarf joint suitable for tension applications is the halved and tabled. (Fig. 167d) Bridled abutments improve the joint by preventing lateral deflection. (Fig. 167e) Non-linear halving falls under the heading of lap jointing. The two halves of a lap joint are rarely identical – for example, the end of a collar beam is lap-jointed to a housing recess in the spar. (Fig. 167 f.)
The notched joint could be regarded as a special variation of the halved joint which is simply not recessed as deeply. (Fig. 168) It is found, for example, in timber-frame construction where the ends of the floor joists project beyond the head beam of the storey below in order to jetty out the storey above.
Tenon joints (Fig. 169) also form a very extensive group. The tenon is placed either in an open mortise (Fig. 169a) or in a tenon hole (Fig. 169b). A tenon may pass right through a hole, depend-

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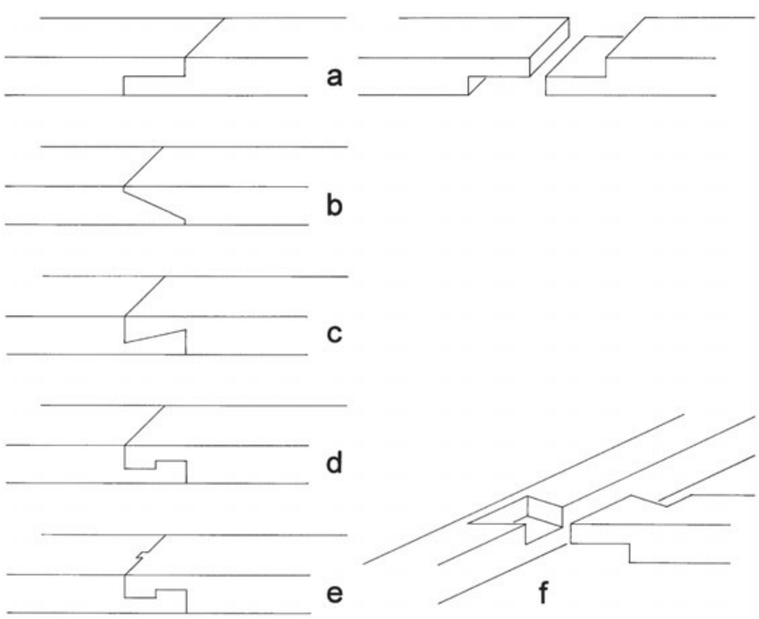

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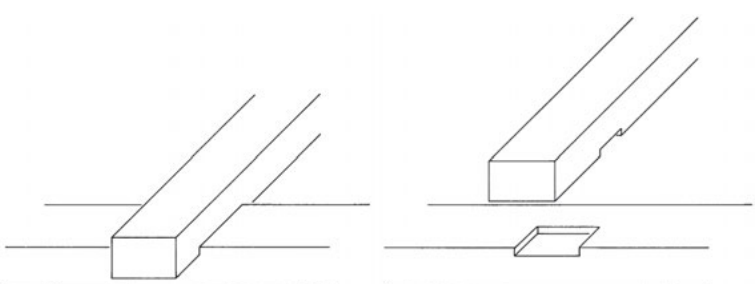

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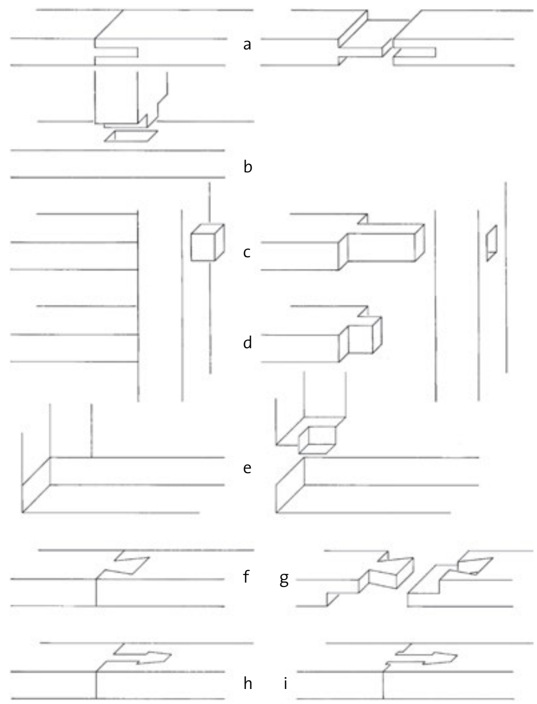
ing on circumstances (Fig. 169c). In post-and-beam as well as column-and-beam construction, this type of joint was for a long time the predecessor of the through-tenon secured with a key. In other cases a stub tenon may have been required (Fig. 169d); at corners it was plugged for obvious reasons, and often bevelled. (Fig. 169e) If the two pieces of timber were also to be subjected to tension as well as compression, then it was necessary to prevent the two pieces from simply pulling apart; the dovetail was one answer. (Fig. 169 f.) If the angle of the dovetail's cheeks was cut too shallow, the joint could still be pulled apart under tension; as the angle increased so the danger of shear rose. Every carpenter knew the correct angle. To make this joint also suitable for unsupported compressive loads from above, the dovetail could be reinforced. The combination of halved-scarf and dovetailed bridling was a joint frequently encountered. (Fig. 169g) Not very common in Europe but standard in Japan was the "gooseneck" splice. (Fig. 169h) Additional rebates secure the "female" side of the joint against any lateral buckling which might cause the gooseneck to slip out of its anchorage. (Fig. 169i)
Both the halved and the tenon joints were all formed at the end of at least one of the pieces, i. e. in the end grain. When a mortise-and-tenon joint was applied with the grain it was referred to as a tongue and groove. So if two boards were joined edge to edge, a tongue-and-groove joint might be employed.
Even in presenting these few basic types it is not possible to mention the type of joint without describing the form of the joint. Two pieces of timber can be connected end-grain to end-grain in one direction. Regardless of whether horizontal or vertical, these are known as splicing joints. (Fig. 170)
Another form is the oblique joint. (Fig. 171) Among the most common in European timber construction were the step joints with housed oblique tenons (Fig. 171a), the birdsmouth joint, (Fig. 171b) and the brace joint. (Fig. 171c)
In the group of L-, T- and X-joints (Fig. 172), the open mortise and tenon-jointed spars at the ridge can be regarded as representing the L-joints. (Fig. 172a) The forked tenon, the successor to the forked support, is a typical T-joint. (Fig. 172b) The connection between a diagonal member and a truss post would be one example of an X-joint. (Fig. 172c)
The term edge-to-edge-joints has been mentioned already (Fig. 173) in the sense of the tongue-and-groove joint. (Fig. 173a) This joint is not very stable and needs to be at least nailed to a support. A considerably better form of the edge-to-edge joint is provided by butted or shiplapped boards connected by a fillet housed in a dovetailed trench perpendicular to the grain of the boards. (Fig. 173b) This fillet joins the loose boards together into one unified surface. (Just how fraught with problems is the above evaluation, is demonstrated by the counterexample of the stave churches, the walls of which have indeed stood the test of time. However, in those churches, the planks joined by means of tounge-and-groove joints to form a flat surface are clamped in a fixed frame in the truest sense of the word.)
The final form of connection is the L-joint. (Fig. 174) This joint will crop up so frequently from here on that only two examples will be mentioned at this point. A simple halved joint can be produced in one plane at a corner (Fig. 174a); in this case both



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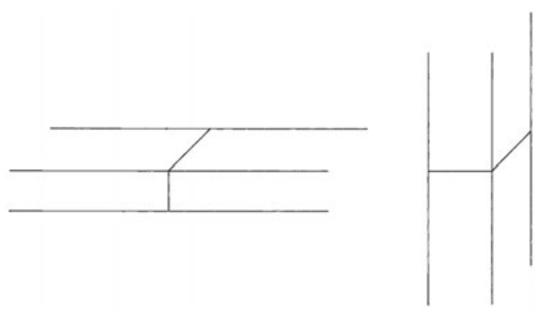

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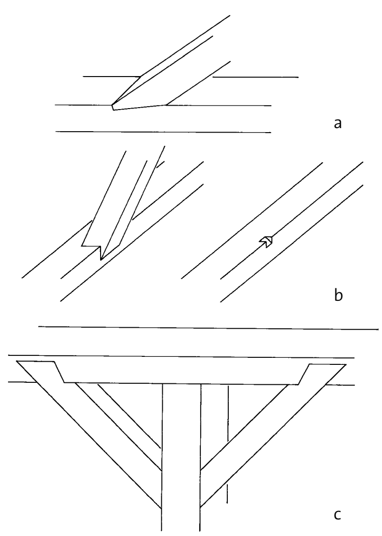

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pieces are normally reduced to half their cross-section. However, the same connection can also be made with the pieces simply notched. (Fig. 174b)
The corners of sill beams are often made as flush corner joints – just to introduce a further expression. In log construction they were not usually formed flush because it is precisely the pectination of the beams at the corners which gives the structure its strength. How sensible it is to apply this criterion must be considered for every individual case. For instance, if a smaller member is connected to a larger one, one side of the joint can be flush, the other not.
The situation is very similar when we come to describe whether a joint is horizontal or vertical. There is a whole series of joints which have been used identically in both horizontal and vertical applications. However, there are many others for which this is not true; most edge-and-face-halved scarf joints are useless in the vertical direction. (Fig. 175) In Japan such edge-and-face halved joints were widely used in a variety of forms; in Europe on the other hand, this further development of the splayed scarf is not found very often. Another, further development is finger jointing, well known today. The guaranteed availability of so-called "solid wood", which hardly exhibits any of the characteristics of wood anymore, has turned this connection into an indispensable, unrivalled method of jointing in today's timber construction industry.

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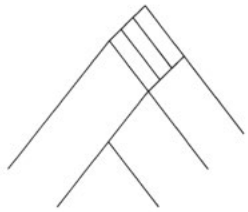

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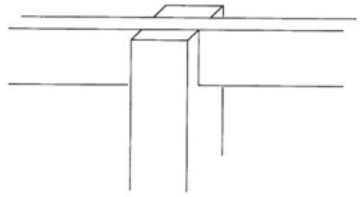

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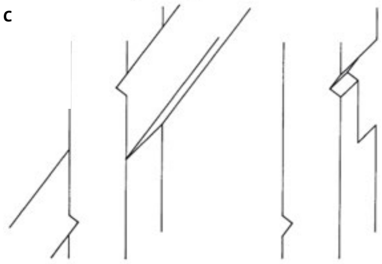

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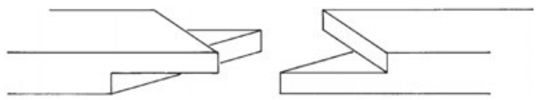

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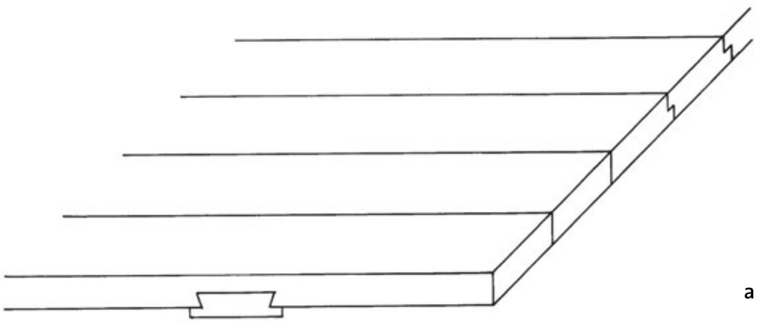

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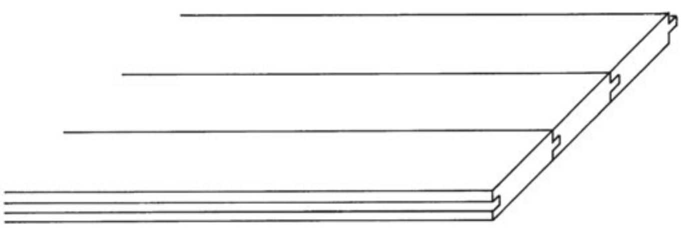

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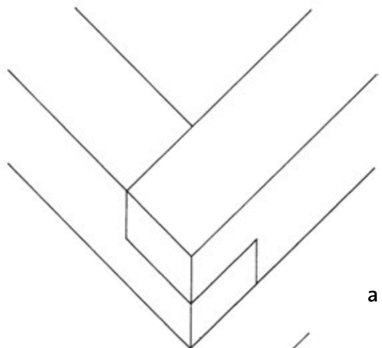

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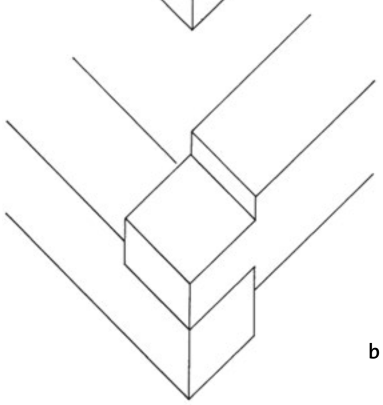

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Although a typology chosen at random cannot a priori be disputed, we have surely shown that it only makes sense when it can also be applied. Consequently, we fall back unwillingly on the traditional classification, the benefits of which lie in the hierarchical structuring which is possible. By way of explanation, in the following, two examples from Germany, which provide very detailed breakdowns in a way unique for Europe up to now, will be compared with a Japanese model which is often to be found in the literature with only minor deviations.
Our generally accepted starting point is that every category needs to be broken down further. The rough breakdown will be carried out with the highest classification criterion, depending on the freely chosen or arbitrarily set priority.
Gerner's first distinguishing criterion is the type of joint.[17] For him the types are: butt, tenon, scarf, notched, forked, step joint, birdsmouth, log construction joint, stave construction joint and repair joint. Arranged in order, his list is further subdivided thus: form of joint, position of joint, direction of joint and flush or not flush. Form of joint is in turn broken down into splicing joints, L-, T- and X-joints; position of joint into vertical and horizontal; direction of joint as straight, right-angled and skew; the final distinction is flush or not flush.
Of course, with this classification it is not quite clear how we should deal with borderline cases. Does the combination of scarf and tenon belong to the scarf or the tenon group? Is it a tenoned scarf or a scarf tenon? Gerner chooses to list such joints twice, probably the only sensible solution.
The attempt to squeeze log construction joints into this system remains problematic, although the author does point out the necessity for straying beyond the classification guidelines in this case. The satisfactory solution is undoubtedly to respect the independence of this form of construction in linguistic terms as well. On the other hand, Gerner lands himself with another problem by grouping the stave construction joints separately. Had he included edge-to-edge joints as a category in the "type of joint" group, then all those joints which fall under the heading of "stave construction joints" would have been sensibly covered. It is not adequate to list the tongue-and-groove joints of shingle roofs as stave construction joints simply because they do not fit in anywhere else![18]
In his classification system, Graubner swaps round the first two distinguishing criteria listed by Gerner.[19] He distinguishes between splicing joints, oblique joints, L-, T- and X-joints, and board joints, according to their forms. He only considers the type of joint as a subordinate category. However, whereas Gerner employs an appropriately meticulous system throughout, Graubner's system goes no further! The advantage this brings the author is that he can specifically avoid overlaps. Thanks to his categories, he does not encounter the problem with the stave wall as Gerner does. On the other hand, Graubner believes he has managed to integrate log construction; by simply omitting all log construction joints which cannot be included under his heading of "lap joints in log construction", he skirts around the problem which Gerner had addressed.[20]
Graubner's differentiation of timber joints does in some cases

go into very great detail. There are two main reasons for this. Firstly, his book is based on an enviable collection of models of Japanese joints for which he wanted to establish a framework. Secondly, derived from this is the need to integrate cabinetmakers' joints as well – our Japanese colleague is after all both building joiner and cabinetmaker. In the tabular comparison of European and Japanese systems which appears in the appendix to his book, however, Graubner inexplicably departs from the classification used throughout the book itself. Dividing Japanese joints into those for boards and those for squared timbers is certainly possible, if a little unconventional. But such a system is just as unhelpful as the subdivision into detachable and permanent joints.

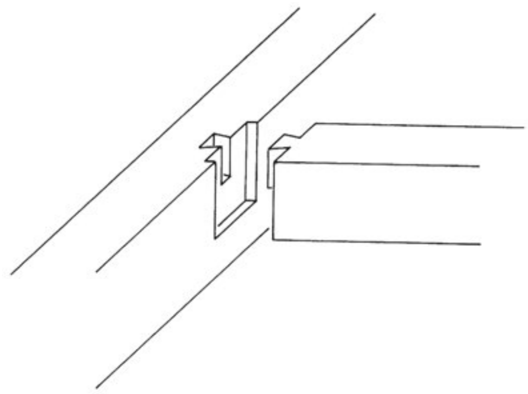
The usual method in Japan is to classify joints according to their form, i. e. *tsugi* and *shiguchi*.[21] A *tsugi* is normally a joint in a straight line, i. e. a splicing or lengthening joint. However, as, for example, in some pagodas based on a circular plan the head beam has to be circular and such a ring can only be assembled from pieces, such joints are also treated as *tsugi*. Generally speaking, it connects two pieces of wood in the direction in which they run.[22]

If in some explanations *tsugi* are presented as joints between elements having the same function and *shiguchi* as joints between those with different functions,[23] we must conclude that, for example, the connection between two inferior purlins at a corner, like the *engawa-no-keta* (see p. 57), should be included under the heading of *tsugi*. But that would be wrong! What could be meant here is the distinction the Japanese make between the main part and the piece joined to it. This is expressed by the word *kake*, and is normally only possible with *shiguchi*. (Figs 176 & 177)

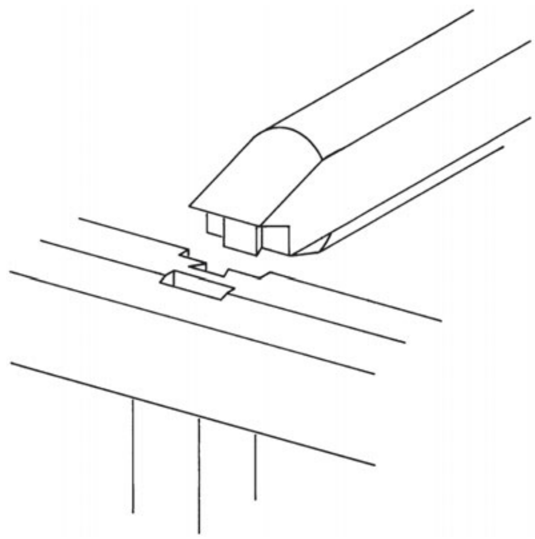
Tsugi designates the joint: e. g. *ari-tsugi* (dovetail …), *kama-tsugi* (gooseneck …). *Tsugite* is the name for a joint used at a very specific location: e. g. *kayaoi-no-tsugite* (*kayaoi* is the soffit board between exposed rafters and flying rafters, so *kayaoi-no-tsugite* is the extension of this board), *tenjo-no-sarubou-saobuchi-no-tsugite* (*tenjo* is the ceiling, *saobuchi* the grid carrying the ceiling boards, and *sarubou* describes the profile of the grid battens which look like the lower mandible (*hou, bou*) of an ape *(saru)* – consequently this joint serves to extend battens with a very specific profile which, suspended in a grid from the concealed construction, support the ceiling boards). This fine distinction is often neglected, even in writings on the subject.

The most common method of classifying *tsugi* is according to their form, in Gerner's vocabulary the type of connection: *dozuki* (butt joints), *aigaki* (scarf …), *mechigai* (joints with short or stub tenons – including, for example, *kai-no-kuchi-tsugi* – see p. 233), *ari* (dovetail …), *kama* (gooseneck …), *sao* (joints with long tenons), *okkake* (dadoed rabbeted edge-halved scarf), *sogi* (face- and edge-halved scarfs such as the *Miyajima-tsugi* – see p. 251) as well as odd ones which cannot be included under any heading, e. g. *ryusui-tsugi* (a joint portraying the image of running water – see p. 260).

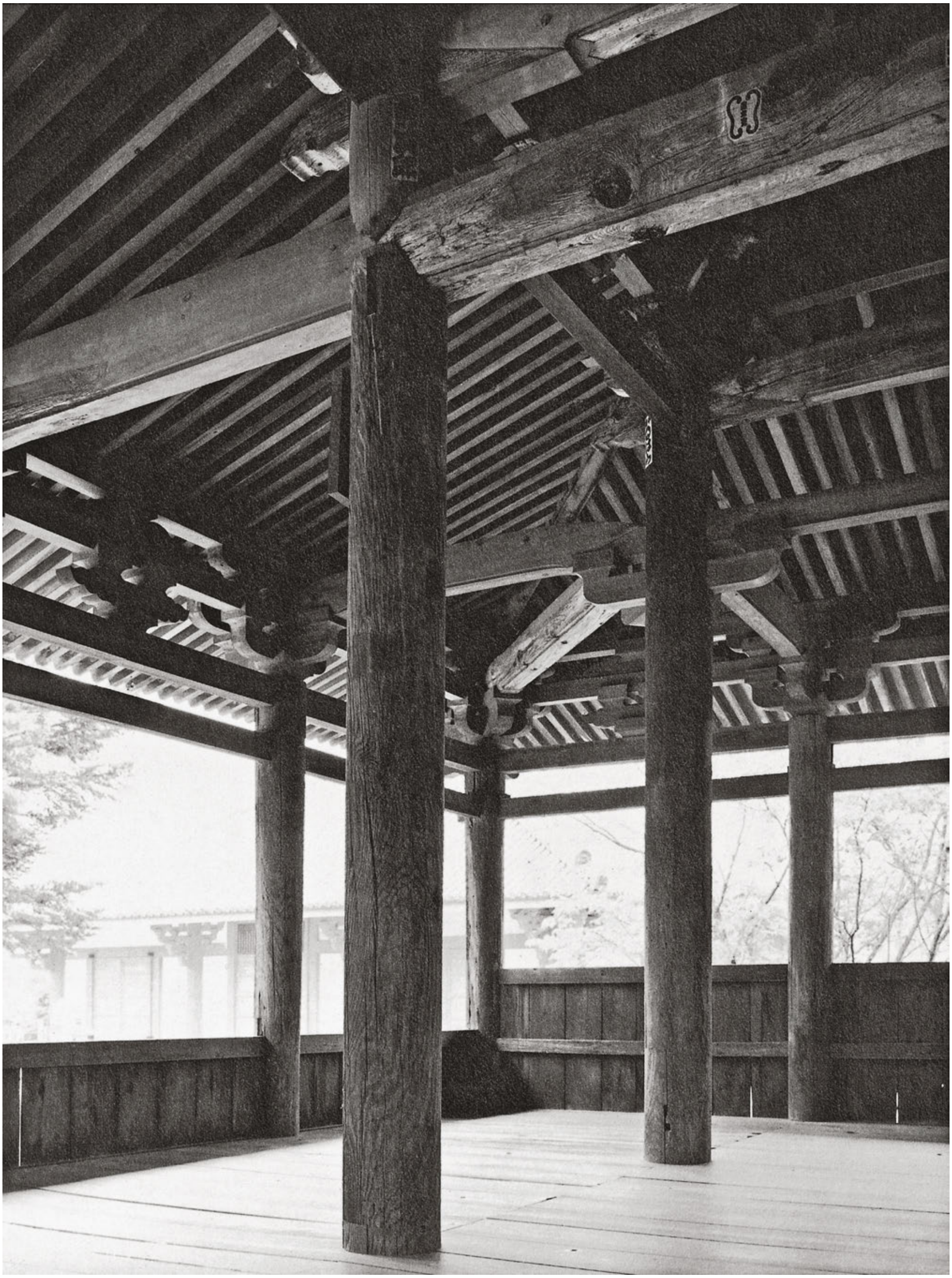
Another means of classification would be to organize *tsugi* according to their place in the construction: over vertical, load-bearing members (Fig. 178), over supports such as horizontal beams or blocks which are provided with corresponding load-



176 ***Oire-ari-kake*: the minor member in the joint is supported in the major member by means of a dovetail.**

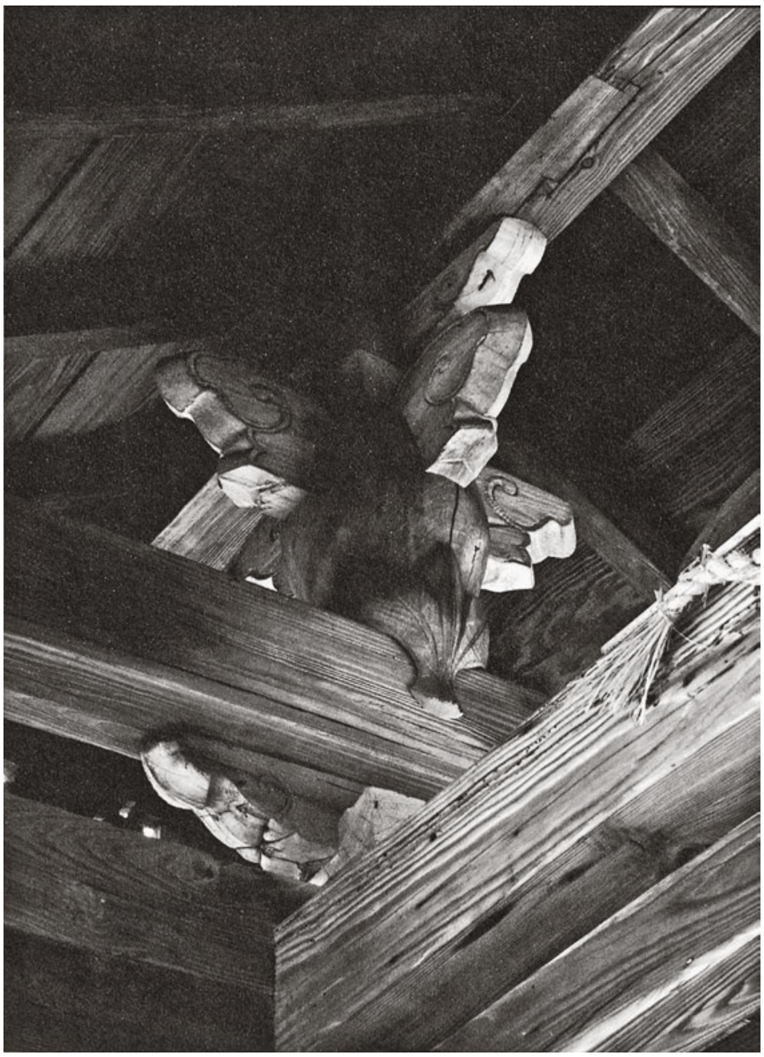


177 ***Kabuto-ari-kake*: helmet-shaped end lap joint with through single dovetail.**

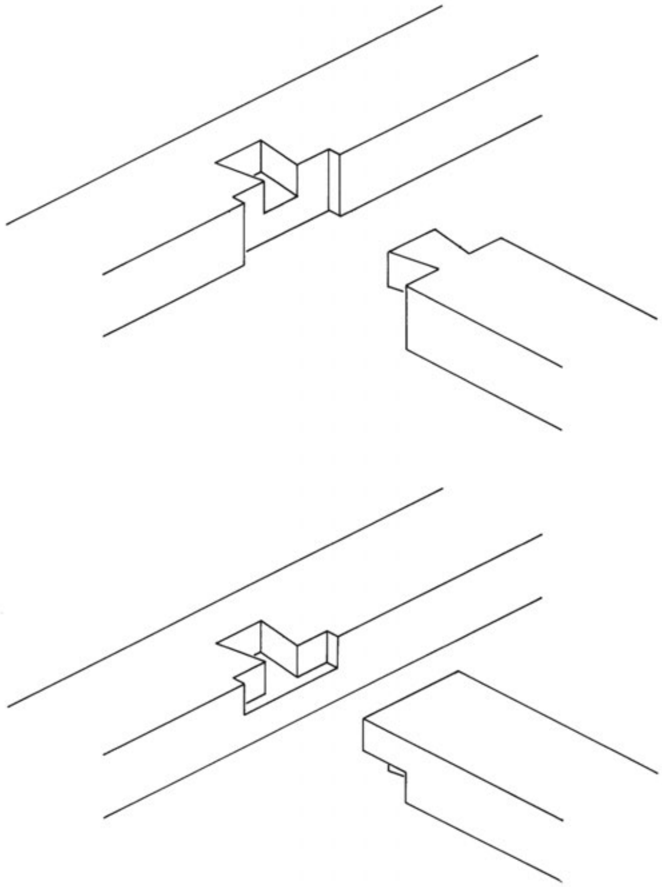


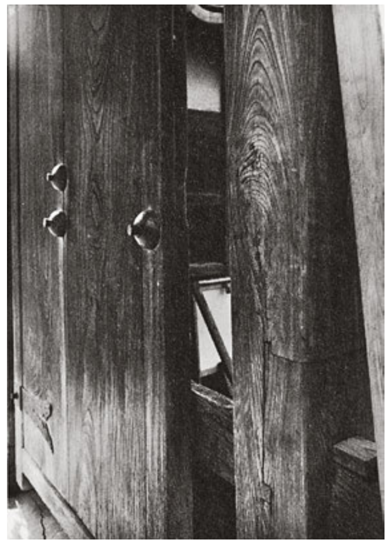
178 The horizontal beams are joined together directly above the loadbearing column. – Hachiman-jingu haiden in the Jodo-ji complex, Hyogo, Japan.

ings specifically at such points, or *tsugi* remote from loadbearing points.[24] (Fig. 179)
A particularly interesting classification is the one which takes account of the direction of the grain. It was as important in Japan as it was unknown in Europe. We have three possibilities: *okuri-tsugi*, the most common form, connects root end to crown end, with the male part of the joint always being formed in the crown end; *yukiai-tsugi*, connecting crown to crown, and *wakare-tsugi*, for joining two root ends. (Fig. 180) This last form of joint is conspicuous by its total absence! Many reasons have been given for this but none have proved conclusive.[25]
The second major group is the *shiguchi*. These are among the "most characteristic features of Japanese architecture which have rendered possible complex compositions of timber elements."[26] If Graubner feels that angled connections play a subordinate role in Japan, he should not conclude that the corresponding joints have undergone "comparatively little development."[27] The *kashigi-oire* is a step joint with a haunched blind tenon in the outer half of the joint, i. e. an angled joint, exactly as found in Europe. In contrast to a *tsugi*, a *shiguchi* connects two or more members at an angle, with the joint itself cut in one, several or all of the members.
The *shiguchi* can also be subdivided according to the type of connection: *dozuki* (butted), *oire* (e. g. joining a horizontal mem-



179 The ridge purlin above the gateway of the shokei-yashiki residence on Miyajima, Hiroshima, Japan, is joined adjacent the support.





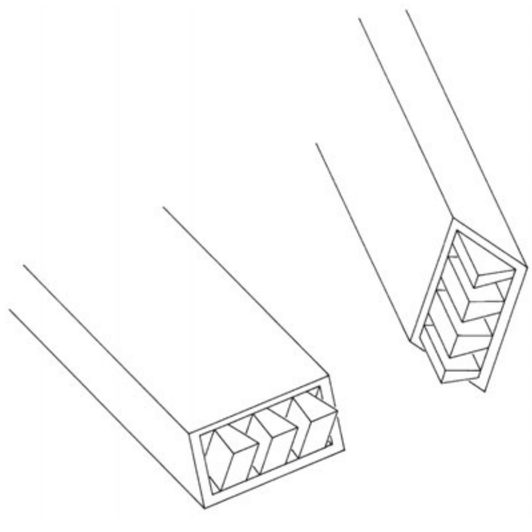
180 *Wakare-tsugi* on a temple door in Tokyo, Japan.

181 Both joints are called *ari-kake*, irrespective of whether they interconnect flush or not.

ber to a column), *kakikome* (notching of horizontal and vertical members), *aigaki* (lap …), *watari-ago* (cogging of horizontal members, although the *todasuke*, the joint fixing a beam in a block, also belongs to this group), *hozo-sashi* (tenon joints), *ari* (including, for instance, *suitsuke-zan* or *tsukami-ari*, dovetailed fillets which connect several boards to form a flat surface), *kama* (gooseneck …) and *tome* (L-joints which are distinguished according to the outer corner by way of a continuous, vertical mitre).[28]

This classification is just one of several possible which, however, do not differ in principle.[29] They all avoid overlaps between various groups by designating related joints identically. (Fig. 181) But they also acknowledge that more than one name exists for one and the same joint. (Fig. 182)

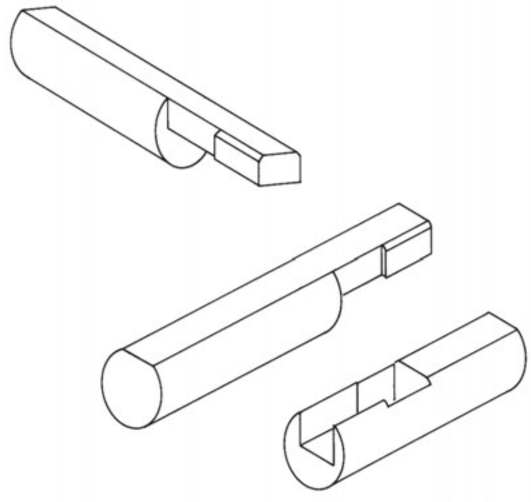
Now and again, the lack of identification in some of the names given to joints appears excessively liberal. But other names more than make up for this. For many joints, both *tsugi* and *shiguchi*, designate exactly the place at which they are to be incorporated. While in Europe a long name for a joint lets us suppose a complicated variant, a similar conclusion would be totally erroneous in Japan. *Zushi-dodai-sumi-shiguchi* tells us absolutely nothing about the complexity of the connection but instead solely describes where it is used: the corner connection of a sill in a small shrine. (see Fig. 484) *Naijin-keta-yuki-gagyou-tsugite* is a very simple *kama-tsugi* joint. In this case too, the name discloses nothing about the type of joint but again establishes the position in which the joint can be found: the splicing of a round-section beam in the direction of the ridge in the *naijin*, the innermost part of a temple, roughly comparable to the chancel in a church. (Fig. 183)



182 The secret dovetail corner joint, only used in Europe by cabinetmakers, is to be found on many Japanese temples and shrines. In Japan this joint is variously called *kakushi-ari* (hidden dovetail) and *sumi-tome-ari* (mitred corner dovetail).

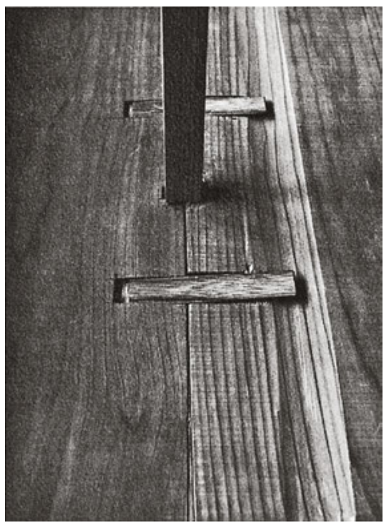
There remains the *hagi* group. The board joint so designated is actually a type of *shiguchi*. What has led to this classification is the idea that boards are, first and foremost, connected edge-to-edge, next to each other. However, they are also joined lengthwise; so *tsugi* is the appropriate designation. This dilemma can only be overcome by grouping them separately.[30] A prominent example is provided by the columns in the Todai-ji hondo. As columns with the necessary measurements were no longer to be had in 1705, during the reconstruction, the carpenters decided to thicken up a slimmer core to the required diameter by providing a jacket made from pieces of timber. These had to be fixed with iron straps. The pieces of timber are connected both laterally and longitudinally, i. e. *tsugi* and *shiguchi*. This special status is not customary elsewhere in the literature. By far the majority of authors classify *hagi* as a subgroup of *tsugi* – no ifs or buts![31]

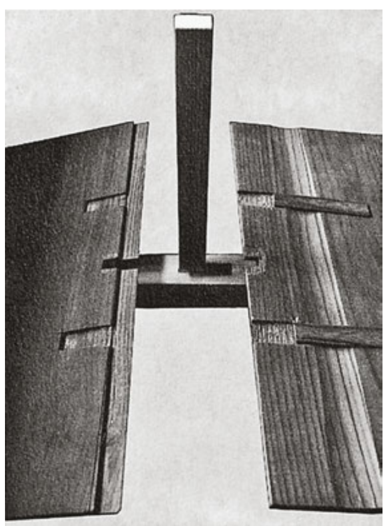
Europeans find it curious that boards joined with dovetailed fillets, *suitsuke-zan*, are always classified differently from the so-called *inago-zashi* joint (Figs 184 & 185); these are visibly distinguished solely by the incredible lightness of the former. Relatively weak dovetail joints, *yose-ari*, carry suspended ceilings, and just like them the *suitsuke-zan* joints belong to the *shiguchi* group, while the *inago-zashi* belongs to the *hagi* group, the board joints.

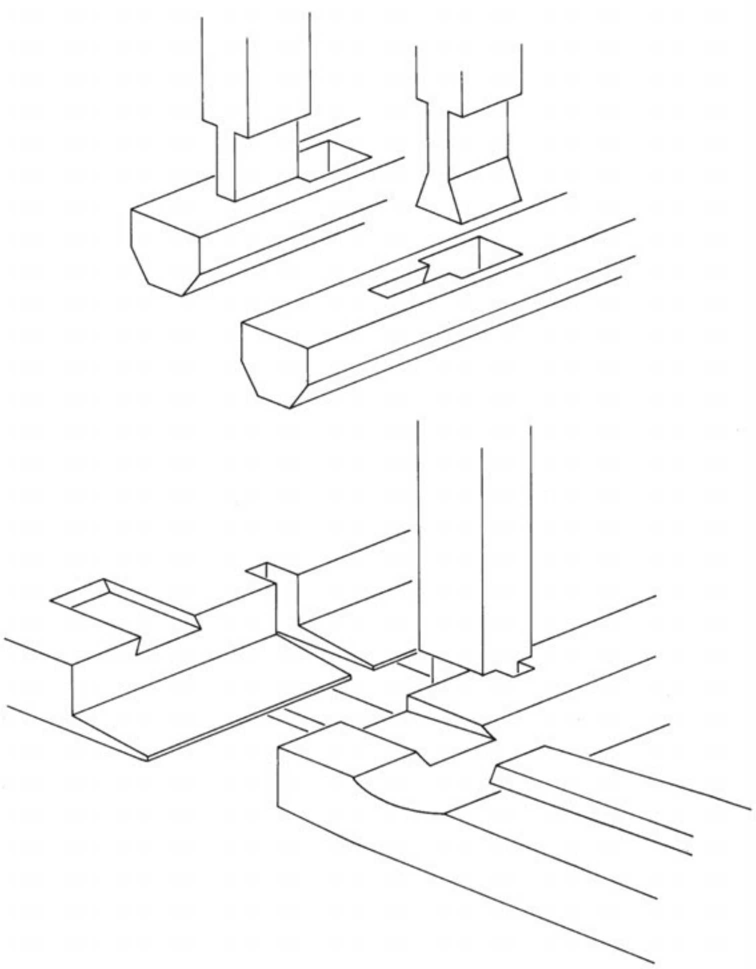


183 ***Naijin-keta-yuki-gagyou-tsugite*** **in the Taimadera hondo, Nara, Japan. (according to:** ***Bunkazai . . .*****, 1986, p. 109/3)**

184 Suspended ceiling boards with ***inago-zashi*** **(model in the Nihon minka en).**







185 Detail of ceiling construction.

The oldest handbooks for carpenters typically contain virtually no details of wood joints.[32] For carpenters, joints were so intrinsic to their whole culture that the drawing of them, let alone the dimensioning, was never even considered. Although Gerner's collection of wood joints is impressive and valuable, it is precisely the exact dimensioning and meticulous recording of the most diverse forms of subgroups of timber joints which demonstrates the break with tradition.

The idea of how a scientific treatise on the names of wood joints actually comes about can help discovering the variety which prevails. The scientist asks the woodworker for the names he uses, collects these and places them in order. The terms used in the region investigated then appear in publications. What could never have become a problem in the workshop has now been turned into one by the scientist: no carpenter would have had the notion of calling one and the same joint by different names! However, nobody can deny the carpenters of other regions the right to apply different terms! Frequently, it is merely a supplementary designation, like the *Jupiterschnitt*[33]o the *Klingschrot*,[34] which are not customary in other areas. It is only when our scientist records these in a list that the problems arise. It is obvious that there are countless examples for the diversity and inaccuracy of designations – perhaps more than the number of joints themselves. Let us look at a typical example taken from the German literature on our topic.

To produce a corner in log construction, in other words to alter the direction of a wall, the logs must be joined together in a very particular way. The factors which interest us here are solely the imperviousness of the wall and the appearance of the corner. Whether the logs arranged on top of each other in one plane touch or a gap of a certain size is left intentionally, that depends on the joint. Whether the change in direction of the wall, in geometric terms, is defined by a line or is articulated by way of the projecting logs extending one plane, again depends on the joint chosen.

The four possible solutions are given the following designations: halved joint (jointing one member above the other), halved joint (jointing one member with the other), notched joint (one member above the other), notched joint (one member with the other), dovetailed jointing, tabling and pectination. Allocating one or more of these names to one joint would in no way present a serious problem. The situation becomes difficult when the allocation applies in reverse, i. e. one name describes two different joints!

As on the one hand the linguistic confusion can hardly be made worse, and on the other hand a clear linguistic means of description seems almost at hand, a further definition will be introduced at this point ahead of a discussion on the terms used in the literature.

In a halved joint, enough material is cut away from the two pieces of wood to be joined so that they can be fitted together flush in one plane. The formation of a notched joint is very similar to that of the halved joint except that the housing of the notched joint is shallower, about 20–30 mm deep in fact.[35] The reader might feel that these two terms are adequate; however, to properly include a log joint, ring of beams over ring of beams, we need to go further. A rigid connection can only be achieved when the logs are pectinate. "Pectination" is a key word in the description of joints for log construction; it should be understood as the alternate interlocking of the logs[36] of one wall with those of another, creating a sealed or open construction, i. e. without gaps or rib-like respectively. This term – pectination – does not define whether the members are squared or left round, whether the ends project or not. For a joint name which needs to be supplemented with certain additional information is much better than resorting to the expressions listed earlier which are already used for other purposes and so lose some of their significance through being assigned to yet another situation. A typical example of this is the halved joint which, apart from a very few exceptions, simply does not exist in log construction. If we take the church in Hervartov, Slovakia, for instance, we realize that the lap joints there are only a superficial discovery – every joint on the inside is additionally secured by means of a cog.

Let us turn to the literature. For Phleps, "notched" (in the second meaning, cf. p. 97) is "to lay in one plane".[37] Breymann understands the term to mean a sealed pectination, with the connection being arranged in such a way that both pieces to be joined are worked.[38] Yet others think of a "notched" joint (in the second meaning) as a sealed pectination but with only one of the pieces having to be worked to obtain the joint.[39] So the difference is that in the first case both pieces of wood, one on the upper surface the other on the underside, are each reduced by one-quarter of their cross-section in order to produce the joint, while in the second case one-half of just one piece is removed.[40] The term "single notched" is an attempt to highlight the difference linguistically.[41]

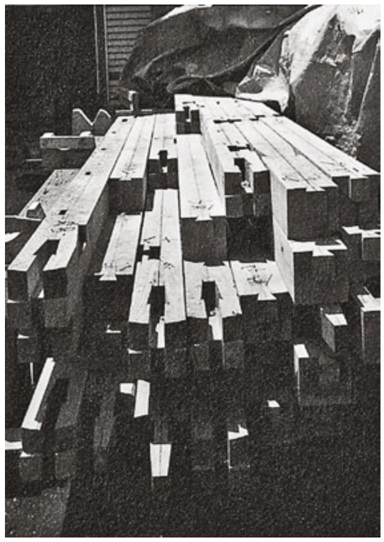
Schier's "tabled halved notching" (in the first meaning) with notches in one or both logs is also a pectination, in this case expressly with projecting end.[42] Baumgarten takes a "corner notching" to be a halved joint at a corner and without a projecting end.[43] "Tabling" or "tabled halved notching" is basically a sealed pectination on logs left round and having projecting ends. The log is halved in the vertical direction from the position of the joint to its end; the joint is then formed, single-sided, in this half of the log.[44] Gerner sees the term differently and describes the desired effect of an extra "table" in the joint.[45] And finally, a sealed pectination without projecting ends is called a "halved joint" (in the second meaning) by many authors.[46] Zippelius distinguishes between "single and double halved" (in the second meaning), depending on whether the joint is formed in one or both pieces. And when Werner speaks of a "half-lap", it is precisely this joint to which he is referring.[47]

It is felt that the family of "halved joints" (in the first meaning) should be reserved for the cabinetmaker because of the particular manner in which each person forms the assembly. The cabinetmaker produces a box in such a way that two surfaces are dovetailed. The carpenter, on the other hand, builds a box-shaped object by inserting members one by one from above into the construction[48] and simultaneously building the walls with the room. "Dovetailing" are for both Schier and Werner a synonym for their designations "halved joint" (in the second and first meaning respectively).[49] Schier talks of "dovetailing", while Werner understands a "dovetail" to be dovetailed ends of logs which do not project. Gerner uses the expressions "dovetailing" and "dovetailing with projecting ends".

The term "pectination", introduced above to test the waters, is used by Werner, Zippelius and Lissenko in the sense of a sealed pectination, formed by working both pieces, with projecting end. Lissenko also introduces the expression "stopped economy pectination",[50] the same joint but in a notched version.[51]

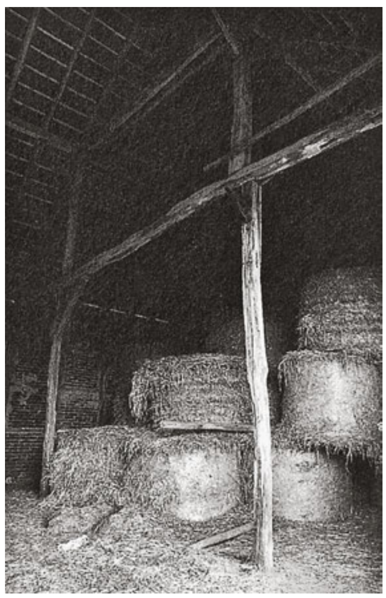
This example shows us just what a task the detective has if he wishes to sort out this jumble of names. The more desirable this is – because only that would ease the work of comparison – , the more hopeless it appears to be. Incidentally, I would especially like to point out that I have only included those authors in this comparative study who have defined their terminology in one form or another! Put another way: even in less problematic areas, e. g. the construction principles of inclined roofing members, it appears that clear distinctions between the terms used, e. g. between rafters and spars, have not been established and actually cannot be established owing to the mixed forms of construction. In the case of joints, now and again these really are only nuances which force linguistic descriptions and hence justisfy the scientists' activities. But they hardly help matters; and they do even less credit to the spirit of the craftsman.

"The function of a loadbearing structural wood joint in terms of the construction is to join together pieces of timber permanently and securely in such a way that the required structural interaction of the constructional element or the construction itself is enabled."[52] There are various ways in which we can reach this goal, as a peculiarity of Japanese timber construction illustrates superbly. What at first sight distinguishes a Japanese building from its European equivalent is the almost total absence of diagonal bracing. This is suspected as being one of the reasons why large buildings too have survived severe earthquakes without suffering more serious damage. To be able to absorb these destructive forces has always been one of the prime tasks of Japanese wood joints.[53] If we forget for a moment other demands which go beyond the constructional functions, e. g. economic considerations[54] or other conditions like joints should remain invisible as far as possible,[55] the definition cited above actually contains everything we can demand from a wood joint – but at the same time misses the point. It is, so to speak, a symptom for our present malady: we have grubbed up the roots which could have produced new growths – without the collective wisdom of our predecessors there is no alternative but to begin again from zero. (Fig. 186)



186 This pile of wood ready for assembly in Kitakata, Fukushima, Japan, shows how in Japan too the variety of forms which was once so diverse has been decimated. *Koshikake-kama-tsugi* and *ari-kake-shiguchi* are virtually the only joints to be seen.

If a groove, a hole or a slot is cut in a piece of wood in order to join another piece of wood to it, we automatically take it for granted that one or both pieces will be weakened. We must rely on the experience of the carpenter to find the right balance. When making any joint, the carpenter must keep in mind the purpose for which that joint is intended. If horizontal members are to cross and will be equally loaded, then the cross-halving joint may well prove to be best. But it certainly will not be the right answer for connecting a vertical column and a continuous horizontal rail, for to rob a column of half its cross-section is highly inadvisable. If, instead, the horizontal rail is mortised into both sides of the column, extra measures must be taken to prevent the tenons from being pulled out. (Fig. 187)



187 This timber-frame construction in a barn in Schapdetten, North Rhine-Westphalia, Germany, represents an attempt to maintain the cross-section of the tie beam as much as possible where the vertical members intersect. The column and the queen post are offset by the width of their tenons; this guarantees that the loads in the queen post are transferred into the supporting column.

In buildings designed purely for utility purposes the scope for taking into account the properties of timber is often greater than in those buildings where aesthetics play a greater role; in the latter situation increased use of material is often the only solution. But in all cases we should remember that every joint is only as good as its weakest link and that it is the sum of all the connections in a structure which determines the constructional value of that structure.

If we wish to refrain from defining the task of a wood joint because of the above-mentioned uneasiness, and instead merely describe the joints which exist, we land ourselves with an intractable problem. Providing which joint at which position for which function is not at all easy.[56] Given the fact that it is hardly possible to list all the different types of timber joints, their varying applications may well multiply this number to such an extent that all hope vanishes.

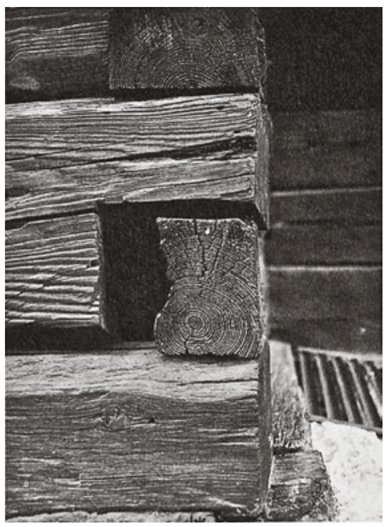
The only possibility is to provide a number of examples for our definition. These examples are intended to illustrate, both in positive and negative terms, how important just one single

188 The corner of the bell-tower in Malé Ozorovce, Slovakia. The thrust of the inclined column has split apart the poorly selected sill beam to a worrying degree.

timber property can be if joints are to fulfil our expectations of them. Thoughtlessness in this aspect can turn out to be just as disastrous as lack of knowledge. Every mortise weakens the timber in which it is cut, and even a thin tenon can turn into a destructive lever if, for example, twisted growth and splits are not heeded sufficiently. (Fig. 188) Although there is much redundancy in many old joints, this aspect should not be overestimated. The appearance or the complexity of a joint may say very little about its value in the construction; the question of value can only be seen in relation to the function of the joint. A simple lap joint fulfils its function better (Fig. 189) than an elegant dovetailed lap, which only has to be slightly damaged once to be rendered useless. (Fig. 190)
The strength of wood is defined clearly and unambiguously in engineering terms. But in practice the situation looks very different. For example, hidden notches are provided on pectinate timbers in log construction to give them the stability they once had before the ends of the logs were amputated. However, precisely the twisting of the member, which should be prevented, can lead to an unintended test of the shear strength of wood. (Fig. 191) The carpenter is not necessarily to blame for the fact that the hook of the joint broke off; no piece of timber reliably divulges its true nature. However, this example surely illustrates that only an experienced woodworker can take account of such eventualities.
Two beams are only as strong as one twice the size when they are firmly fastened together. Even when our modern codes of practice specify how large knots may be and how many we are allowed to have in one piece of timber, it is down to the carpenter on site or in the workshop to actually combine the two knotty pieces and, maybe, make a fatal error. (Fig. 192)
Indented beams represented the ideal solution but they were expensive and time-consuming. While in the Middle Ages the ironic expression "carpenter's hair"[57] was applied to inaccuracies,[58] particularly in the case of lap or step joints, in the 19th century the degree of accuracy required to fabricate the many serrations or indentations of a built-up beam was already being spoken of as the disadvantage of this form of jointing.[59] The increasingly shoddy workmanship of the carpenter,

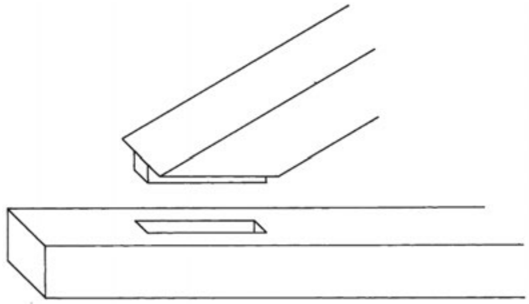
189 The crossovers formed by these simple lapped joints both secure and decorate the ridge covering of this *minka* in Tamugimata, Yamagata, Japan.

190 The down braces on the bell-tower in Stará Halič, Slovakia, are fixed to the sill beam with single-dovetail lap joints.

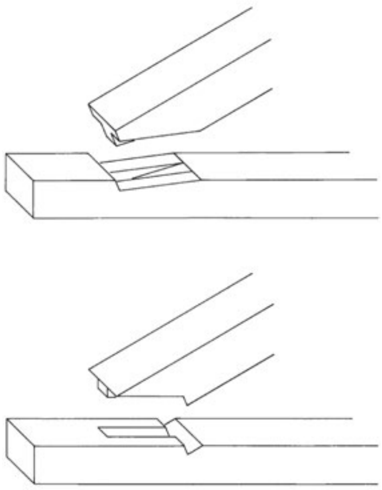


191 Due to the warping of the whole log, the joint on the end of the log has broken off the piece of wood which hides the notching and hence negated its purpose. – Church in Hervartov, Slovakia

forced by economics, was made to look like a problem in the joint itself and so this form was eradicated. Dowelling and wedging once again became first choice, a form of jointing which carpenters had rejected back in Roman times in favour of the better serrated or indented joint.[60]
In European timber construction the step joint was an extraordinarily important element and solved a major problem: every oblique tenon carried the full shear force on its tenon. (Fig. 193) In order to distribute this load better, the joint cried out to be strengthened at the place where the tenon could be sensibly reinforced, i. e. by way of a bevelled shoulder in the notch at the toe or heel of the incoming member. (Fig. 194) A series of double-step joints led to the built-up beam with indented adjacent surfaces. Of course, the bevelled shoulder was only worthwhile when it really did relieve the stub tenon, i. e. when the joint was made so accurately that it actually resulted in a distribution of the load and not simply a weakening of the cross-section. The more joints in the series, the greater the chance of inaccuracies accumulating.
The frequency of diagonal members led to the development of a very diverse range of step joints. For example, one version was designed for truss posts with diagonal braces. In this case it was important that as much as possible of the cross-section of the post be retained. Therefore, our carpenter did not cut a mortise in the post but instead spread the joint of the incoming strut over the full width of the strut and only made use of the tenon to prevent the joint slipping. This type of joint also led



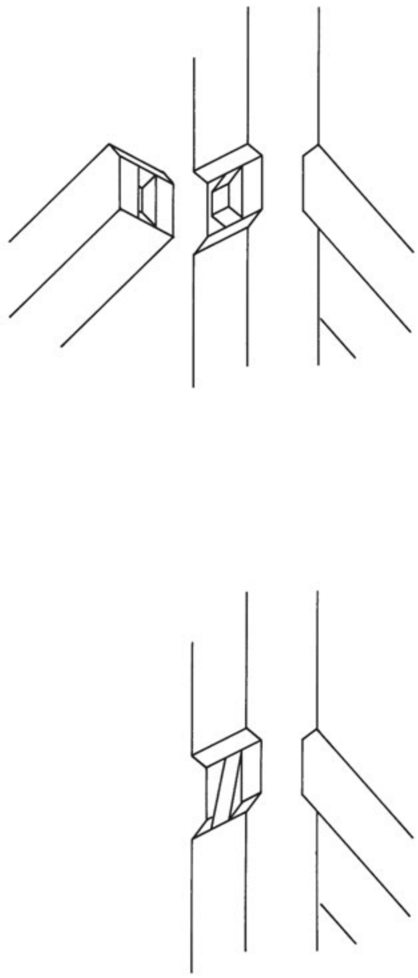
193 Oblique tenon joint (according to: Warth, 1900, Fig. 82)



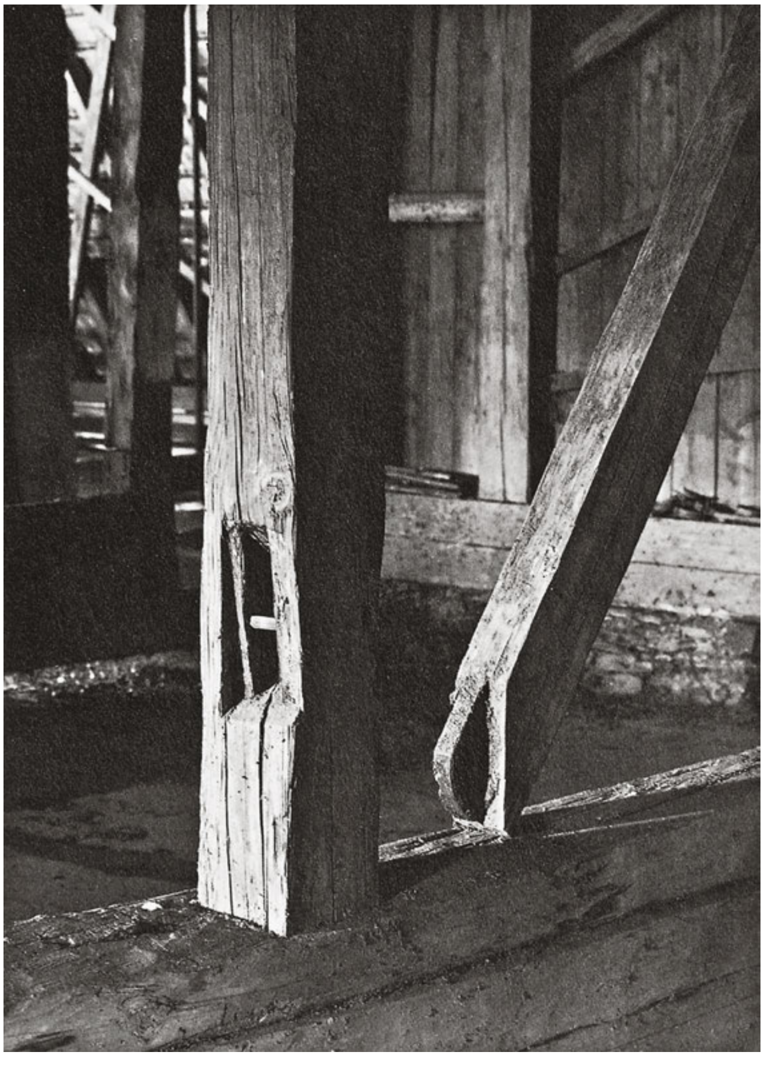
194 The shear section of the tenon can be enlarged by including bevelled shoulders at the toe or the heel in step joints. (according to: ibid., Figs 83, 84)

192 Two unconnected beams over a passageway in Heppenheim, Hessen, Germany, demonstrate the weak point of knots dissected parallel with the grain.

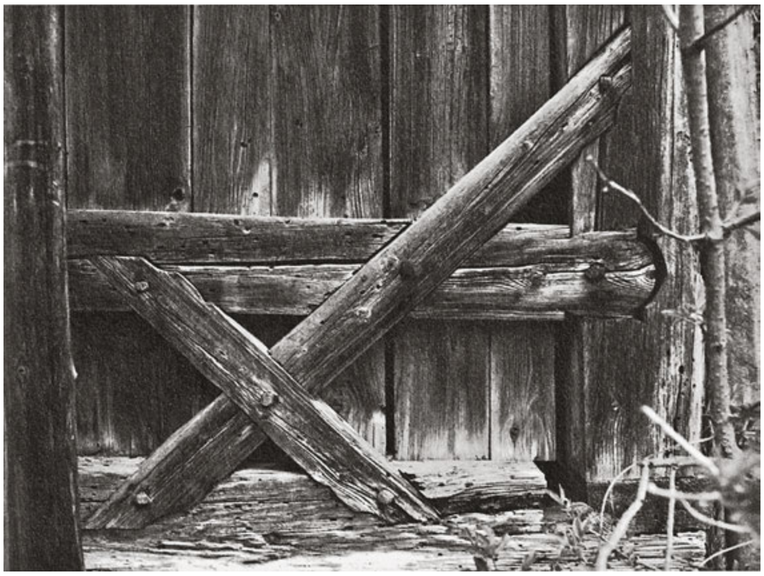
to a number of worrying designs even finding their way into textbooks.[61] (Fig. 195)
In his textbook, Opderbecke criticises joints employing wooden nails or pegs because "they have a low resistance". However, history has shown us that generations of carpenters had made do with the shear strength of wooden nails. Opderbecke quite rightly sees the real problem of the wooden nail as its unreliability – it dries out severely over the years.[62] (Fig. 196)
Once again, we give way to economic pressures which tell us that it is impossible to first let the timber for wooden nails dry out sufficiently to take account of its properties; however, this situation is presented as a problem in the textbooks,[63] a problem of something which cannot easily be taught: the experience of the actual effects of the shrinkage of timber. At one time it was customary to employ very dry wood for wooden nails in order to ensure they remained firmly in place. In Japan they have gone one stage further and now employ modern technology to exploit the properties of wood: the members to be assembled are artificially dried to well below the average atmospheric humidity. This means carpenters' joints are held absolutely tight and rigid with the smallest gaps because after being assembled, the wood has to regain its hygroscopic equilibrium.[64]
Without doubt responsibility for the demise of hand-crafted woodworking joints cannot be blamed solely on economic con-



195 The tenon parallel with the grain in the upper step joint especially designed for truss posts (according to: ibid., Fig. 87) is very much at risk. The second version would be just as effective and much less problematic with respect to twisting of the wood.

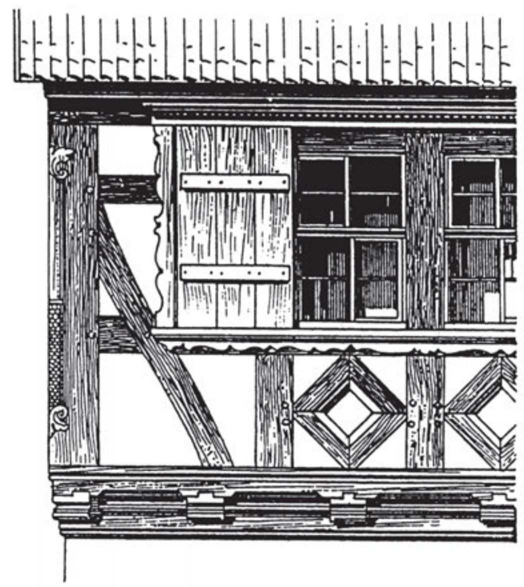


196 Bracing members no longer function as such when a lost nail no longer holds the tenon in position. Nevertheless, in this case from the roof truss of Pöckstein Castle in Zwischernwässern, Carinthia, Austria, the roof is not in danger of imminent collapse!

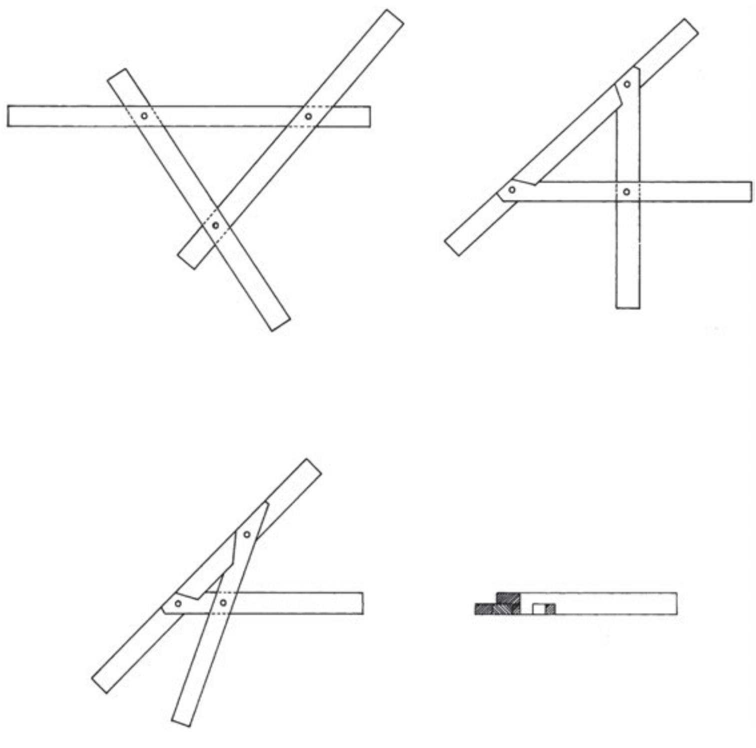


197 The shear strength of the wooden nail is many times greater than the tensile strength of this decorated lap on a building in Haus near Tengling, Bavaria, Germany.

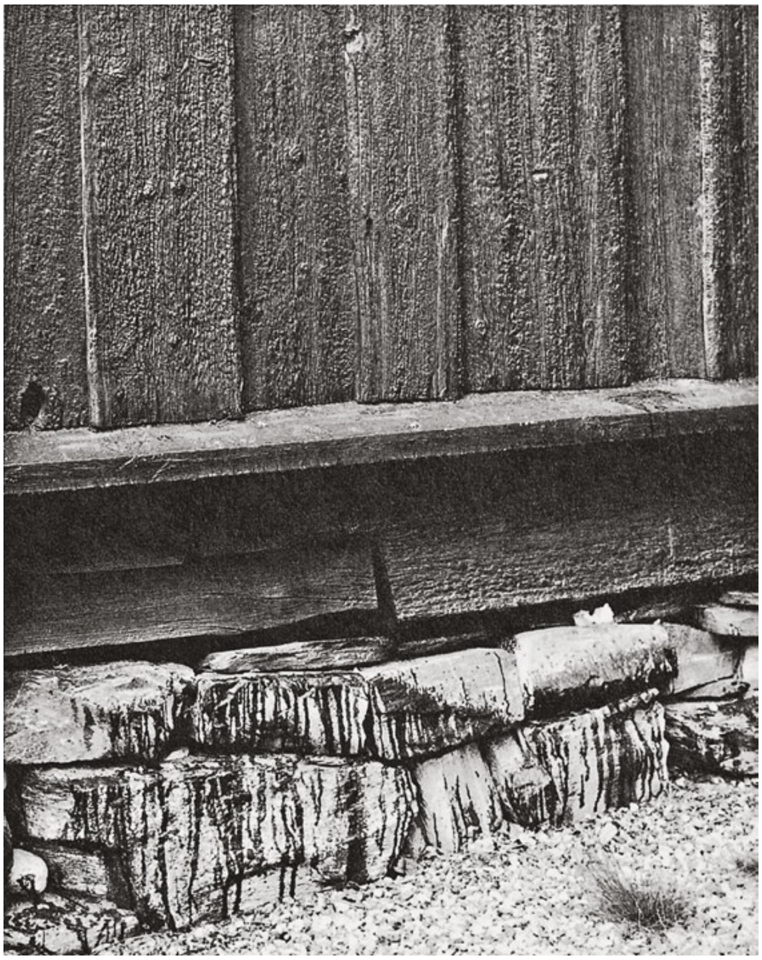
ditions, and, likewise, not on the craftsmen themselves who were simply trying to earn a living. Nevertheless, the carpenter cannot escape his reponsibilities entirely. If carpenters, in a frenzy of exuberance, deliberately ignored the function of a joint,[65] (Fig. 197) we should not accuse the draughtsman of not understanding the task of the timber joint. (Fig. 198) Incidentally, if one reads how, not infrequently, even buildings destined for high-ranking persons deflected perilously under the imposed loads, then one can conclude that the treatment of the individual parts, just like the whole, had not taken place with the due care and attention befitting the experience of even court architects. For the common man then, for whom it was not found necessary to record such things, how often must the walls and roofs have shaken and swayed?[66]
In his *Statistische Übersicht bemerkenswerter Holzverbindungen* (Statistical survey of remarkable wood joints) published in 1841, Geier discusses a whole series of very complex roof designs. At



198 What is actually the function of the nails in the vertical members of this house in Wasungen, Saxony, Germany? (source: Neumeister, Häberle, 1894, Pl. 36)



199 Sketches of concepts for stable angular jointing (according to: Geier, 1841, Figs 5–8)

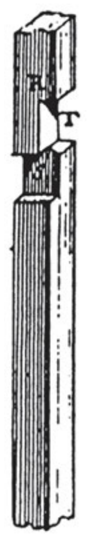


201 If this unkeyed tabled scarf joint on the sill beam under the *svalgang* to this stave church manages to fulfil its purpose, it is not thanks to the carpenter! – Ringebu, Oppland, Norway

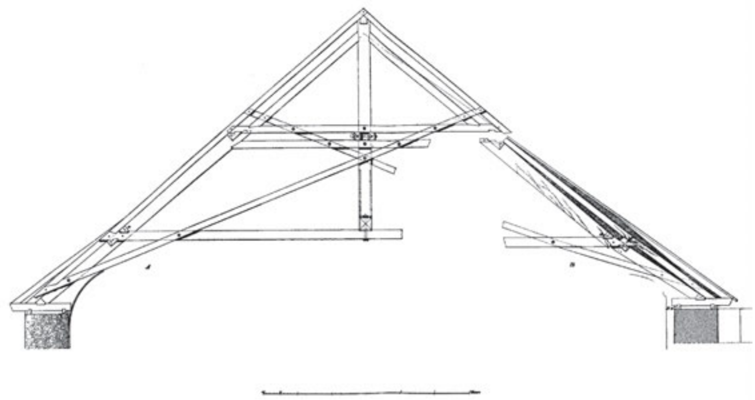
the start of his book he presents the principle of triangulation. He clearly demonstrates that the immobility of the assembly is not the only matter which should concern the carpenter[67] (Fig. 199) and uses the roof truss built in 1766 at the electoral horse-racing track in Mainz, Germany, by way of an example. (Fig. 200) "This roof truss … provides us with a very clear example of how disadvantageous it is if the architect commits himself to one type which he applies and retains in blind faith for all cases; although one should research the general laws appertaining to a construction and deal with them, such as the truth of the geometry which shall apply for all eternity, one should comply with special conditions in each individual case and hence impress on every new task the mark of intellectual creation."[68]

The quality of a joint, in terms of how it fulfils its allotted task, can only be assessed after many years of practical application. A joint might turn out to be an unnecessary, excessive safety measure which owes its existence to an unquestioning loyalty to tradition. (Fig. 201) We can find many specimens which justify the criticism of old types of wood joints. For example, simple lap joints are especially at risk from shrinkage of the material, particularly since timber was often used green. (Fig. 202)

So, when we find the same problematic joints from the Middle Ages still being used for the more complicated tasks of the Baroque period, we are quite justified in questioning the wisdom of retaining traditional methods. (Fig. 203 & 204) We may be sure that joints which "often gape open several centimetres

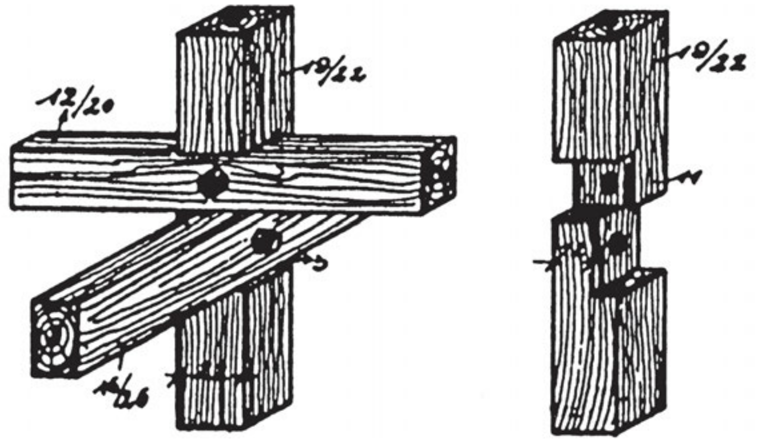


203 Three-way joint – truss post/collar beam/longitudinal bracing – for a fictitious composite truss frame. (source: Schübler, 1736, Pl. 17)

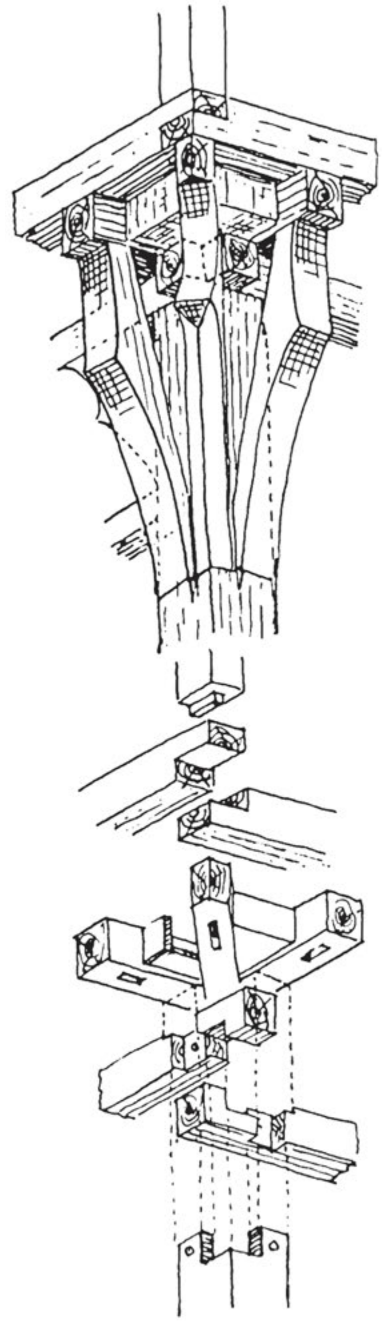


200 This section through the truss of the the electoral horse-racing track in Mainz shows the almost criminal carelessness of the builders. The carpenter has weakened the inclined queen strut at the joints to well under half its cross-section exactly at the most heavily stressed point. The weight of the roof causes a tensile stress in the inclined strut counter to the compression in the transverse bracing; the cross-sections of the inclined struts were not capable of taking such compression. (source: ibid., Pl. I.4.)

202 The same detail on St Mary's Collegiate Church in Frankfurt am Main, Germany, built in 1344. (source: Schnell, 1915, Pl. 16)



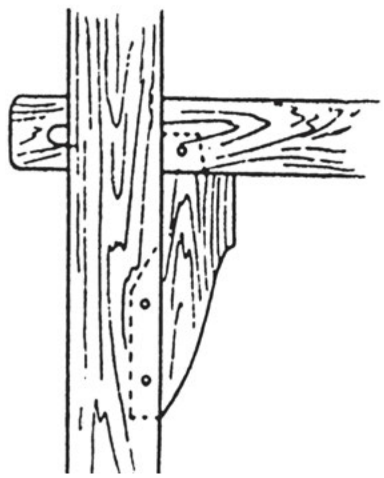
after the wood has shrunk"[69] do not place the carpenter in a very good light. Today, far removed from any bond with traditional methods of construction, we can indeed sit back and criticise much of what was done in the past, including solutions from authors who have often put to the test their keen critical abilities. (Figs 205, 206 & 207)
The problem faced by the carpenter building the roof truss over the town hall in Marienburg (see Fig. 116) is one which has occurred often. Similar examples from England illustrate the possibilities open to the mentally alert carpenter. To show the absurdity of the dovetail – the shape of which is certainly the result of a hoped-for fulfilment of a function –, but not in such an indescribable manner as in Marienburg, we can first locate the tenon asymmetric. (Fig. 208) Adding a second tenon in a symmetrical arrangement represents a plausible progression; two tenons can not only be made slimmer, they can also improve the joint. (Fig. 209)
The importance of the interplay between the properties of wood and the working of wood will now be demonstrated by way of a number of selected examples from Japan. The reason for choosing these particular examples is not, as the reader may think, to confront poor European examples with good



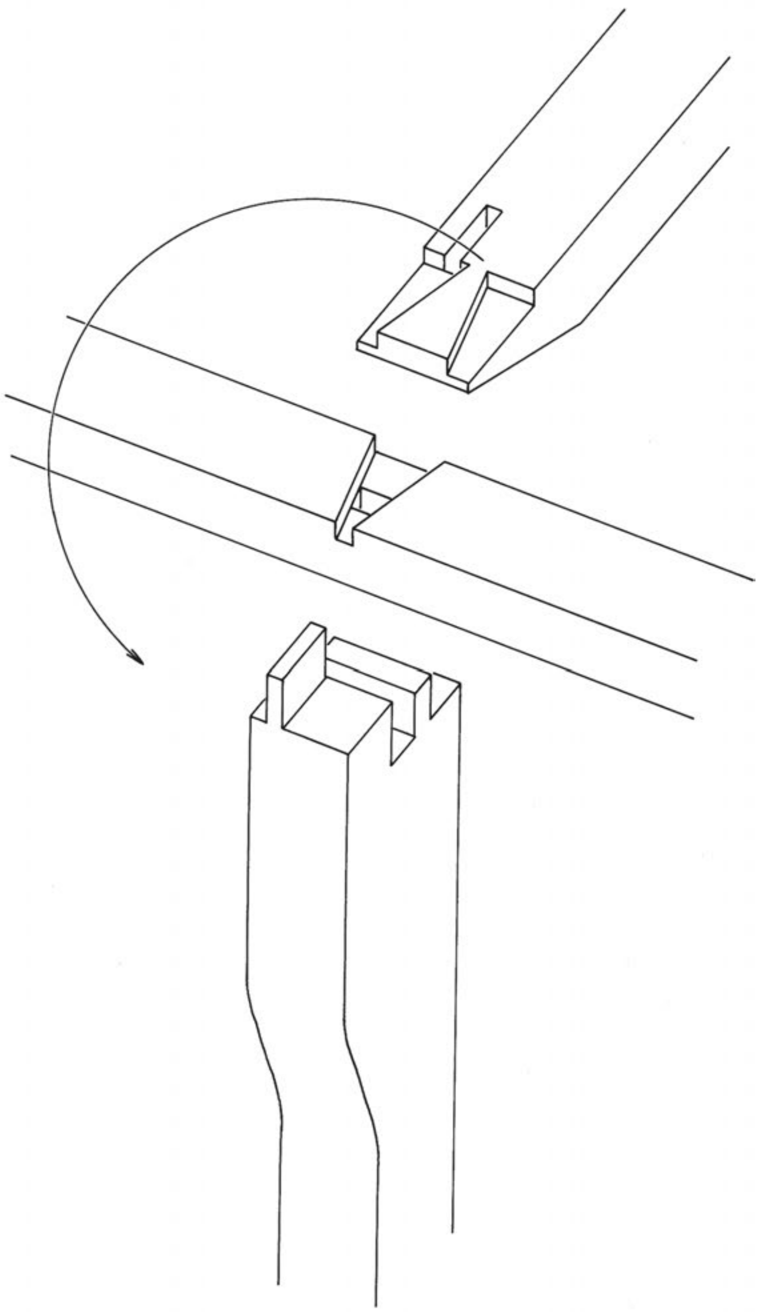
204 The same joint with additional restraint at the supports and incorporated in a different context must of course be judged in a different light. – Jettied corner in Steinheim am Main, Hessen, Germany (source: Winter, 1961, Fig. 8)

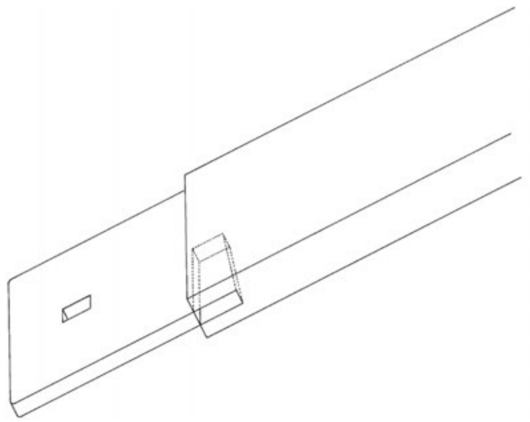
Japanese ones, but rather their suitability for conveying a message.

The first example is a keyed through tenon in the framing to the Kyuhonjin kinenkan in Hirata, Shimane. (Fig. 210) As the horizontal beam supports the purlin, it must be more substantial than the vertical support in order to rule out any deflection. Such an arrangement also reduces the stresses on the wedges in the projecting tenon. The vertical support remain very short in order to reduce the danger of buckling. Since the support is so slender, the tenon passing through it must be made as thin as possible; its slimness is compensated for by its depth as well as by the smaller slot for its bearing in the support. A short projection would be split off by the wedges, so this projection is made correspondingly longer; the thinner the tenon, and hence the projection, the greater is this risk. Characteristic of many Japanese joints are the lateral shoulders which "embrace" the support; these prevent the horizontal member from twisting –

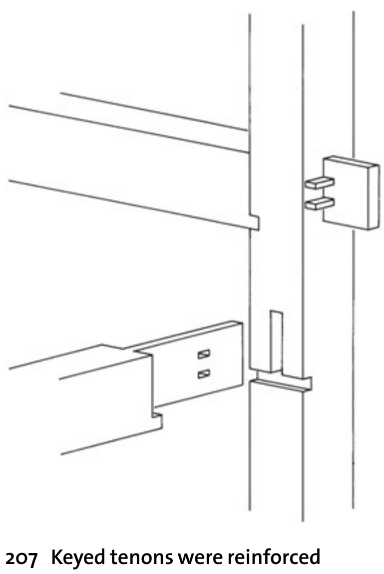


205 "The post reinforced by a mortised jowl was a useful way of improving the bearing . . . This arrangement is really quite perfect." (source: Hanftmann, 1907, Fig. 8b)





206 This axonometric projection shows how much the anchor beam is weakened by "the strengthening".



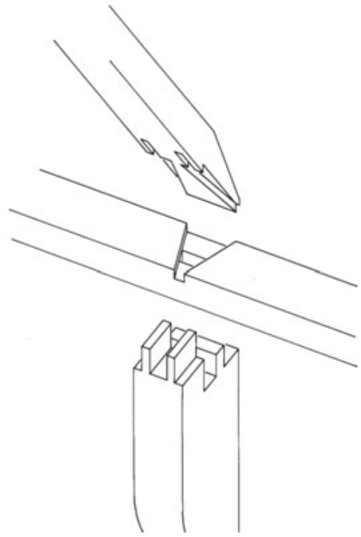
207 Keyed tenons were reinforced differently in Japan.

208 Three-way joint – column/header/tie beam – on a granary in Cressing, Essex, England, dating from the 17th century. (according to: Hewett, 1980, Fig. 281)

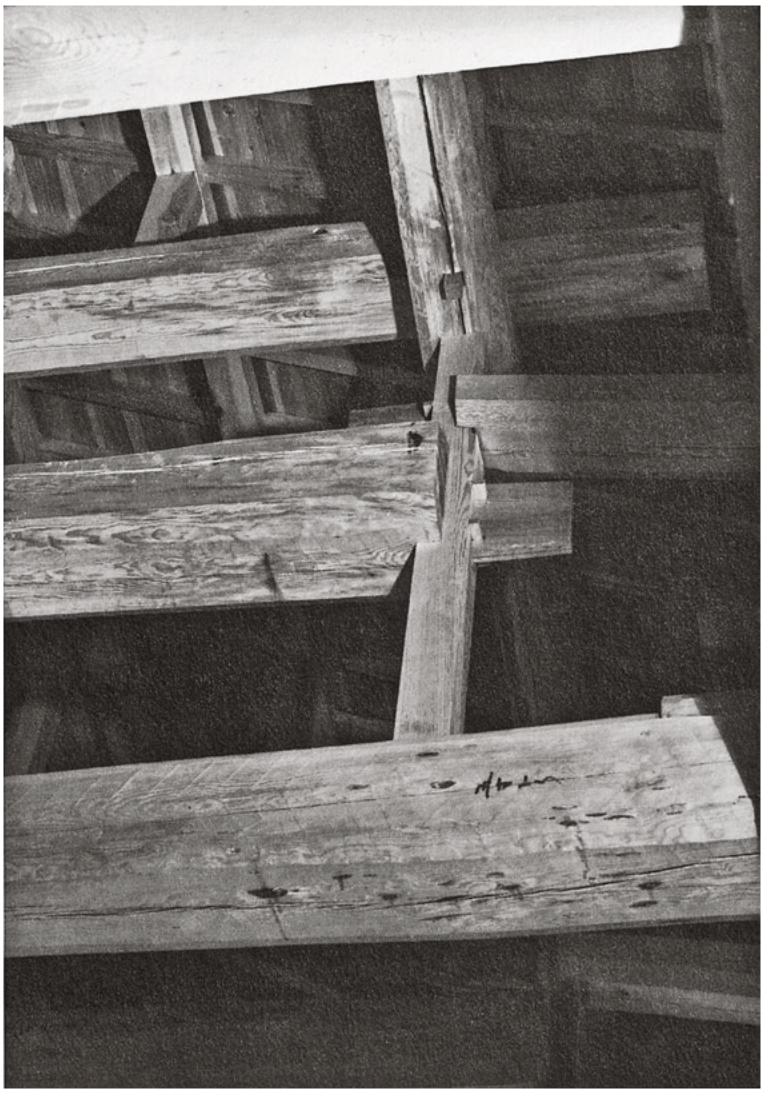
which would seriously endanger such a thin tenon. At the same time, this partial enclosing of the support seems to be its weak point, caused by the mortise. This method of construction is employed for the *wagoya-gumi* roof.[70] The reason for using this type of joint was to offset the lack of straight building timber and to enable construction with timber of poorer quality. Only at first sight does this appear to contradict the enormous volume of wood used in building.

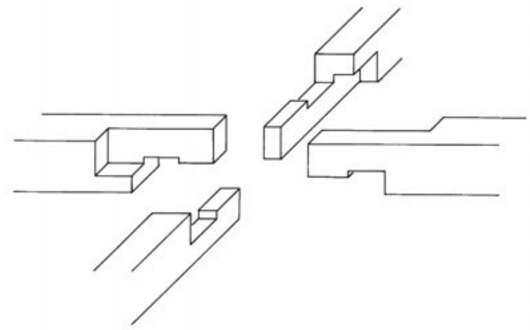
Accuracy of fit was no mere ideal in Japanese building. “It was the absolute minimum requirement for everyday practice.”[71] The joints themselves are the best examples of the interplay: the more branches to the joint, the more accurately the carpenter had to work. The reverse of this is that the carpenter would obviously only invest time and effort in evermore complicated intersections if his work had a practical objective, if a real improvement in the joint, with its increasing complexity, could be expected.

The longitudinal and transverse stiffening of a framework by means of rails and beams was solved very differently by the Japanese in comparison with their European colleagues. While the latter often only accomplished their task through the vertical displacement of horizontal members leading away from columns, in Japan every effort was made to remain in one plane. (Fig. 211) In doing so, the basic pattern – how much space can



209 The same detail but this time on Walker’s manor house barn in Farnham, Essex, England, dating from the 15th century. (according to: Hewett, 1980, Fig. 282)

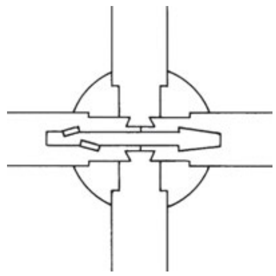




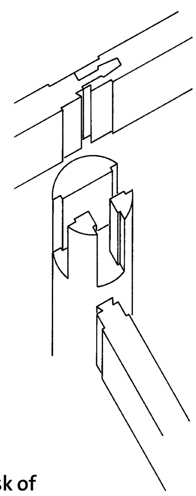
211 In the Todai-ji nandaimon, Nara, Japan, the solution in 1199 was to treat each member equally, all parts being weakened in the same way. (according to: *Zairai koho no kenkyu*, 1993, Fig. 4–40–7)

210 No matter which of the properties of wood one cares to name, they all seem to have been taken into account in this Japanese variety of keyed tenon.

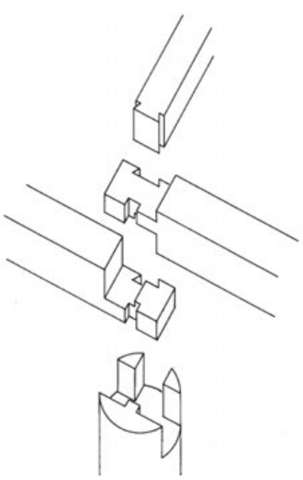
be assigned to each element in the joint – has to be thought out in great detail, e.g. to avoid weakening the column unnecessarily but at the same time leaving enough room when the head beam is spliced directly above. The extremely long key haunch mortise and tenon joints or gooseneck tenons have presented themselves as good solutions. (Fig. 212) In tension, both types are much better than dovetail joints.[72] The main weakness of these long, thin tenons is their low resistance to lateral loads. However, by introducing bridled abutments or rebates they could be made progressively slimmer. The inclusion of further members necessitated the use of dovetails which, likewise, were provided with shoulders to strengthen them. (Fig. 213)
The development work necessary for creating such highly complex joints was worth the effort so long as columns remained larger. In the Todai-ji kaisando the horizontal diameter of the head beams was almost three times that of comparable beams in the Enkyo-ji zikido, and the vertical diameter over twice.[73] (Fig. 214) A not unimportant factor in this evolution might have been the fact that the problems linked with dwindling timber reserves could be minimized through the use of strategically placed additional bracing.
The case of the Taisan-ji hondo illustrates quite clearly that the carpenters knew of no other solution to the general reduction in cross-section dictated by contemporary tastes other than to simply cut away the cross-section and see whether the remaining material was capable of doing the job it was supposed to![74] (Fig. 215)
Although these two examples, Todai-ji and Taisan-ji, stem from roughly the same period in the 13th century, the gamble of taking the next step did not come for another 200 years. The solution for the Zizobu-ji hondo, although not dissimilar, (Fig. 216) had nevertheless been altered to such a great extent that the distance to the principle outlined above (Fig. 212) had almost been covered. Rotating the head beam had reduced at a stroke the resistance to lateral pressure offered by the scarf joint now transformed virtually into a tenon. It is not for nothing that the shoulder is clearly reduced.
And these examples teach us something else as well: as there is only a finite, relatively limited number of sensible wood joints, these joints must be constantly developed and adapted to the respective, prevailing conditions.



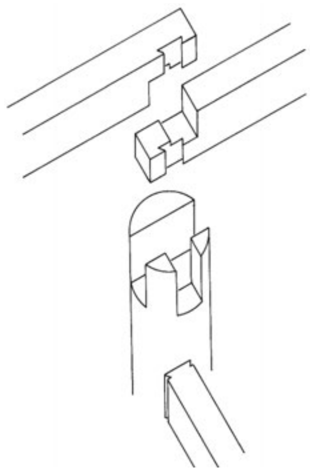
212 Japanese principle for a tension-resistant jointing of four beams at the top of a column.



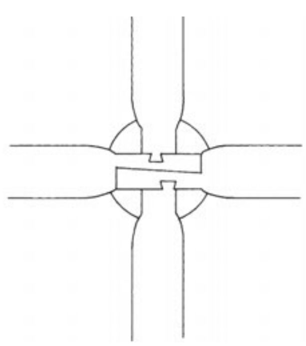
213 Exactly at the point where the risk of breakage for the tenons was greatest, their reinforced shoulders weakened the column the least. – Enkyo-ji zikido, Hyogo, Japan (according to: *Bunkazai* …, 1986, p. 335/3)



214 In the Todai-ji kaisando, Nara, Japan, the longitudinal members with halved-and-tabled scarf joints were connected to the forked columns. A tenon cut vertically into the column engaged with the scarf in such a way that the tabling was strengthened against tensile loads. The transverse member perpendicular to this, jointed via a dovetail, made it practically impossible for the header joint to deflect. The shoulder inserted into the column still remained as wide as the beam. (according to: ibid., p. 142/1)



215 In the Taisan-ji hondo, Hyogo, Japan, the column tenon had to be omitted owing to lack of space. The beams had been reduced to half the diameter. (according to: ibid., p. 190/1)



216 In the Zizobu-ji hondo, Wakayama, Japan, the tenons on top of the column could be omitted because the central column had to be braced in both directions. Remarkable is the rather inconsistent arrangement of the dovetails, which have become much smaller owing to lack of space. The beam cross-sections are already reduced. The halved-and-tabled scarf beams of the jointed header part was turned through 90° here and has become the single dovetail, again, probably for reasons of space. (according to: ibid., p. 291/3)

1 Hewett, 1985, p. 8
2 Holan, 1990, p. 166; Schier, 1966, p. 346. A *loft* is a two-storey storehouse used on traditional Norwegian farms. (Holan, ibid., p. 17)
3 Kaiser, Ottenjann, 1988, p. 18
4 Petrescu, 1974, p. 53
5 Gunda, 1986, p. 81
6 Ibid., p. 90
7 Ibid., p. 82
8 Petrescu, ibid.; Gunda, ibid., p. 90
9 Dienwiebel, 1938, p. 148
10 Gschwend, 1988, p. 236 f.
11 Ibid., p. 303; Bygdøy-Führer, 1988, p. 33
12 Klöckner, 1982, p. 56
13 Bussagli, 1985, p. 165; Masuda, 1969, p. 88; Miyagawa, 1959/1,2, p. 64; Soper, 1990, pp. 301, 445, note 11
14 Brown, 1989, p. 36
15 Parent, 1977/1, p. 81
16 Haiding, 1985, p. 58
17 Gerner, 1992, p. 35 ff.
18 cf. p. 219
19 Graubner, 1986
20 Ibid., p. 128
21 Seike, 1981; *Takenaka daiku dogu kan*, 1989; Sumiyoshi, Matsui, 1991; Nakahara, 1990; *Bunkazai kenzo butsu hozon gi jiutsu kyokai*, 1986
22 Kretschmar employs the same categories in his textbook as are customary in Japan. And in designating the junction of two stair stringers which pass around a corner as a splicing joint, he does remain consistent. (Kretschmar, 1885, pp. VIf., 48)
23 Speidel, 1983, p. 22
24 A European joint on the same principle is the Gerber butt joint.
25 Zwerger, 1995, pp. 42–44
26 *Bunkazai* …, 1986, p. 590
27 Graubner, ibid., p. 86
28 Seike does not follow this classification. He calls the *otoshi-ari* joint, a housed dovetail, an *ari-tome* in the case of an L-joint. (Seike, ibid., pp. 68, 78)
29 Introduced here is the one proposed in *Bunkazai kenzo butsu hozon gi jiutsu kyokai*. Another omits the *kama* joints and instead makes much more of a distinction between cogged, scarf and tenon joints. (*Takenaka daiku dogu kan*, ibid., p. 49 f.)
30 *Bunkazai* …, ibid., p. 590
31 *Takenaka daiku dogu kan*, ibid.; Seike, ibid., p. 102 f.; Nakahara, ibid., p. 37
32 Of the over 450 illustrations in Schübler's *Zimmermannskunst*, only an insignificant number deal with timber joint details. (Schübler, 1736)
33 cf. p. 236
34 cf. p. 253 f.
35 Both definitions stem from Graubner. They have been chosen because they present a sensible and at the same time unambiguous distinction. (Graubner, 1986, pp. 123, 137)
36 Klöckner, 1982, p. 67
37 Phleps, 1958, p. 46
38 Breymann, 1900, p. 61
39 Gerner, ibid., p. 157; Lissenko, 1989, pp. 57, 222; Zippelius, 1954, p. 33
40 The successive layers of several logs will in the first case lead to each log being reduced to half its cross-section at the connection point because one-quarter has to be cut out from above and from below.
41 Werner, 1978, p. 204
42 Schier, 1966, p. 101
43 Baumgarten, 1961, p. 59
44 Lissenko, ibid., p. 57
45 Gerner, ibid., p. 162
46 Schier, ibid.; Zippelius, ibid.; Lissenko, ibid.; Grisebach, 1917, Figs 7–9
47 Werner, ibid.
48 *Malschrot* does not fall into line. See p. 254 for an explanation of why in this case the members, although inserted into the joint separately, are done so horizontally, unlike in the case of box joints.
49 Schier, ibid.; Werner, ibid.
50 Werner, ibid.; Zippelius, ibid., p. 33; Lissenko, ibid.
51 To complicate the whole matter even further, the German prefixes *"über-"* and "*ver-" are* used by some German writers on the subject to identify corners with or without projecting ends, e. g. *Überkämmung* (notched joint) meaning one member above the other, *Verblattung* (halved joint) interlocking one member with the other. (Gerner, ibid., p. 7; Schier, ibid.; Grisebach, ibid., Pl. I-III)
Graubner, on the other hand, when describing an actual halved joint, talks of a "halved lap" (in the first meaning, cf. p. 97, i. e. a ring-type assembly in one plane. His use of the terms "pectinate halved joint" (in the second meaning), "quarter halved assembly" and "staggered halved joint" (in the second meaning) (*verschränkte Verblattung, Viertelblattverband* and *versetzte Verblattung* respectively) is really quite meaningless because they all describe one and the same joint! (Graubner, 1986, p. 128 f.)
Other authors do not make any distinction at all between the two prefixes in their writings. (Werner, ibid.)
52 Mönck, 1985, p. 77
53 Seike, ibid., pp. 12, 91
54 Brunskill, 1985, p. 36
55 cf. p. 248 ff.
56 Graubner, 1986, p. 16
57 "Carpenter's hair" was the derogatory name given to a gap which resulted from inadequate care being taken when making a joint.
58 Deinhard, 1962, p. 14
59 Kretschmar, 1885, p. 70
60 Schübler, 1736, Fig. 131
61 Breymann, 1900, p. 30
62 Opderbecke, 1909, p. 126
63 Ibid.
64 Seike, 1981, p. 92
65 Gerner, ibid., p. 77
66 Hanftmann, 1907, p. 13
67 Geier, 1841
68 Ibid.
69 Gerner, ibid., p. 101
70 cf. p. 83
71 Coaldrake, ibid., p. 48
72 Sumiyoshi, Matsui, 1991, pp. 6, 9
73 *Bunkazai* …, 1986, pp. 142, 335
74 Ibid., p. 190

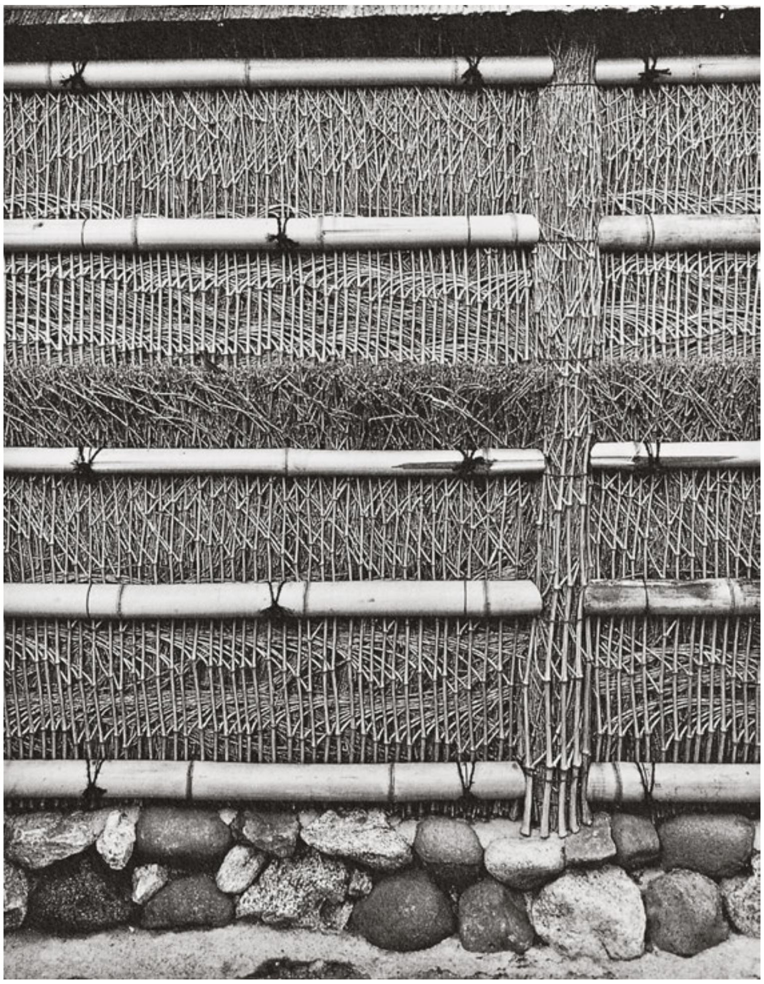
The role of the tool

"Every tool serves to extend the activity with the hand."[1] Today this quote has only limited validity as tools take on many activities in their entirety and, in fact, not only manual operations. We might be tempted to say that the human mind is the one single tool which is indispensable. But the more the worker lets himself be degraded to the tool of the tool he devised, the less indispensable the tool characterizing and distinguishing him becomes. When machine tools, grown to giant size, outgrow their supportive attendants, they begin to take over from their masters step by step. As mankind is liberated more and more from manual work, the threat that we will let the chances for individual design and decision-making slip through our fingers becomes greater and greater.
At any rate, the development of wood joints would not have been possible without that marvellous tool – the human mind. Further, some designs could even be realized without the use of any "artificial" tools – just resorting to hands and feet. (Fig. 217) A large sector which might be regarded as an example of this is wattlework.
Wattlework,[2] refined to a very high degree, accompanied mankind into the present century. There was nothing left to invent

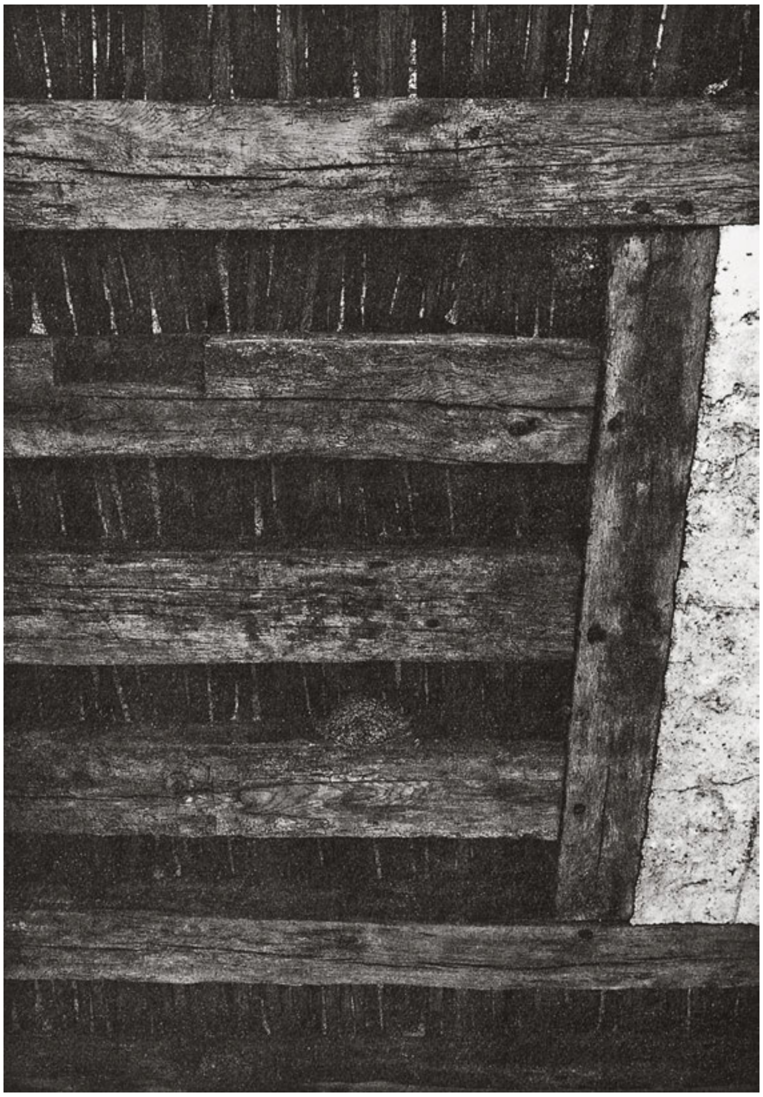
217 This temporary sheep fold near Xanthi, Macedonia, Greece, was fenced off using loose brushwood and reeds simply placed in a row.

218 Decorative wattle fencing. – Sat Şugatag, Maramureş, Romania

in the wattlework sector so the wattleworker was tempted into presenting his abilities in an aesthetically sophisticated way. In Europe, the best specimens belong to the past, (Fig. 218) while in Japan they are still found today. (Fig. 219)
Pieces of wood – simply gathered and in no way processed – placed next to each other represent the archetypal form of jointing parallel with the grain. (Fig. 220) Although such windbreaks were relatively impervious, they were insufficiently stable, even for nomads. Placing the vertical pieces further apart enabled horizontal pieces to be woven in between. (Fig. 221)
Weaving the pieces into regular geometric forms brought a further gain in terms of stability. (Fig. 222) Suitably covered, such frameworks may even have offered rudimentary protection against the elements. (Fig. 223) At the start of the 20th century Finno-Ugric peoples were still building huts which although much heavier than those of the southern Europeans (to suit the extreme weather conditions of the north instead of the mild Mediterranean climate), were identical in terms of type of construction.[3]
During the Bronze Age and right up until the early Middle Ages, the inhabitants of the northern part of Ireland and the Celtic areas of Britain lived in double round houses made up of two circles of twin-leaf wattle walls. The 300-mm "cavity" was filled with an organic material (however, a very specialized tool was used to build these structures). According to our present state of knowledge, what is unique about these houses is they remained without any plaster,[4] as had already been common during the



219 Bamboo fence near Nagasaki, Japan.



220 The gaps between the beams over a passageway through a house in Coulommiers, Île de France, are filled in with loose, unworked wooden sticks laid next to each other; these then carry a filling material.

221 Wattle fencing forming part of a shepherd's shelter near Komothini, Macedonia, Greece.

222 The framework of a primitive one-man hut near Komothini, Macedonia, Greece.

223 Shepherd's hut near Wrasna, Macedonia, Greece.

225 The wattle gable is the last surviving reminder of the wattle house. – Dunaszekcsö, Hungary

224 A lot of attention was paid to the building of "corn baskets" to store what was once the most important crop in many regions. – Mara, Maramureş, Romania

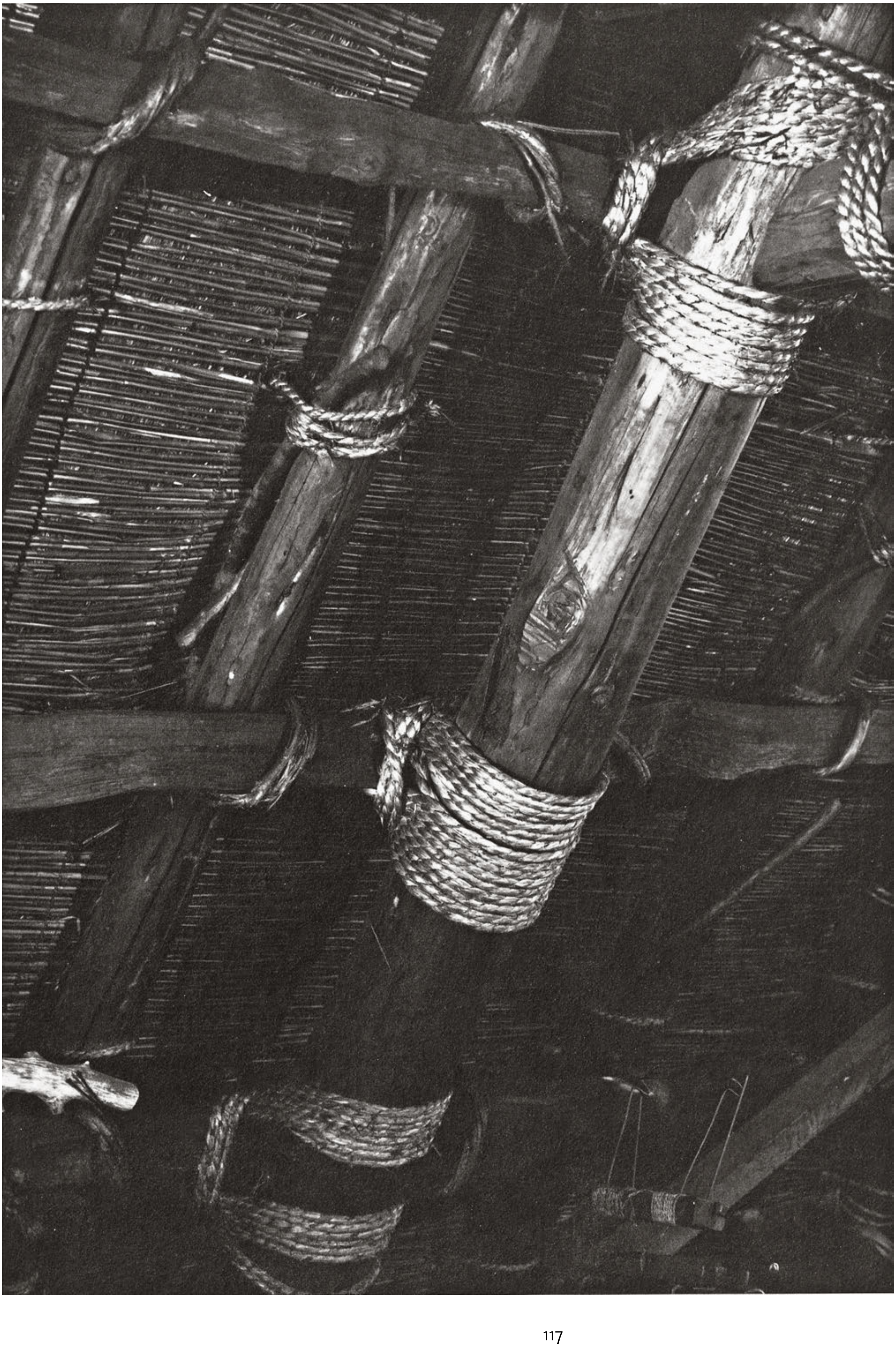
Stone Age.[5] Unplastered wattlework, if built properly, can be very stable and will always allow the passage of sufficient air. (Fig. 224) In Russia houses were built with wattlework up until about AD 500. *Plotnik*, the wattleworker, became and remained the expression for carpenter.[6] Wattlework was still used for the production of, as a rule, uninhabited buildings in a large part of eastern Europe until well into the 20th century.[7] The deeply rooted tradition of smearing daub on wattle walls is supposed to be the reason behind the custom of even covering log buildings with daub in many regions of Poland as well as in the Sudetenland and the Carpathian Mountains.[8] In Italy and Spain too, this type of construction was no stranger,[9] likewise in England and northern Europe.[10]

Perhaps the most obvious feature of wattlework structures is their oval or circular plan shape, in contrast to buildings which only use wattle as an infill material for the walls. In a sense, rural buildings combining wattle walls with skeleton-framed, more solid walls represent a transitionary form. While timber-framed walls were filled in with (usually) plastered wattle panels, in those instances where the attic space needed to be separated for functional purposes the triangle formed by the roof timbers, i. e. the visible gable triangle, was itself built as a wattle wall.[11] (Fig. 225) The techniques had become so well developed that chimneys (Fig. 226) and even ovens were constructed from wattlework![12]

The introduction of tying members together was a fundamental extension of the concept. (Fig. 227) The quick assembly and easy dismantling secured for this jointing technique a virtually exclusive place in the scaffolding of the Middle Ages,[13] in many places even surviving into the 20th century. In this way it was possible to fasten not-very-strong pieces of timber, in curved forms as well. In this way the volume of a tent-like hut could be increased by over 50 %. Tied connections do not require the pieces to be joined to be worked in any way. (Fig. 228) They even meet today's standards and can be applied universally. For example, the walls of Japanese timber-framed buildings are still filled with a lattice of tied bamboo strips finished with plaster. The older *okabe* wall integrated the vertical supports

227 "Stone-Age knots" tied in bass or coir rope. (source: Reinerth, 1929, Fig. 14)

228 Tied joints on a *minka* in Shirakawa mura, Gifu, Japan.



229 **Wattle-and-daub infill panels on a *minka* in Iwate Futsukamachi, Iwate, Japan.**

226 **Wattlework chimney in the Bardejovské Kúpele Open-air Museum, Slovakia.**

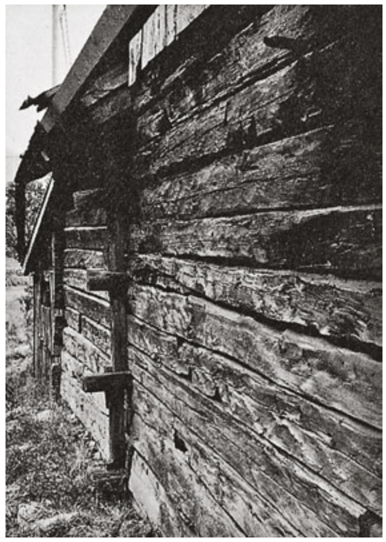
in the latticework so that they too disappeared behind the plaster, increasing the wall's fire resistance and making it more airtight. However, the aesthetic appeal of the so-called hanging wall *(shinkabe)*, although much more complicated to build, guaranteed it a position in the repertoire, especially for prestige buildings.[14] (Fig. 229)

Incidentally, the order in which weaving and tying have been dealt with here is in no way intended to reflect their appearance in a chronological sense. The intention is merely to highlight the fact that two different techniques were employed. The buried bases of posts in palisade walls were lashed together.[15] So, using the tying method, people could also construct more massive fences. Such fences ranged from very impervious (Fig. 230) to more solid wall-like constructions, (Fig. 231) depending on the materials used.

In log construction, besides joints at the corners, the layers of logs were often additionally secured by means of ties. (Fig. 232) Generally, and here too, it is assumed that jointing techniques were always first tried out on a small scale and practised before it was dared to use them on a large scale.[16] (Fig. 233) Walls with corners – called post-and-rail walls by Zippelius – were reconstructed for the Taubried Neolithic settlement in the Federsee Moor, Germany.[17] (Figs. 234 & 235) They stand independently owing to the pairs of posts bound together, while log walls require specific joints at the corners in order that they can be

231 **Boarded fence near Uvdal, Numedal, Norway.**

230 Post-and-rail fence near St Corona, NE Austria.



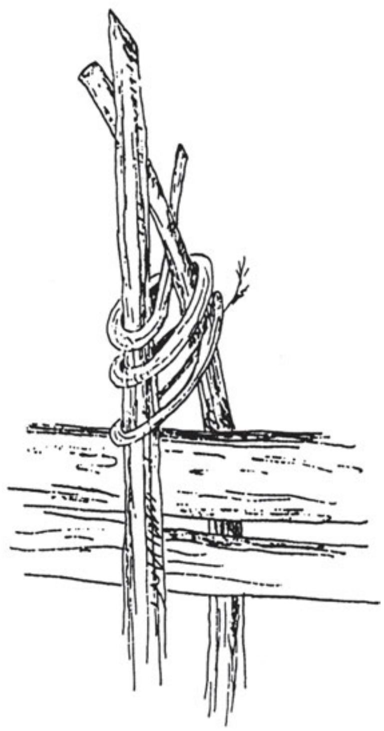
232 The log wall of a house in Børgo, Sogn, Norway, secured with a retaining pole.

erected at all! The post-and-rail walls were, in principle, identical with the walls of some old Swedish houses. In Swedish, connecting together two earthfast timber poles by means of a piece of branch wound around them, e. g. to build a fence, is called *knut timra*, "making a knot by carpentry". Elsewhere, doing carpentry work is first spoken of from the stage in the history of carpentry marked by the production of man-made forked supports or mortise-and-tenon joints.

Fundamentally similar assumptions were made for Japan with respect to the Neolithic Age. During the Jomon period (10,000 to 300 BC)[18] timbers were only lashed together,[19] with those early peoples managing, basically, without tools. Carpenters called this the "construction from the time of the myths" *(tenchi gongen zukuri)*.[20] But this does not mean to say that Stone-Age man had no stone tools.[21] For example, hewn ridge-supporting columns 450 mm in diameter have been found, even trunks worked into squared timber, which could be handled easier, using an axe and a forerunner of the *chona*. However, mortise-and-tenon joints were unknown.[22]

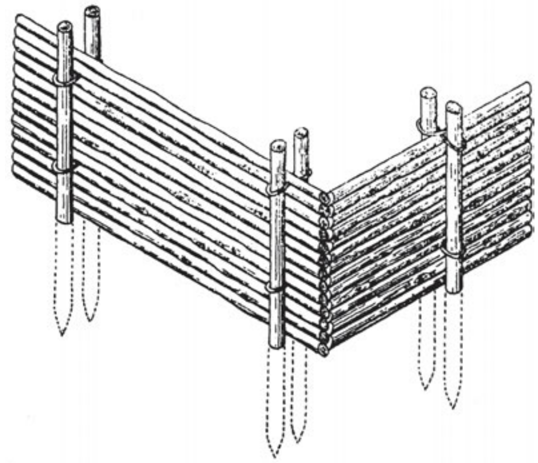
The first important step in the use of tools was the utilization of forked branches.[23] These were available in sufficient quantities but the moment they were set up in a row to carry one or more ridge beams, the desire grew to adapt their naturally grown shape or to fell trees which seemed suitable. (Fig. 236) To do this, a tool to assist the hand was essential. The proper use of tools enabled Stone-Age man to accomplish feats which we today can hardly fathom. The fewer technical aids were available to force the material to do our bidding, the greater our understanding of the material had to be; for even the experience which later eases and assists the working process had to be gained first.

Ash wood from the transition between root and bole was specifically and exclusively chosen for the handle of a stone hatchet. The blade was made from particularly hard stone. To prevent the handle from splitting, the stone was placed in a "chuck" made from a stag's antlers. Handles were of different lengths to suit the particular purpose of the tool.[24] With this tool in his hands, our Stone-Age worker was now in the position to fell trees, to split them and to produce forked posts resembling natural forked branches.[25] The ability to split wood and cut it to the desired length expanded the possibilities of building

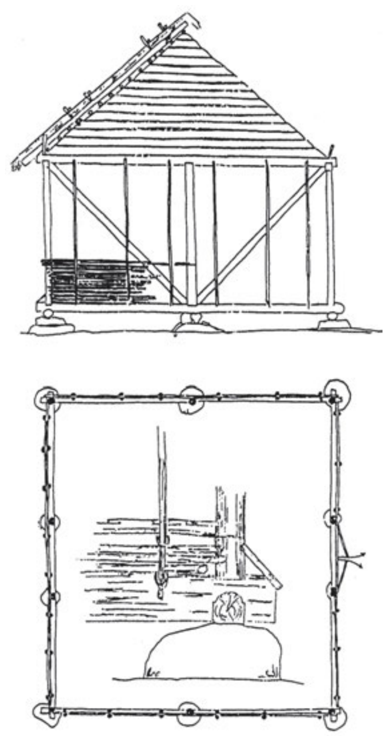


233 Post-and-rail fence construction (source: Bygden, 1925, Fig. 2a)

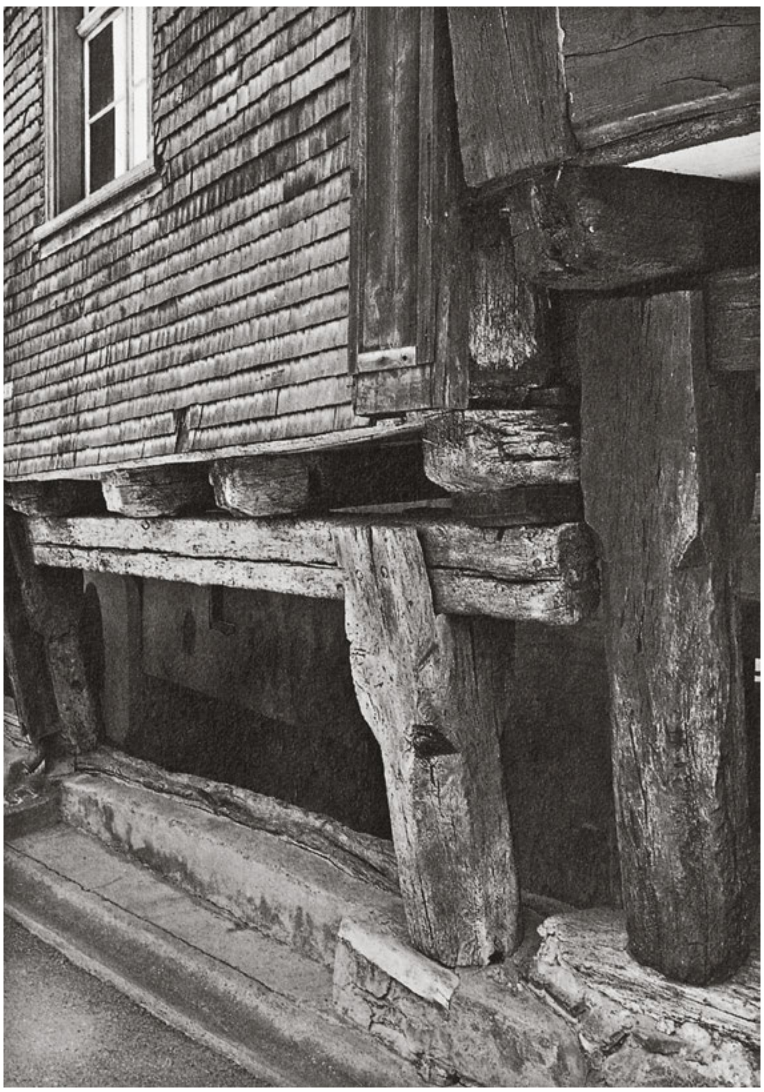
very considerably. "To be able to immerse oneself in early forms of construction, it is recommended to also observe how modern work is carried out in a makeshift way by unskilled labour. This will reveal some unsophisticated approaches from time to time."[26] Such comparative observations lead us to believe that the last witnesses of the once predominant weaving and tying technique were wooden fences, so much so in fact that this is not questioned by researchers.[27] (Figs 237 & 238)
The abilities referred to enabled people to redesign huts to become houses.[28] So long as the inclined roof timbers were supported directly on the walls, they could not be satisfactorily fixed by simply tying them, neither over circular nor over rectangular layouts. The thrust of the rafters was even too great when a forked branch was hung over the ridge purlin.[29] But if the forked branch was turned around and placed over the eaves purlin, this allowed a pitched roof to be connected to the walls.
During the Neolithic Age, three differently shaped chopping tools were available in Europe: the axe for felling trees, the hatchet for chopping up and finishing the wood, and the adze for whittling and producing holes.[30] Now, among their capabilities, humans were in the position to work timber into squared sections,[31] which enabled them to produce fork-like joints.[32] Up until then they had been forced to tie a piece of wood in



234 Partial reconstruction of a post-and-rail wall from the Taubried Neolithic settlement. (drawn by Zippelius; source: *Rhenish Ethnology Yearbook*, 1954, Fig. 12)



235 Fence construction as wall cladding to a column-and-beam structure. (source: Bygden, 1925, Figs 7, 8, 10)



236 Builders no longer wanted to forego the principle of the forked branch. Forked branches supporting jettied upper floors in Werdenberg, St Gallen, Switzerland.

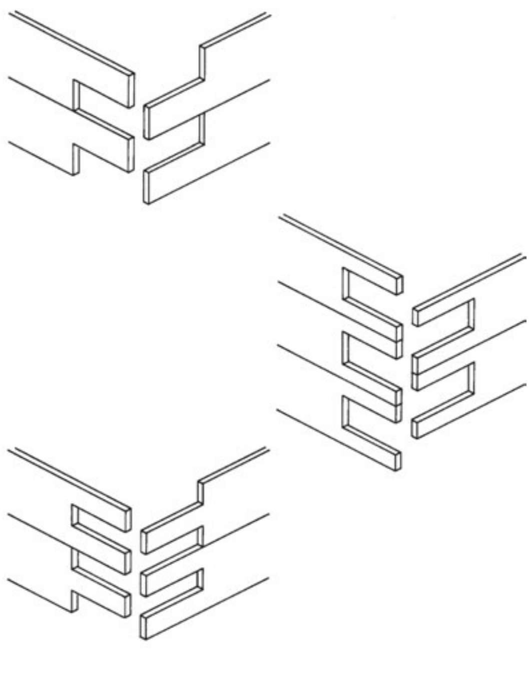
237 **The appearance of wooden fences reflects the possibilities for building that Stone-Age peoples had at their disposal. – Maihaugen in Lillehammer, Oppland, Norway**

the fork of a branch if they wanted to secure it; now though, the new joint not only secured the piece of wood it also provided restraint against torsion. Various forms of mortise-and-tenon joints could be fabricated.[33] Doors were also possible, their spigots pivoting in lintel and sill.[34]

The transition to bronze tools brought about the next leap in the evolutionary progression. The superiority of the bronze tool lay primarily not in its being a much better material with which to work wood but rather in the fact that the tool-user was now able to determine the shape of the tool and significantly improve the fastening of the handle.[35] The unanimous opinion is that bronze tools are responsible for the appearance of log construction in Europe.[36] However, this type of construction would have been possible even earlier. A trial has shown that, using a flint-head axe, 26 pine trees with a diameter of 200 mm can be felled in 9½ hours.[37] And the very first log joint – a semicircular notch on the top to receive the next log – would also have been manageable with stone tools. Nevertheless, the important and now more easily solved requirement to provide each log with at least two joints matched exactly to their counterpart might not be the most insignificant reason for the late appearance of log construction.

During Japan's Bronze Age (beginning about 300 BC) joints were still tied on the structures which had in the meantime been raised off the ground on stilts. However, a good proportion of other joints already needed saw, chisel and axe for their fabrication.[38] In the Iron Age (up to AD 300), axe, *chona* and chisel were used not only to produce mortise-and-tenon joints but also, closely related to these, the first joints for log construction.[39] (Fig. 239) In these the majority of the squared timbers were joined together into separate rings and there was only one single variation which interlocked the rings with each other. Nevertheless, in order to attain a certain stability, the ensuing log construction had to be clamped by corner columns which were mortised into the half-lapped ring of sill and header. As additional anchorage, tie-like beams were necessary in the longitudinal direction. Cutting out a door was unthinkable with such a construction. If you wanted to enter the store, you had to clamber through the triangle of the gable.[40] (Fig. 240)

238 **Wooden fence in Stübing Open-air Museum, Steiermark, Austria.**



239 **Conjectured jointing techniques for Japan's first log buildings. (according to: Nishi, Hozumi, 1985, Fig. 98)**

The inhabitants of the area covered by modern Switzerland already knew how to make dovetail joints.[41] This joint linking two parallel log walls can still be found in the region today. The logs with the dovetail cut in their end grain are not visible externally. They alternate with the logs with projecting ends. Apart from European wells – the log walls of which are connected in an astonishingly similar manner to the first Japanese ones but do not exhibit projecting ends at the corners because they were buried and so did not require the same secure joints –,[42] we get the impression that right from the outset of European log construction the building of an adequate wall must have been of prime importance. If we look at the earliest Japanese joints in log construction, we are reminded of pairs of rafters laid on the ground which are stacked one on top of the other in a horizontal arrangement, identical to the way they were draped, next to each other, over the ridge. In contrast, the pectinate European logs formed, via the joints, a self-supporting three-dimensional object right from the start, while the Japanese equivalents, without their vertical retaining supports, would have fallen apart. Therefore, the fundamental question raised is: To what extent can we speak of a log construction here, from *azekura*, as it is called throughout the Japanese literature? Is it not almost an infill panel in column-and-beam construction, with amazing similarities to log construction?

Again, the emergence of another material – iron – led to the development of completely new tools with which, at last, all the joints familiar to us today could be made. Among the most important were undoubtedly the joints employing wooden nails or pegs. Their use in European timber construction is perhaps the most dominant of any type. Starting with the wedge, which could also be formed with an axe, this gradually mutated to become the more or less parallel-sided nail. (Fig. 241)

The prerequsite for this was the development of the drill.[43] As the wooden nail had to fulfil such important and diverse tasks, it is not surprising that special techniques evolved for the production of bored holes. For example, in order to produce an optimum mortise-and-tenon joint connecting two members subjected to tension, the so-called “drawboring” method involved

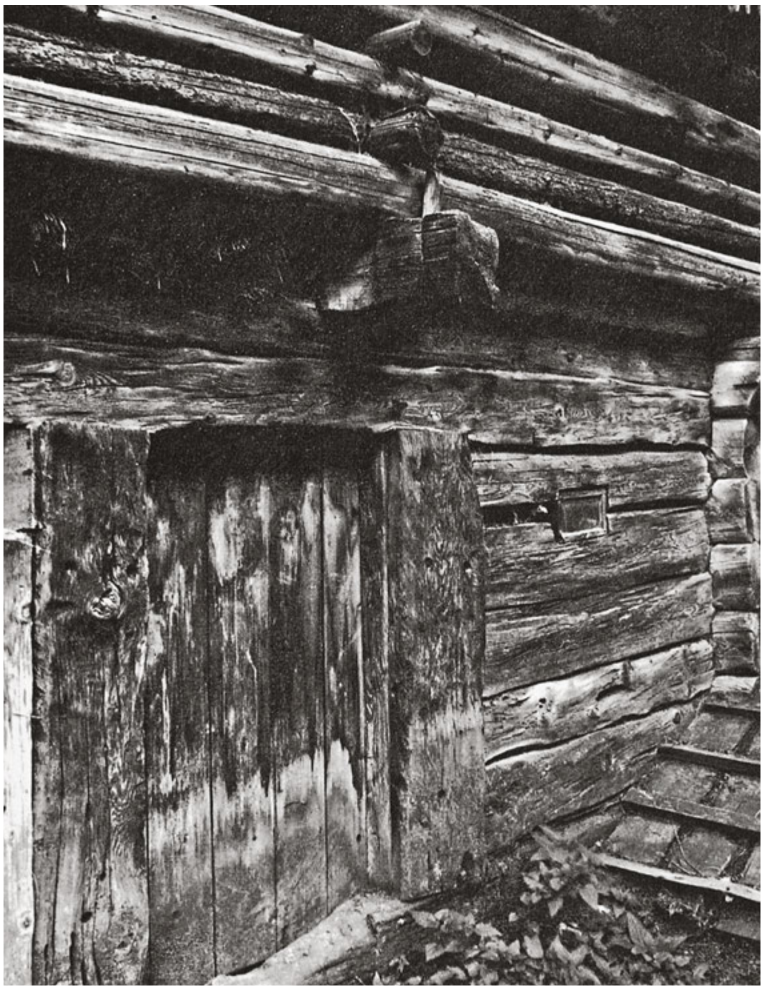
240 Restored log building from Japan’s Iron Age. (source: ibid., Fig. 97)

241 Wooden nails secure the lap joints on the town hall in Markgröningen, Baden-Württemberg, Germany.

drilling a hole through one side and the tenon at an angle counter to the direction of the tensile force. The tenon was then removed and the remainder of the hole drilled at a right-angle through to the other side. A nail driven into this joint drew the members together to form an incredibly tight joint.[44]
The wedge was not only the forerunner of the jointing nail (Figs 242 & 243); it was also the predecessor to the simple peg used to retain a piece of wood in its allotted position. (Fig. 244) To be used in the form of a nail as we understand the word today was only one of its many functions. Itself having become a joint, the tiny wooden wedge was a well-loved support for plaster.[45] (Fig. 245)
With boring a straight-sided hole through wood now being technically feasible, the through-tenon was now a sensible proposition. (Figs 246 & 247) Europe and Japan both benefited equally from the keyed tenon. This joint was useful for both log construction (Fig. 248) and column-and-beam construction. (Fig. 249) It was just as welcome in small buildings (Fig. 250) as it was necessary in the largest, (Fig. 251) irrespective of whether assembled vertically or horizontally. (Fig. 252)
The interlocking effect and hence the stability of the mortise-and-tenon is particularly well illustrated at corners. (Fig. 253) However, for this type of joint, nature was no longer available as a supplier of ideas. Man was totally and utterly reliant on experimenting with his fingers before he could start turning his ideas into reality using the material itself.
An interesting application of the keyed tenon was developed

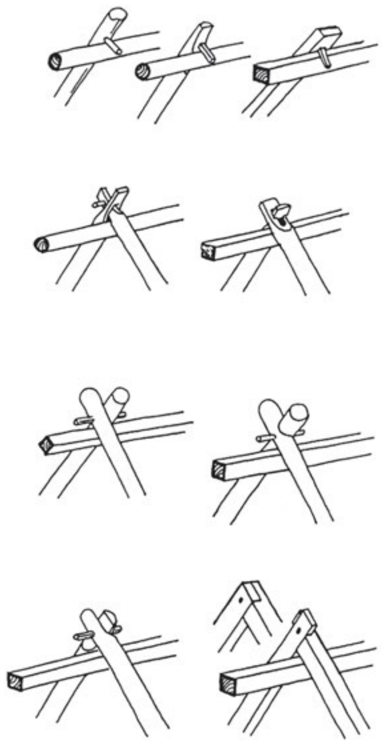
242 Jointing nails driven in at an angle fasten the floorboards in the rebate of the sill beam of a stave church. – Øye, Oppland, Norway

243 In the transition to nailing of the lap in its housing, the first change was the replacement of the jointing wedge by the jointing nail. – Sagrad, Carinthia, Austria

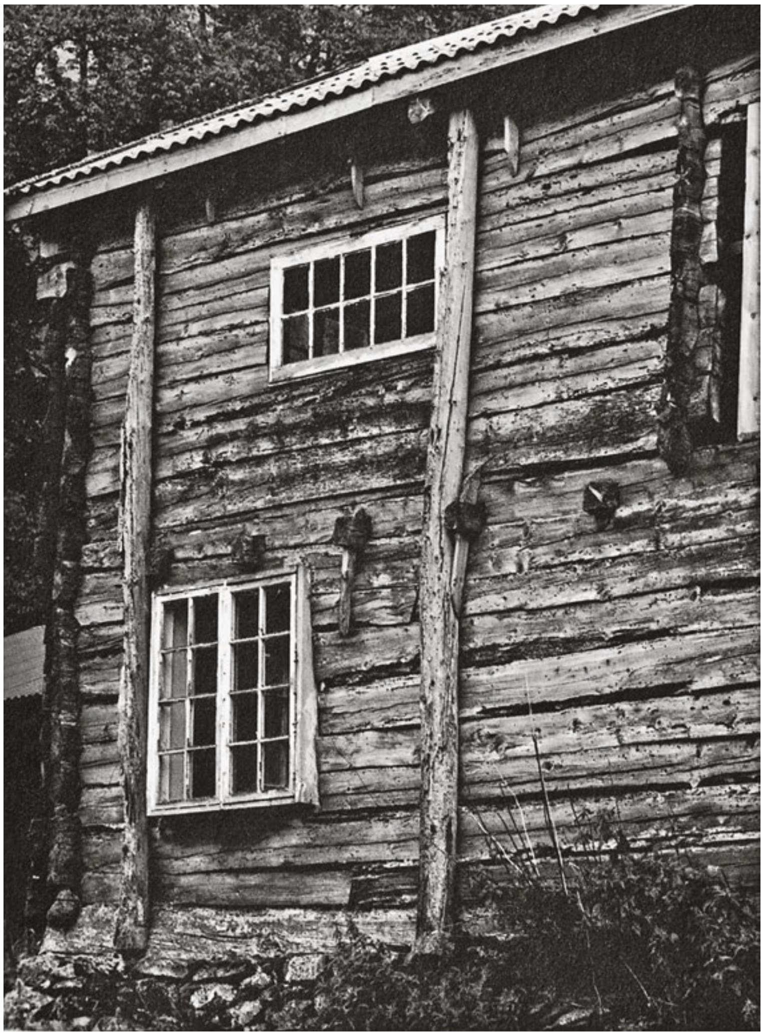


244 Wooden pegs prevent movement of the lowest beam of the "ventilated" timbering to the jettied hayloft over this cowshed in Langesthei, Tyrol, Austria.

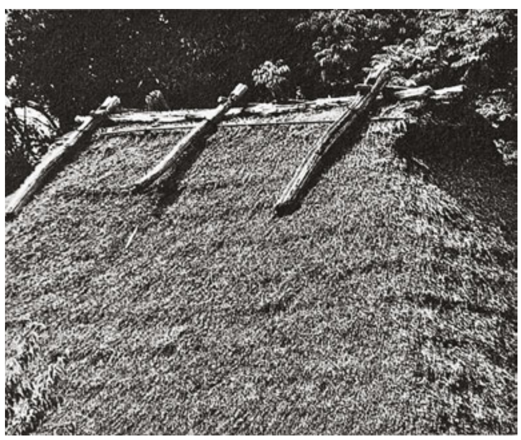
245 Timber wedges as a plaster base for a kitting (store hut) in Dąbrówka Łubiańska, Poland.



246 Thanks to the wooden nail, builders no longer had to search for suitable branch roots in order to hang the rafters over the ridge purlin. (source: Moser, 1976, Fig. 8)



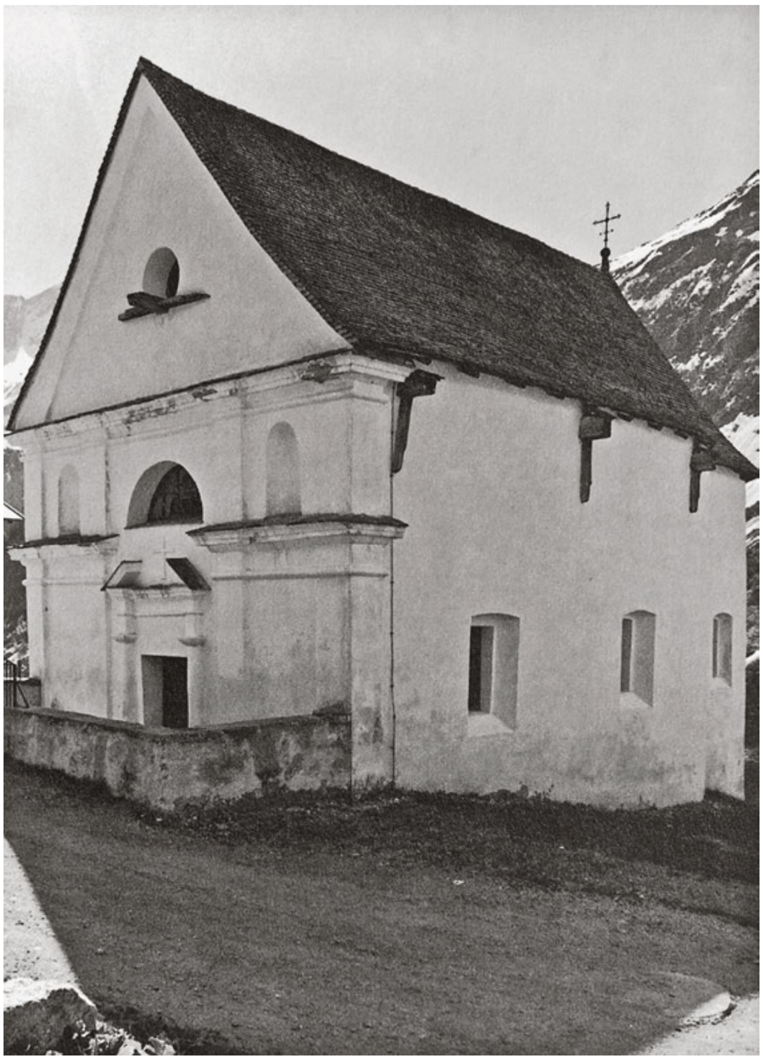
248 Keyed tenons fix the tie beams defining the storey height in a log building in Fortun, Sogn, Norway.



247 Ridge “finials” fasten the ridge covering of a cowshed from Tsuruga, Fukui, Japan. – In the Toyonaka minka shuraku

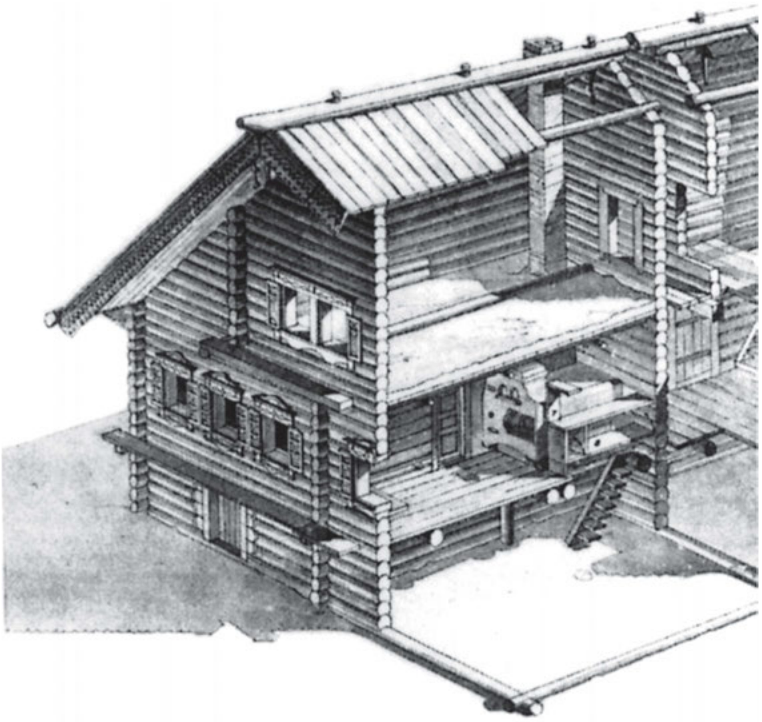
in Russia. The boards covering the roof rested in a sort of gutter, and a ridge covering was needed to protect the roof construction. (Fig. 254) This system was served very well by the keyed tenon, at least so long as the end grain of the nail held out against the humidity. (Fig. 255)
Like in so many other cases, the example of the through-tenon also provided evidence that in Japan the language of the cabinetmaker was much more frequently translated into that of the carpenter than was the case in Europe. The wedged tenon, in Europe, was used almost exclusively by the cabinetmaker. (Fig. 256) The reason for this lay certainly first and foremost in the emphasis on working hardwood.[46]
Corresponding to the importance of the mortise-and-tenon, the twybill was for a long time one of the European carpenter's best-loved tools. For producing mortises it was really only in the 19th century that it was superseded by the chisel,[47] a transition which had already been looming for many years. The chisel was perhaps not as fast when it came to cutting out a hole but it was more accurate. When a teazle tenon was used to locate two beams one above the other – a connection which became particularly interesting as builders began to realize the dangers of reducing the beam cross-section too much –, then all parts had to be worked exceedingly precisely. (Fig. 257) Such precision could only be achieved with a chisel. (Figs 258 & 259) Carpenters had been gathering experience with the chisel

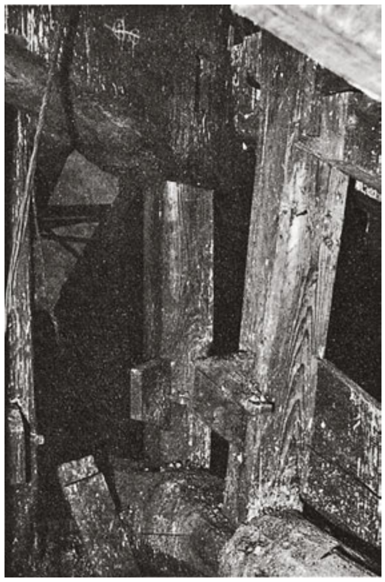
249 Anchor beams defined the room divisions and also served to carry the roof construction. – Bouttoncourt, Normandy, France



250 A stone wall secured with wooden anchors in Vinaders, Tyrol, Austria.

251 Wedges anchor the tenons of both the longitudinal and transverse members in this church in Sogn Giusep, Graubünden, Switzerland.



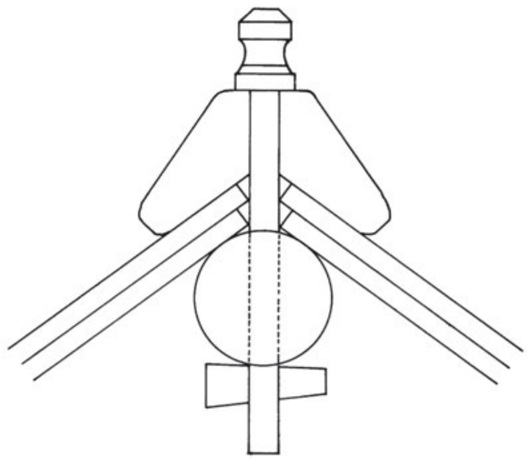


252 Roof detail – Kencho-ji sanmon, Kamakura, Kanagawa, Japan

254 Drawing of a model of a Russian house. (detail taken from: Lissenko, 1989, Fig. 3.3)

253 On prestige buildings joints such as this one on a *minka* in Iwate Futsukamachi, Iwate, Japan, would only be allowed in non-exposed positions.

256 It is only the wedges which disclose the presence of incoming transverse members. – House in Aozawa, Iwate, Japan



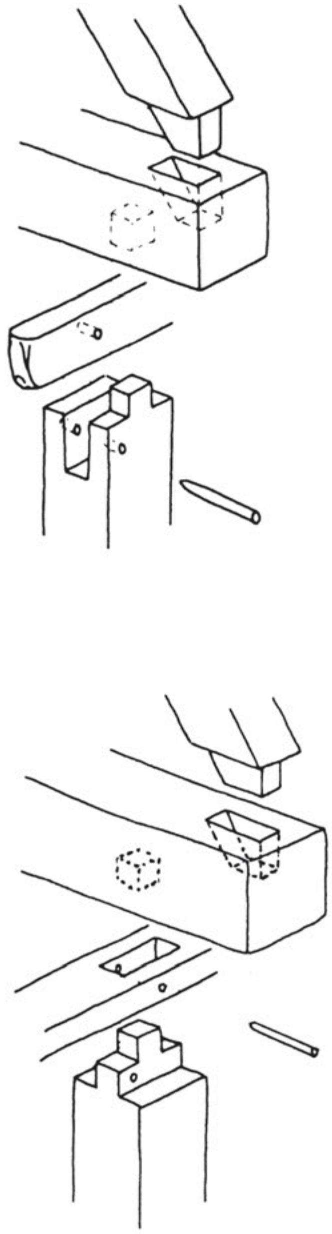
255 A wedge pulls the wooden nail firmly down onto the ridge purlin. The broader head of the nail transfers the pressure onto the ridge covering. (according to: Lissenko, ibid., Fig. 4.25c)

and the gouge for forming many joints other than the necessary lap since before the High Middle Ages. (Fig. 260) In contrast, the carpenter's axe was adequate for simple laps and tenons.[48]

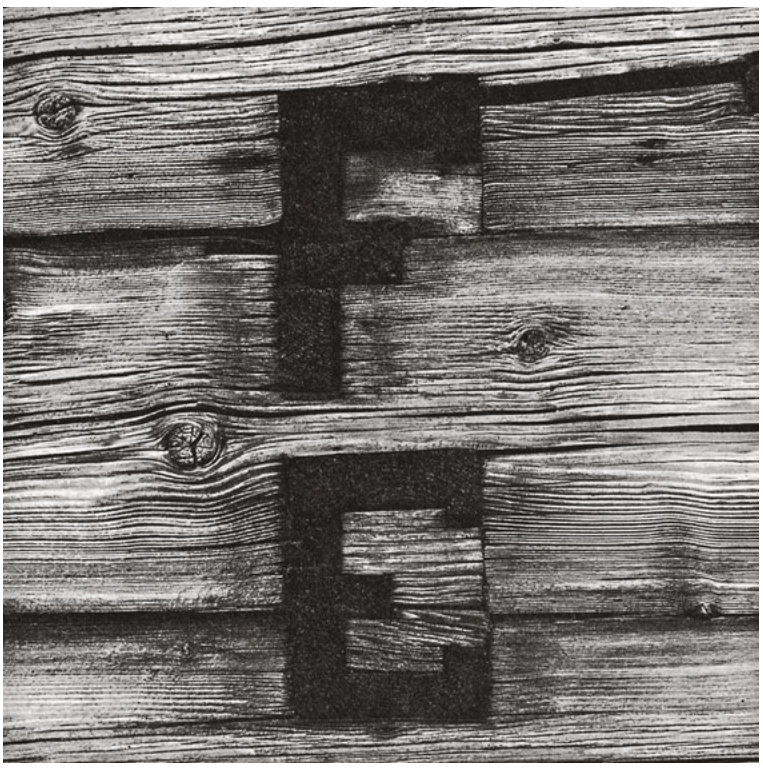
In Japan the chisel was ranked equal with the axe and the *chona* right from the very start. Almost all the joints of the Horyu-ji were made with a chisel.[49] Surprisingly, the mortise-and-tenon joints of the horizontal beams were not very deep in relation to the colossal cross-section of the timbers used.[50] They also served a purpose hidden in the ground: the enormous weight (self-weight + roof loads) which rested on the buried temple posts was distributed over a greater area in various ways by means of the mortised cross-members. The holes in the bases of the columns were also cut with chisels.[51]

Incidentally, combining this idea with that of the keyed tenon gave rise to the support and anchorage of the central column in Russian church towers. (Fig. 261)

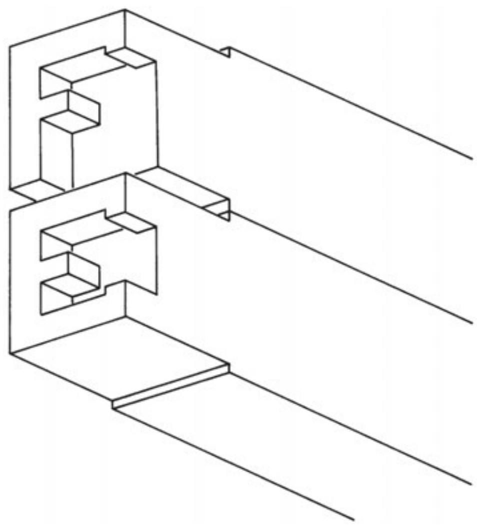
In Japan's Middle Ages (1185–1868) various factors brought about considerable progress. New challenges in construction, which demanded new methods, as well as the now noticeable lack of satisfactory building timber could only be faced by the carpenter who used revised techniques and tools made from steel. Working towards the body coupled with the more-easily-sharpened tool had far-reaching consequences for wood joints, both in terms of their form and their production.[52]



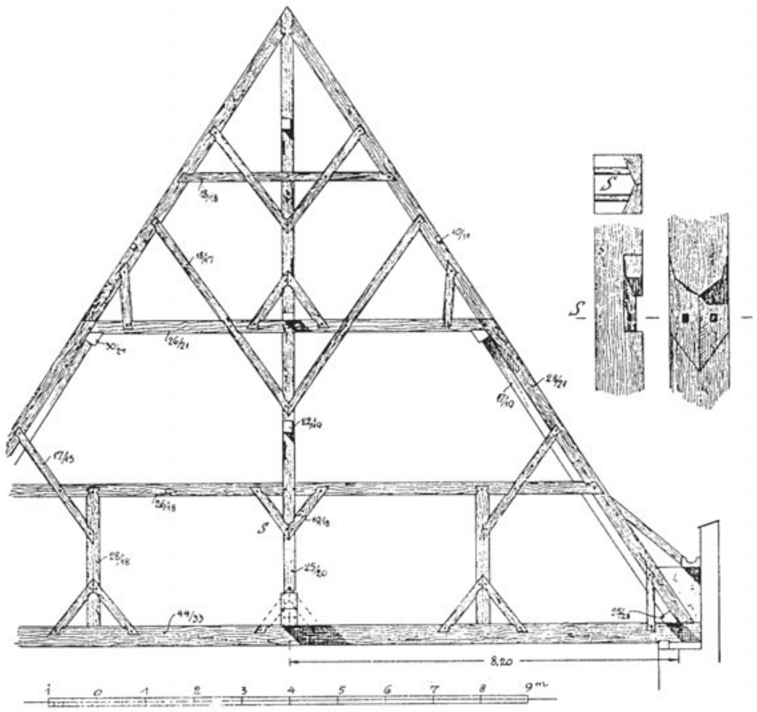
257 Various teazle tenons in normal assembly. (source: Bedal, K., 1978, Pl. 11)



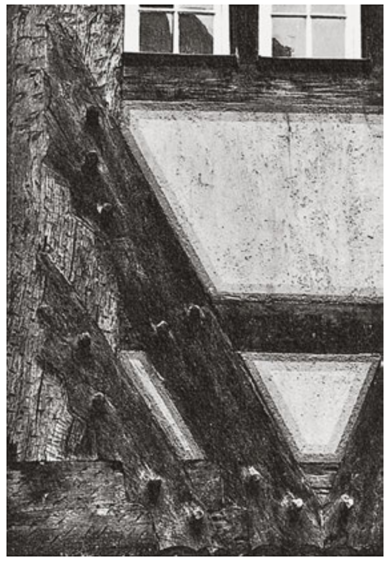
258 Now and then, it is precisely through those examples which illustrate how all consideration for the material has been thrown overboard in an unbridled frenzy of decoration that we can see how indispensable a certain tool had become. – Aurach, Tyrol, Austria



259 Only parts of such joints were made in the form visible from the outside.



262 Spars to the *Artushof* in Gdańsk, Poland, with a detail of the lap housings with bevelled edges. (source: Heyn, 1913, Fig. 16)



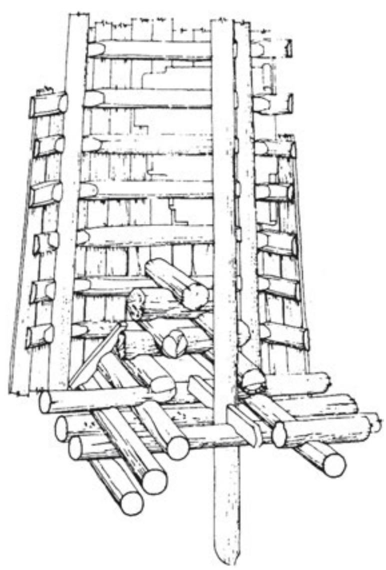
260 The creation of curved shapes required a tool which could be wielded with far more precision than the carpenter's axe. – Town hall in Esslingen, Baden-Württemberg, Germany

Although the interdependencies and relationships between tools and the development of joints can be clearly classified up to the introduction of iron tools, the following period is impossible to put into any unambiguous order. The relationship is there as before but with the continual development of new tools and the creation of ever more refined and more specialized joints, classifying which part of a joint was made by which tool tends to become less and less viable.

For instance, to what extent saws – and which versions thereof – were linked with the development of particular wood joints can only be surmised for Europe. In Japan it is suspected that saws were used in producing tenons as early as the 7th century.[53] In Europe the frame saw was not put to use until the end of the 14th century;[54] from this date onwards it was certainly employed in all cases where it speeded up or simplified the work. This is probably a correct assumption for most of those areas in which column-and-beam construction was common; such construction prevailed in the towns where it was erected by professional carpenters who had recognized the advantages of saws much earlier and had already put them into use.

The pit-saw was essential for the economic conversion of tree trunks. The squared timbers could then be used on edge, e. g. for rafters, without any heartwood (i. e. free from splits). The yield of wood to be gained from one trunk doubled and then trebled. Wind bracing only became sensible when in the form of sawn squared timbers its self-weight no longer placed an extra burden on the construction.[55]

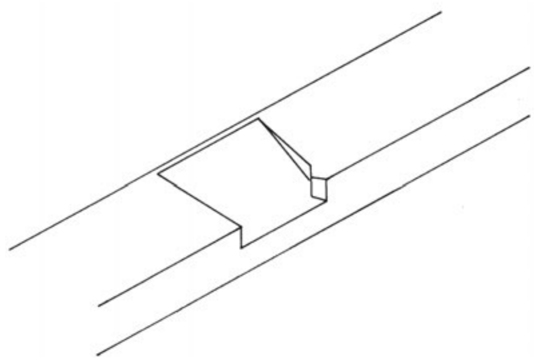
Schier attempts to chart the spread of the saw as a tool. He sees a direct consequence of the use of the saw in the progression from the "primitive shaped, tabled halved notching" of the log constructions of the eastern Slavonic peoples to the "artistic corner connections" of the lateral and longitudinal bevelled halved corner joints creating dovetail shapes in pectin-



261 Detail of the central column under the main tower of the Church of the Virgin Mary in Kimsha, Archangels, Russia. (source: Lissenko, 1989, Fig. 3.12)

ation. Schier infers that German influence had introduced this development into the Carpathians.[56] This, at first sight, very muddled statement, disqualified due to the linguistic formulation probably suitable at the time, does, however, deserve a second look, if we can throw some light onto the terms Schier uses to describe the joints used in log construction. By "tabled halved notching" he means the aforementioned log jointing known as long ago as the Bronze Age.[57] Besides this there is a certain variation on the lap which leads us to speculate whether its form is not due to the influence of the saw. The lap joint, in its dovetail form, describes very impressively the task it was assigned to perform.[58] However, this joint brings about a massive reduction in the cross-section of the member and this must have given cause for concern, at the latest when considerations of weight and resources started to be taken into account.

Lap joints in angled intersections, as were common in roof trusses in all manner of variations, were normally provided with stopped housings, i. e. as a rule, the saw could only be used for making the initial cuts for a deeper housing; at the same time however, the cut-out obtained with the saw still led to a joint capable of resisting tension. Once the carpenter had realized this, then further reasons eased the progression to a new form. Less material was now being removed from the cross-sections of both members (Figs 262 & 263) so the advantage, in the reversed version too, would now apply. Intuitively, there is in fact something to be said for the reverse situation, i. e. strengthening the end of the dovetail at the expense of its throat, so that a dovetail shape would also be attained in the perpendicular direction. However, the extremely critical point – the throat – would be weakened too severely. The reason why the dovetail variation described did not gain favour on a wider scale may be because the direct transition to the rediscovered tenon was able to gain acceptance much more rapidly.



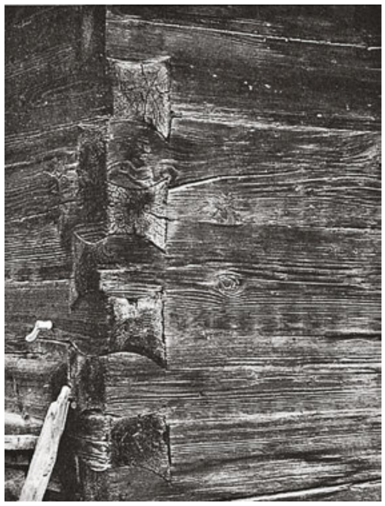
263 Lap housing in a spar of the former convent infirmary in Lübeck, Schleswig-Holstein, Germany, for the lowest collar. (according to: Binding, 1991, Fig. 76)

Only in isolated instances are there clear indications for the creation of a very specific tool to cope with the production of a very particular joint. One example is the *Schindeleisen* which was used for cutting the groove in grooved shingles. Among the advantages of employing this tool instead of a plane for cutting the edge-to-edge joints was that it was quicker to use and the clamping effect of the joined shingles was far better. The *Schindeleisen* really demanded consideration for the fibres of the wood; it was this fact, that they never run exactly straight, that resulted in the better, tighter fit.[59] Shaping the grooved shingle was carried out exclusively using the method of working towards the body – with the drawknife and the *Schindeleisen*. The rural landscape characterized in former times by its roofscape is attributable to a not inconsiderable extent to this sensitive technique used by the shinglemaker.

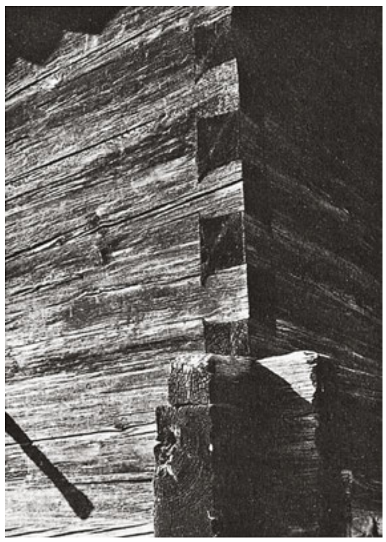
Another example is the *Klingeisen*, a curved knife without a handle. Because it was easier to make and probably also dictated more obvious forms of log joints, this very simple-looking, curved piece of iron could only have evolved in areas which the saw had not yet reached.[60][61](Fig. 264) The question of whether all *Klingschrot* joints were made with *Klingeisen* or perhaps some of them with variously shaped gouges is hardly relevant here.[62] In many cases however, it will hardly be possible to establish which joint was made with which tool. (Fig. 265)

The right tool determined not only the feasibility of individual forms of construction but also their degree of perfection. For a long time, the stacking of rings of logs to form a log assembly proved unsatisfactory, even when the timber had been specially selected. Normally, gaps remained which had to be filled in different ways with a huge variety of materials. This problem was solved differently in northern countries; they developed the "drawknife" – *medrag* in Norwegian,[62] *dragjärn* in Swedish.[63] From Sweden this tool also found its way to Russia, where in fact it was used in helping to make log joints.[64] For the first time, this tool made it possible to cut the recess on the underside of each log with such accuracy that a perfect seal was achieved between the unsquared timbers. (Fig. 266) Like in northern Europe, the same tool, known as the *hikari-osa*, was also used in Japan.[65] The unremarkableness of the drawknife reminds us of another tool used by Japanese carpenters, the *osa-jogi*. This device for gauging column profiles enables the exact jointing of unworked pieces of timber at any angle, likewise the perfect fit of a column to its padstone. (Fig. 267)

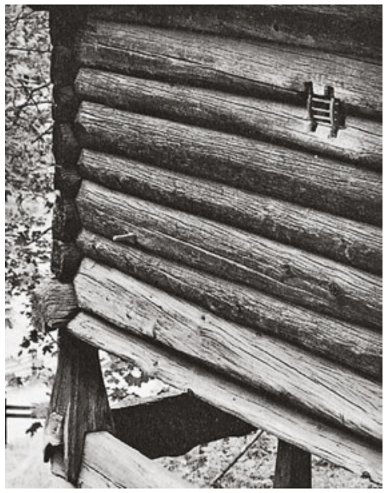
That, in the end, a totally unspecialized and traditional tool can render possible the development of a new joint is shown by the example of the hatchet. In Sweden up to the 16th century the ends of logs were shaped into cones for their connection. Therefore, the joints were not secured against slipping outwards. Using the hatchet, carpenters hit upon the idea of also cutting the joint in from the end of the log and retaining the full cross-section at the end itself. An initial notch marked the required depth to which the carpenter worked towards from the direction of the middle of the log and from the end. The outcome was a substantial improvement of the individual joints, and hence the whole assembly as well. (Fig. 268)



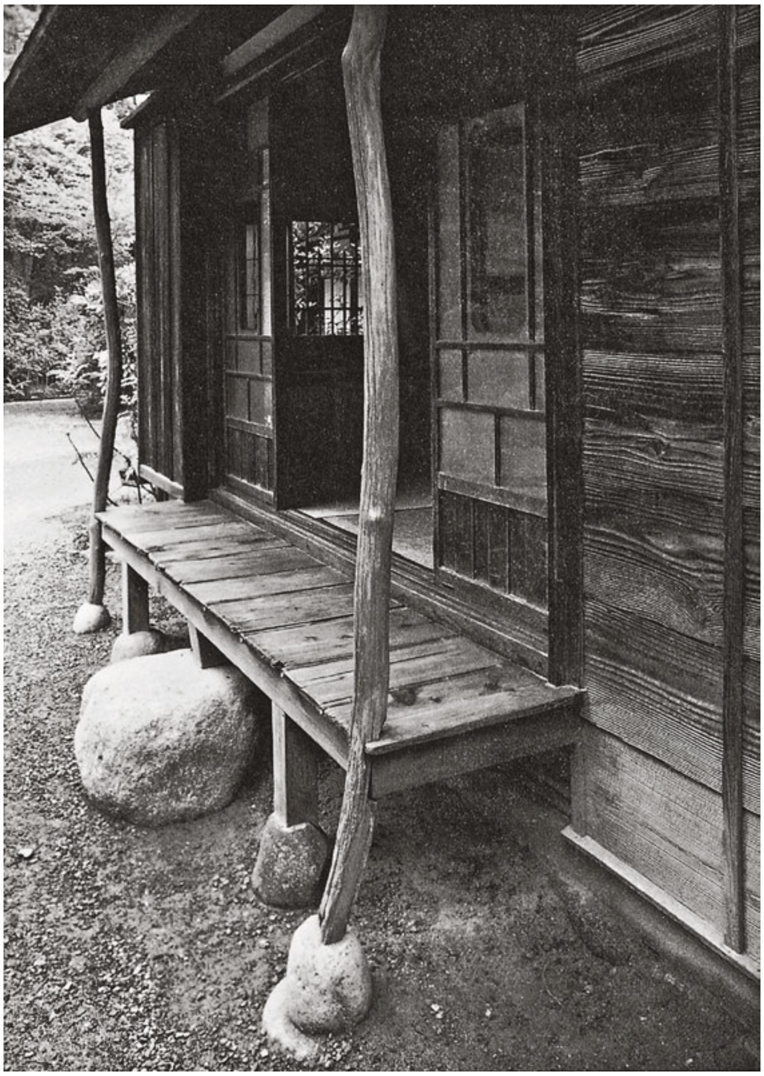
264 The production of curved joint interfaces required a tool which allowed more accurate working than was possible with the hatchet and more effective than the chisel. – Westendorf, Tyrol, Austria



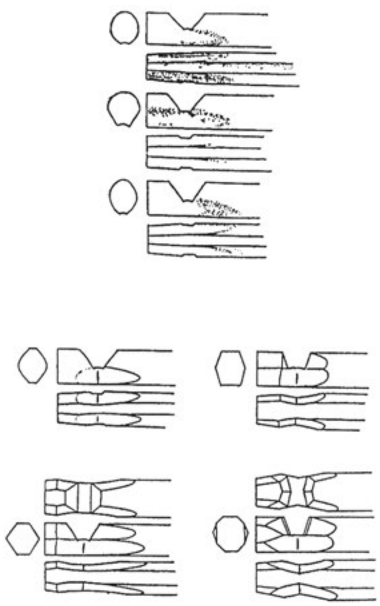
265 Many different forms of *Klingschrot* can be found. This specimen in St Corona, NE Austria, exhibits very acccurate jointing.



266 Unhewn logs could be sealed as tightly as this. A tiny opening, with a grille to prevent birds entering, served for ventilation (and perhaps light too). Mice and rats could not scale the stilts. – Storehouse from Budal, Oppdal, Norway, in the Bygdøy Open-air Museum.



267 Erecting the columns, adapting them to the padstones, characterizes craftsmanship in the truest sense of the word. – Meiji mura, Japan

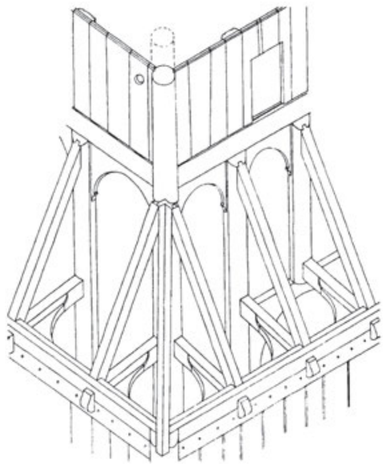


268 Evolution of log joints in Sweden in the Middle Ages and from the 16th to the 18th centuries. (source: Erixon, 1937B, Fig. 14)

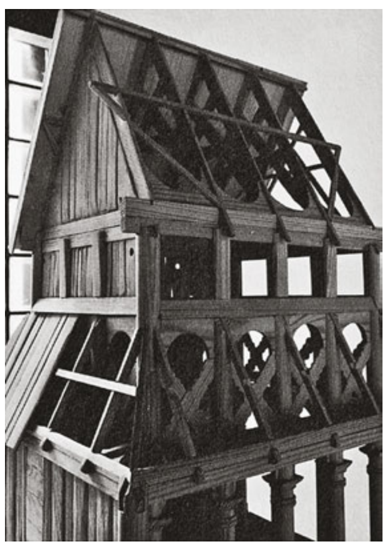
The basic form of the dovetail exists as an ideal image but appears in such a multitude of combinations that a serious and informative list seems to be utterly impossible. This dilemma – which in principle is true for all wood joints – only leads to the definition of our interest in the findings: interesting for us are the variations on the various basic types adapted to the respective building tasks and the question why a joint took on the particular form which we now see. Clearly, this question encompasses all joints in one way or another. Admittedly, the reason why a roof is built with an overhang, i. e. why the building task "overhanging roof" came about, can be equally well attributed to climatic conditions as it can a shortage of suitable timber with which to build the walls. We cannot sweep the intertwining of the causes under the carpet. Nevertheless, the selection chosen can be used to make meaningful distinctions.

Only a tiny minority of building tasks required new joints. For example, if we analyse a carpentry detail from a stave church, the support for the monopitch roof on the columns of the main nave, then we see that here, very simple, established joints have enabled the carpenters to accomplish a masterly feat of engineering. The spars of the monopitch roof over the surrounding aisle do not bear on the head beam – which would be the least complicated solution – as then they would not be able to withstand the wind pressure.[66] (Fig. 269) Instead, struts are first cog-jointed to the upper head beam of the outer wall and, rising gently, are mortised into the columns. Another head was then fixed above the lower head beam in such a way that, cog-jointed to the struts, it held these like a tie. Only on the upper head beam were the spars now provided with a mortise-and-tenon joint over their full width. With their upper ends mortised into the columns, a rigid triangle was created which, spaced evenly around the church, lent it the necessary stability. (Fig. 270) The head beams were in turn connected to the corner columns by way of simple tenons. The lateral support necessary was provided by brackets simply nailed on.[67]

Neolithic Age, becoming settled and housebuilding are three expressions which belong together, according to the present state of research,[68] three expressions which signify a decisive step in human evolution. Temporary accommodation was adequate for hunters and gatherers; being able to erect a shelter quickly and easily was the important factor. The transition to a way of life which relied on the growing of crops and the breeding of livestock called for a rejection of the unsettled, nomadic ways. By remaining in one place it very soon became clear to our early ancestors how rapidly nature could retake what was once hers. Storing supplies until the next harvest required more than just a roof over your head! With an average life expectancy of 30 years, it seems very obvious to us today that the humans of that period finally realized that a well-built house could last a whole lifetime.[69] The time gained could be put to use for other pursuits. And it was not only humans who needed accommodation; fences were needed to prevent domesticated animals from wandering off and, where climatic conditions dictated it, animals had to be kept indoors, at least during the winter. The



269 Columns, spars over aisle and transverse members form a rigid triangle. Arranged around the core of the column stave church, this system guarantees the stability of the structure. (drawn by K. Bjerknes in: Ahrens, 1981, Fig. 103)

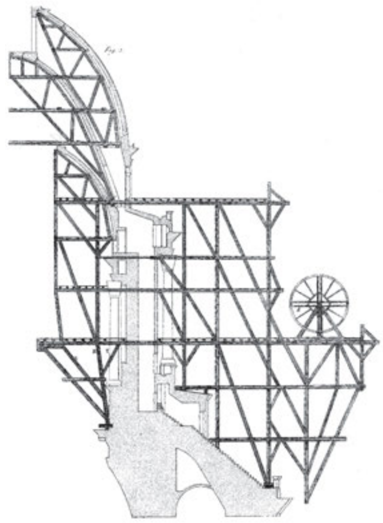


270 Model of Torpo stave church in the Helms Museum, Oslo, Norway.

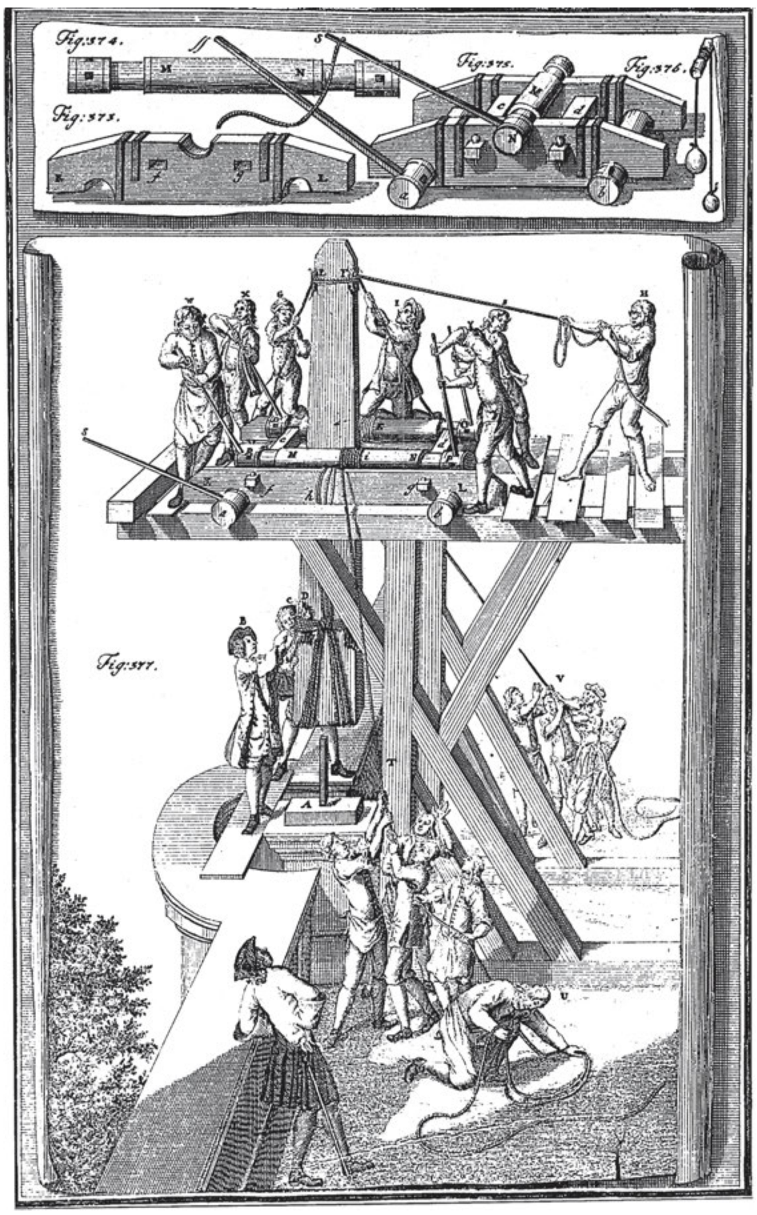
less hazardous, less strenuous way of life and, thanks to the emergence of stockpiling, the bridging-over of difficult periods, allowed populations to increase. As the number of people grew, so likewise did their needs and demands, which in turn led to new building tasks.

The terms log construction and skeleton-frame construction do not disclose very much about the jobs the carpenter had to perform. Farmhouses and palaces, town houses and town halls, inns, theatres and halls – prestige buildings were just as likely to be built from timber as were homes and utility structures: mills, bridges, temporary works, mine galleries, towers – the list is virtually endless. (Figs 271 & 272) In Japan the first masonry structures only appeared during the Meiji era. Even as building with stone began to supersede building with wood, the carpenter still had plenty to keep him occupied. Roof trusses as well as gates and fences continued to be built using timber.

The countless wars and conflicts waged throughout the history of the world meant countless important contributions from the carpenter; whether for attack or defence, siege towers or stave walls, structures for military purposes have "greatly nurtured



271 Scaffolding "for the construction of the dome of the new Church of St Genevieve with hoisting machines of a new type in place". (Rondelet, 1833, pp. 168, 170, Pl. CXXIV, Fig. 2)

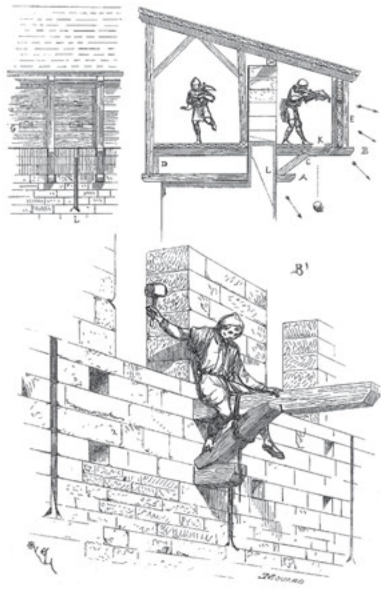


272 Erecting an obelisk with the help of a scaffold. (source: Schübler, 1763, Pl. 36)

the art of carpentry".[70] (Fig. 273) The reasons why wood was assigned such a significant role in belligerent conflicts was, on the one hand, its easy availability and, on the other, the methods of jointing also familiar to the simple soldier. Two walls employing simple lap joints – one in front, one behind the soldiers – formed a mobile fort. Dismantled, they could be pulled along.[71] How crucial simple joints could be is demonstrated by the example of the motte-tower.[72] Schepers quotes Dutch sources when he writes: "One morning, Arnaud van Gent awoke to find that the burgrave Hendrik van Broekburg had conjured up a permanent, wooden tower next door in which to live." As the ability to set up such a multistorey tower under the nose of your opponent overnight could be crucial, transportable, easily connected subassemblies must have already been available. The Japan of the 13th and 14th centuries was no exception either. In order to do justice to the criteria of effectiveness, the joints of Japanese fortifications were also of the very simplest kind.[73] However, this does not include palaces; these were built exclusively by hand-picked master craftsmen.

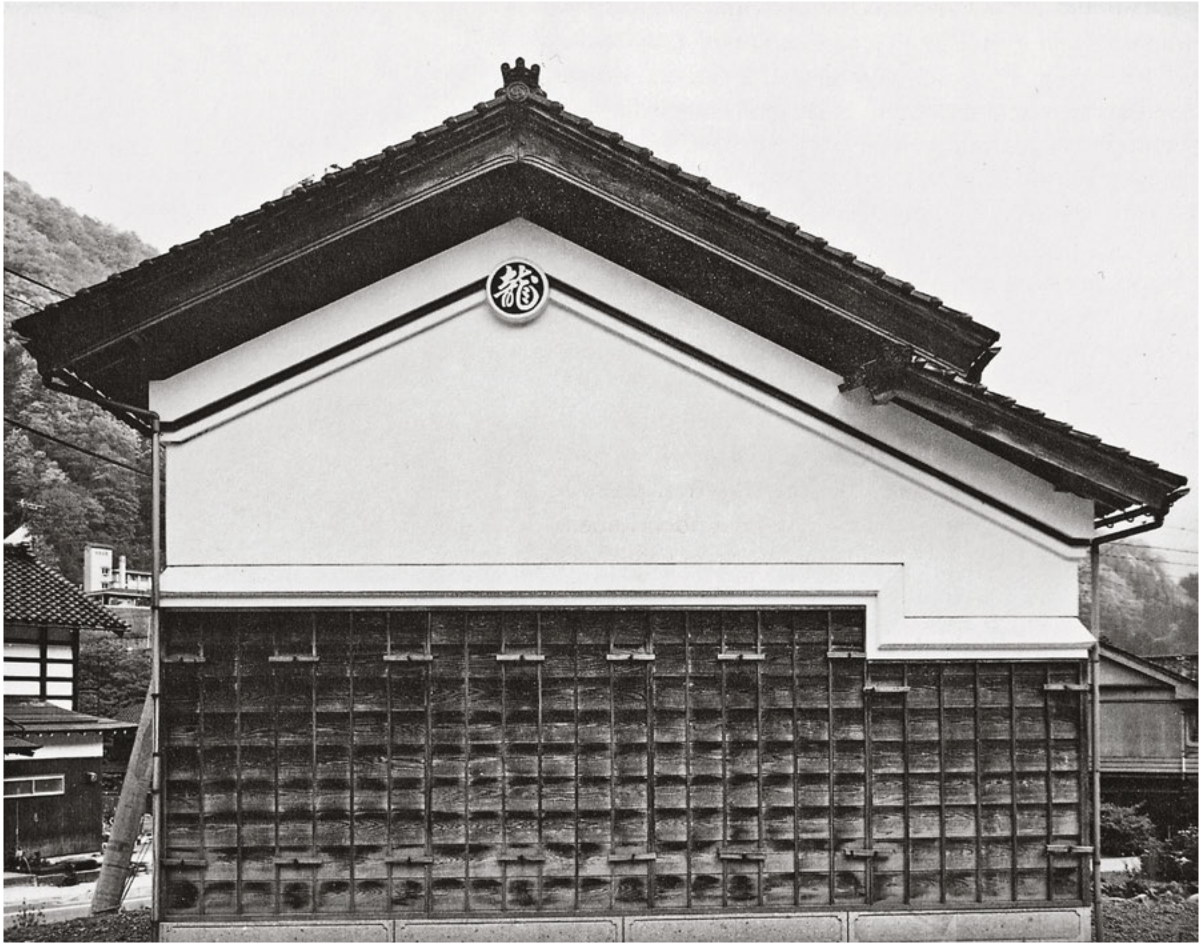
Over the course of time, carpenters assembled a notable repertoire of joints. They were fully aware of how to deal with diverse building tasks by means of variously intricate versions. A simple barn did not stimulate the imagination and patience of the carpenter as much as a church;[74] likewise the client paying for the work. Every joint newly developed for a specific task was clearly taken on board as a mental acquisition to be used, improved or adapted on a future occasion. This is how the layperson learned from the skilled craftsman. This appropriation of ideas meant that a variation on a joint seen for the first time on a church roof truss could a short time later perhaps be found again in the roof truss of a farmhouse.

Surplus production contributed to the growing importance of the storehouse. Originally intended for storing the products of the harvest, they increasingly became a symbol of their owners' wealth. They were used for storing valuables of every kind. As the best building on the farmstead,[75] as "little treasure chest",[76] the storehouse was not only a symbol of social status and wealth[77] but also a "place of last defence".[78] This was expressed in a very particular form which in turn increased its value once again. (Fig. 274) In both European and Japanese storehouses, the twin-leaf roof construction is especially noteworthy. The daub shell enclosing the entire structure had to be protected against rain. (Fig. 275) But builders knew of no materials for building the roof of the store other than those which were also combustible. In the event of a fire, it had to be pulled off as quickly as possible without endangering the store itself.[79] Curious is the different dates at which stores were raised clear of the ground to protect them: in Scandinavia not until the 17th century,[80] while the beginning of the elevated storehouse is set in the same period as those of Japan, namely in the Iron Age.[81] The reason behind raising the buildings was the problem of ventilation: the building had to be sealed as far as possible against all kinds of thieves and apart from that everything lay on the ground, as stored goods do. However, the conventional European building stood on the ground, hence the ventilation tended to be poor. The problem was solved by lifting the storehouses off the ground, as the Japanese had done with all their



273 Brackets enabled cantilevers at any height on any wall and, therefore, were indispensable in the building of fortifications. (source: Viollet-le-Duc, 1859, Vol. IV, p. 124)

274 The fire-resistant daub shell of this storehouse from Petrová, Slovakia, is a visible expression of the value of the building's contents or rather the fear of losing them.



275 In Japan even wide overhanging eaves offered little protection against torrential rain. The daub shell protecting the timber construction against fire was itself protected against water by using wood. – Taira mura, Toyama, Japan.

buildings, so that air could circulate exactly where it was most urgently required.

It is astounding how many different solutions mankind has come up with for the task of building an elevated storehouse. The simplest remedy was posts or stilts secured by way of tenons.[82] If the store was to be built over another building, the house or the cowshed, then the bases of the supports also had to be secured. (Fig. 276) As in this case the cross-sectional size of the support was usually limited by the thickness of the wall underneath, the carpenter preferred to resort to a dovetail joint for safety. In Finland for example, dovetails joined the posts with the sill beams which carried the log construction.[83] In the Tyrol it seems that the image of the fingers was once again employed in approaching this problem. A cruciform cut-out in the axis of the member accommodates a couple of layers of pectinate beams. (Fig. 277) Essential to this design was the presence of a projecting *Kopfschrot* joint. Of course, the shrinkage characteristics of timber were also taken into account in this joint. One version had notches which tapered slightly inwards at the bottom; the logs were forced into these by the load from above. Another version required the logs to be tapered exactly at the point concealed between the upward-pointing fingers of the forked support. As the support fingers left and right of the log were provided with little notches, shrinkage was compensated for to a certain degree and the danger of a finger of the support being broken off due to lateral pressure was prevented.[84] In any case, there was no very great danger of a finger being broken off because knotty wood was selected for these supports.[85]

276 Storehouse raised on stilts. – Geschinen, Wallis, Switzerland

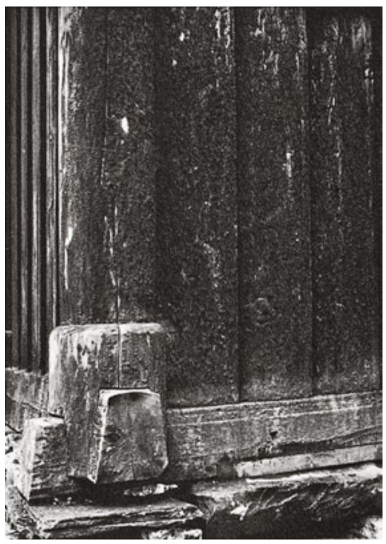
The very much more difficult working was offset by the considerably improved durability.
In view of the late raising of Norwegian storehouses it is not surprising that protecting the supports against moisture was also taken into account immediately there, (Fig. 278) especially as Norway's carpenters had been familiar with this type of construction for a long time.[86] (Fig. 279)
The earlier attempts to protect log buildings against moisture could conceivably be regarded as the forerunners of the *bur*. Posts were cut off not very high above the ground; the ring of sill beams was then mounted – probably mortised – on these,[87] just like the early elevated storehouses almost everywhere else. Strangely though, there then followed a long intervening period during which these structures were lowered again onto stone foundations.
In Japan the importance of the *kura* is far in excess of that of any warehouse.[88] The storehouse of the Yayoi[89] provided the archetype for the Shinto shrine.[90] Even the *loft* and the *bur* had exceeded their material values: they became the bedchambers of young maidens and newly-weds spent their wedding nights in them![91]
The insuperable aesthetic perfection of the Ise-jingu or the unbeatable gigantic size of the Izumo-taisha[92] embody one direction taken by the development of the *kura*. The simple rice store, isolated specimens of which are still to be found and which seems to be purely functional, could be regarded as marking the

277 The form of stilt used on this storehouse from Längenfeld, Tyrol, Austria, makes it resistant to bending.

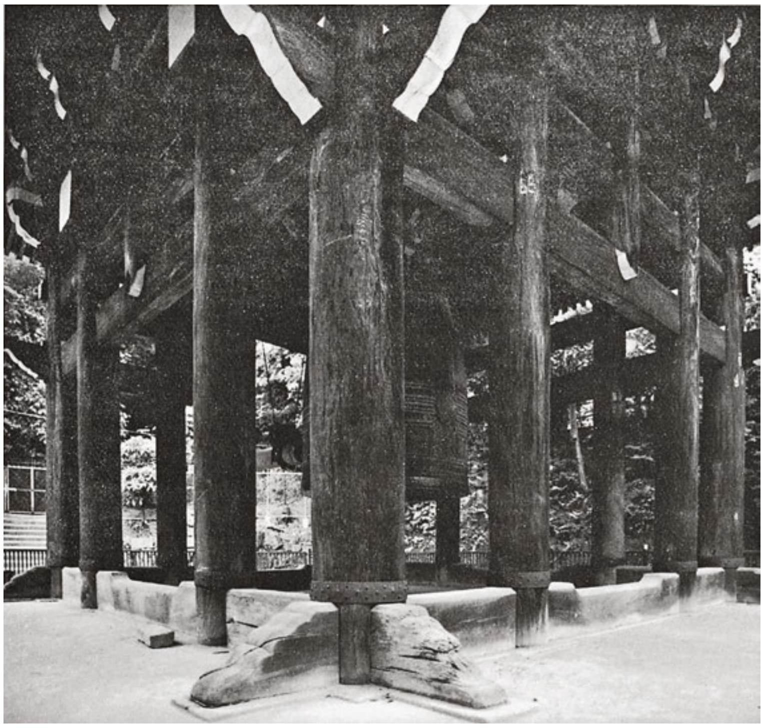
278 A *stabbur* in Gjellerud, Norway.

280 The Todai-ji shoso-in in Nara, Japan, is actually divided into three parts. The central section in column-and-beam construction with plank infills *(itakura)* is flanked by log construction *(azekura)*.

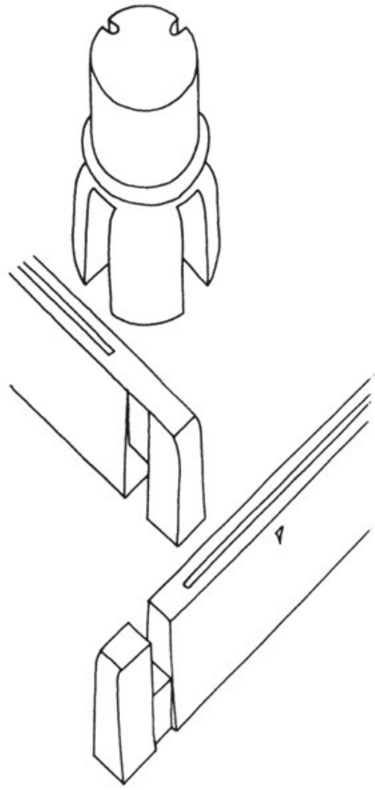
other end of the spectrum.[93] Many link the term *azekura* (storehouse in log construction style) spontaneously with the Todai-ji shoso-in, the treasure house of the Todai Temple. (Fig. 280)
Their massive walls alone make the *kura* stand out from almost all other Japanese structures. Walls inside buildings were only met with in palaces; various room dividers of course, but no walls in the European sense of the word: thermal, acoustic or protective partitions.[94] This distinction made the *kura* predestined for storing treasure, for the safe keeping of a temple's most valuable possessions.[95] These buildings, unique in Japan because they were closed off from their surroundings, made them ideal places for shutting up children in the dark, for eliminating unpopular persons or for performing the initiation ceremonies of forbidden sects.[96]
In raising their storehouses, the Japanese did not use the method we know from the bell-towers of the Chion-in in Kyoto (Fig. 281) or the Todai-ji in Nara. The columns supporting these bell-towers are placed on a ring of sill beams just like any Norwegian elevated storehouse or stave church. (Fig. 282) They overlap the cross-halved-and-housed sill beams, thereby creating a rigid connection. (Figs 283 & 284) That the storehouse supports were basically a specially carpentered frame onto which the log structure was more or less just laid may seem baffling because it is easy to see the link to a sort of column support system from the Yayoi period (cf. Fig. 148) and because the cruciform notching of storehouse supports was so widespread in Europe. Unfortunately, the suspicion that this technique could have evolved from post-and-beam construction cannot be confirmed. Investigations of earlier structures have revealed that in previous ages corner posts for the purpose of fixing only exhibited two slots facing the corner of the room for the beams meeting at a right-angle. Two slots passing right through and crossing in the centre only became common at a later date.



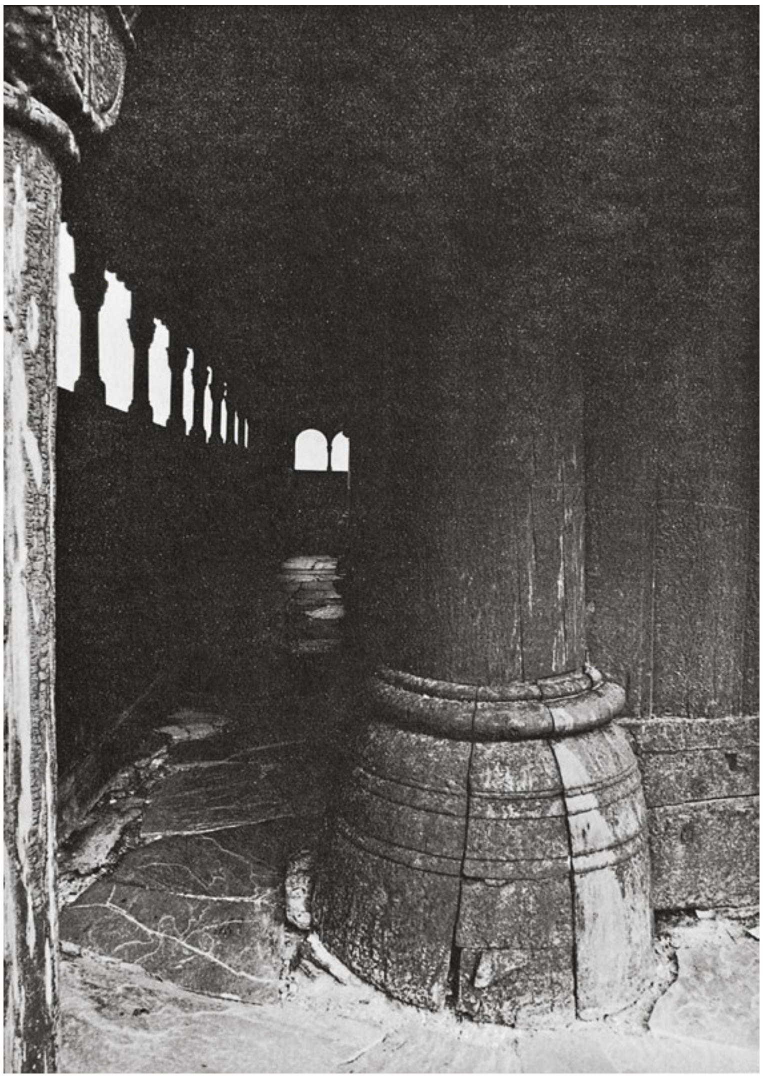
279 The trapezoidal cross-section of the beams underneath the support had the effect of providing a stabilizing, wide bearing. The taper towards the top allowed the supports to slip down as the timber shrank. – Corner of *svalgang*, stave church in Hopperstad, Sogn, Norway.



281 Column-and-beam construction under the Chion-in bell-tower, Kyoto, Japan.

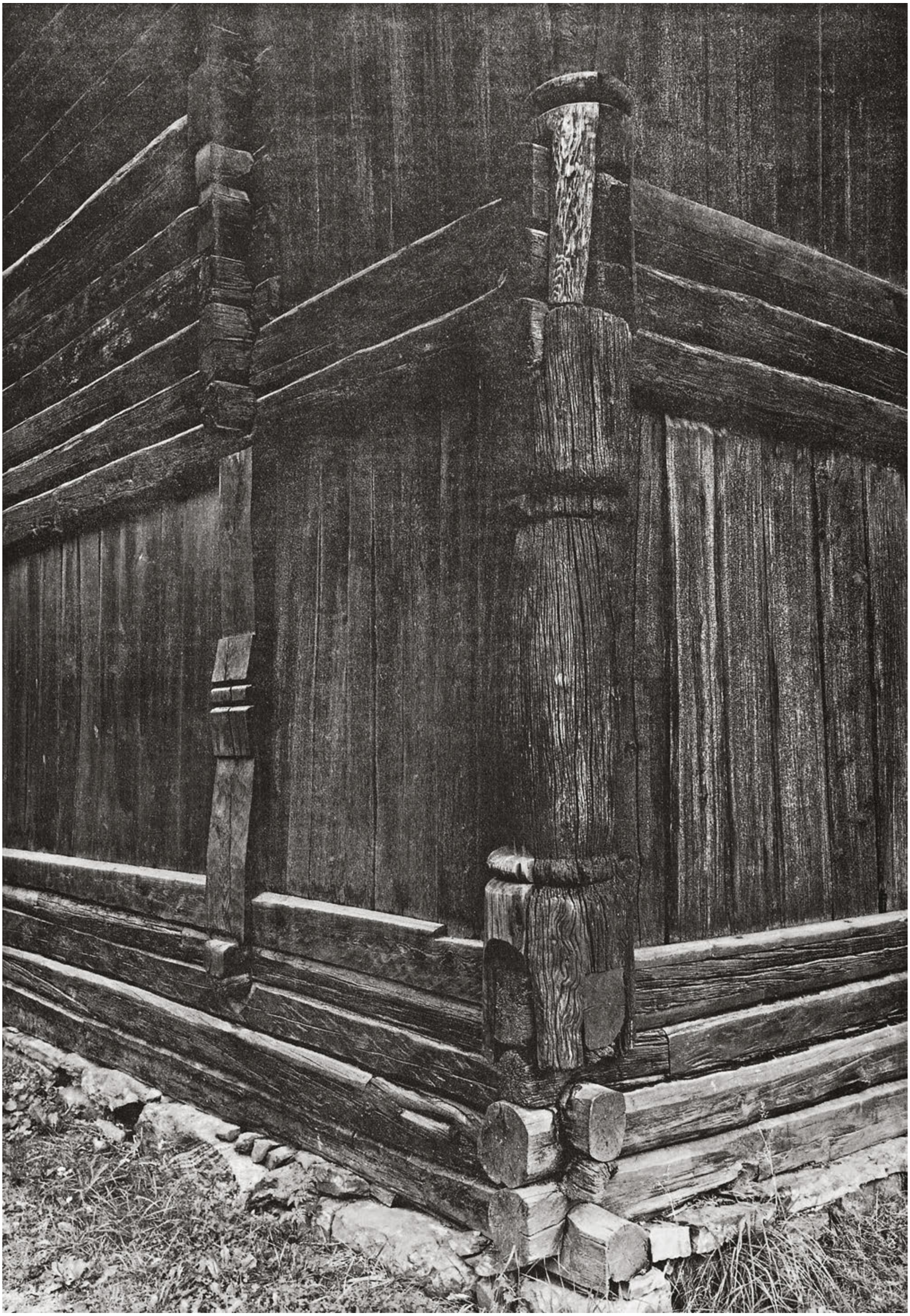


282 The columns overlap the cross-halved-and-housed sill beams, thereby creating a rigid connection. (detail taken from: Christie, 1976, Fig. 31)



283 One of the gigantic corner columns of the church in Hopperstad, Sogn, Norway.

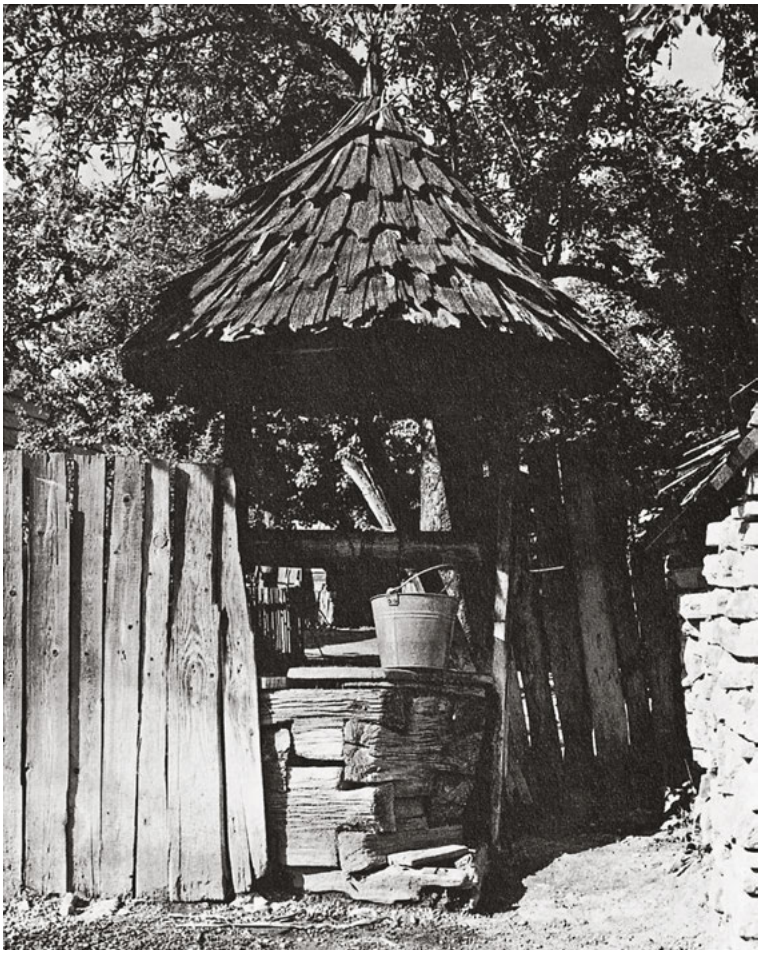
284 Opposite page: The columns of the annexed galleries follow exactly the principle of stave church construction. – Bygdøy, Norway.



If they are to form a wall, members stacked horizontally one on top of the other must be held in the desired position by one means or another. True, there is a certain similarity to the self-supporting wattle wall,[97] but the question of whether we really can conclude that log construction is derived directly from wattlework remains unanswered – for a right-angled joint is in any case much easier to imagine and, hence, easier to produce. Looked at in this way it could indeed be the case that builders only progressed to non-rectangular layouts after they had become sufficiently experienced in the appropriate means of jointing. Nevertheless, there is much to be said for the development of log construction having been influenced by wattle walls, not least because of the fact that log construction later returned to polygonal layouts. (Fig. 285)
Apart from churches, very few buildings survive which were erected over a non-rectangular layout.[98] (Fig. 286) Churches also provide us with another possible explanation for why log construction took on polygonal forms: the apse of stone churches could be copied.[99] It is interesting at this point to make a comparison with Japan, where the apse as such is totally unknown but where wattlework was very much in evidence. During the Yayoi era rudimentary huts were built over an oval shape formed by earth-filled twin-leaf wattle walls.[100] However, log buildings, at least those ones which have survived or which we know of, are rectangular without exception!

286 Non-rectangular barns, such as this one in Hodslavice, Slovakia, have already become a rarity.

287 With a little bit of fantasy you could imagine you were looking at a wickerwork basket! – Apse of church of Zábrež in Zuberec, Slovakia

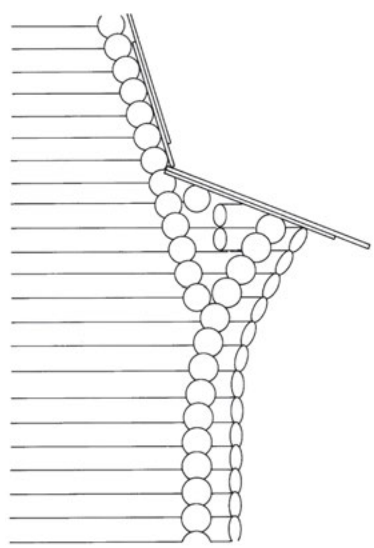


285 This well in Bogdan Vodă, Maramureş, Romania, has a polygonal plan shape. In fact it is very nearly a circle – the cylinder being virtually nothing but joints!

There is further cause for speculation in our considerations about whether log construction is descended from wattlework. Look at the wall of a polygonal log structure and you could easily imagine a wattle construction; (Fig. 287) in your mind simply link each pair of successive end-grain ends along an imaginary spiral line and imagine the vertical pole between the real wall and the fictitious curved wall around which the laths or withies are woven. As in solid wood the connections of the separate layers can be formed in many different ways and not, as is the case for wattle walls, just laid on top of each other; our imaginary wattle wall can be cut in such a way that the (real) log construction remains.
Basically, a column-and-beam structure can be erected over a layout of any shape. However, what distinguishes log construction is its ability to recreate any curved surface. The simplest examples of this are found in the basket-like cross-section of some log storehouses.[101] Following the successful attempt to question the verticality of the wall, the next step was to overcome the flatness. The roof presented itself as the obvious guinea-pig for this task. The *Ansdach* and its variations were a visible expression of the experimentation with forms.[102] (Fig. 288)
Besides the purely formal considerations presented here, there were of course very sound reasons for such a completely enclosed type of structure. Thieves, also the two-legged variety, had to be prevented from gaining access to storehouses; what form of construction could have been more expedient?[103]
The retention of symmetry must have imposed itself on square layouts at least. The pyramid-shaped roof termination was found very frequently.[104] Only the Russians have thought log construction through to its logical conclusion, exploiting all the possibilities available. The onion tower was the result.[105] (Fig. 289) However, besides aesthetics, functional matters also played a major role in the formal design of Russian churches. This is particularly clearly expressed in the *poval*, the valley cornice, which was only developed for the purpose of protecting the wall against rain.[106] (Fig. 290)
The complexity of the structure of Russian churches tempts us to assume complicated jointing techniques.[107] Actually, the majority of joints exhibit the simplest form of pectination.[108] A detailed inspection reveals that the use of a single joint has made possible incredibly elaborate structures. Precisely because the construction is limited to horizontal members we get an impresssion of complexity.
When erecting a log building, the primary consideration is the construction of the corners. If we try for a moment to follow the train of thought of our ancestors, then we will inevitably come to the conclusion that the first solution which occurred to them really was the most obvious one. In order to prevent the upper log from rolling off the one below, it must be suitably supported. This train of thought leads us to the idea of cutting the lower log in such a way that the rounded shape of the one above fits into the cut-out.[109] It must have been realized quite quickly that this form of jointing was very susceptible to the effects of the weather. Nevertheless this jointing method was used not only into the 20th century but modified so that a sealed joint between logs was achieved.[110] Simply rotating the principle through 180° leads to a substantial improvement: by cutting into

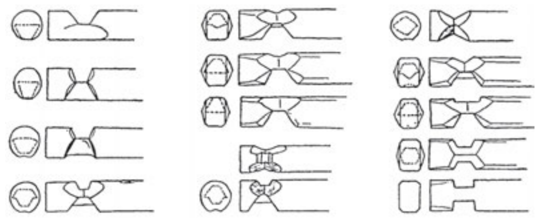
288 A very odd *Ansdach* roof is hidden, protected from wind and weather, under the pitched roof of a lumberjack's hut near Mixnitz, Steiermark, Austria.

289 The old dome from the Nikolai Church in Ljavlja, Archangel, Russia. (source: Lissenko, 1989, Fig. 3.22; photo: Lew Lissenko)

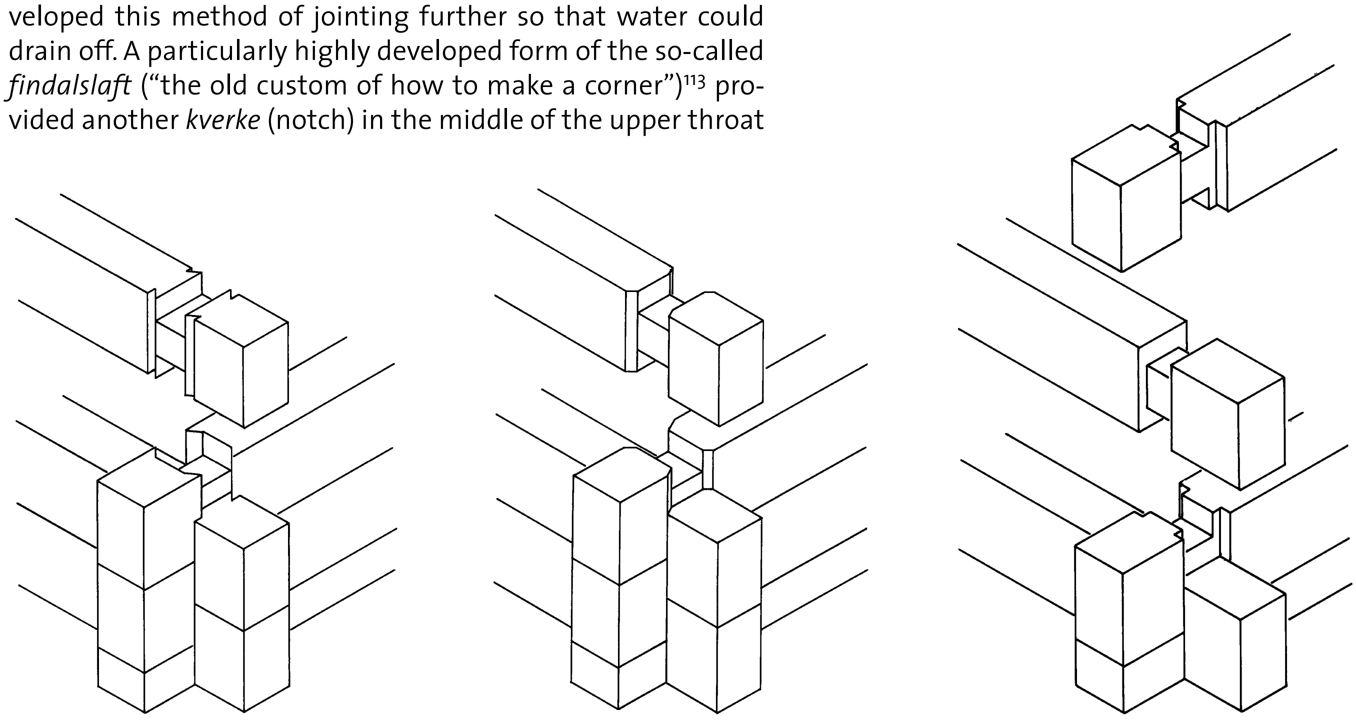


290 Detail (simplified) of the *poval* of a Russian church roof. (according to: ibid., Fig. 3.21b)

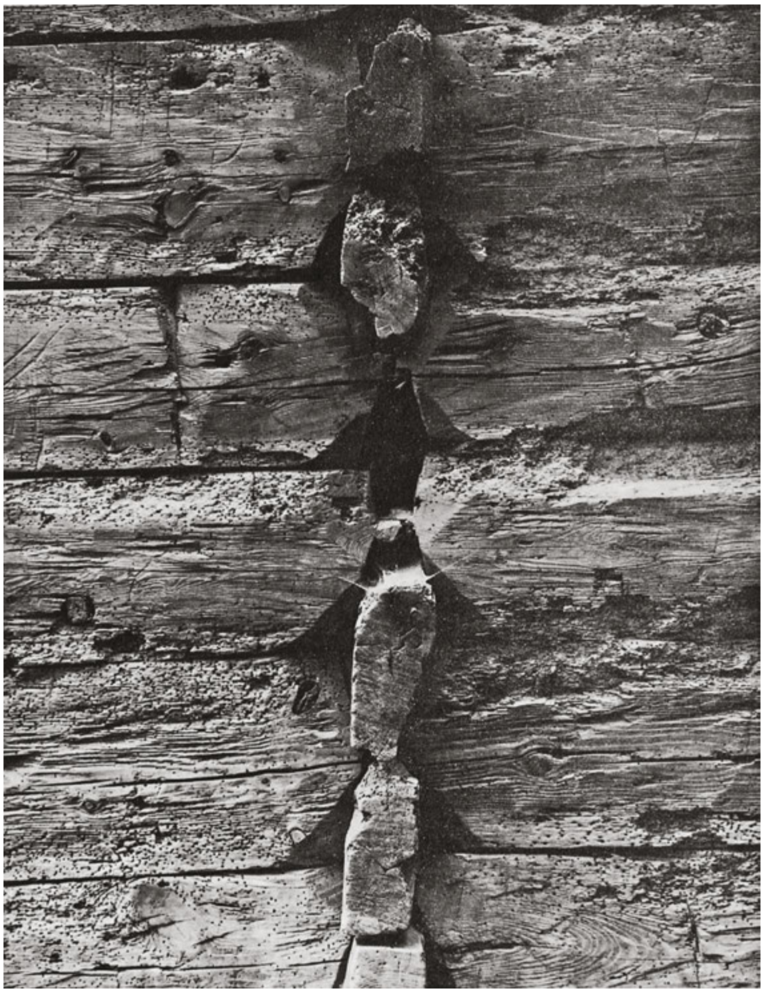
the underside of the upper log, the joint fulfilled the same purpose but rainwater and splashing water could not enter the joint, or if they did it simply drained out again.
The, without doubt, not always straight logs and the very primitive way of connecting them enabled walls to be constructed; however, they were not impervious. Generally, this "ventilated" form of timbering was only retained for special purposes. There were two reasons for trying to increase the imperviousness of log walls. Firstly, early builders tried, in the most favourable cases, to bring logs into contact by cutting a longitudinal groove out of one of them to fit its neighbour. The more accurately this groove was cut, the better the logs were pressed together. Here again, it was only negative experiences which forced carpenters to cut the groove in the underside of the upper log instead of in the top of the lower one, as had been practised initially.
The second point concerned the corner joints themselves. As long as the projecting end of the log was still available,[111] cutting the notch flat instead of rounded proved successful. (Without a projecting end the upper log, owing to the now straight bearing surface, would have had nothing to stop it slipping out of the joint.) Although the mating piece now had to be worked as well, this had the advantage that straight faces could be matched to each other. If the joint was made trapezoidal, as preferred by the Scandinavians,[112] a former advantage could be exploited again: allowing the log to sink into the joint due to its own weight and the effects of shrinkage. (Fig. 291) The cross-section tapering on all sides of the joint offered considerably less frictional resistance than vertical sides. The special status enjoyed by the Scandinavian joints becomes that much clearer when we compare them with very complicated versions from the Alps. No matter which variation the carpenter chose, a vertical incision could never cope with a reduction in stability which came about as a result of the shrinkage process of the wood as it dried. (Fig. 292)
The Norwegians approached the problem differently and did not discard cutting into the tops of the logs but instead developed this method of jointing further so that water could drain off. A particularly highly developed form of the so-called *findalslaft* ("the old custom of how to make a corner")[113] provided another *kverke* (notch) in the middle of the upper throat



291 While the Swedes occupied themselves with the position of the joint, the Norwegians directed their attention to the joint itself. (source: Erixon, 1937B, Fig. 15)



292 In the Alps various methods were tried out for stabilizing the assembly but always with vertical cuts. (according to: Phleps, 1942, Fig. 76)



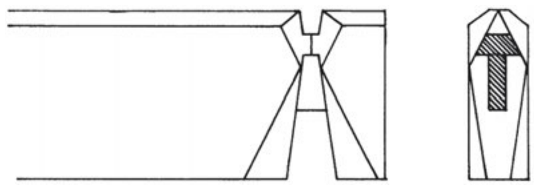
293 **An accurately fitted *kinning* was decisive for sealing the joint. – Bergen, Hordaland, Norway.**

termination which functioned like an additional cogging. Crucial to the guarantee of a perfectly sealed mating of this joint were the bevelled surfaces left and right – *kinning* – kept very narrow and serving as a transition between throat and log. This joint is no longer met with after about 1350.[114] However, the Norwegians very probably also developed a form of joint in which the throat was arranged in the middle of the log. *Raulandslaft*, named after the place where one of the oldest discoveries of this type of joint was made, had the *kverke* facing downwards.

It is thought that the height of Norway's log jointing achievements can be seen in the log cross-sections which, at the joints, were diminished to an almost ridiculous size. (Figs 293 & 294).

The Scandinavians employed a much simpler method for their log churches. Basically, the logs for the walls were squared and the joints made in the form of dovetailed pectinations – *sinkelaft*. One notices how this type of jointing represents the other extreme to those used in secular buildings. Not only the flatness of the interior and exterior walls of the churches but also the consistent lack of projecting ends at the corners of these log constructions distinguishes them quite definitely from the assorted other forms.[115] It was not until the 19th century that secular buildings first copied this type of jointing from church-building.

In Russia it was mainly[116] the rounded cross-section which remained in use for logs. This fact may also be one reason why Russian log construction is thought of as being primitive.[117] In

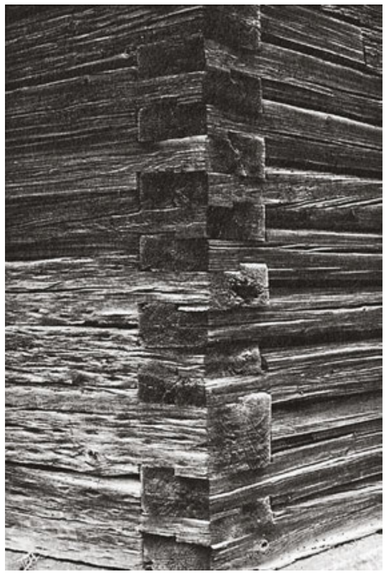


294 **The bevelled cheeks of the joint had to accept all the pressure which the tiny throat would never have been capable of resisting. (according to: Reimers, 1982, Fig. 9e)**

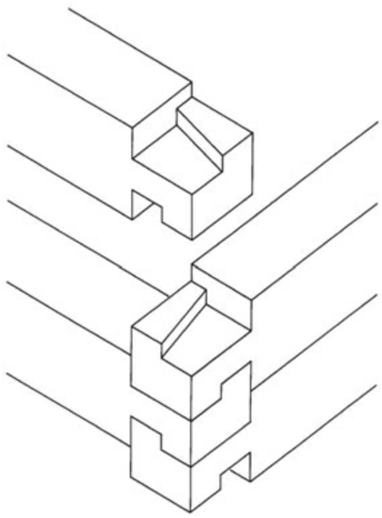
contrast, the thoroughly unique oval form found favour in Norway. In most other regions where log buildings are found, builders sooner or later changed to the rectangular cross-section, the advantages of which were plain to see. When the carpenter squared the trunk he automatically made sure he maintained straight edges. If faces were placed together, a certain degree of sealing was obtained right from the outset. Given the shape of the log's cross-section it was only too understandable why joints too were cut with 90° angles and why further development proceeded along these lines.

If it was desired to omit the end of the log protruding beyond the wall, then new joints were called for. Two basic types were available: the shaped, notched and tabled (Figs 295 & 296) and the dovetailed pectination. (Fig. 297) The terms *Deutschhaken* (German hook) and *Tiroler Haken* (Tyrolean hook) applied to the dovetailed pectination in the Carpathians indicate the regionally emphasized distribution.[118] (Fig. 298) Like all constructional phenomena, this should not be taken too literally. On the one hand, a combined form of the two techniques is also supposed to have existed,[119] and on the other hand, the shaped, halved and tabled joint was certainly also found in western Europe.[120]

It was the properties of wood which forced the carpenter to continue the evolutionary process of wood joints. Wood twisted out of its allotted position, regardless of the load placed upon it. (Fig. 299) Inserting a wooden dowel into every joint, likewise the development of the dovetail into the *Klingschrot*, were both attempts to cope with the wilfulness of this organic material.

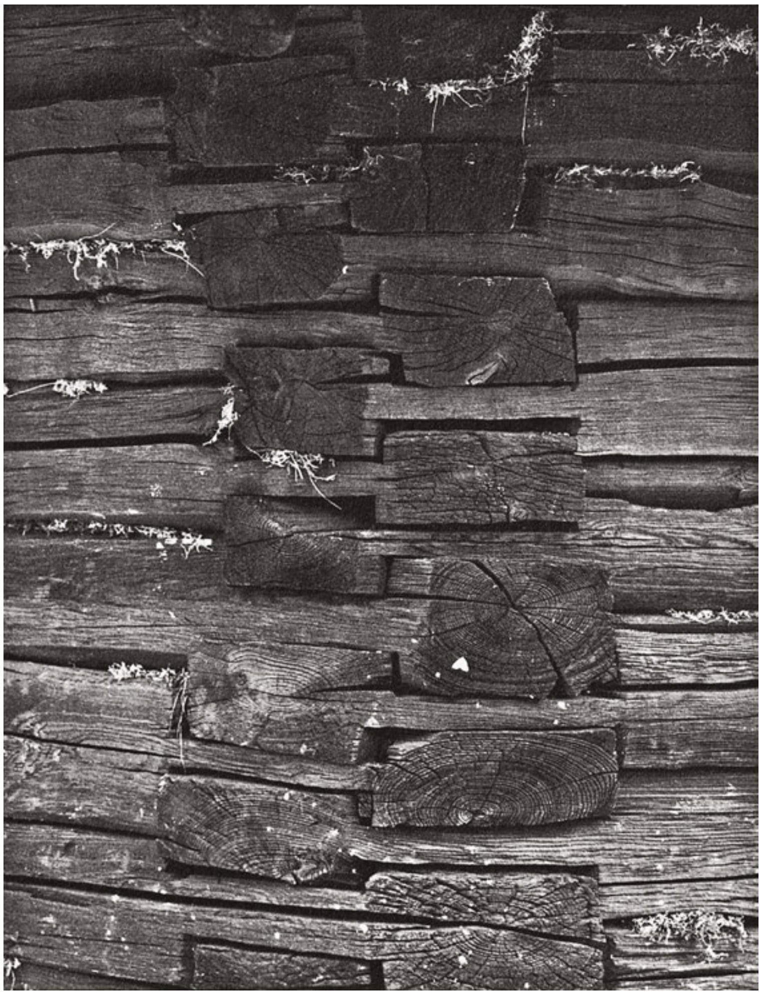


295 **Shaped, notched and tabled pectination was used to join the logs of the church in Loučná Hora, Czech Republic.**



296 **This drawing shows why the tables in the right-angled joint can only be formed on one side.**

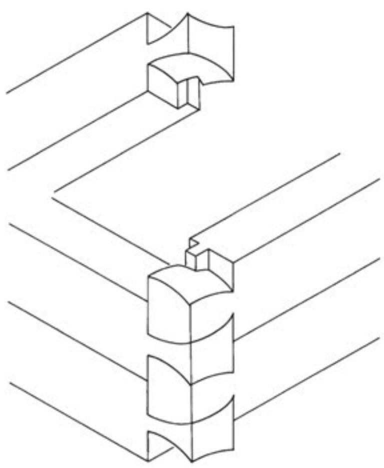
297 **Dovetailed pectination is employed to join the wall logs of the church in Hidişelu de Jos, Bihor, Romania.**



298 Jointed at an obtuse angle the table can be arranged on both sides. – Ruský Potok, Slovakia

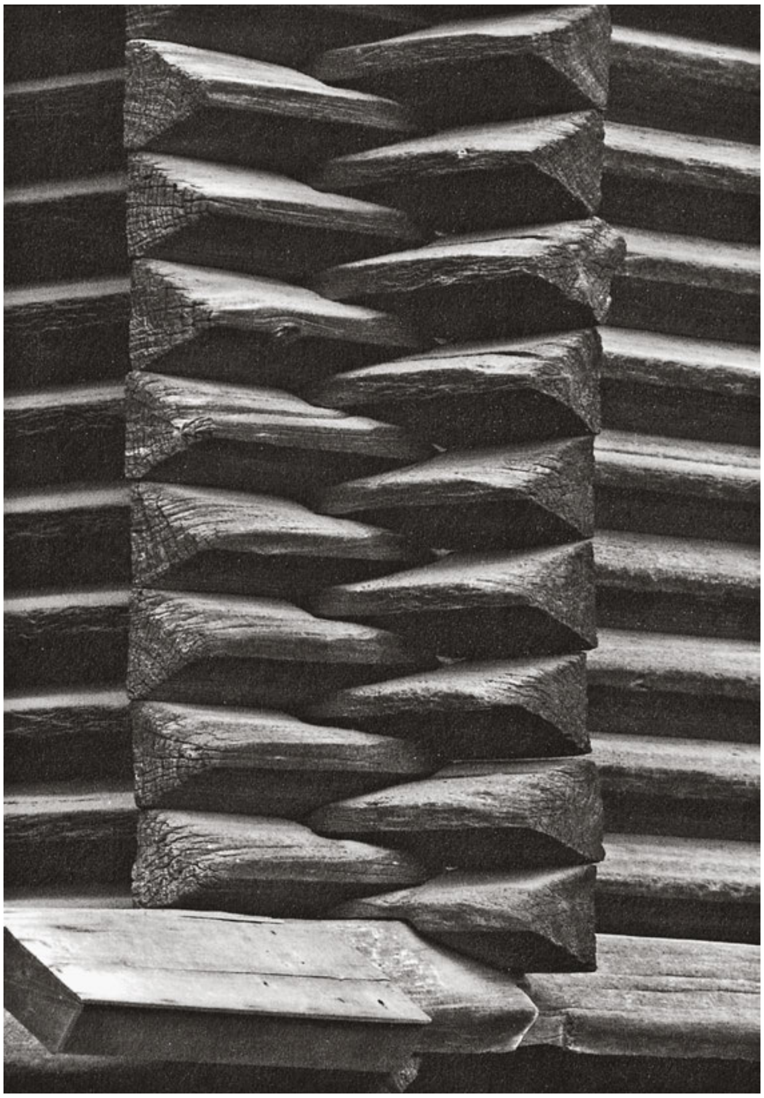
299 The sill beam of the church in Hervartov, Slovakia, has twisted out of its joint despite the weight of the whole church resting on it!

300 The pieces of end grain have been sprung off and so reveal the hidden cogs. – Molzegg, NE Austria

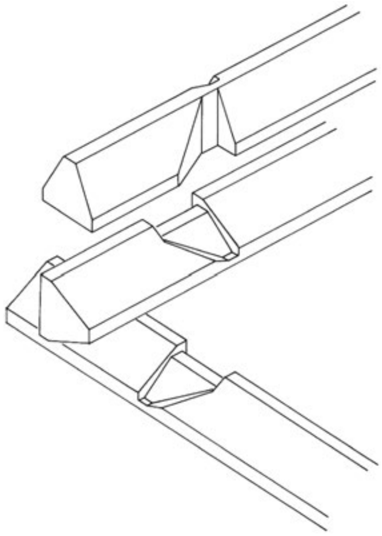


301 Exactly at the point where we humans have hit upon the idea of introducing a special securing feature, nature has outwitted us.

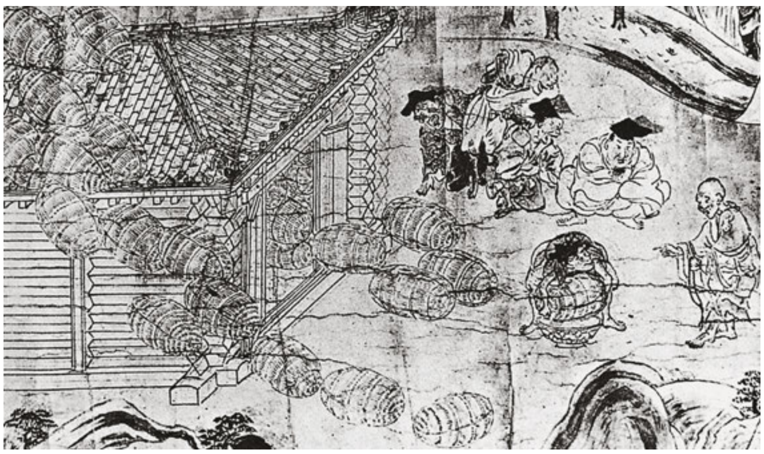
Placing notches on the inside faces of a joint was yet another experiment. (Figs 300 & 301)
In Japan too, carpenters changed to making log buildings with squared timbers. Only pictures remain to show us that one of the most common cross-sections was square.[121] (Fig. 303) What is remarkable is the unique way in which the members are stacked to form a wall: they do not rest on a face but rather on an edge. The very few examples of old log buildings which still exist in Japan are characterized by a cross-section in the shape of an equilateral triangle, although in reality the cross-section is hexagonal because each of the corners is truncated. (Fig. 302) The members are erected in such a way that a unified surface faces inwards in each case. A lack of suitable jointing methods is one reason which has been occasionally suggested for this relatively unstable stacking method;[122] looking at the joints, however, this reasoning seems questionable. At least these joints can take comfort in the fact that they are comparable with European log construction methods in terms of the amount of work required. (Fig. 304) The real weakness of these joints is to be found not in their shape but in the cross-section of the wood. The positions of the members cannot be properly and adequately fixed by these joints because the cross-section necessitates extremely shallow bevels to the throat of the joint; these allow the members to be relatively easily twisted out of position.
Some modern Japanese log buildings appear very similar to those of Europe at first sight. (Fig. 305) However, there are others



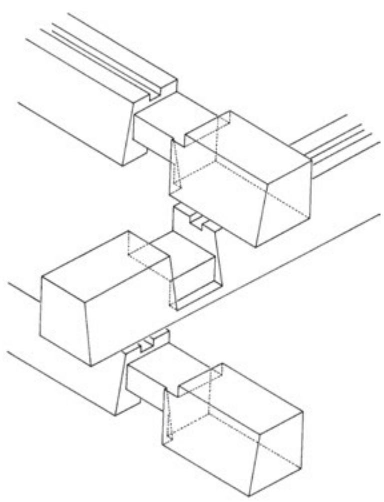
302 From the structural point of view the stacking of members edge-on-edge is incomprehensible. – Wall of the Toshodai-ji kyozo, Nara, Japan



304 *Azeki-sumi-kumite* (finger joint) on the Todai-ji hondo kyoko, Japan. (according to: *Bunkazai …*, 1989, pp. 88/7)

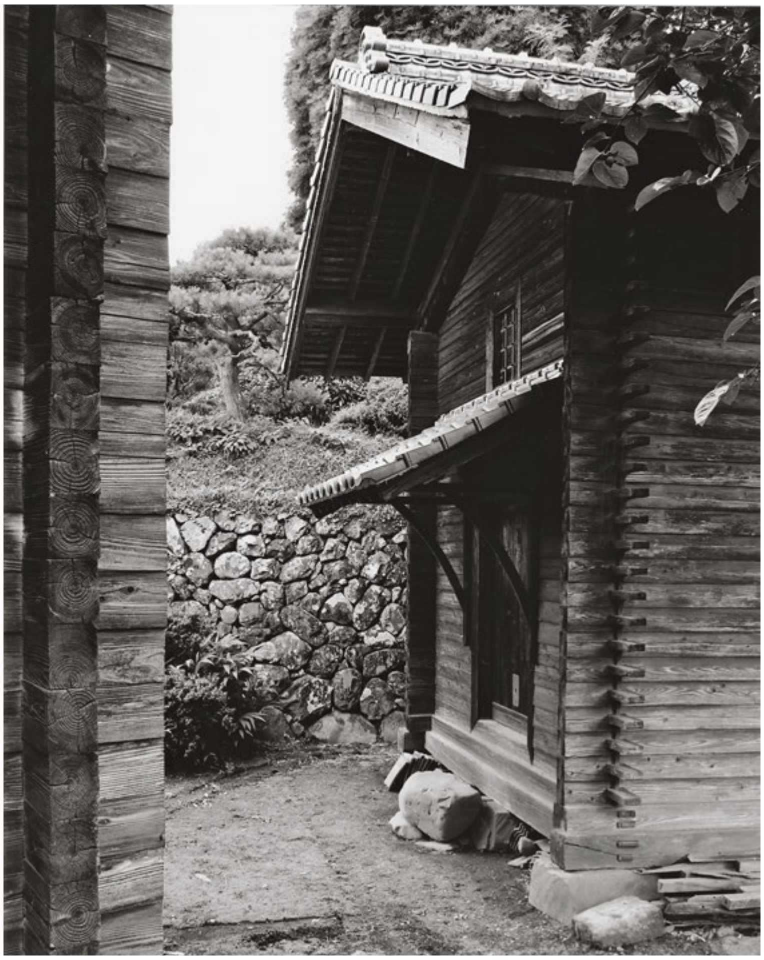


303 A scene from the *Shigi-san engi* scroll in the Chogosonshi-ji, Nara, Japan.

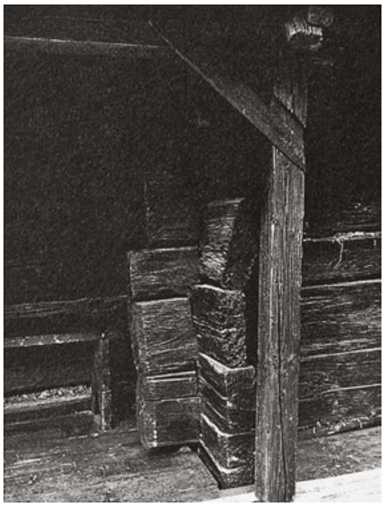


305 Careful examination of the make-up of the wall reveals that the exterior side of the member is cut at an angle and stepped. This allows the joint to be relatively easily produced (apart from the corner at which two bevelled faces meet). (source: Ando, 1995, p. 135)

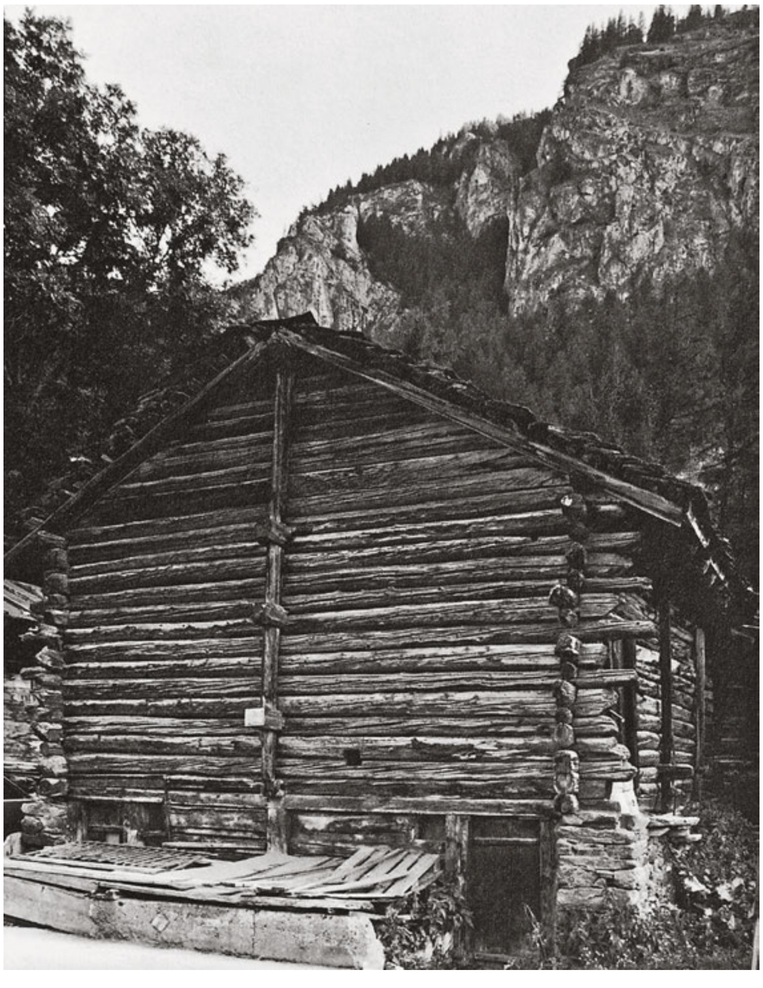
which, in terms of their appearance, tend to remind us more of the log construction of the Yayoi period. (Fig. 306)
One fundamental problem with log construction is that the self-weight of the members can add up to such a colossal figure that the wall threatens to buckle under the load. (Fig. 307) The higher the log wall is to rise or the greater the enclosed area is to be, the more crucial it is to take the properties of the material into account. The same problem loomed when the distance from one joint to the next was too great, i. e. when the corner returns were too far apart. Bugge shows us an example in which



306 The logs on this building are also cut at an angle. However, those on the gable end pass through those on the eaves side, forming a sort of keyed tenon secured with a continuous pole. Daigo machi-Kamigo, Japan. I am indebted to Kunihiro Ando for showing me this jewel of a building.



307 “Bulging” describes superbly the buckling of these logs on the church in Topola, Slovakia.

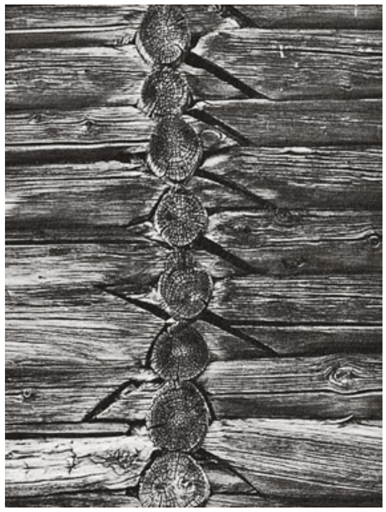


308 The retaining pole on this log building in Evolène, Wallis, Switzerland, also supports the ridge purlin. The irregularity of the projecting ends shows that the logs were cut to length using an axe and not a saw.

we can see that the members were fixed at a spacing of 8 m.[123] Phleps gives 6 m as an empirical guideline.[124] The reader will search in vain for a generally valid statement regarding the maximum length of a log, i. e. the length up to which buckling of the wall can be safely disregarded. Too many factors are involved: the species of timber, its quality, its cross-section, the type of fixing, the height of the wall, its degree of exposure, etc.

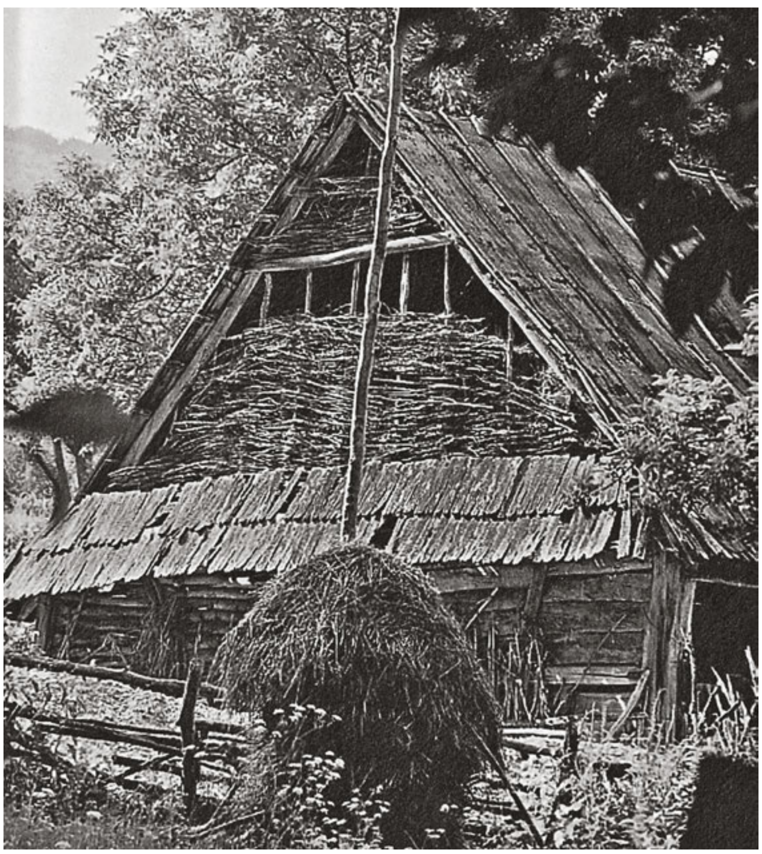
The preventive measures devised to deal with the problem were of a diverse nature. Walls could be held in position by hidden, offset dowels which secured each pair of members together.[125] Another possibility was the retaining pole,[126] (Fig. 308) or the stabilizing of the eaves sides by building in the partition walls. (Fig. 309) If a dividing wall was not wanted, there was even the possibility of utilizing their structural properties "pure" so to speak: from the outside the so-called *Kegelwand*, a strengthening timber pier, appears to be an integrated intermediate wall but is in fact no such thing! It terminates internally exactly the same as it does externally. (Fig. 310)

A simple, short board, as Sirelius discovered among the Komi, the Finno-Ugric peoples of the north-western Urals, could be regarded as a forerunner of the *Kegelwand*. Semicircular cutouts were made opposite each other on each of the two long sides of the board, their diameter corresponding to that of the logs to be used for the wall. Placed between two logs, the ends of the boards faced inwards and outwards, exactly like the *Kegelwand*.[127] Without this form of stabilizing, high walls could surely not have been built. The concept became established in Russia, albeit in a modified form and for a different purpose.[128] (Fig. 311)



309 It is a Norwegian idiosyncracy to splice the logs where the partition walls are built in. This greatly weakens the members – nevertheless, it is a tradition … – Hindseter in the Vågå Highlands, Oppland, Norway

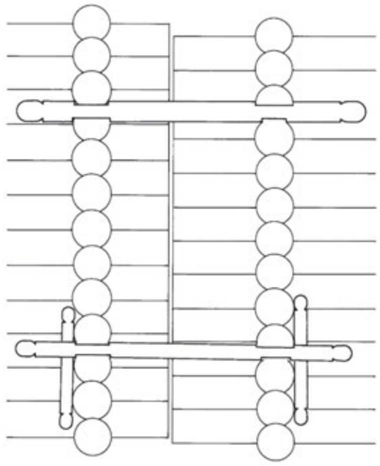
310 The one and only function of the short, wall-like stack of stub logs is to prevent the members of the gable end from buckling. – Feld, eastern Tyrol, Austria



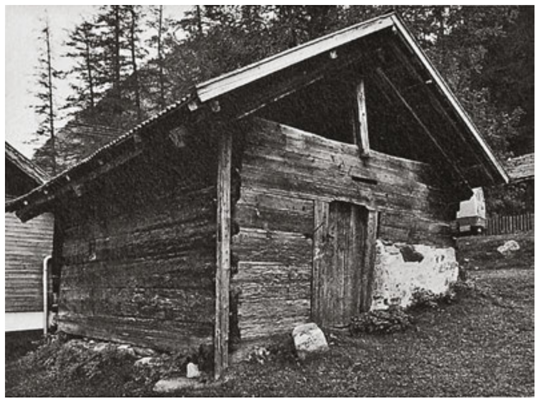
312 Both wattle-and-daub and log buildings were given wattlework gables so long as their builders remained unsure about constructing them in a solid form. – Huta, Salaj, Romania

In the early days of log construction, builders may well have wondered how the triangle of the gable end might be satisfactorily accomplished using the same log building techniques. When the rectangular box had reached the desired height, the gable ends could be built no further; how would the members be fitted together? Initially, the old wattlework method was retained but sooner or later this solution became unsatisfactory.[129] (Fig. 312) At first, carpenters borrowed ideas from column-and-beam construction, namely, plank infills. (Fig. 313) The ridge purlin could be supported by placing a support over the topmost member of the gable wall; grooves in both sides of the support allowed planks to be slotted into place. Despite having made use of this method, the Swiss found it so alien to log construction that they called this sort of king post a *Heidenbalken*, a "pagan support".[130] And the Japanese too resorted to this characteristic of column-and-beam construction where it was necessary to extend short sections of wall.[131] As the evolution of log construction continued so the bonding of the *Änse*, the fixing most consistently used in log construction, appeared. If the logs of the gable end were successively shortened, as is necessitated by the profile of the triangle of the gable, the logs on the eaves sides (called *Änse* on the roof) were automatically drawn successively into the centre of the building as they rose up the roof until the ridge was reached. Looked at from the point of view of the joints there is no problem. A pitched roof formed in this way can be transformed into a pyramid roof by shortening the members on every side. Extrapolating this principle to its logical conclusion gives us the onion tower introduced earlier.

A log wall can only be provided with openings at the expense of its stability. As long as there remained no remedy for this deficit, builders strived to sever as few of the logs as possible where doors and windows were required. The Norwegians must be acclaimed as the indubitable victors in this competition. (Fig. 314) Basically, their carpenters only revamped an old idea. If in a log building a tongue was left on the cut members which could then be inserted into the grooved jambs of the door frame, this was simply applying the techniques learned from the infill planking of column-and-beam construction. (Fig. 315)



311 The Russian "tying beam" was designed to firmly attach a new log extension to an existing building. (according to: Lissenko, 1989, Fig. 3.30)



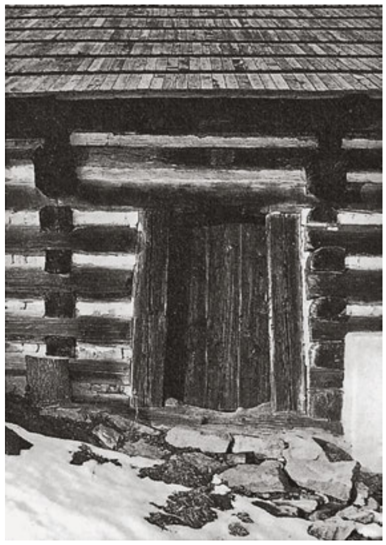
313 Just the direction of the ridge-supporting column betrays the fact that this construction is borrowed. – Unterried-Lehn, Tyrol, Austria.

314 Only one log had to be severed completely for the doors to this *loft* on Helle Uppigard Farm, Aust-Agder, Norway.

However, if our builder decided that such fixings were superfluous, unwelcome surprises were in store for him. (Fig. 316) Incidentally, if the reverse was done, i. e. the door jambs fitted into mortises in the wall members, the result was identical. (Fig. 317) Peculiar to Norway were W-shaped grooves.[132] As has already been mentioned several times,[133] the intersection of horizontal and vertical elements in a fixed assembly remained troublesome.[134]

All these means of securing the wall – building in partition walls, including a *Kegelwand*, the grooved column, the tying beam, even the use of dowels[135] – could also be applied for lengthening.[136]

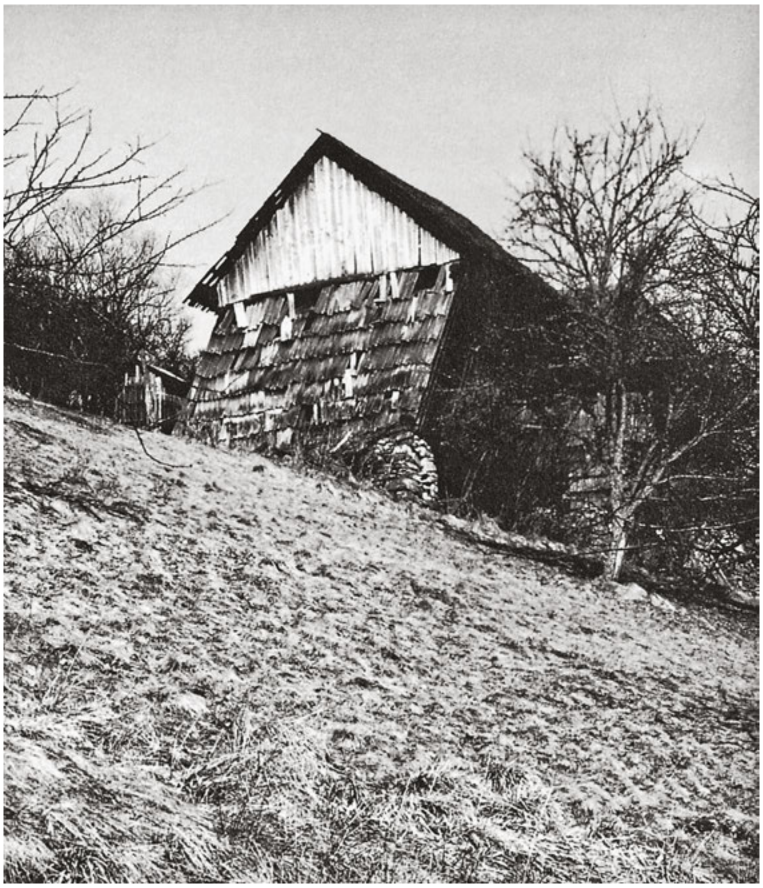
Church-building presented a new problem. It was not only their size which should distinguish them but their height as well. The higher the walls were designed to be, the greater was the threat that the entire structure would deform or slip out of vertical alignment, not least owing to the weight of the roof. (Fig. 318) Bearing in mind the type of construction, an interesting solution was found in the North. In Finland a right-angled, hollow pier was built into the wall assembly inside the church.[137] Strzygowski expressly points out that this idea originated with Finnish farmers; that would explain why this principle can be found on so many other types of buildings.[138] (Fig. 319) If this log pier was now replaced by re-entrant angles which guaranteed the same stability, the result was a cruciform church.[139] In Russia on the other hand, the necessary stability for the tall church walls was achieved by attaching a square structure on



315 **Belt and braces! Despite the adjoining intermediate walls, the builder still included door jambs! – Sádek, Czech Republic**

316 **The owner of this farmstead near Vågåmo, Oppland, Norway, certainly believed it was worth the savings to provide the door as shown here instead of installing a proper framed opening!**

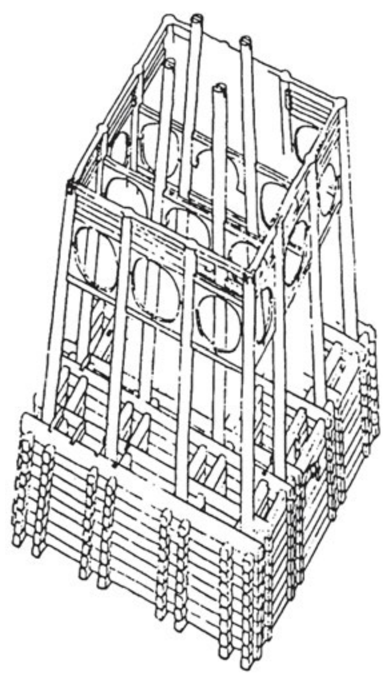
317 **Door jambs securely fitted into grooved logs. – Maihaugen in Lillehammer, Oppland, Norway**



318 A log building which has lost its equilibrium is extremely unstable. – near Javorina nad Rimavicou, Slovakia

319 Boathouse from Ikaalinen, Finland, in the Seurasaari Open-air Museum.

each side.[140] Shortening the walls and frequently changing their direction brought about the desired rigidity. Bugge shows us an almost satirical example from Häverö, Sweden: a grillage of logs creates cage-like cells which are obviously intended to provide the stability required by the special needs of a bell-tower. (Fig. 320)
Jettied storeys were even simpler to incorporate in log construction than in column-and-beam construction. It is no great problem, neither in materials nor in engineering terms, to arrange for an upper storey to cantilever impressively beyond the walls below. (Fig. 321) And if the carpenter only desired a discreet projection, that was child's play. (Fig. 322) Very distinct examples were to be found in Romania: on polygonal structures the jettying above door-lintel height increased layer by layer. That, coupled with the polygonal plan shape, led to the projections touching by the third or fourth layer. It must have been a clandestine desire on the part of the carpenters which led to this idea being extended to its logical conclusion, i. e. cantilevering the members of one wall through a recess in those of the adjoining wall and joining them to the projecting members of the next-but-one wall at a point practically invisible to the observer; only the initiated knew that the purpose of this bracket was to support the roof which extended a long way down the sides of the building.[141] (Figs 323 & 324)



320 Bell-tower in Häverö, Uppland, Sweden. (source: Bugge, 1984, p. 18)

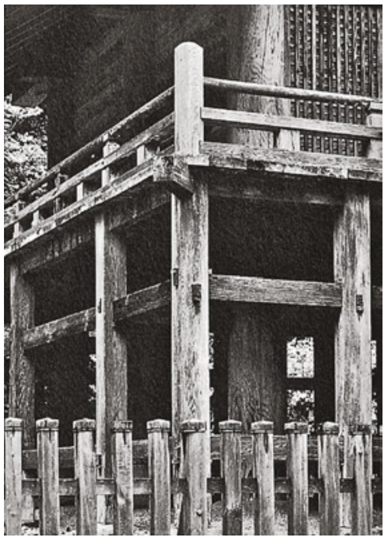
321 Brackets are easily incorporated in log construction. – Bygdøy Open-air Museum, Oslo, Norway

323 The crossing of the bracket timbers was sometimes carried out in an almost overpowering form. – Poarta Salajului, Salaj, Romania

322 To highlight the wall divisions by means of the carved spandrel beneath the windows, the spandrel cantilevers by the width of the member. – Werdenberg, St Gallen, Switzerland

324 On the church in Călineşti, Maramureş , Romania, the same type of construction is achieved in a graceful and frivolous style.

Two tasks which characterize column-and-beam construction will be singled out here, the manner and extent of which do not carry the same weight in Europe and Japan. The first part deals with the bracing required to stabilize the framework, while the second part looks at how sections of buildings are cantilevered.
As posts were lifted out of the ground, our carpenter also bid farewell to his knowledge of structural engineering. (Fig. 325) Well, not completely. However, a large number of joints had to be adapted or new ones invented after the bottom of the structure was no longer buried in the ground and so the fixed column-base concept was lost; our carpenter had to re-establish the stability that such a foundation had once offered.
An extreme example from Japan illustrates the new problem. The nine columns of the old Izumo-honden are said to have risen 48 m out of the ground. Only the top one-quarter of the whole construction formed the actual shrine. The structure collapsed four times because the columns were of such a height that inspection was impossible; rotting of their upper section went simply unnoticed. It was only when the structure was rebuilt in 1248 that the consequences were realized and the height reduced.[142] Even burying these ones in the ground must have been at the limit of what was feasible at the time – not to mention the timbering! Wherever suitable, carpenters used only whole trees in order to connect the columns.[143] That the doubts expressed by Watanabe about the earlier extreme version described by the restorer Fukuyama were justified[144] is revealed by looking at the massive columns of the Kamosu-jinja, which are only one-third the height. (Fig. 326)
Horizontal members, sill beams and head beams were fitted into columns to define their positions, normally with simple lap, mortise-and-tenon or forked tenon joints. As horizontal intermediate elements did not provide adequate bracing for the walls, in European timber construction diagonal bracing was lap-jointed over the horizontal members. (Fig. 327) Such passing braces were retained for a long time for structures which required extra stability, e. g. bell-towers or mobile siege towers.[145]



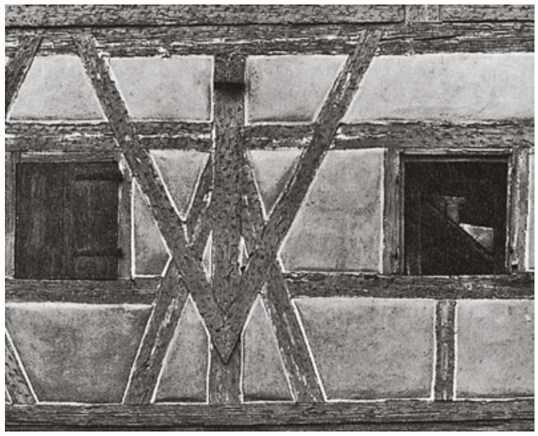
326 View below floor level. – Kamosu-jinja, Shimane, Japan

327 Diagonal cross bracing over several storeys characterise this house in Gemünden an der Wohra in the state of Hessia, Germany.

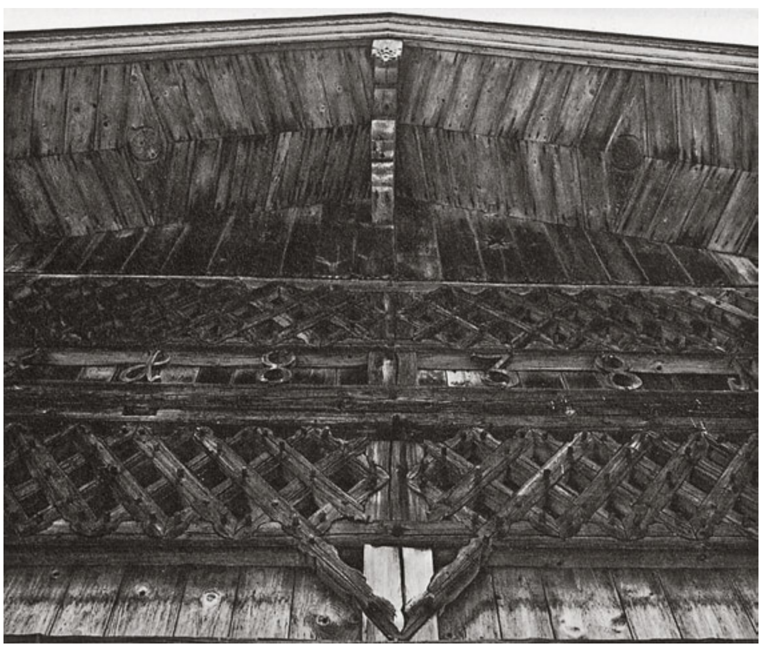
325 Despite the many columns, the wall cladding to this storehouse in Peper Harow, Surrey, England, has made the structure so heavy that without bracing to the bases of the columns its stability would no longer be guaranteed.

The transition to this type of bracing may well have been derived from supporting struts.
Economic considerations may well have favoured the introduction of up and down braces, likewise the desire for a return to "cleaner" and more regular façades otherwise severely impaired in visual terms by the inclusion of diagonal bracing. One of the earliest architectural highlights of this development were the so-called "human figures". (Fig. 328)
To somewhat relieve the load on wooden nails, which secured joints and probably often assisted them as well, there was a transition to dovetailed or notched lap joints which were intended to absorb some of the tensile loading. That they were actually stronger than their form suggested was proved by their successful use in the first truss posts in church roof trusses. Another example is their use in the fabrication of lattice girders. (Fig. 329) "Only [dovetailed] half-lap joints are capable of resisting the tensile forces and bending moments which occur …; they cannot be replaced by just any other joints."[146] The increase in the number of bracing members to meet aesthetic requirements led to the development of the *Bundwerk*[146A]. To regard "an excessive depiction of the construction principle"[147] as the background to the development, as we are doing here, does in this case not contradict the explanation that the much stronger wind pressures in mountainous regions have been resisted by heavier bracing, i. e. an increased number of up braces. Apart from that, the "column-and-beam construction of mountainous regions boarded from the inside" prevented "diagonal braces from twisting out of their housings as a result of shrinkage".[148] (Fig. 330)
Nevertheless, carpenters detached themselves from the lap joints over the course of time, replacing them more and more, and soon completely, by the mortise-and-tenon, which was by no means a newcomer. While the lap more or less disappeared from Germany in the 16th century and only survived in *Bundwerk* until into the 1800s,[149] the mortise-and-tenon had already taken over completely in the Lisieux Cathedral in France as early as 1180.[150] Steadfast resistance in some areas appears to

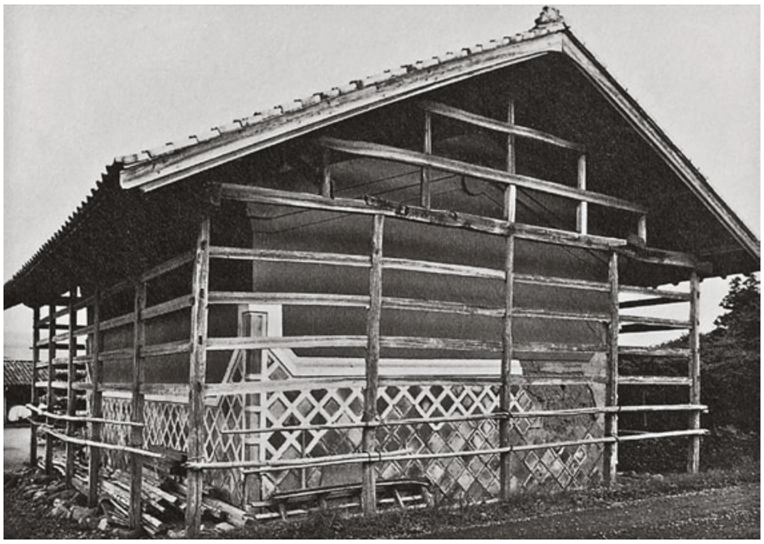
329 Lattice girders enabled a generous spacing of the columns in *Umgebinde* construction. – Heřmanice, Czech Republic



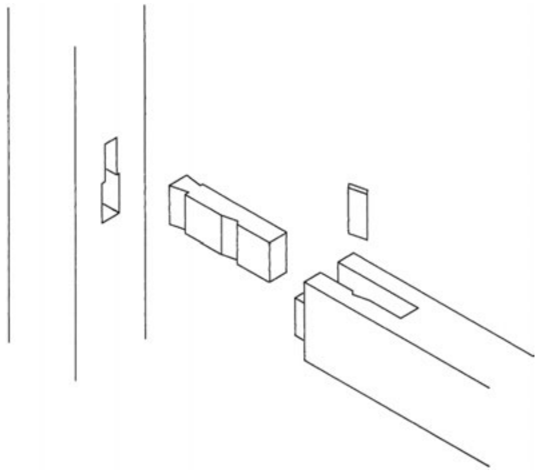
328 The gradual transition from lapped to mortise-and-tenon joints can be clearly seen in these up and down braces. – Rothenburg, Bavaria, Germany



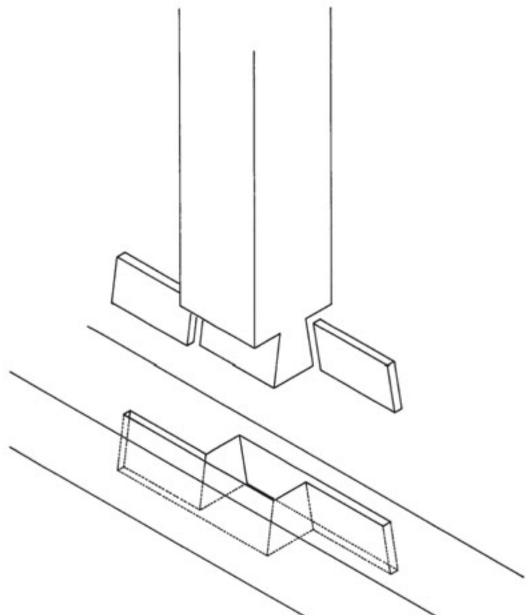
330 *Bundwerk* gable in Forsthof, Bavaria, Germany.



331 *Kura* with continuous peripheral drying frame in Iwate Kamigo, Iwate, Japan.

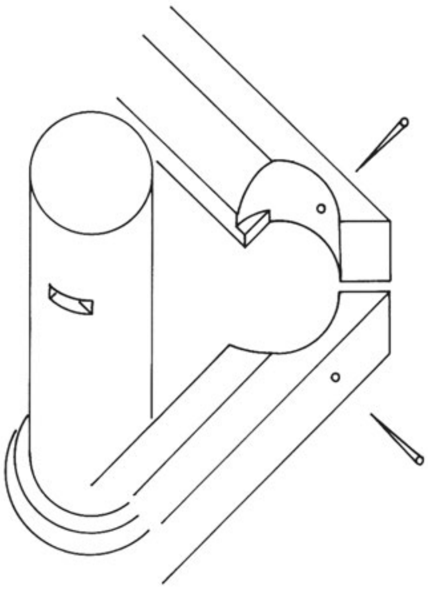


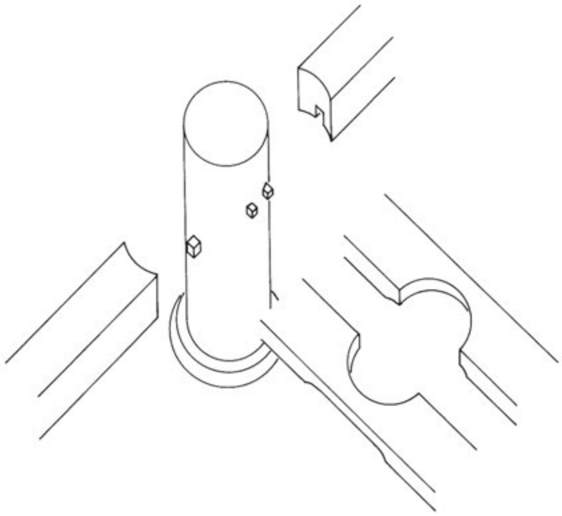
332 The dovetail of the loose tenon is inserted into the column and pushed upwards. The rail, erected afterwards, is now inserted into the column. The protruding end of the loose tenon slips into the rail and is held firmly in place by means of a key.



333 In order to incorporate a ceiling, for instance, battens to carry the ceiling can be suspended in this manner. A member fixed under the roof construction has a dovetail end which fits into the batten. Keys are then inserted into the batten left and right of the hanger and pushed into place either side of the dovetail to secure the batten.

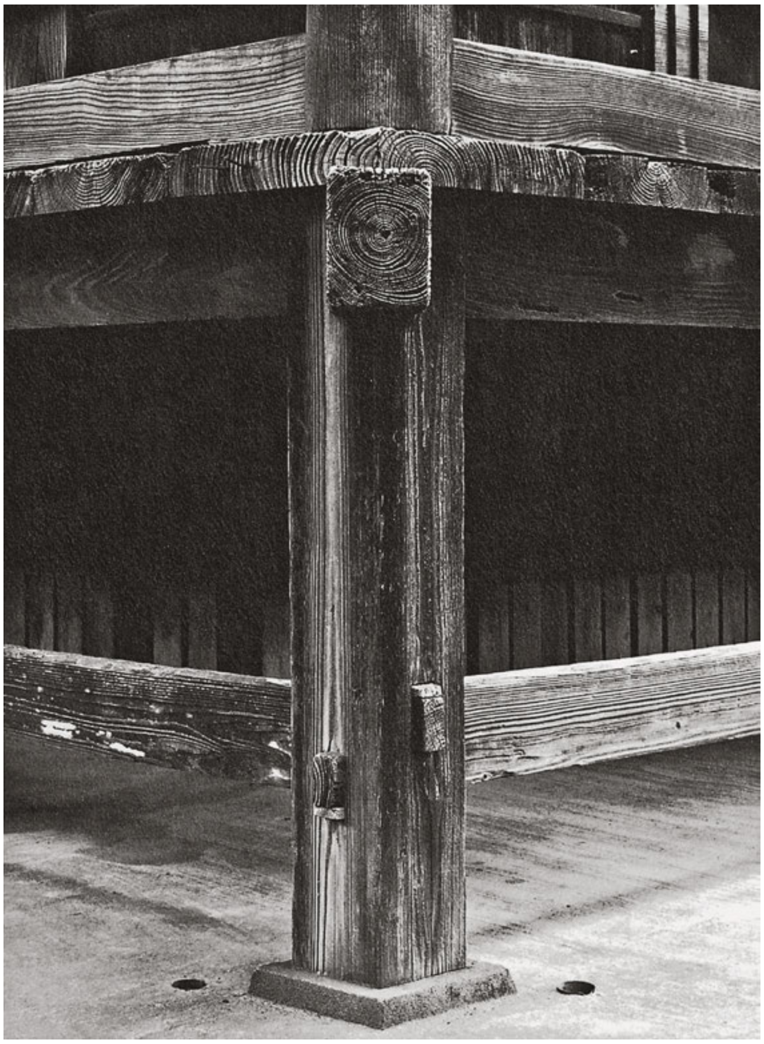
have made statutory regulations necessary to implement the change.[151] If we consider the changes to the construction procedure,[152] this also appears understandable: attaching diagonal bracing with lap joints constitutes a second stage after the main framework has been set up. If, though, mortised diagonal braces are to be integrated, this must be carried out at the same time as the main frame is assembled. Such reasoning would not apply to Japanese construction because in Japan a multitude of joints have been developed which allow members to be incorporated subsequently. (Figs 332 & 333)
The making of a lap joint is far more demanding than the making of a mortise-and-tenon.[153] As the lap is exposed, it must be more accurately worked for visual reasons; it is precisely this reason that gives rise to decorated versions. Furthermore, due to the nature of wood, a lap has the disadvantage that it is very liable to be twisted out of its housing.[154] Nails can only prevent this to a certain degree.
While wind bracing in Europe was based on fixing the angles between members, attained through triangulation, the emphasis in Japan was on the maxim "solid and resilient".[155] This leitmotiv in Japanese column-and-beam construction clearly illustrates the reason why diagonal braces are encountered comparatively rarely. Only in this way could builders achieve the elasticity required to cope with the many earthquakes. The carpenters obtained stability by way of the revolutionary introduction of the tenon which passed right through the column. (Fig. 336) This form of joint had arrived with the *daibutsuyo*, an architectural style which found its way from China to Japan at the end of the 12th century.[156] In contrast, *wayo*, another style of architecture imported from China much earlier and which was already so firmly anchored in Japan in the Middle Ages that it became known as "Japanese style", still employed bracing members below floor level, at floor level and as head beams nailed to both sides of the columns like ties. (Fig. 334) This did not require any particularly ingenious joints. To complement the nailing, a peg-like tenon bearing for the horizontal members was often included. (Fig. 335)
To obtain real stability it would not have been adequate to simply extend the mortising of the head beams on both sides until the two tenons met, as had been done on occasions in the





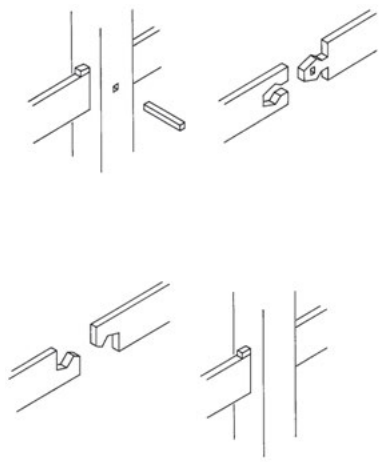
334 Corner column framing on the Kibata jinja romon, Tochigi, Japan. (according to: *Bunkazai* . . ., 1986, p. 300/3)

335 Framing to the columns of the Horyu-ji toin denpodo, Nara, Japan. (according to: ibid., p. 86/1)



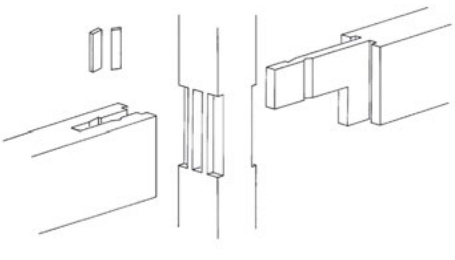
336 In Japan it is specified exactly which tenon should penetrate the corner column above and which below. One identifies the longitudinal direction, the other the transverse.

past. The stabilizing, horizontal members had to be continuous, if possible through the entire row of columns. (Fig. 331) To do this it was necessary to join several rails together because sufficient quantities of the lengths required were not available. (Fig. 337) They were secured by driving wedges into the slots in the column from both sides. (Figs 338 & 339)
Although in the *daibutsuyo* it was relatively easy to insert rails into the massive columns, the task became ever more difficult as columns became thinner. Moreover, connections between columns and rails of equal or nearly equal cross-section were specified again and again. It was only now that the technique of creating the joint within the vertical member came fully into its own. (Fig. 340) The *engawa-no-keta* joint (purlin-over-the-*engawa* joint) has the slot cut in one purlin. The other is divided in two such that the two pieces are joined together and to the first purlin with the help of *shachisen* (see note 173) in a way capable of resisting tension. (Fig. 341) A relatively simple solution like the keyed mortise and tenon of Fig. 340 might have supplied the impetus for really complicated joints like the *engawa-no-keta*, which goes way beyond the principle of joining within another constructional element. The identical, round cross-section of the intersecting members calls for a sophisticated idea such as turning one piece of the purlin through 90° in order to be able to make the connection.
Three-dimensional constructions require not only bracing in two planes but in a third plane perpendicular to the first two. (Fig. 343) In these cases many of the same constructional concepts and joints which have been applied successfully in two

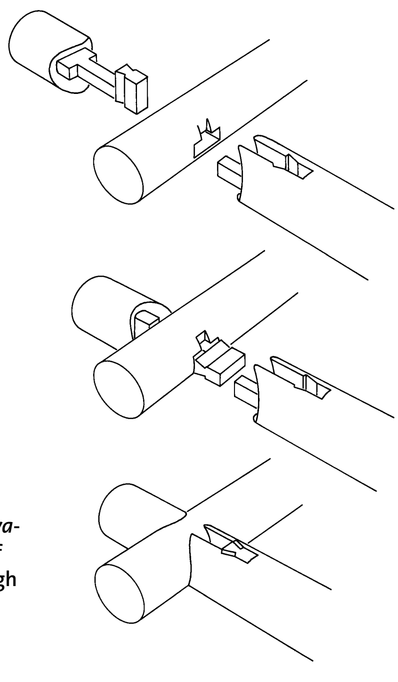


337 Diverse types of tension joints (shown here are *sashiawase-komisen-uchi* and *nimaikama*) were used at the columns to prevent movement and for aesthetic reasons. An additional benefit was that they were also better protected against the effects of the weather.

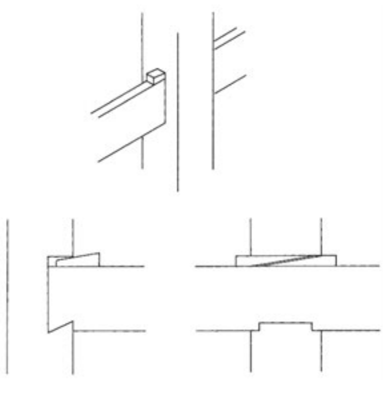
338 *Kakezukuri* construction – Ishiyama-dera hondo, Shiga, Japan



340 *Konozu-zashi*



341 The curious thing about the *engawa-no-keta* joint is that the shorter piece of the divided purlin must be turned through 90° in order to be able to insert it into the slot. (according to: Sumiyoshi, 1991, p. 109 f.)

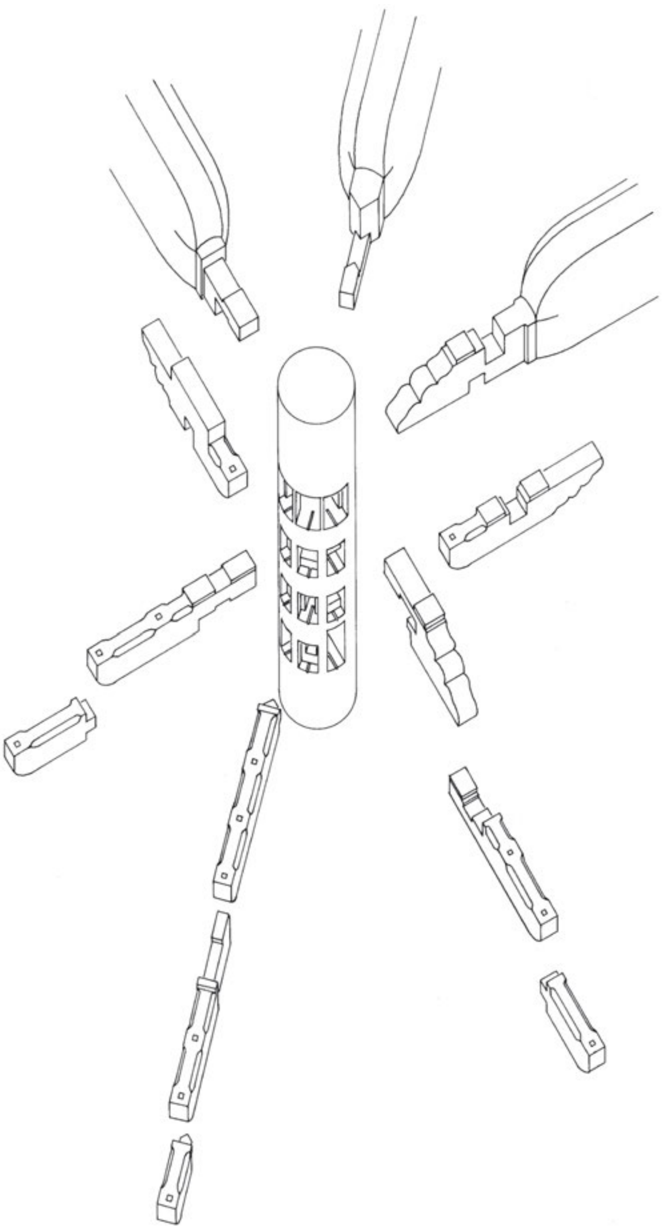


339 The principle of fixing the rails to the columns.

342 Besides being an admirable engineering solution, the way in which the, relative to the column, unbelievably large beams are attached to each of the four columns of the Jodo-ji jododo is really quite impressive.

dimensions can be used again here, both in Europe and in Japan.
In Europe, transferring the principle of bracing from the second to the third dimension can be seen most clearly and logically in Norway's stave churches. Only these made use of horizontal brackets for bracing in the horizontal plane – exposed forms as well.[157] If we trace the development of Norwegian stave churches from the many columns of Kaupanger church, braced only with arched quadrant brackets (so-called *arcading*), to the rows of columns in Borgund church, held with ties in the Japanese *wayo* style of temple architecture, to its culmination in the churches of Hurum and Lomen, which, supported on just four columns, exude the incredible confidence and experience of their carpenters in handling this form of construction, it is evident that the structural form chosen by the carpenters led to the best solution in every case.[158]
The Jodo-ji jododo is a prime example of the architecture of the *daibutsuyo*. At first sight its fat columns may seem rather clumsy. (Fig. 342) However, if we take a closer look at the joints, we become more and more amazed. When carpenters are con-

343 Construction detail – Jodo-ji jododo, Hyogo, Japan



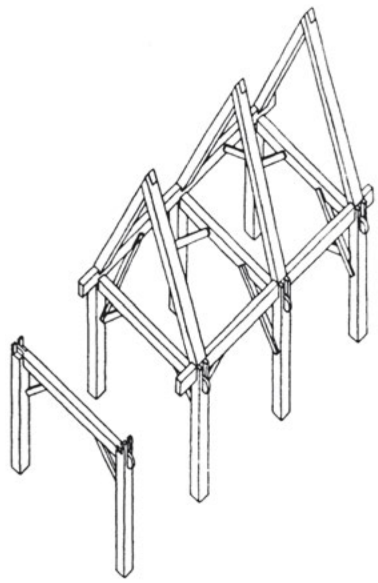
344 This exploded view shows that all horizontal elements exhibit the through-tenon so characteristic of the *daibutsuyo*. (according to: *Bunkazai …*, pp. 120/3, 126/1)

fident enough to perforate columns to such an extent, we can only attribute this to vast experience. (Fig. 344) The long, clear spans compelled the builders to use beams of massive cross-section.[159] To avoid ungainly overlaps, the carpenters tapered the members into what can only be described as "bottlenecks" directly adjacent the column in order to maintain the full cross-section as far as possible, especially as at this point an adequate cross-section was required for structural purposes. The tenon itself, inserted through the column, was square in section – which is not only easier to fabricate but also, where a tenon is concerned, takes into account the properties of wood better than a circular section. Consideration of the direction of the wood fibres in the column shows that a square tenon bears on a smaller horizontal area within the column than a circular tenon of the same cross-sectional area. Also noteworthy is the arrangement of the tenon: as for design reasons the horizontal members were tapered towards the column in the vertical direction as well, the tenon was cut on the lower end in order to achieve the best possible transfer of forces.

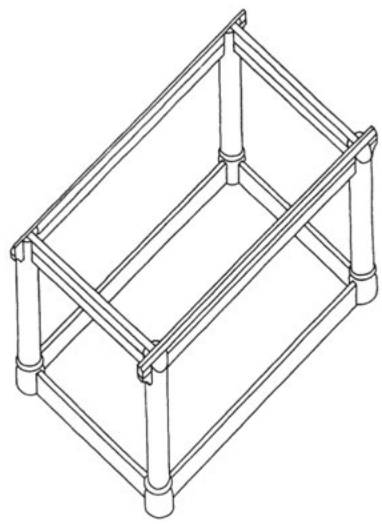
There were two principal methods of column-and-beam construction: the simpler post-and-truss method (Fig. 345) and the box-frame method. (Fig. 346) To form a three-dimensional framework, the row of frames is linked together by means of a continuous horizontal member above the columns. This principle was retained longest in the Low German *Hallenhaus* and in cruck roof construction. Box-frame construction, among the best examples of which are Norway's stave churches, was the more demanding form in principle. Rooms were created by linking walls together; three-dimensional joints were a prerequisite.

The frameworks of column-and-beam buildings are composed of three defining constructional elements: the vertical columns, the horizontal head beams for the longitudinal stability, and the likewise horizontal tie beams responsible for the transverse stability. European timber-framing was divided into three distinctive assemblies, depending on the arrangement of these three elements: normal assembly, reversed assembly and what we shall call raised header assembly. In the latter form of construction the tie beam is jointed to the columns more or less distinctly below the header. (Fig. 349) We encounter a virtually identical breakdown in Japan: *kyoro gumi, sashizuke gumi* and *orioki gumi*.[160]

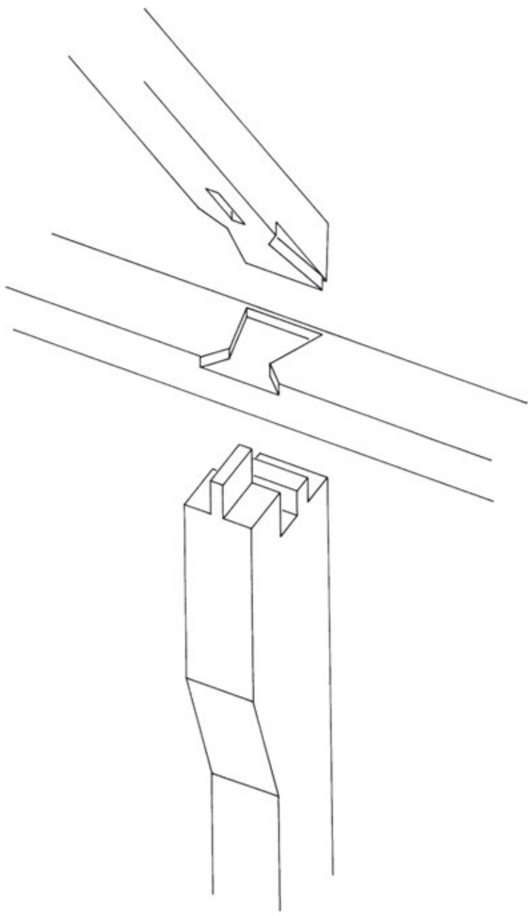
Opinions concerning the sequence of developments and correlations among the various types of construction were for a long time divided. In his interesting study – somewhat at odds with Ostendorf's older view –, Eitzen claims that the normal assembly should be regarded as the predecessor of the raised-header form, which is used in conjunction with anchor beams having through-tenon joints.[161] A number of authors have opposed this idea.[162] Without going into the details of the joints here, it can be regarded as highly unlikely that the successive improvements to normal assembly frames should have been relinquished by carpenters in favour of raised-header frames. Nevertheless, this is the conclusion reached by Eitzen; he presents his conclusion so compellingly that irrefutable findings backed up by dendrochronological data would be needed in order to cast doubt on his ideas.



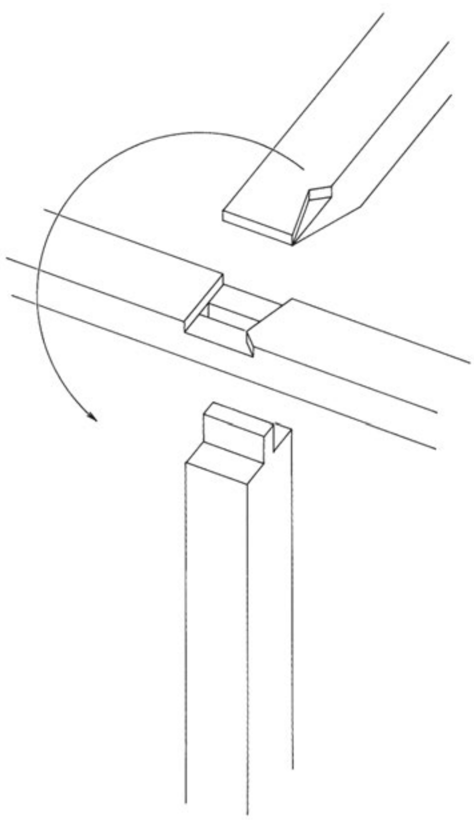
345 The principle of post-and-truss construction. (drawn by P. Pundt; source: Ahrens, 1981, Fig. 72) Each pair of opposing columns or posts is linked by means of a horizontal beam to form a frame. Header beams join the frames together.



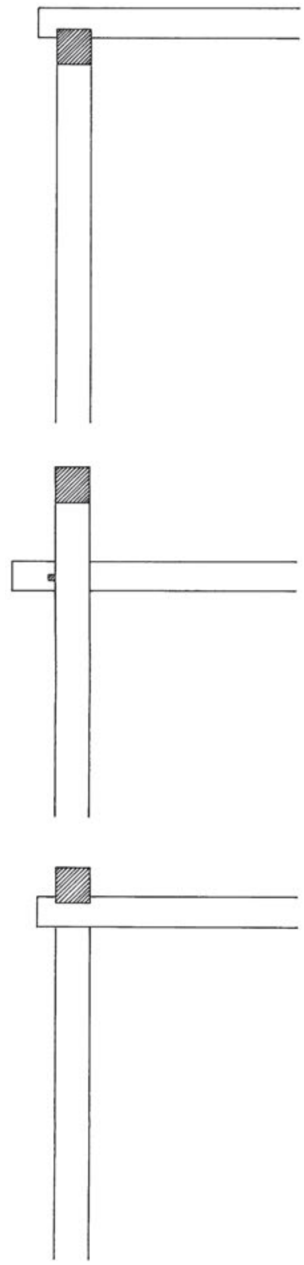
346 The principle of box-frame construction. (drawn by P. Pundt; source: ibid., Fig. 73) The rigidly connected members – sill beam, columns or posts, and header beam – form a frame on each side of the structure.



347 Intersection of column, header and beam in the wheat barn at Cressing Temple, Essex, England. (according to: Hewett, 1980, Fig. 276)



348 Intersection of column, header and beam in the barley barn at Cressing Temple. (according to: ibid., Fig. 275)



349 The principles of normal, raised-header and reversed assembly.
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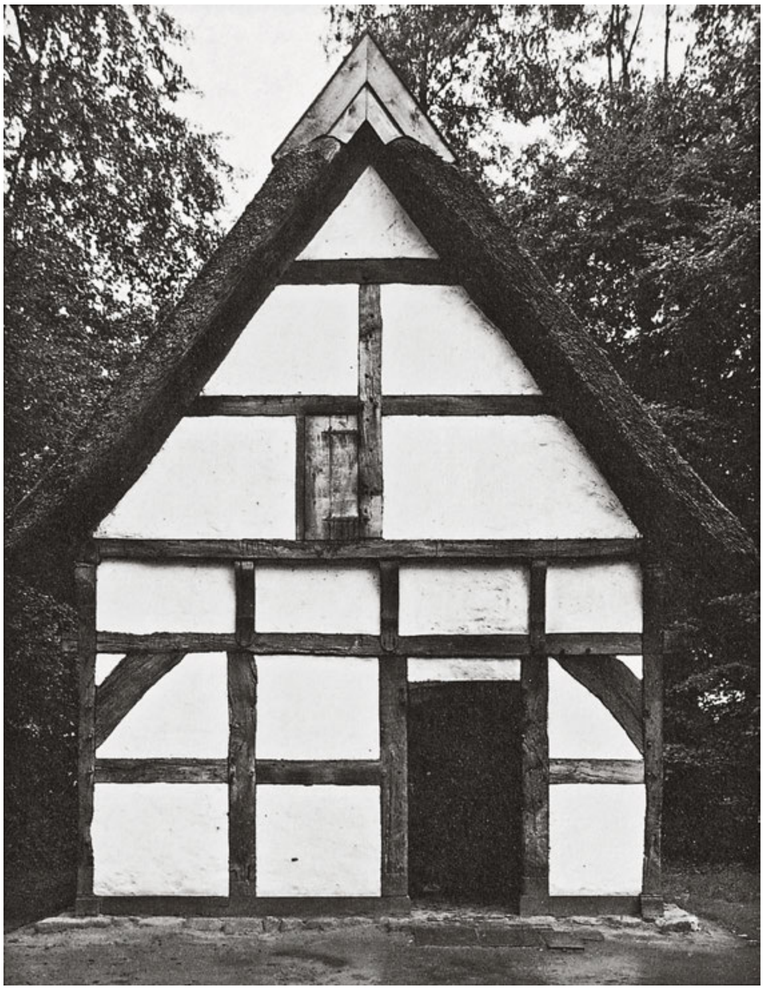
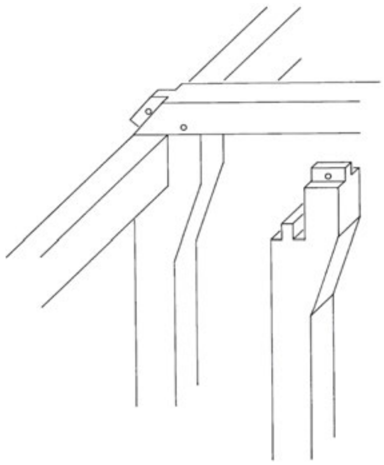


350 The kneebraces reveal the location of the anchor beam essential to the construction; furthermore, we can see that a raised-header assembly has been employed. – Bakery from Astrup, Lower Saxony, Germany, in Cloppenburg Open-air Museum.



351 The three-dimensional aspect is particularly well expressed in the case of a jowled column head with two tenons at right-angles to each other and placed at different levels. (according to: Rumpf, 1989, p. 161)

352 In normal assembly the beams are laid on top of the header which bears on the columns. – Barn from Grönloh, Lower Saxony, Germany, in Cloppenburg Open-air Museum.

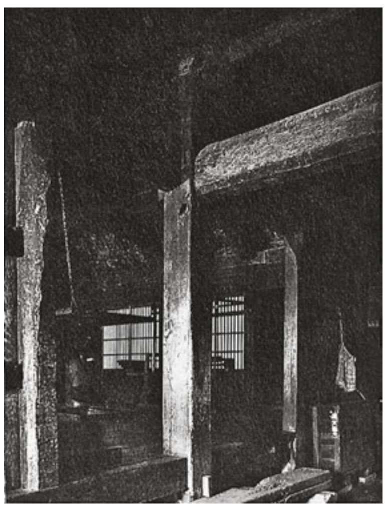
In the wheat barn at Cressing Temple, Essex, England, carpenters had learned as early as the 13th century how to join together the three principal elements of column-and-beam construction, i. e. columns, headers and beams; (Fig. 350) not each pair of members separately, like in the barley barn at Cressing Temple, (Fig. 348) (which of course ultimately leads to all three being connected) but really each of the three elements being joined to the other two.[163] The difference is significant from a carpentry point of view, for apart from the fact that every joint is automatically additionally secured, the carpenter is forced to think in three dimensions to a far greater extent when creating the joint. (Figs 351 & 353)
In the course of development the normal assembly was provided with notched beams to which the spars were attached. (Fig. 352) The thrust of the spars no longer placed a load on the head beam but instead was resisted by the tie beam parallel with the grain. With the spars no longer supported on the header, the tie beams no longer had to fasten spars and header together like in the past; a notched joint was sufficient to link header and tie.
In the raised-header form the spars were carried on the head beam and exerted a considerably greater thrust because the anchor beams holding the frame together were located well below the tops of the columns. Earlier in their development, the anchor beams, now connected to the columns by means of through-tenons, were attached by way of deeply forked tenons. (Fig. 350) By cutting slots in the columns from both sides at the

353 The jowl of the column head suggests a rigid joint between the incoming members and hence the reliable stability of the structure. – Potterne, Wiltshire, England

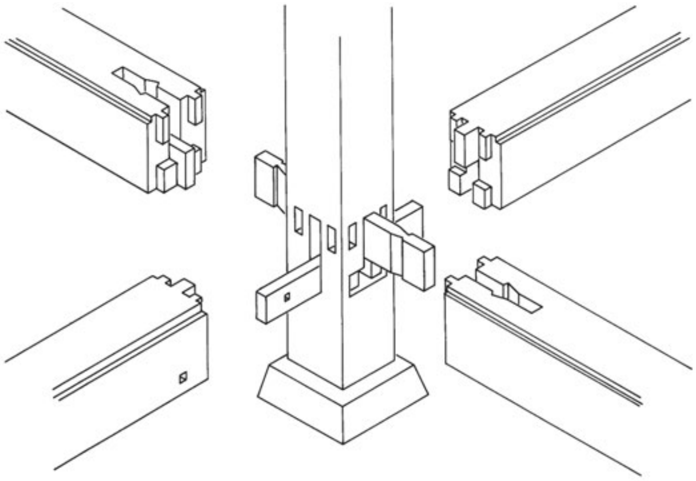
354 Up braces like these adjacent the entrance to a temple in Hagi, Yamaguchi, Japan, are easily recognized as imports.

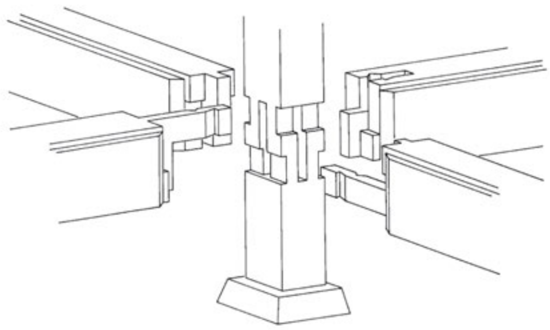
points where the beams were inserted, these were provided with a torsion-resistant joint. The great advantage of the forked tenon joint over its successor, the through-tenon, was the much more secure fixing of the tie beam. The end left projecting beyond the column resisted tensile forces better than the nail or wedge driven through the protruding tenon of later designs. Despite this the keyed tenon became established because a column with a through-hole is far less susceptible to deformation than one with an open slot. (Fig. 355)
Looked at from the beneficiary's viewpoint it is clear that the raised-header construction described above could not lead to the most advanced form, the reversed assembly.[164] This form of construction, which "in building technology terms … [was] superior to all other forms of *Hallenhaus* framing and was really quite perfect in its own way",[165] itself cannot be regarded as an intermediate step in the development of the aforementioned forms of construction either. It was considerably easier to build than the normal assembly and, above all, enabled a completely free hand in designing the column layout as the inclined roof members were supported on the head beam. As dendrochronology helps us to date more and more structures with certainty, so we discover that the theories which have been put forward concerning the evolution of these forms of construction seem to be based on incorrect assumptions. These different forms of framing may well have developed in parallel and possibly even stood side by side.[166]
Attention has already been drawn to the fact that Japanese carpenters made very little use of diagonal bracing. In the *minka*, the dwellings of ordinary people, it was not used at all.[167] (Fig. 354) However, there was one position determined by function and aesthetics where they were certainly very useful: at non-exposed locations in roofs.[168] These mainly involve complicated tenon or bevelled-shoulder tenon joints.[169]
If the span of an area to be roofed over exceeds a certain length, then intermediate columns must be provided. *Daikoku bashira* was the "key column" in the *minka*.[170] As a loadbearing column it was regarded as holy in the past. Its uniqueness and its function as the most important support for the construction of the whole house bestows on it more prestige than the ridge-supporting column of European housebuilding.[171] And its status is firmly anchored in everyday speech: address the owner of a house or his wife with this title and they will feel highly honoured.[172]
Carpenters made an effort to do justice to this esteem. They designed a joint which not only never existed in Europe, it never even existed in our European carpenter's wildest dreams! The central position of the *daikoku bashira* made it the pivotal point for the horizontal framing, or any horizontal joists which may have been required, on three, even four sides. A difficulty which did not arise in Europe but with which the Japanese carpenters had to cope was that the support or fixing for the horizontal beams by way of braces or brackets was unusual. A second, perhaps far more demanding requirement was the need to connect all beams leading away from the *daikoku bashira* at one and the same level. (Fig. 356)
Whether as *sampo-zashi* joint on three sides or as *shiho-zashi* on four, (Fig. 357) carpenters set themselves this task time and time again, each time trying to obtain new facets by way of their

355 Nails or wedges are required to prevent through-tenons from coming apart. – Quedlinburg/Saxony-Anhalt, Germany



356 Visible expressions of the importance of the *daikoku bashira* were its enormous size, its position on the boundary between the raised living accommodation and the ground, and, not least, the choice of timber. – Nohara House, Toyama, Japan, in the Nihon minka en



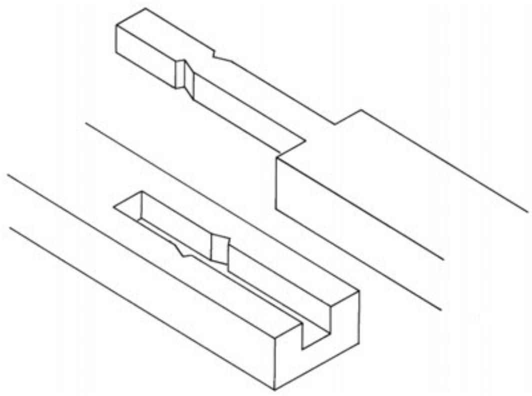


357 **Various *shiho-zashi* joints. (according to: Nakahara, 1990, pp. 98–99) The principle of this joint is that each pair of opposing beams forms a tension connection.**

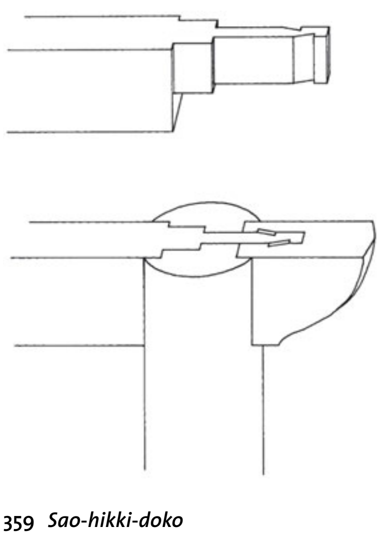
own, independent experimentation. The male part of the joint, usually a keyed mortise and tenon *(sao-tsugi)*, engages in the female part and is held in place by one or more *shachisen*.[173] (Fig. 358) To secure the long, thin, keyed mortise and tenon at its most delicate point, i. e. the start of the throat, diverse precautions are warranted, like for the *kama-tsugi*. Several constructions serve the purpose of withstanding forces exerted on the *sao-tsugi* perpendicular to the grain: edge-halved scarfs with very short halvings and a gooseneck tenon on the upper side only, bridled abutments or rebates. The excessively long tenon is basically only responsible for dealing with tension. Our carpenter needed an in-depth understanding of his material to be able to know how long and how wide the tenon had to be in order to allow the properties of wood, in this case the tensile strength, to be exploited to full effect.

A great many of the applications of the keyed mortise-and-tenon joints are not *tsugi* joints but rather *shiguchi* joints, as the Japanese understand them.[174] That does not seem entirely plausible to the European mind. The idea behind this is not a joint between two pieces which continue linearly but instead to join them at an angle to the column. *Sao-hikki-doko*, (Fig. 359) a stepped and keyed mortise and tenon, is a variation which is encountered just as frequently as *konozu-zashi*, (Fig. 360) another keyed mortise and tenon but with rebates and shoulder. In these cases the male and female sections pass through the column and are locked together. In the *sampo-zashi,* however, the member without a partner must be connected in a different manner to resist tension: Tanaka Fumio uses a *warikusabi*,[175] (Fig. 361) Sumiyoshi Torashichi a *daisen*.[176] However, this key is concealed by the opposing beams erected later, which Sumiyoshi additionally secures not only with *shachisen* but, oddly enough, also with a *daisen*. (Fig. 362)

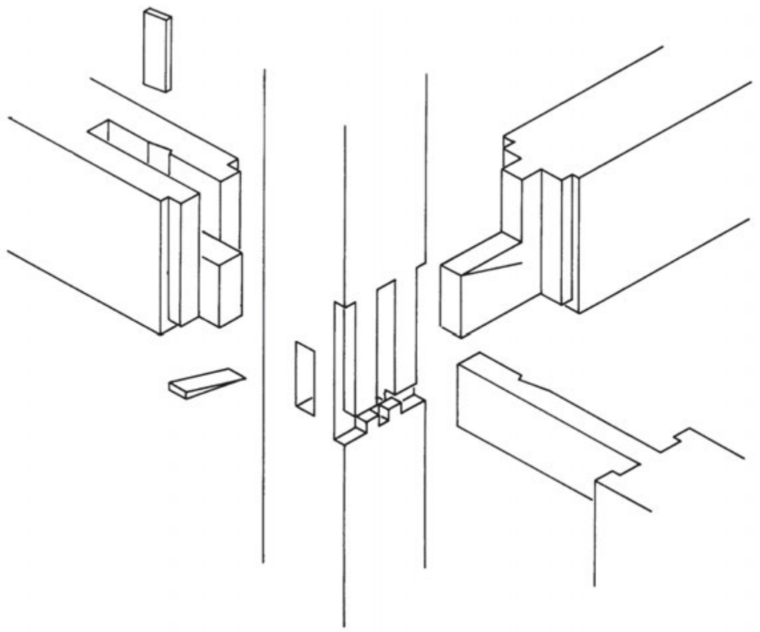
In order to accommodate both beam axes at one level in the *daikoku bashira*, in sizing the beams account must be taken of the fact that, of course, only half of the cross-section will be available for each axis. This aspect is even more serious when we come to design the column. Only when the joints engage without any play whatsoever can the individual members of the construction fulfil the tasks assigned to them. However, I do not wish to hide the fact that the huge dimensions of the beams and, above all, the *daikoku bashira* can in part be attributed to a sagacious foresight, the realization that the weakened



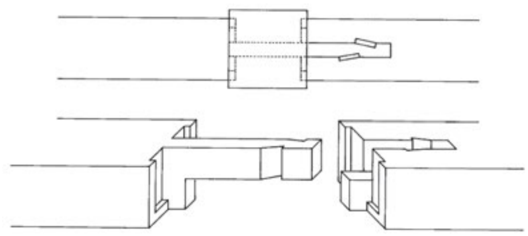
358 ***Sao-tsugi***



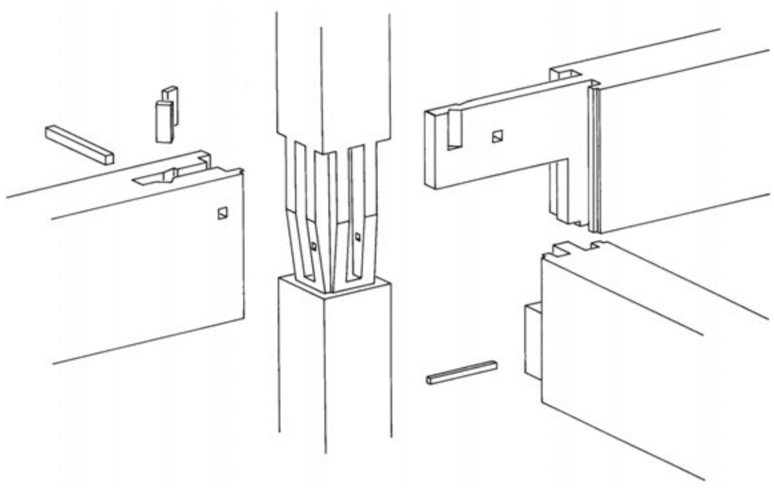
359 ***Sao-hikki-doko***



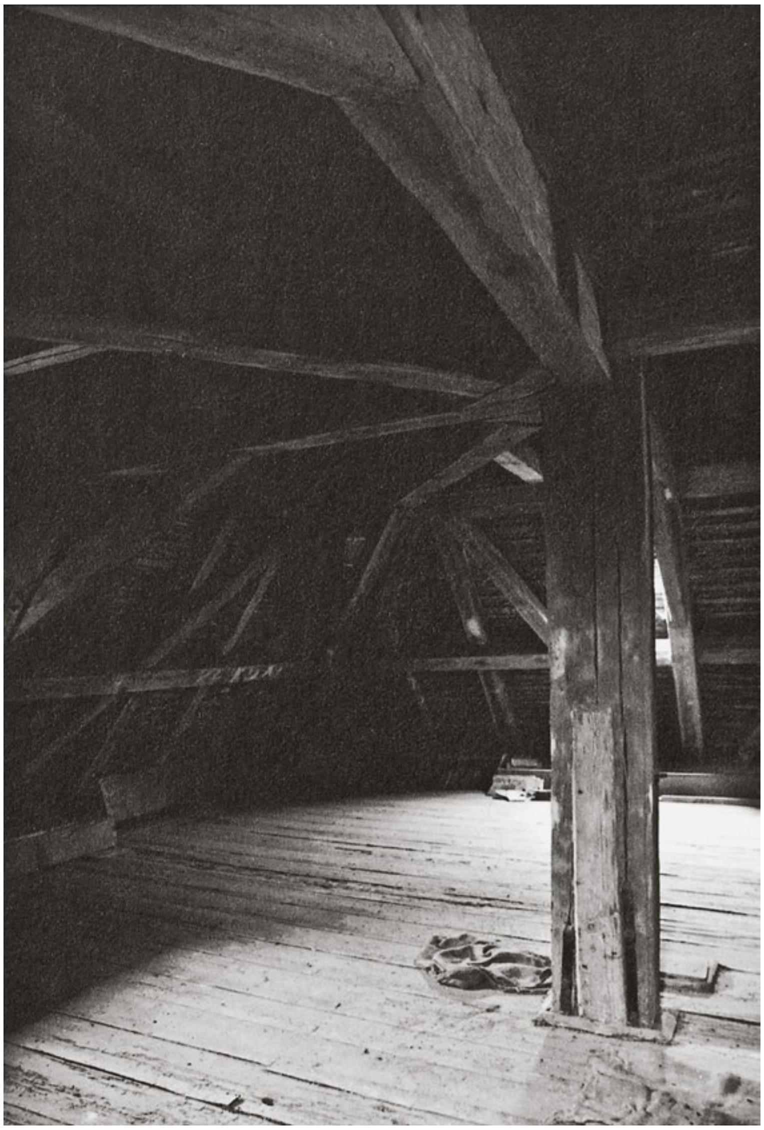
361 *Sampo-zashi* with *warikusabi* retainer (according to: Graubner, 1986, p. 70)

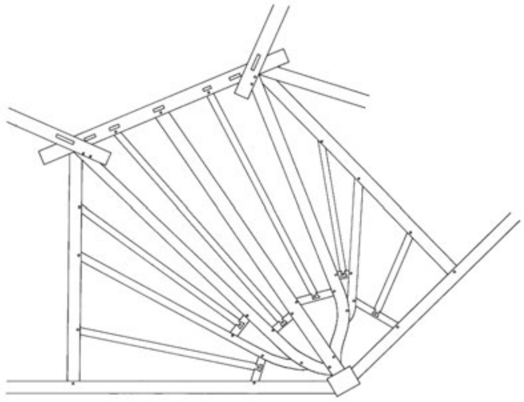


360 *Konozu-zashi*



362 *Sampo-zashi* with *daisen* retainer (according to: Sumiyoshi, Matsui, 1991, p. 67)

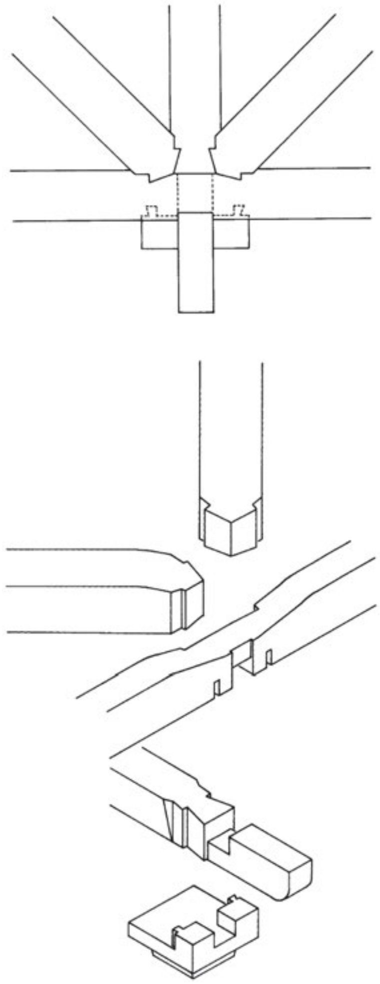




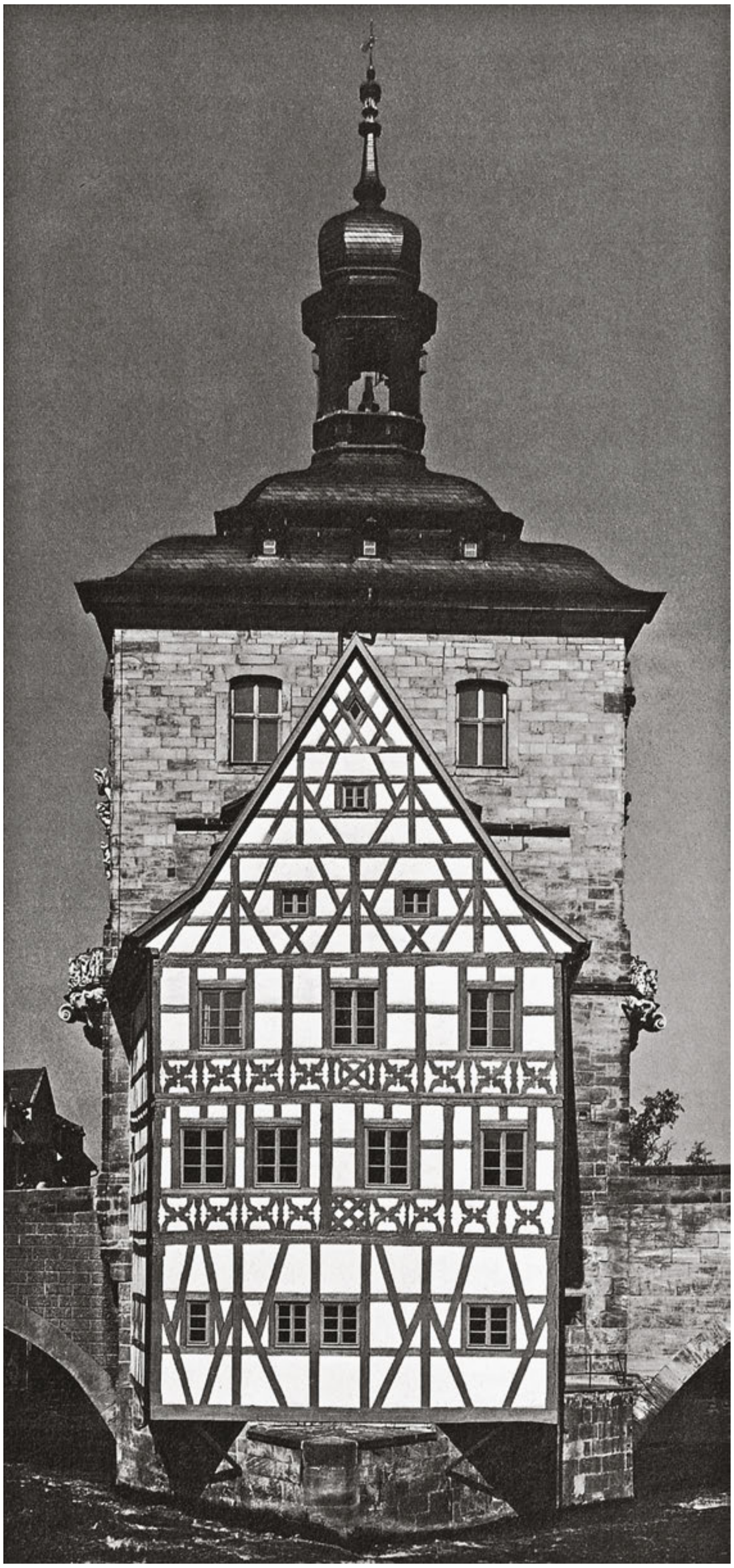
363 As this segment from the octagonal floor of the lantern at Ely Cathedral, Cambridgeshire, England, illustrates, the system of providing trimmer beams was a principle which was certainly common throughout Europe. (according to: Hewett, 1985, Fig. 113)

364 By providing a trimmer between the main beams, carpenters created space for fixing an additional beam. – Granary of Ernstbrunn Castle, NE Austria

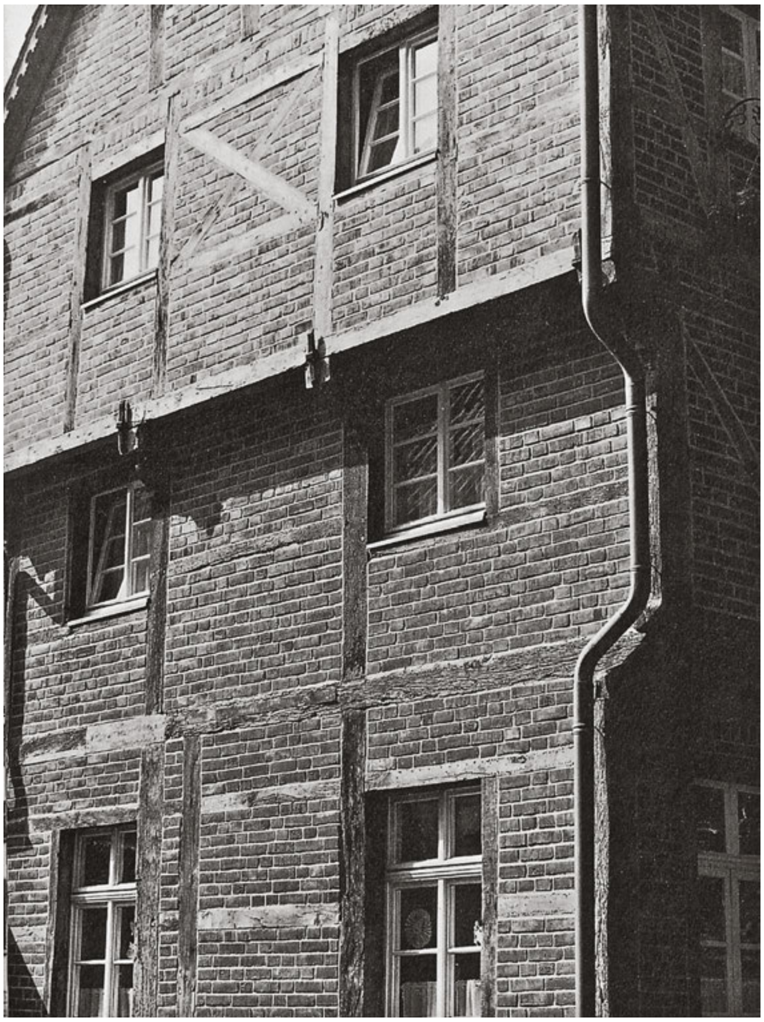
column is certainly not only governed by aesthetic criteria – indeed it must resist virtually all structural loads. If we look at, for example, Sumiyoshi's *sampo-zashi* a little more closely, then we will realize that he has weakened the column beyond that which is usual. He wanted to provide the beams with an improved bearing, as would be the case with a horizontal rail jointed with oblique dadoed mortise and tenon.
When the area enclosed by two horizontal beams meeting at a right-angle was too large, this area had to be halved by adding a further beam. It is interesting to observe here to what extent carpenters remained loyal to their respective traditions. In Europe they simply provided a trimmer to pick up the load from the extra beam and transfer it back to the two main beams. (Figs 363 & 364) In Japan they continued to design tension joints in the manner to which they were accustomed. (Fig. 365)
Japanese buildings seldom exceeded two storeys; in fact, as a rule, they were only single-storey structures.[177] The only multistorey constructions were prestige buildings such as palaces or pagodas; these were platform-framed structures, each storey being a self-contained unit. Even when the central column of a pagoda penetrated all storeys, this had absolutely no effect on the constructional form itself. The Himeji-jo is the one and only exception. Two enormous 25-m-high columns continue right



365 The carpenters of the Kyuan-ji romon, Osaka, Japan, first secured the main axis beyond the usual dimension by means of two dovetailed rebates in order to secure the other beams in the intersection using suitably adapted dovetails. (according to: *Bunkazai …*, p. 306/1)



366 Storey-height assemblies enabled, above all, the free positioning of columns, i. e. an essentially free hand in the design of the façade. – Bamberg, Bavaria, Germany



367 Before the introduction of trimmer beams the construction could be jettied using the projecting tie beams or the projecting header beams if they were supported on joists. – *Goekmanns Spieker* in Nottuln, North Rhine-Westphalia, Germany

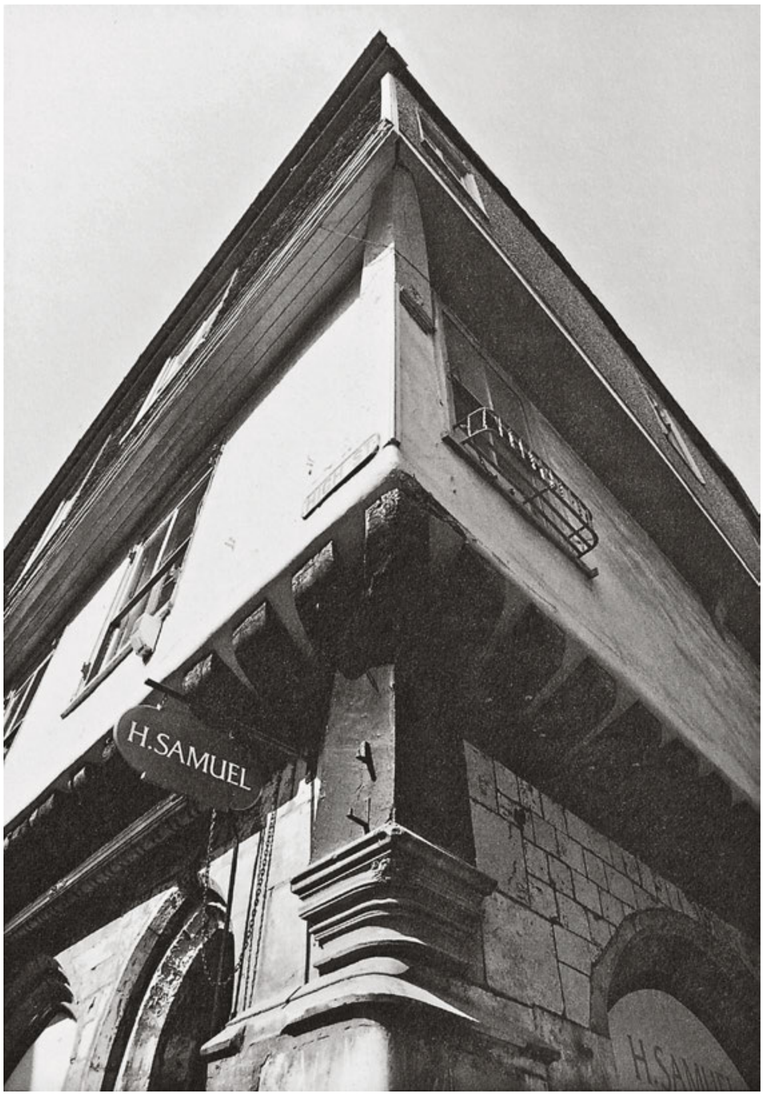
through to the sixth floor. They are integrated into the whole structure of the palace – and were responsible for its leaning! Uneven settlement of the centrally located columns was the cause. It is suspected that a lack of faith in the proven methods of the carpenters was to blame for linking the whole structure to these two central cores.[178]

In the town houses of Europe the anchor beam may well have been the decisive factor for introducing a floor and hence paving the way for the development of multistorey construction.[179] The more or less limited area within the walls surrounding towns and cities in the Middle Ages was an obstacle to the need for extra space to meet constantly expanding urban populations. The only way out was up! Still not satisfied, carpenters began to jetty out each storey beyond the one below.

One form reminiscent of balloon-frame construction was characterized by the columns continuing through all floors, which in the ancient form of construction, the *Firstsäulenhaus*, extended right up to the ridge. (Fig. 366)

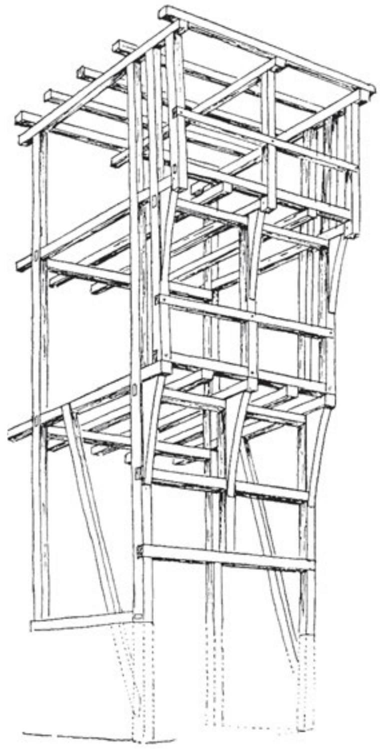
Conditions for a construction reminiscent of the platform frame, distinguished by storey-height assemblies, were:

- the substitution of up and down braces for multistorey passing braces,
- the substitution of tie beams bearing on header beams for anchor-beam construction, and,
- if a building was jettied on several sides, the introduction of the dragon beam. (Figs 367 & 368)



368 The inclusion of tail beams at beam level was necessary in order to be able to cantilever the sill beams in one plane beyond the storey below. – Canterbury, Kent, England

A whole host of reasons have been given for jettying. For example, to gain space is backed up by the fact that in Frankfurt, Germany, even cellars were allowed to grow underground beyond the edge of the road.[180] And Brunskill lists a whole series of other reasons. Besides enlarging the available space, jettying was a legal way of encroaching on the street or marketplace. Counterbalancing the weight of people and furniture within the building with the weight of the jettied wall has also been suggested as a reason, likewise a method of reducing the "springiness" of a floor. Even defence purposes have been mooted. However, in every case Brunskill puts forward arguments for why the reason given does not hold water! He initially finds credible the idea that jettying was a feature of forms resembling platform-frame construction, the use of timbers not more than one storey high. But this too is rejected: columns continuous over two or more storeys are to be found in the rear walls of buildings with jettied fronts. The situation is the same with perhaps the only reason which Brunskill fails to mention: jettying as weather protection for the storeys below. Here too, it must be pointed out straight away that jettying is not to be found on the side facing the prevailing wind but in the majority of cases on the main visible façade of the building. Decoration, impressing the neighbours and providing a field for display purposes are the only motives which Brunskill admits as valid.[181]



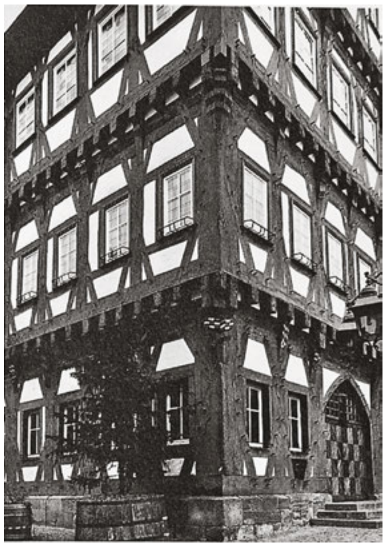
370 The shorter the cantilever, the more likely it was that kneebraces, which had to carry the jettied beams, could be replaced by brackets. (source: Winter, 1965, Fig. 17)

369 The gable wall of the town hall in Esslingen, Baden-Württemberg, Germany, illustrates the transition to the mounting of the columns on the sill beam cog-jointed to the ends of the projecting beams.

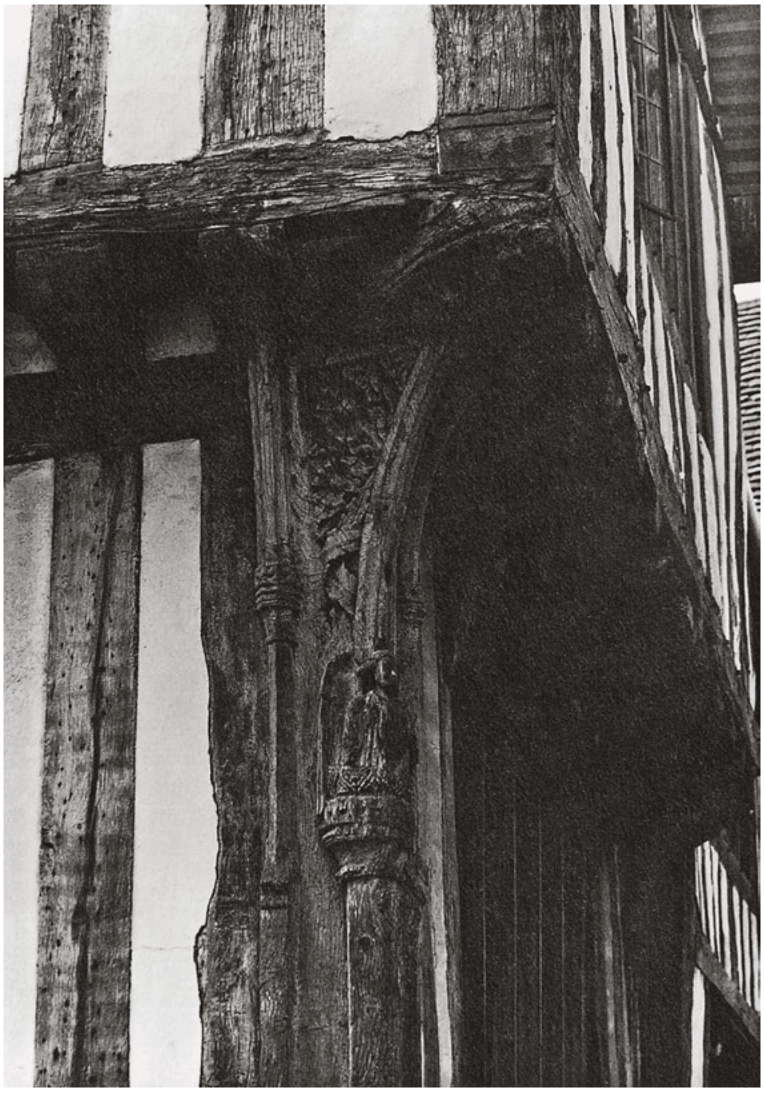
Whatever the reasons may have been, the fact remains that jettying had been turned into a building task which characterized the urban landscape of many European towns and cities. Examination of the construction of jetties, the form of the joints used, leads to the conclusion that jettying, even in its early stages, was never simply carpenters parading the construction which they had designed for stabilizing the building internally. The columns of the first jettied storey were suspended from the beams jettying above this. Tenons on the ends of the beams held the columns' bases. (Fig. 369) The unbridled expansion of jettying further and further went unchecked for a long time until, finally, legislative action instigated a sense of discipline.[182] (Fig. 370)

The junction of two jettied sides at a corner was a problematic detail. In Germany carpenters tried not to interrupt the lines of the elevations achieved through the beam supports by providing an accurately cut geometric triple bracket when the line of brackets had to be turned around a corner. (Fig. 371) In England they seem to have taken a tree as their model when designing a solution, a tree which conveys its greatest strength where it opens up towards the crown. (Fig. 372)

Despite the associated reduction in cross-section there was a gradual transition to a notched sill beam. Actually, this weakening was not very significant. (Fig. 373) The beam also had to be

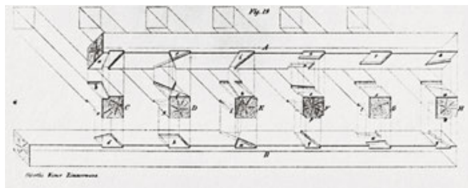


371 The ends of the beams turned around the corner at one level accumulate in the corner in such a way that there the visually obvious main load in the huge corner columns can be transferred into the massive corner columns below via a multiple bracket. – Town hall in Markgröningen, Baden-Württemberg, Germany

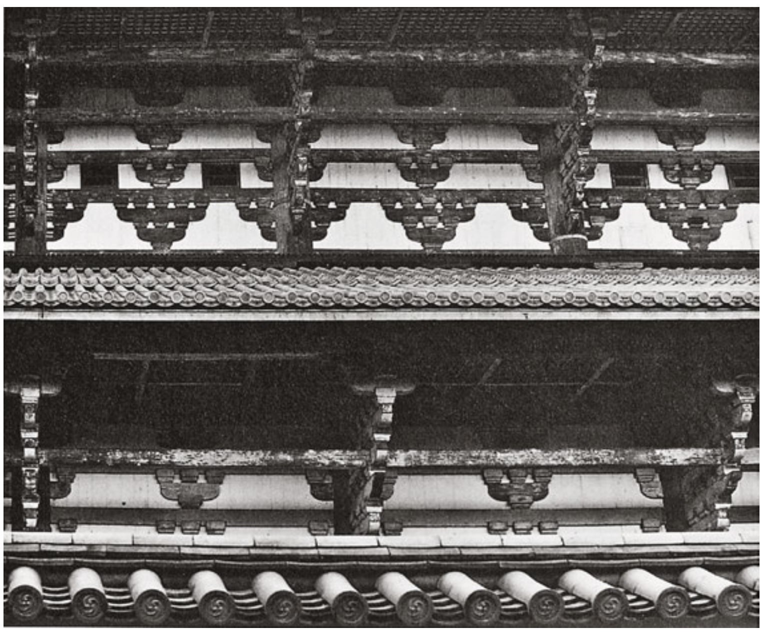


372 This naturally grown corner column was emphasized through carving and the observer was made aware of its function just like Phleps wished to see in the German examples. (Phleps, 1967, p. 137 ff.) – The Chantry, Sudbury, Suffolk, England

374 The jettying of the upper storey hardly casts a shadow here. – Schleusingen, Thuringia, Germany



373 Examples of notched and cogged joints. (source: Gierth, 1840, Pl. XI)



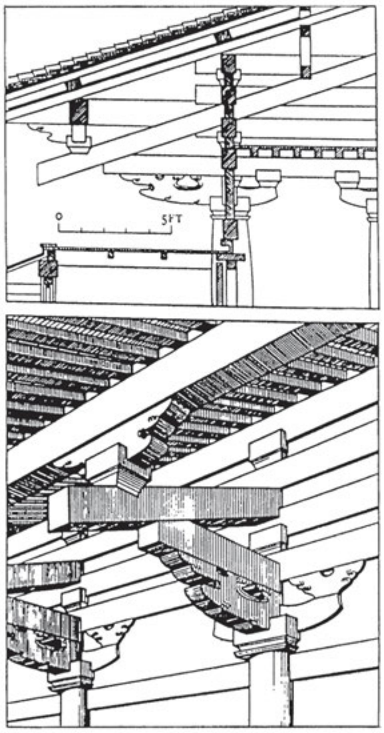
375 The eaves detail of the Todai-ji daibutsuden, Nara, Japan, illustrates the characteristic form of cantilevering in the *daibutsuyo* style.

376 The cantilever brackets of the Horyu-ji gojunoto, Nara, Japan, were obviously overloaded as the bearing for a lever arm, not least due to their distinctive and unique "cloud-pattern" shaping.

weakened for mounting the brackets, to accommodate their tenons. As the ends of the beams themselves finally started to be presented as brackets, flat walls were becoming fashionable again! (Fig. 374)

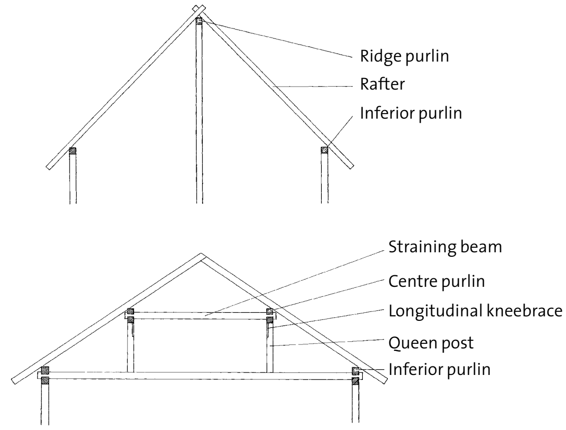
In Japan cantilevered construction was mainly limited to the overhanging roof. In the Todai-ji daibutsuden it is quite clear that the external cantilever does not differ in any fundamental way from the rest of the construction. (Fig. 375) The cantilevers are remarkable for their audacity. In the Horyu-ji the extent to which carpenters had learned how to tackle this challenge is astonishing. The five-storey pagoda of the Horyu-ji does not conceal the fact that mankind, in its desire for greater and greater cantilevers, was not yet in the position to adequately appraise the complex interplay between the joints and the constructional elements. (Figs 376, 377)

The stylistic changes from the *wayo* of the Horyu-ji to the *daibutsuyo* of the Todai-ji brought about an unbelievable leap in developments in the engineering of wood joints. Especially in the light of this move from one style to another, which in no way affected all buildings, it should not be forgotten that new ideas did not appear overnight. Nevertheless, we assume that Japanese carpenters had a harder time of it than their European colleagues. Although Ahrens can state for Europe that "the means to the ends were known to the carpenters of early history and the Middle Ages, and were in some instances based on centuries-old traditions",[183] the first Japanese structures in the new styles cannot hide the fact that they have been built in a clumsy manner owing to the lack of expertise in the jointing techniques accompanying the new, imported styles.[184] Out of necessity, carpenters had to resort to the knowledge available to them. Having been thrown in at the deep end they had to learn to swim fast! This was particularly clearly expressed in temple roof construction, which we shall discuss in the next chapter.

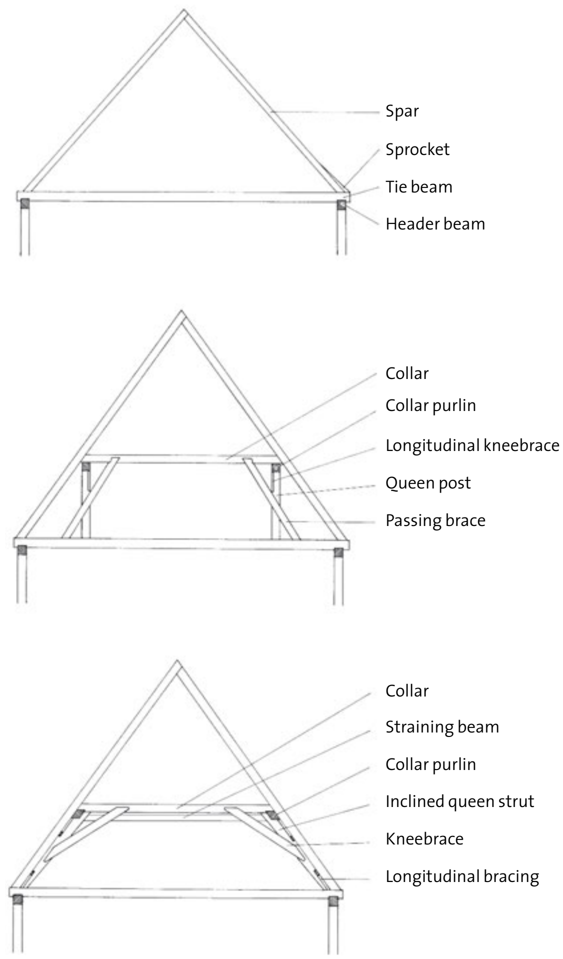


377 The tie beam emerging from the interior of the Horyu-ji kondo was subjected to the entire load of the eaves via the *odaruki* (= "tail rafter", apparently so named because of its isolated protrusion). (source: Paine, Soper, 1990, Fig. 199)

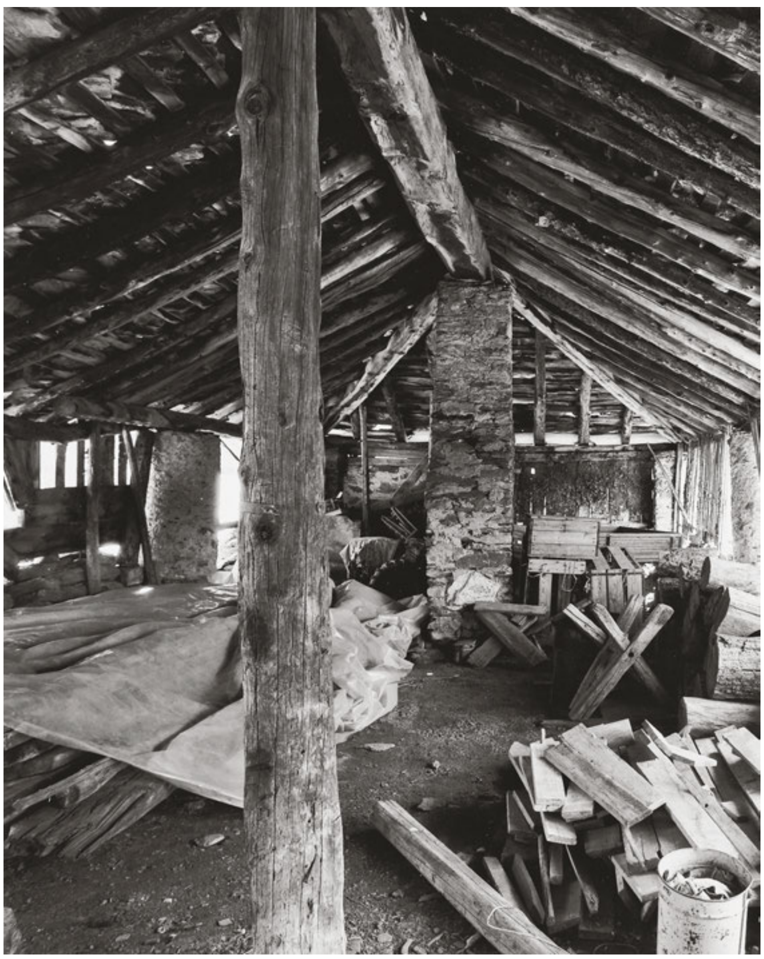
The roof, as the most complex part of a building, became the measure of a carpenter's abilities. The aim here is to present those fundamental principles of this, the most inaccessible part of any building, which brought about two totally contrasting forms of construction: in Europe the truss post, in Japan the "hidden roof". In both cases we are dealing with extremely elaborate, ingenious ideas which took shape in many evolutionary stages throughout the history of carpentry.
Two types of roof based on completely different principles can be found in Europe: the purlin roof (Fig. 378) and the spar roof. (Fig. 379) The purlin roof takes its name from the purlins which have to carry the inclined roof members (rafters). (Figs 380 & 381) The earliest rafters could have been small trunks stripped of their branches, the lowest branch root being simply hooked over the ridge purlin. The distinguishing feature of the rafter is that it is not fixed. Even as rafters began to be hung from the ridge in pairs, the sole purpose of joining them together was to prevent them sliding down the roof.
It is suspected that purlins were originally placed in the forks of two posts. (Fig. 382) This principle was carried over into house-building but soon proved to be a nuisance. (Fig. 383) Even banishing the column which supported the ridge within the roof space was ultimately nothing more than an interim measure on the road to the invention of the spar roof.[185] It was this type of roof which first brought about a real change. (Fig. 384)
Generally, the emergence of the spar roof is linked to urban



378 The principles of the most simple type of purlin roof and a version with queen posts.

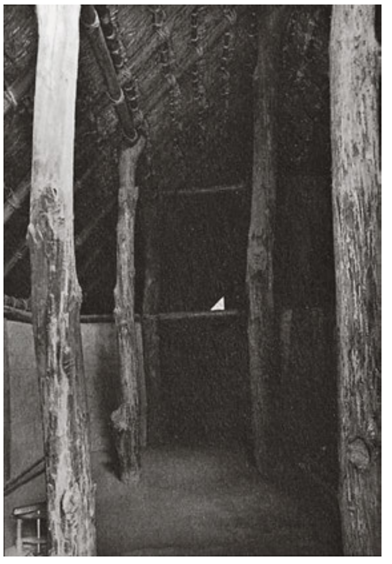


379 The principles of the most simple type of spar roof, a version with vertical queen posts and one with inclined queen struts.

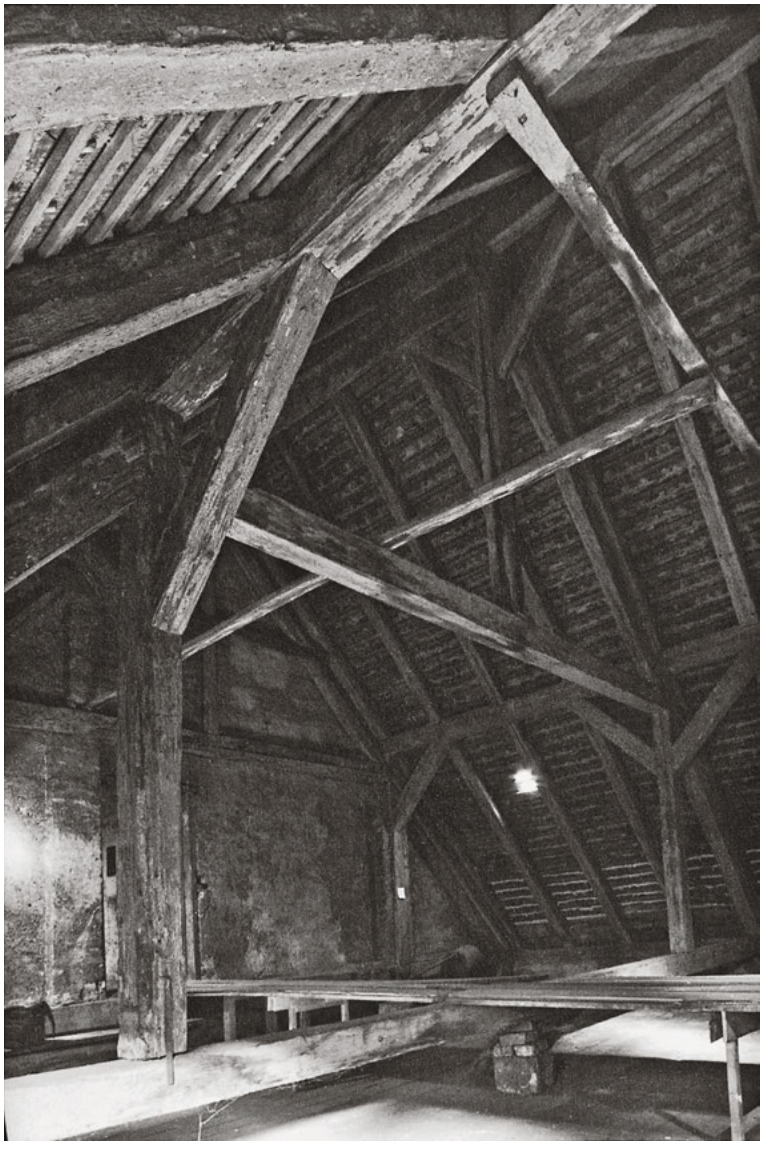


380 For small buildings one ridge purlin and two eaves or inferior purlins were adequate. – Cuneaz, Valle d'Aosta, Italy

381 If the rafters deflected excessively – due to a long span from eaves to ridge or heavy roof loads –, then intermediate purlins were inserted. – Grub, Appenzell, Switzerland



382 Purlin roof supported on rows of posts. – Asparn an der Zaya Open-air Museum, NE Austria



384 The purlin roof is still with us today. This example has two queen posts each carrying a purlin. The straining beam preventing the queen posts from being forced inwards by the load of the rafters in turn carries an upper king post to support the ridge purlin. – Vienna, Austria

383 Larger columns meant less of them but still had to divide up the area below the roof according to the needs of the layout. – Izumo taisha, Shimane, Japan

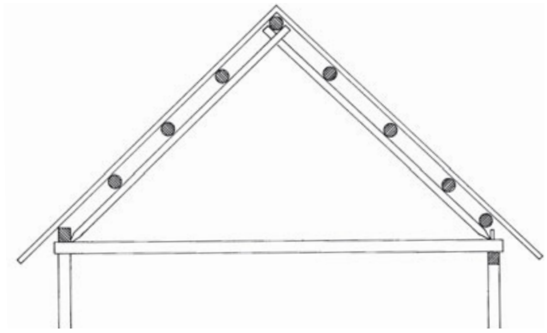
385 We can see from the gable end that the roof space was utilized right up to the ridge. – Rothenburg, Bavaria, Germany

expansion in the Middle Ages and the accompanying economic criteria.[186] (Fig. 385) The construction was based on establishing a stable triangle. This is only possible when the inclined roof members, arranged in pairs, which we will call spars here to distinguish them from rafters, are fixed to a third, horizontal member. They also have to be fixed at the ridge. (Fig. 386)
Therefore, this form of roof construction, also called a standing roof to distinguish it from the hanging, purlin roof, rendered possible the ever more slender walls of timber-framed buildings; for the lateral thrust of the roof was now resisted by tie beams. The jointing at this point underwent a development away from the lap joint to the mortise-and-tenon, which, above all, subjected the securing nail(s) to shear loads, and finally to a multitude of different step joints. The task of resisting the thrust of the spars required taking into account an appropriate length for the projecting end of the tie beam. A sprocket enabled the roof covering to be carried over the eaves. (Fig. 387)
Roofs in Japan can be classified similarly.[187] There too, we find the crossed-spar roof *(sasu-gumi)*. (Figs 388 & 389) Contrasting with the spar roof there are two types of purlin roof in Japan. The *shinzuka-gumi* gets its name from the ridge-supporting columns which originally stood on the ground.[188](Figs 390 & 391) What distinguished this roof from the *wagoya-gumi* was

386 The spar triangle forms a rigid construction. – Sudbury, Suffolk, England

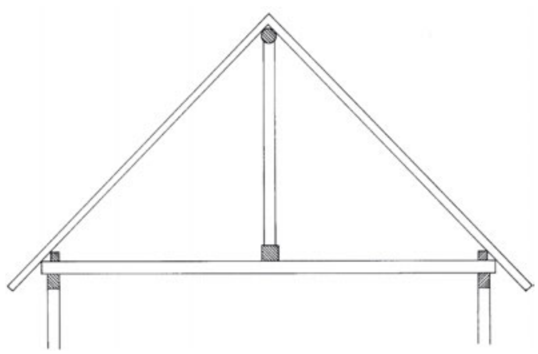
387 Sprocketted eaves lent many buildings a characteristic "kink" in the shape of the roof. – Kammerzell House, Strasbourg, Alsace, France

388 This roof has been specially designed for thatching. – Barn in Shirakawa mura, Gifu, Japan



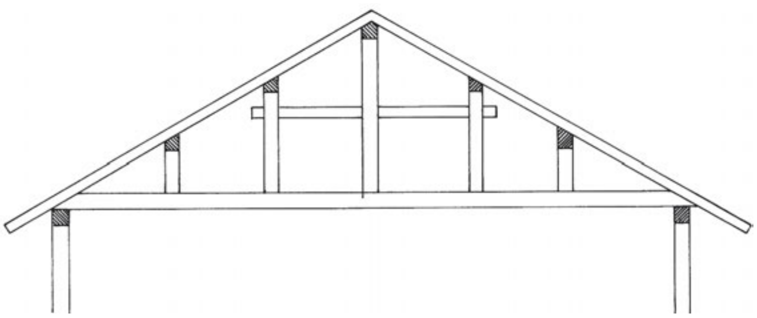
389 The type of construction – normal or reversed assembly – determines whether the pointed foot of the spar is fixed with a wedge or propped against the header beam itself.

390 The *shinzuka-gumi* roof is normally thatched but is also encountered with tiles or shingles. The tie beams are doubled to cope with the very wide span of this *minka* in Kitakata, Fukushima, Japan.



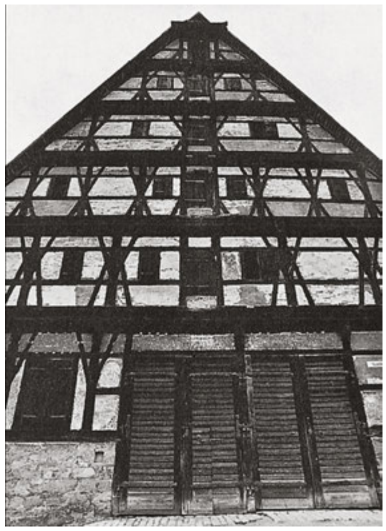
391 The *shinzuka* (king posts) carry the ridge purlin. They stand on a beam which is carried on the tie beams and which also provides longitudinal stability.

392 A *wagoya-gumi* (Japanese roof) over the Senyo kaku in Miyajima, Hiroshima, Japan.



393 The principle of the *wagoya-gumi* is based on carrying the roof loads on the beams. To allow for deflection, beams with a slight camber are often selected. The king and queen posts supporting the purlins are braced longitudinally and transversely.

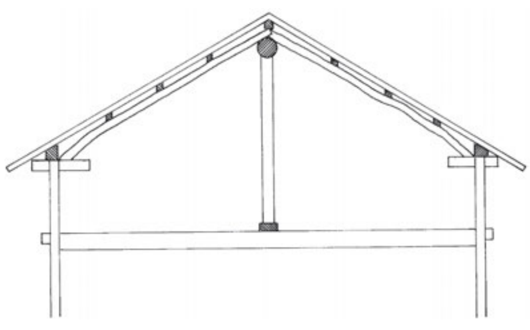
that it exhibited only one single king post per frame whereas the *wagoya-gumi*[189] used a king post plus queen posts in each frame, and also princess posts, depending on the span. (Figs 392 & 393) The appearance of these roofs can vary tremendously, depending on whether large or small members have been used for the longitudinal and transverse bracing to the purlin supports. (Fig. 394) But no matter how they appeared, the observer feels reminded of the "forests" of Gothic roof trusses.
Supplementing these is a further roof type which cannot be easily incorporated in our known European systems: *noboribari-gumi*[190] was specially developed in order to enlarge the available space. (Fig. 399) The section between the bearing of the *noboribari* (= a beam rising to the ridge, i. e. the inclined roof members carrying the purlins) and the tie beam roughly corresponds to a jamb wall.[191] (Fig. 396) Countless combinations and mutated forms are to be found in both Europe and Japan.



395 **Moving down from the ridge, the number of supports must be increased from floor to floor in order to be able to carry the loads. – Kornhaus am Bauhof in Dinkelsbühl, Bavaria, Germany**

394 **Beams which were too short had extra lengths spliced on; in doing so, crown end was always joined to root end! – Kyuhonjin kinenkan near Hirata, Shimane, Japan.**

As time progressed, the demand increased for greater and greater roof constructions. The collar, intended to stabilize the spars which were growing longer and longer as a result of new demands, now itself presented a problem because its self-weight was too heavy for the joints with the spars left and right. The obvious answer seemed to be to provide supports exactly beneath these junctions. It is suspected that the so-called vertical queen post was developed for secular buildings because as roof spaces were needed for economic reasons, above all, for storage purposes, this joint was even more heavily loaded in such buildings. (Fig. 395) However, the so-called vertical queen posts introduced under collars to relieve the joints could only fulfil builders' high hopes of them in the uppermost attic storey. As soon as we consider the next storey below, we can see how the problem had accumulated; and the multistorey attics of medieval town houses provide us with a pictorial representation of the saying "Robbing Peter to pay Paul"! One way out of the dilemma was to carry the loads from the queen posts from floor to floor in the direction of the eaves via struts parallel with the spars, like passing braces.
This was to change with the introduction of the inclined queen strut. They transfer the loads not via the passing brace but instead directly via a member also installed parallel with the spars. Another advantage, which once again primarily served economic interests in secular buildings, was the clearing of the vertical supports which had proved such a hinderance as purlin supporting columns standing on the ground. However,



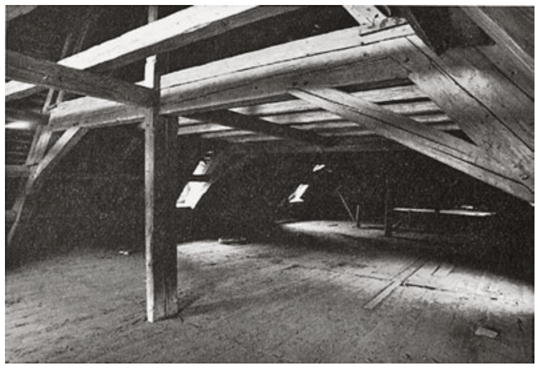
396 **A beam below the ridge purlin is supported by king posts. This beam bears on the gable walls and carries the upper ends of the *noboribari*, the lower ends of which are supported on bracket-like interrupted tie beams. The purlins are carried on the "rising beams".**

when it came to large spans, like over church naves or warehouses, whose stored goods' trust in the carrying capacity of inclined queen struts was based entirely on a, nevertheless, risky test, our carpenter was happy to rely on the help of an extra support in the middle. (Figs 397 & 398) The additional space gained or the better accessibility appears to have justified the extra timber required[192] and likewise the far more complicated jointing[193] of the inclined queen strut. The collar purlin also supporting the collar of the open truss was only gradually integrated into the new form of support. (Figs 400 & 401)

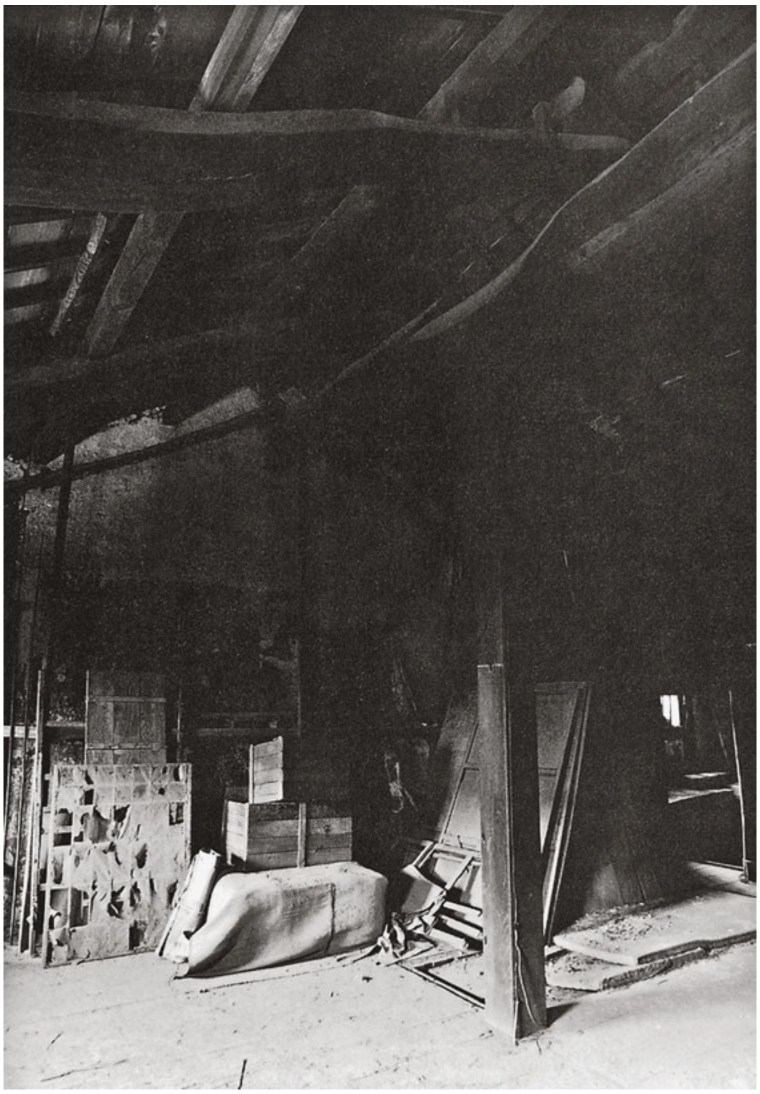
It was certainly not only aesthetic reasons which led to the inclined queen strut tapering from one size at its base to almost twice the size at the collar, as was originally the case in this example from Ulm Minster, Germany. Whatever the reason, this thickening illustrates the trouble and care taken with such joints. (Fig. 402)

The tremendous significance which the new form of construction acquired is shown not least by the spar itself, which was no longer placed on edge but laid flat, covering the construction, so to speak. The make-up of the roof construction now looked like this: the wall plate, no longer square, into which the inclined queen struts were mortised, was in turn notched to the tie beam by means of a dovetail; the spars were mortised

397 In churches in many places, truss posts were still included in the roof construction, not least because of the often heavy ceilings attached underneath. – Liberk, Czech Republic



398 In warehouses it seemed obvious to include a row of king struts passing through every floor for additional support. – Primmersdorf, NE Austria



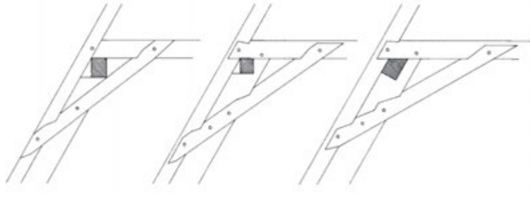
399 This roof construction has emptied the roof space in a unique way. If a beam from gable to gable is permissible, then a maximum of one column intrudes into the room. – Kurashiki, Okayama, Japan

into the tie beam directly in front of this; at its upper end the inclined queen strut carried the collar purlin which supported the collar via a cogged joint, the collar in turn being mortised into the spars. Like an appendix, as it were, a tenon engaged securely with the collar behind the collar purlin. The horizontal straining beam beneath the collar prevented the inclined queen struts from toppling over. These two were joined using oblique dadoed mortise and tenon joints. To triangulate the assembly a kneebrace connected spar, inclined queen strut, straining beam and collar together by means of multiple stopped-lap joints. That a new development must not necessarily completely supersede an older form of construction everywhere is very nicely demonstrated by the example of the vertical queen post versus the inclined queen strut. For example, the town hall in Michelstadt, Germany, has inclined queen struts in its lowest attic storey but vertical queen posts in the middle storey.[194] And it even happened that both types of roof design were employed adjacent each other simultaneously in one roof truss.[195]

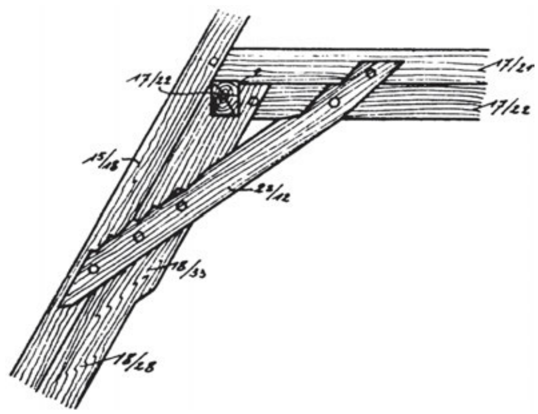
The greatest challenge for the spar roof was over churches or large church-like hall structures. The Romanesque and pre-Romanesque, exclusively vertical and horizontal framing of the spar truss was replaced by new developments from the 12th century onwards. Several open trusses were now placed between each pair of closed trusses, i. e. two spars plus one tie beam. The old framing was now replaced by various designs of diagonal bracing: scissors (St Andrew's cross), secondary spars, (Fig. 403) and, for the first time, longitudinal bracing which went beyond merely the nailing of wind bracings across the spars practised hitherto.[196] This longitudinal bracing at first needed vertical members – columns or truss posts – to which they could be suitably connected.[197] From the 13th century onwards, developments in England began to diverge from those in mainland Europe. On the Continent constructions with one column located in the centre of the collar and supporting the ridge or two columns placed left and right of the centre and supporting the collar gained the upper hand, whereas in England the trend was columns standing on tie beams (crown posts).[198] (Fig. 404)

In some respects the problem of transmitting the loads down to the foundations was easier to solve in churches than it was in secular buildings. Carpenters erected several multistorey queen-strut assemblies above the walls separating nave and side aisles. The higher this assembly, the more bracing it required. (Figs 405 & 406) Generally, the bracing problems increased with the size of the construction. The demands placed on the carpenters can be seen in the growing complexity of the intersections. (Fig. 407) The unsupported tie beams grew larger and larger as the spans increased. However, at some stage the self-weight of these beams became unmanageable and, moreover, such massive timbers were just no longer available. So, to at least relieve the tie beams from the weight of the king and queen posts standing on them, there was a transition to suspended truss posts.[199]

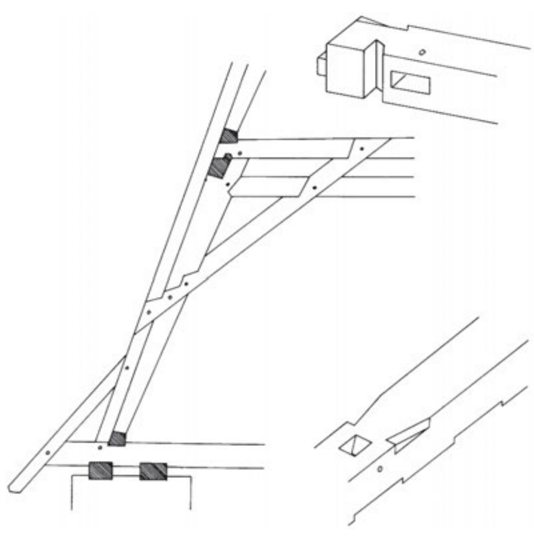
Churches with suspended truss posts had been built as long ago as the Romanesque period.[200] Carpenters seized this rediscovered opportunity with both hands and exploited the constructional possibilities of the suspended post not only to relieve



400 Stages in the development of the integration of the collar purlin into the inclined queen strut construction. (according to: Schnell, 1915, Figs 17–19)

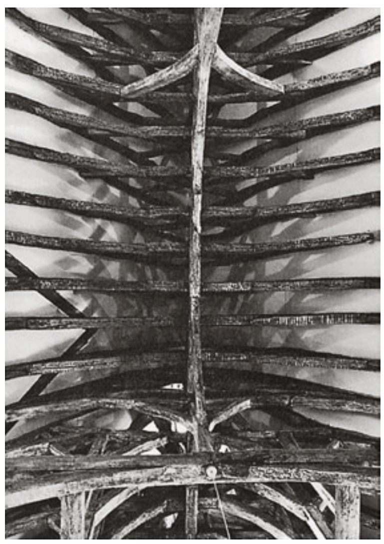


401 Just as the development of the vertical queen post was only completed when the necessary bracing was added, so the inclined queen strut also required an additional straining beam beneath the propped collar. – Connection detail from St Peter's parish church in Herrnsheim near Worms, Rhineland-Palatinate, Germany. (source: ibid. Pl. 31)



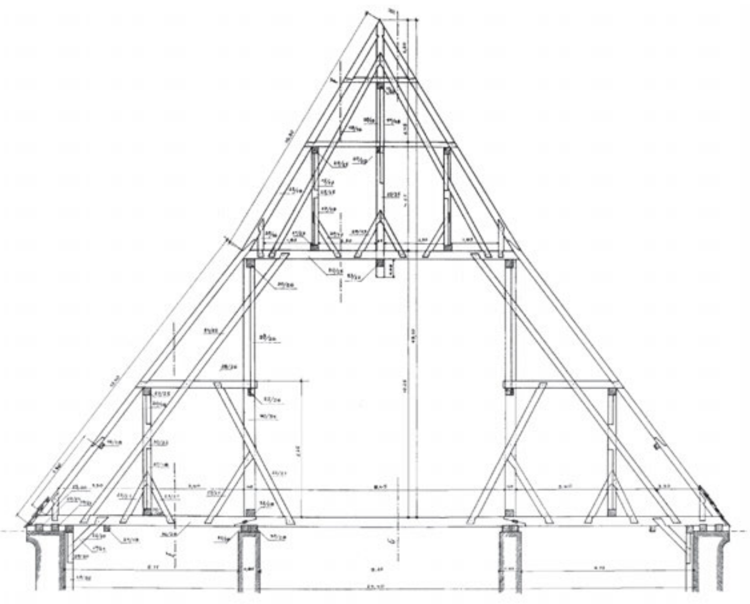
402 Detail of an inclined queen strut. (according to: Deinhard, 1962, Fig. 8)

403 The enormous length of the spars (14 m) in the tithe barn at Great Coxwell, Oxfordshire, England, necessitated a well-thought-out support system. Secondary spars back up the principal spars. Besides the header beam of the reversed assembly there are a number of other purlin-like members which assist in bracing the spars longitudinally. Cruck frames support the header beams of the reversed assembly between the principal frames, with secondary spars (bearing on short hammer beams) again being used above the header.



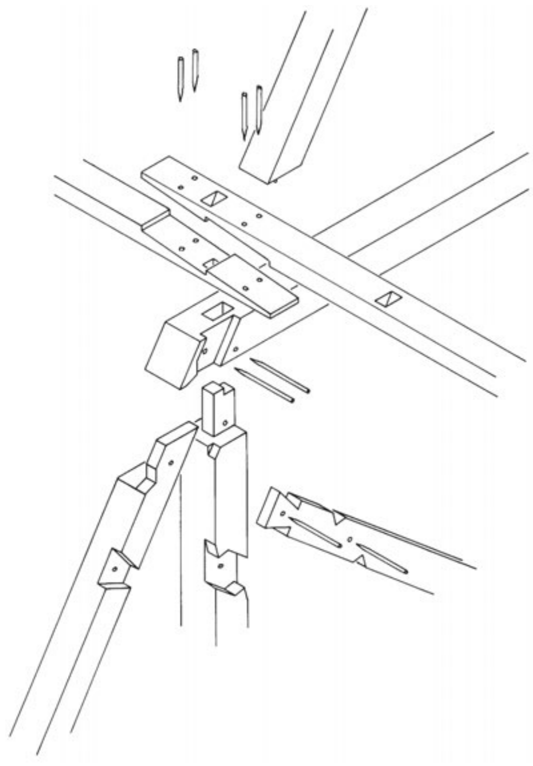
404 Every pair of spars in the chapel of the Pilgrims' Hospital of St Thomas, Canterbury, Kent, England, is braced with a St Andrew's cross and a collar. The longitudinal stability is provided by a collar purlin running beneath the collars and supported on crown posts which in turn stand on tie beams.

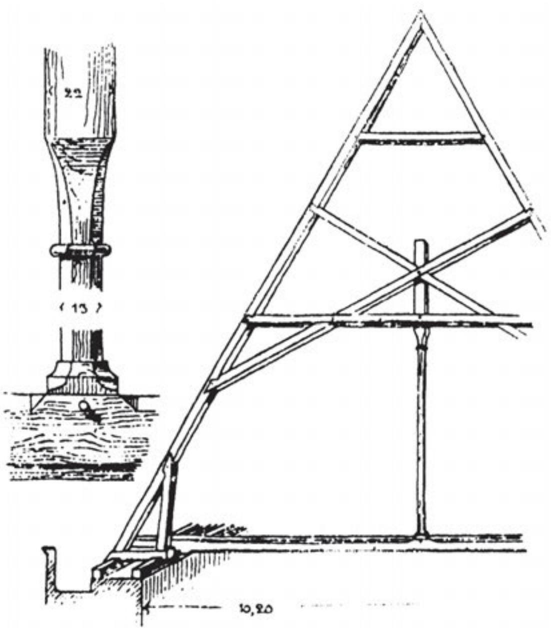
405 Just the queen-post assemblies of the Gothic Collegiate Church in Neuberg, Steiermark, Austria, consume a vast quantity of timber.



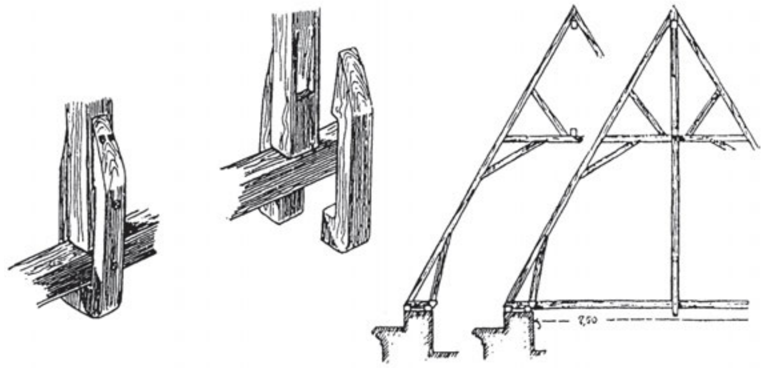
406 **This section shows that the huge columns stand on intermediate walls. Some of the load of the three-storey upper part of the roof truss is suspended from a central king post, the rest is transferred to the lower part of the construction by the two queen posts via passing braces extending parallel to the spars over the three upper storeys.**

407 **Like the Collegiate Church in Neuberg, virtually all roof trusses of this order of magnitude – in this case the *Marktkirche* in Hannover, Lower Saxony, Germany – had to splice at least their spars from smaller pieces. (according to Maier-Gomolka, in: Binding, 1991, Fig. 140)**



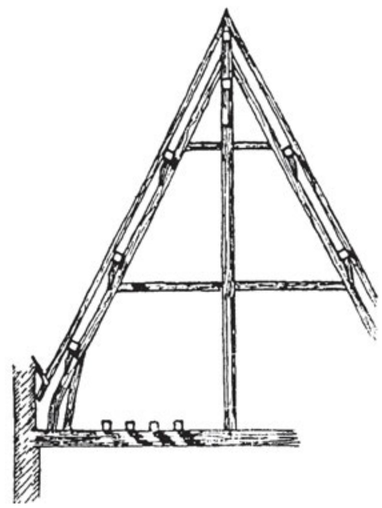


408 **This post, resembling a crown post, is in fact mortised at its base into the tie beam and so is still "standing" on the beam. However, the tie beam is relieved of the weight of the post. – Rouen Cathedral, Normandy, France (source: Ostendorf, 1908, Fig. 15)**

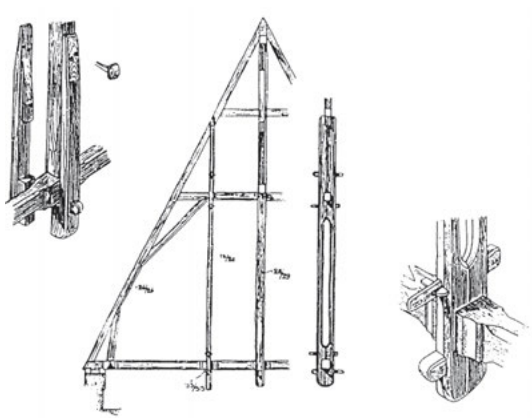


409 In St Piat the tie beam really is suspended. The nature of the construction expresses this visibly and unmistakably. (source: ibid., Fig. 31)

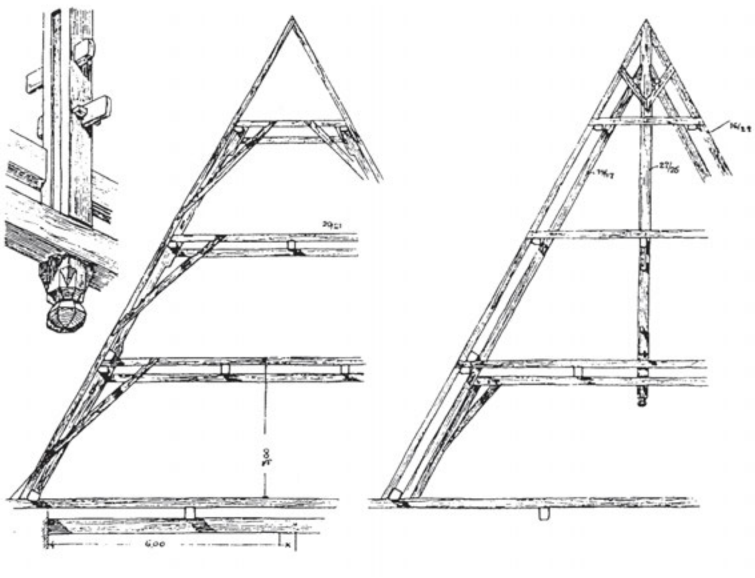
the tie beam but, at the same time, to hang it on the suspended post. As is always the case with such a development, at first the established joints were tried out in the new situation.[201] The dovetail was the joint for tension loads; used here though, it did not prove very effective – but all the more suggestive!
In the early examples of suspended posts it was usually the case that the spars held the king post by means of bevelled shoulders at their heels (cf. Figs 194 & 195) which engaged with the top of the king post. The collar, lap-jointed to the king post, helped to distribute the load to the spars. Sometimes the collars and/or the king posts were also suspended from the spars by means of ties.
A number of examples from the history of roofing should make it clear how many different constructional possibilities the carpenter borrowed from the palette of known forms of construction.
In Rouen Cathedral, Normandy, France, the still standing column is attached to the scissor bracing and the collar. At its base it is mortised into the tie beam. (Fig. 408) Tewkesbury Abbey, Gloucestershire, England, provides us with a similar example. (Fig. 410)
In the Chapel of St Piat behind Chartres Cathedral, Eure-et-Loire, France, two specially shaped hangers, fixed into the king post left and right with oblique tenons, clamped the horizontal beam between them. Nails secured the two hangers. The projecting end below the beam had to be long enough to prevent it from being sheared off. (Fig. 409) In St Ouen in Rouen, Normandy, France, the king post is supported by the spars and two collars. Like in St Piat the tie beam is fixed to the post by clamping it between two short hangers. (Fig. 411) Again it was the hidden cog on the inside of each hanger which helped carry the load of the beam. However, in this case the carpenter no longer wished to rely on the end of the hanger projecting below the beam; by using a tenon under the tie beam he relieved the load on the projecting end and thus prevented it from being sheared off. At the same time, contrary to the example of St Piat, the chosen shape of the two hangers enabled the carpenter to join them together with a tension-resistant joint. While the upper horizontal tenon had no other function than to fasten the two halves of the hanger around the tie beam – a wedge forced the two pieces tightly together –, the task of the lower tenon was to also relieve the lower end of each hanger; it distributed the load of the beam across the whole cross-section of the suspended post. And as if that was not enough, two further



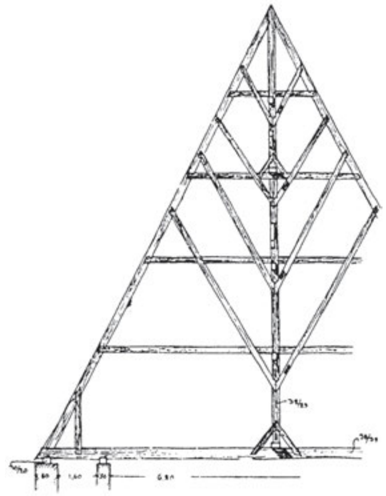
410 Once again, this column is not supported on the tie beam but instead is carried by collars and two braces parallel with the spars. – Tewkesbury Abbey, Gloucestershire, England (source: ibid., Fig. 143)



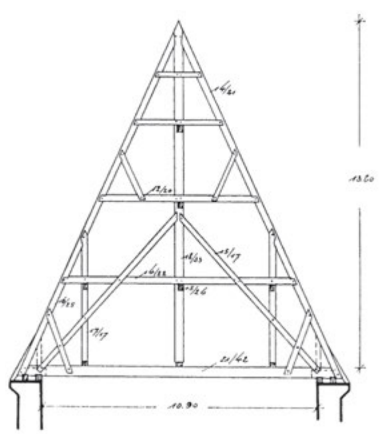
411 The solution in St Ouen's church is far more elegant and lighter. (source: ibid., Fig. 33)



412 The *Tanzhaus* in Rothenburg, Bavaria, Germany, provides us with a very curious detail. (source: ibid., Fig. 90)



413 The wide span of the spars over the Bartholomew Church in Gdańsk, Poland, suggests the suspension of the king post at first sight. (source: ibid., Fig. 52)



414 The former roof construction over the cathedral in Frankfurt am Main, Hessen, Germany, combines a varied assortment of suspension techniques for the truss post. (source: Schnell, 1915, Fig. 9)

suspended queen struts left and right relieved the load on the centre one! Ostendorf did not try to conceal his enthusiasm: "The arrangement … bears … witness to the care which prevailed among the master carpenters of earlier times when building such roof structures, and the painstaking execution in which every piece was treated in a manner befitting its role."[202]

Dubious first prize in the exploitation of the shear strength of wood is taken by the *Tanzhaus* in Rothenburg, Bavaria, Germany. (Fig. 412) The suspended king struts only occur in two frames and are supported by the spars, braced back to the eaves by secondary spars running parallel to the main spars and hung on two lap-jointed ties. The post carries the longitudinal collar purlin supporting the collar as well as, in a very unconventional way, the straining beam to the secondary spar in the first roof storey. This hangs on the "pommel" of a sword-like tapered member whose "blade" is inserted into the slotted end of the post and firmly secured with keyed tenons.

The roof over the Bartholomew Church in Gdańsk, Poland, appears rather less frivolous. The post divided above the third collar (counting from the bottom) is held by the spars at the top. Its upper section, likewise its lower section, is not only supported by the collars but, first and foremost, by the inclined members[203] slung from the spars. Both the tie beam and the third collar are attached to the post by way of down braces. (Fig. 413)

Whereas in the last example most of the load is carried by the spars, in the previous examples from Rothenburg and Tewkesbury the spars were totally relieved of load because the loads on the posts were transferred via the members located under the spars onto the top of the masonry. The structure of the roof to the cathedral in Frankfurt am Main, Hessen, Germany, represents a sort of interim solution. (Fig. 414) Here, four collars and the spars carry the large post in the centre. However, the third collar from the top already needs help and is, therefore, itself suspended from the spars. The lowest collar has no less than five supports: the collar purlin attached to the central king strut, left and right two short vertical queen struts slung under the spars and, above all, two passing braces which pick up the central post halfway up. It is these two braces which are decisive

415 The dovetail clearly shows that the (now missing) rail was suspended. – Suganuma, Toyama, Japan

in relieving the collar, and hence the spars, by diverting a considerable proportion of the load onto the top of the masonry. Not everywhere is the construction so successful. Like so many other country churches the one in Wallhof, Poland, was forced to subsequently prop up the unsuccessful suspended roof construction rather unelegantly from within the church itself.[204]
All these solutions presented here were based entirely on the unique approach of the truss post. It was not until the 17th and 18th centuries that builders managed to achieve the next great evolutionary leap forward – helped by the developments which had already taken place and by the inclusion of iron –, a leap taking them to those roof constructions which, in anticipation of some of the elements of timber engineering, enabled them to suspend the heavy but delicate ornamental wooden ceilings of the Baroque era.[205]
Truss post roof structures were unknown in Japan.[206] Although examples of such forms of construction, e. g. suspended ceilings,[207] can be found everywhere (Fig. 415), they were not developed further on a large scale.
The Japanese roof is in a certain way so interwoven with the rest of the building that a few explanations are necessary before we embark on our journey. The Horyu-ji dempodo, Nara, Japan, is a suitable example with which to explain the basic arrangement of the Japanese temple. (Fig. 416) The core, a central room *(moya)*, is established by a post-and-beam construction which originated in China; this consists of two high columns which carry a beam. In this example it is the so-called "rainbow beam" which is mortised into the *moya* columns. Any number of such frames can be placed one behind the other in a row. To give this extremely fragile design some stability, rows of shorter columns were introduced left and right of the central room. The spaces, resembling side aisles, created in this way are called *hisashi*. These aisles can be joined to the *moya* columns in two ways. In the dempodo the heights of the *moya* and *hisashi* columns are coordinated with each other such that the rafters[208] can be brought down in one sweep from the ridge over both rows of columns. In many cases however, the *moya* columns are considerably taller so that they need to have their own roof. So here the aisle rafters, like the spars hung on the sides of Norwegian stave churches, must be mortised into the

416 The very early construction of the Horyu-ji dempodo allows the division of the frame into *moya* and *hisashi* to be easily recognized.

moya columns. In such a case the room so enclosed is called *mokoshi* and not *hisashi*. However, to make the construction really comparable with Norway's stave churches, the rows of columns left and right need to be taken right around the temple. In China, purlins were obviously adequate for the longitudinal stability; in Norway, additional gable bracing was absolutely indispensable.

What gives the roof of the Japanese temple its very own identity and dignity, besides the roof pitch and the gentle curve of the ridge line, is first and foremost the wide, overhanging eaves and the curved line of the eaves, which varies a great deal between the *wayo* and *zenshuyo* styles. This curvature was achieved by raising the roof contour at the corners. To do this, carpenters doubled up the hip rafters step by step like sprockets. In order not to lose the desired effect over the (sometimes) enormous length of the rafters, a toothed board was added to the top of the eaves end of the rafters onto which the flying rafters[209] were laid, almost like catapults. (Fig. 420) Decorative roofing tiles placed on the very end of the hip helped reinforce the elegant impression.

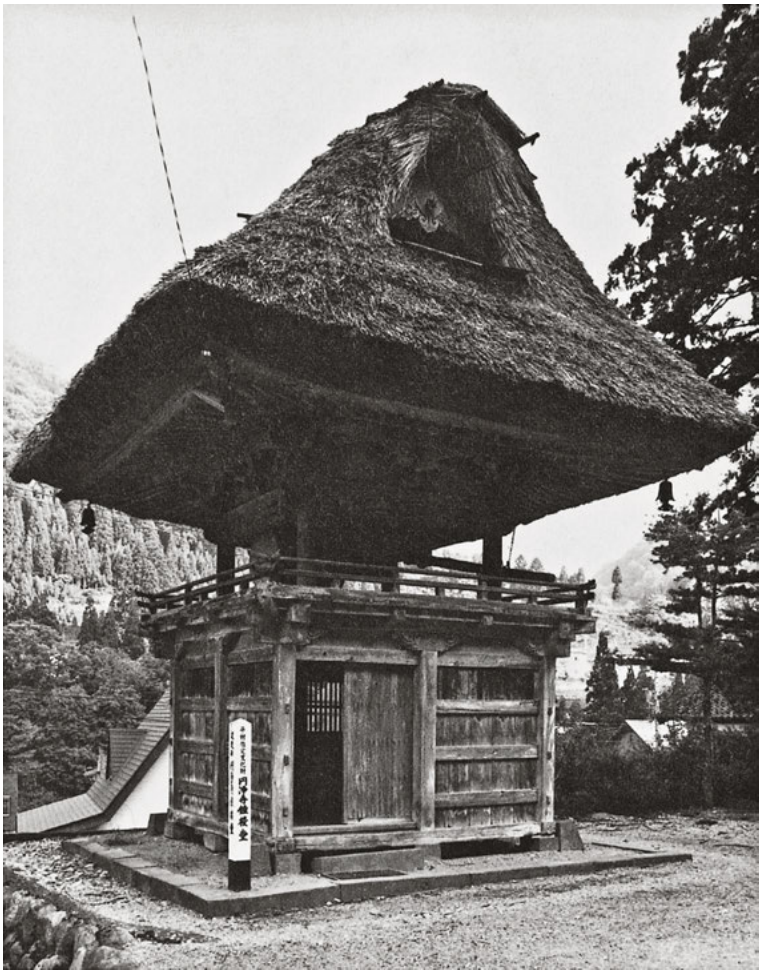
How deeply this form of roof was rooted in the consciousness of the Japanese can be recognized in simple utility buildings. (Fig. 418) To gain an insight into the importance of the roof form requires a detailed examination of the development of the "hidden roof" *(noyane)*.

Up to the end of the 9th century Japanese roof construction was open, i. e. the material of the roof covering could be seen between the rafters. Owing to the climatic conditions, the roof pitch could not be too steep as otherwise water vapour from the humid atmosphere would collect under the roof. (Fig. 419) To avoid this, the Japanese invented the twin-leaf roof. (Fig. 417)

But it was another reason which turned out to be the driving force behind the development of the hidden roof. Sooner or later the wish was expressed to extend the width of the *moya*. This was attempted in various ways: including one *hisashi* aisle in the *moya* area led to the roof pitch becoming too shallow; simply placing two *moyas* together, eaves to eaves – one type of *minka* was based on this idea[210] –, then an unconventional gutter was the outcome, running just above head height through the middle of the building, hardly attractive visually and appearing

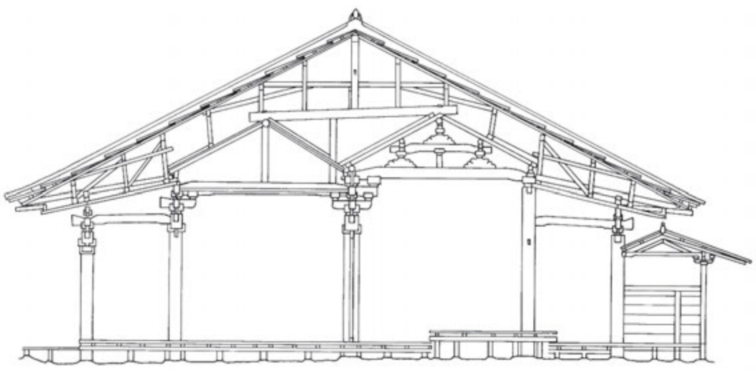
417 The eaves of the Kikunoyo Brewery in Meiji mura illustrate the principle. Underneath, the visible rafters *(kesho taruki)* at an angle corresponding to the ideal of beauty; above, the hidden *notaruki* carry the roof covering.

418 The eaves of this elevated storehouse were planked for functional reasons. – *Takakura* from Yamatohama, Okinawa, Japan



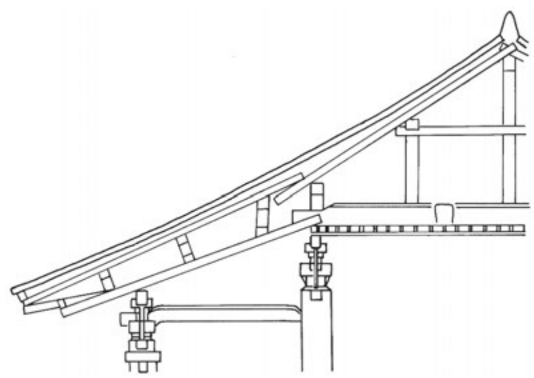
419 The pitch of the roof on the outside is different to that on the inside. – Enjo-ji shoro tou in Kaminashi, Toyama, Japan

420 The ornamental roofing tiles placed on the very ends of the hips reinforced the impression of the raised eaves corners. – Shinyodo in Kyoto, Japan

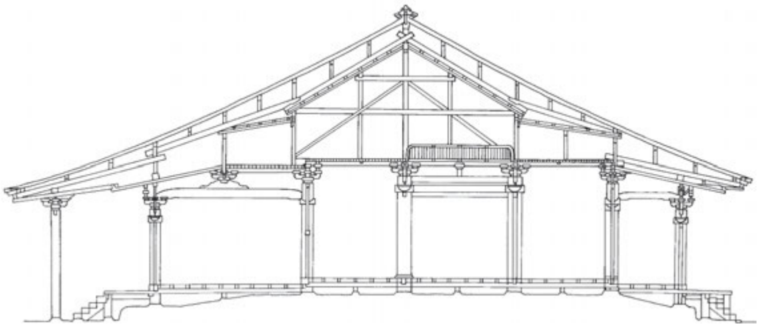


421 Section (simplified) through the Taimadera mandarado, Nara, Japan. (according to: Parent, 1985, Fig. 51b)

to dissect the interior space even more decisively than was actually the case. The external appearance of this visible dissection of the structure was equally unattractive. And simply raising the two outer roof slopes would have completely altered the overall impression and made it far worse.
The solution finally adopted by architects is illustrated by a section through the Taimadera mandarado. (Fig. 421) There were a number of steps which led to this design. At first the Japanese were happy with a hidden rafter construction above the *hisashi*. Little by little though, builders ventured to make changes above the core area itself: in the example of the Horyu-ji daikodo the columns, connected directly with the visible rafters via spreader pieces, carried the hidden purlins defining the roof slope. (Fig. 422) This construction was of course still not terribly stable. The example of the Daihoon-ji hondo demonstrates the next step: cantilevering timber members *(hanegi)*, fitted above the *moya* columns, cantilevered over a beam as far as the eaves. This beam was laid on the visible rafters and hence hidden because it was taken above the *hisashi* columns. (Fig. 423) Henceforth they served as bearings for the supports which carried the purlins. Apart from that, they stiffened the whole construction. (Fig. 424)
With this development on board, carpenters had smoothed the way towards the unrestricted layout of the building. The columns could now be located at will, the width of the structures was no longer limited by the old divisions. (Figs 425 & 426) And with the introduction of the *hanegi* it now became possible to divide the rafters according to visual criteria. (Fig. 427)
The hidden roof was Japanese culture's answer to the demands they had placed on their structures. It was "the gateway to freedom in roof construction … The body of the building was no longer controlled by the roof. The roof and [the roof's] substructure were at last independent of each other."[211] The hidden roof represented a remarkable masterly achievement to compare with the truss post constructions of the Europeans.
The point where column, tie beam and wall purlin meet is not only extremely important for the construction, jointly responsible for the stability of the structure, but also a visual focal point. Bracket complexes gave builders a chance to extend the roof well beyond the walls, initially for protection. During the 7th, 8th and 9th centuries bracketing developed into a visual expression of a building's prestige.[212] Granted this importance, the complexity of bracketing grew.[213] To gain wider eaves these were cantilevered out step by step via the large blocks *(daito)* mounted on top of the columns, with bracket arms and small

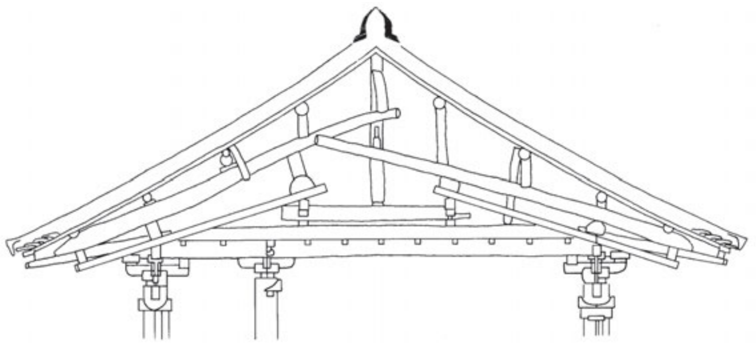


422 Section through part of the Horyu-ji daikodo, Nara, Japan. (by Asano Kiyoshi in: ibid., Fig. 37)

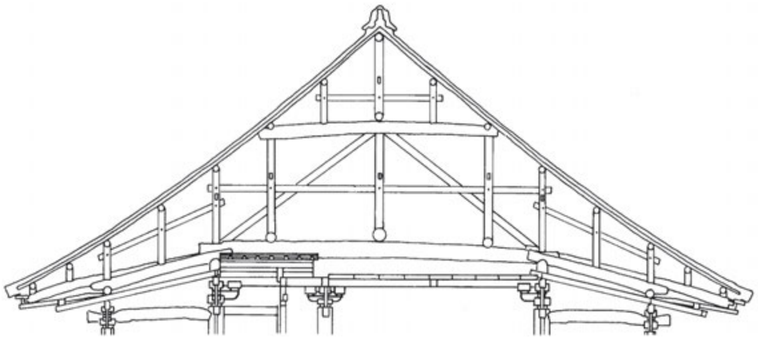


423 Section (simplified) through the Daihoon-ji hondo, Kyoto, Japan. (according to: *Nihon kenchiku gakai*, 1992, p. 47/5)

424 This corner detail of the uncovered roof construction over the *mokoshi* area of the Kencho-ji sanmon in Kamakura, Kanagawa, Japan, shows how much more difficult it is to comprehend Japanese roof design.

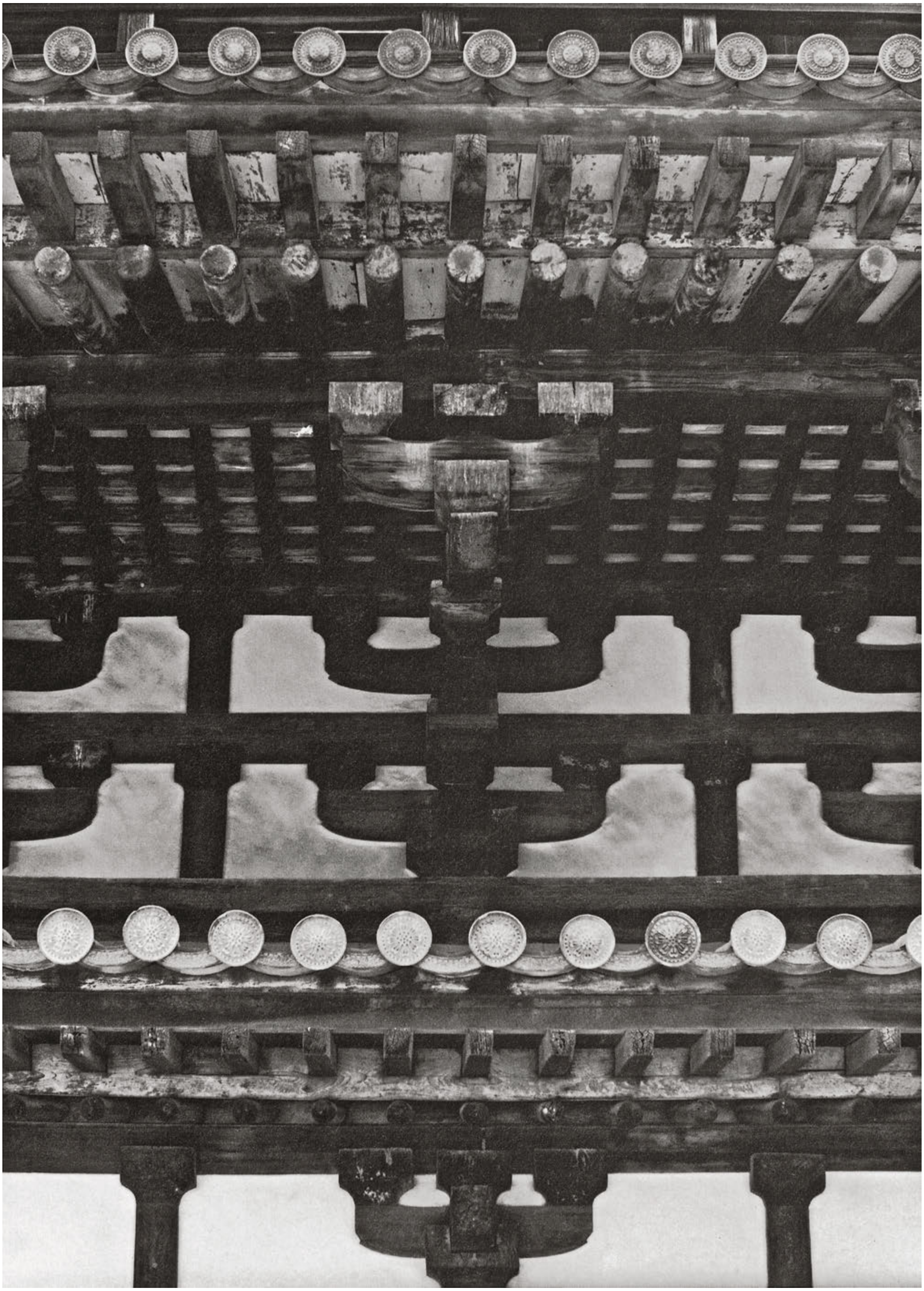


425 The Hodo-ji jikido in Osaka, Japan, illustrates an older solution, recognizable by the very old brackets which are not yet extended as far as the eaves. (according to: Parent, 1985, Fig. 62)



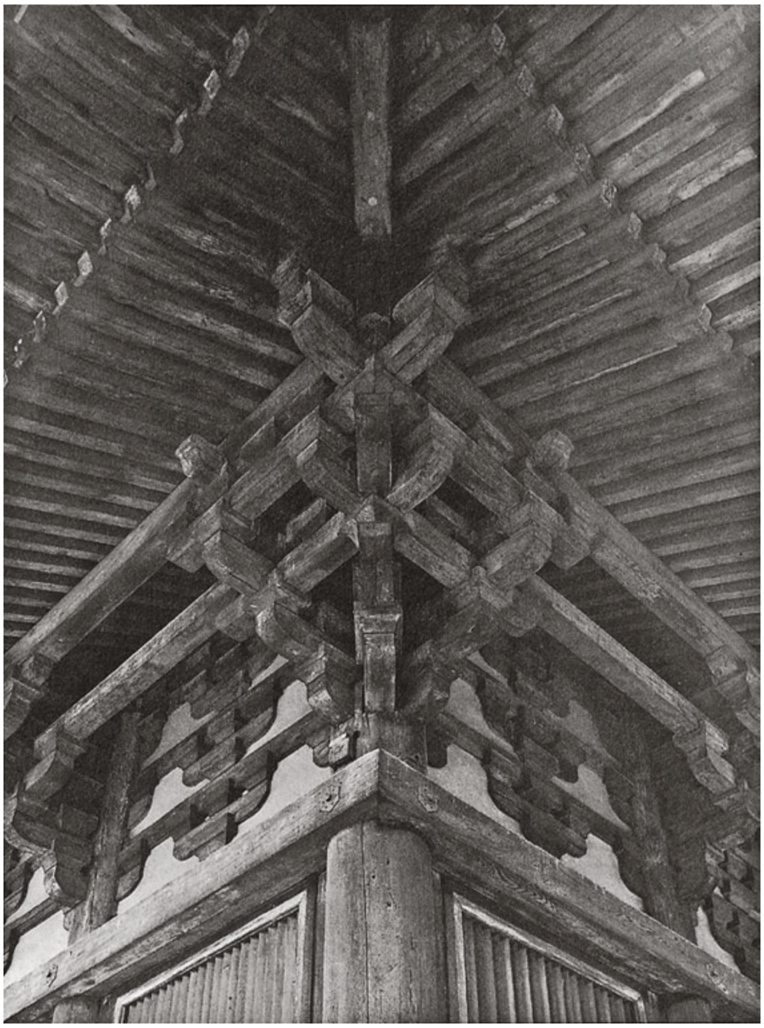
426 The Okura-ji hondo in Nara, Japan, suggests a considerably better planned hidden roof. In this case the brackets were mortised into the eaves closer board. (according to: ibid., Fig. 58)

427 With the introduction of the ***hanegi*** as the actual loadbearing construction the carpenters gained an increasingly free hand for the arrangement of the ***kesho taruki***.



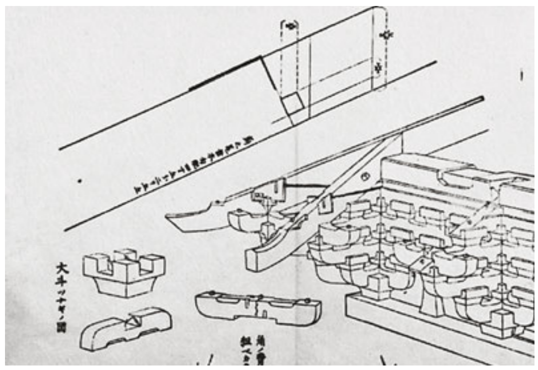
428 Eaves detail – Eastern pagoda, Yakushi-ji, Nara, Japan

429 In the To-ji kodo, Kyoto, Japan, the still very basic bracketing is arranged exclusively above the columns.



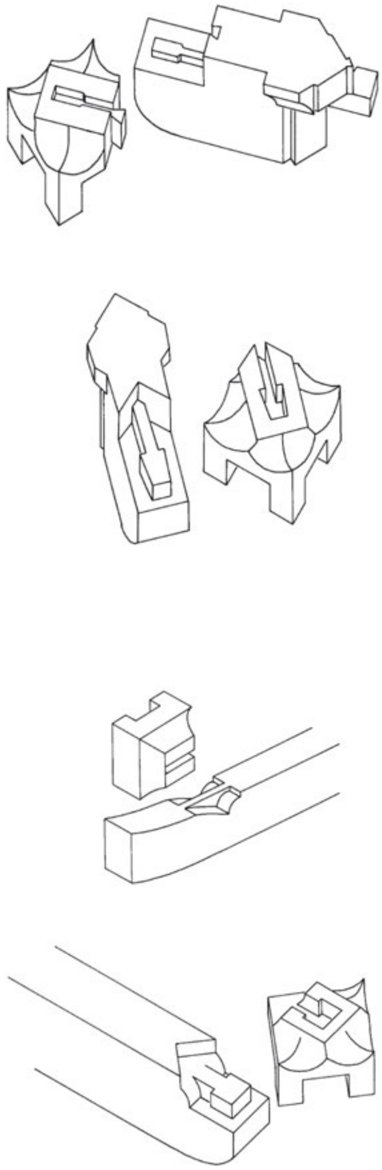
430 In the To-ji kondo, Kyoto, Japan, the aesthetically unsatisfactory supports between the blocks were trimmed appropriately.

blocks *(makito)* mounted on these. (Fig. 428) The brackets were cog-jointed to the blocks in a multitude of variations. In places where they protruded beyond the line of the wall they were half-lapped to the brackets flush with the wall. The blocks themselves were in the simplest case fixed to their bearings with tenons. (Fig. 431) In contrast to the *zenshuyo*, a two-dimensional cantilever is typical for *wayo*. (Figs 429 & 430)
To stabilize the merely horizontal and vertical layering of the bracket system, inclined "tail rafters" *(otaruki)* extended from the interior of the building over each column. (Fig. 431) A small block was mounted on each of these which was not only fitted into its position but also prevented from slipping by an already more complex joint, often a gooseneck tenon. (Fig. 432) Mounted on this was a bracket for supporting the inferior purlin and aligned parallel with it. A small block on the second cantilevering bracket acted as a fulcrum for the resulting lever. The inferior purlin, the rafters on it and the flying rafters on them placed a load on the lower end of this lever. This load was counterbalanced by the weight of the wall of the storey above. (Figs 434, 435 & 437)
In *daibutsuyo* the roof space is totally exposed. Parent sees the irregular division of the bracket arms as a significant feature distinguishing this style from *wayo*.[214] (Figs 436 & 438) This feature was not applied to the Great South Gate of the Todai-ji, where the growing cantilevers were again dominated by the strict division of the blocks and the strict regularity. Con-



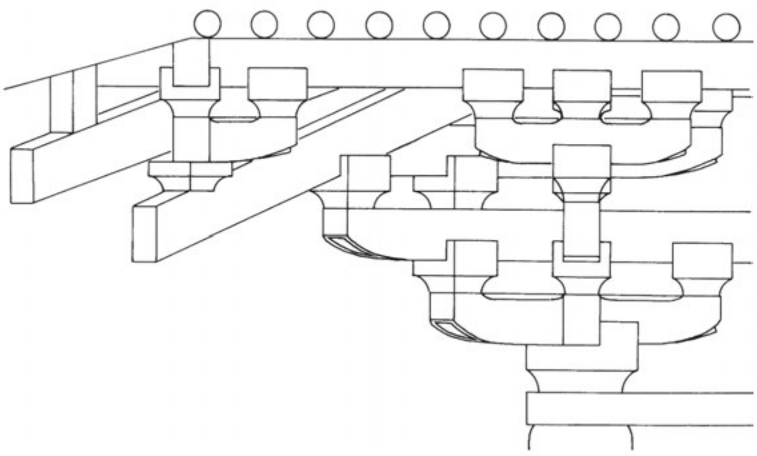
431 Working drawing (source: Suzuki, 1847)

432 *Otaruki* – Kencho-ji sanmon in Kamakura, Japan



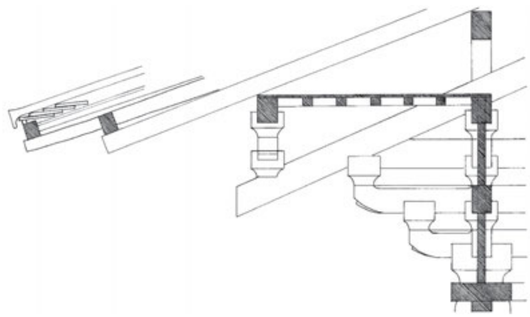
433 Various ways of mounting blocks. (according to: *Bunkazai* …, pp. 92/6, 159/4, 227/1)

434 Corner detail – Eastern pagoda, Yakushi-ji, Nara, Japan



435 Elevation of corner detail.

437 **The exposed roof construction of the Jodo-ji jododo, Hyogo, Japan.**

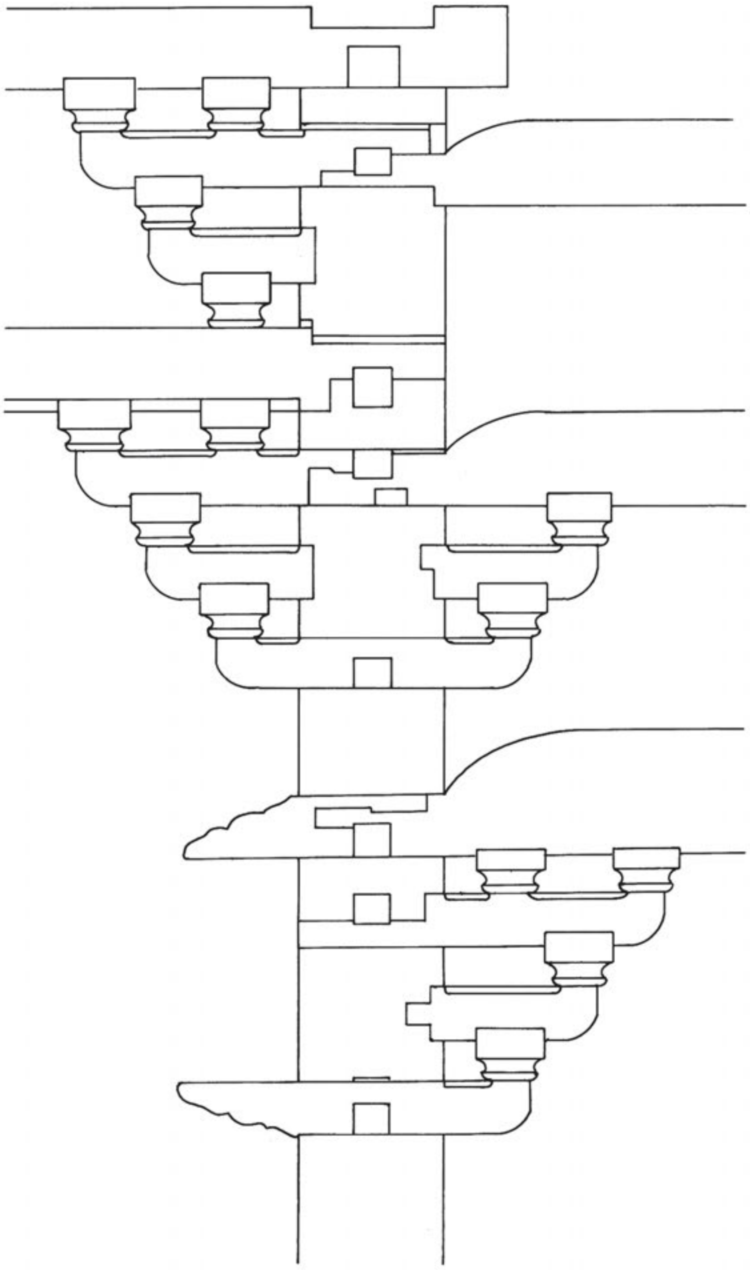


436 **The stack of blocks formed a triangular space where it met the rafters. To hide this a soffit was inserted.**

versely, another characteristic of this style is the almost unbelievable extension of the eaves, achieved through a six-fold cantilever! (Fig. 440) This was only possible because the bracket arms were joined to the columns with through-tenons and the bracket complexes were stabilized with sufficient horizontal bracing.

A peculiarity of the Jodo-ji jododo already marking the transition to *zenshuyo* is the fan-shaped arrangement of the the rafters at the corners. (Fig. 439)

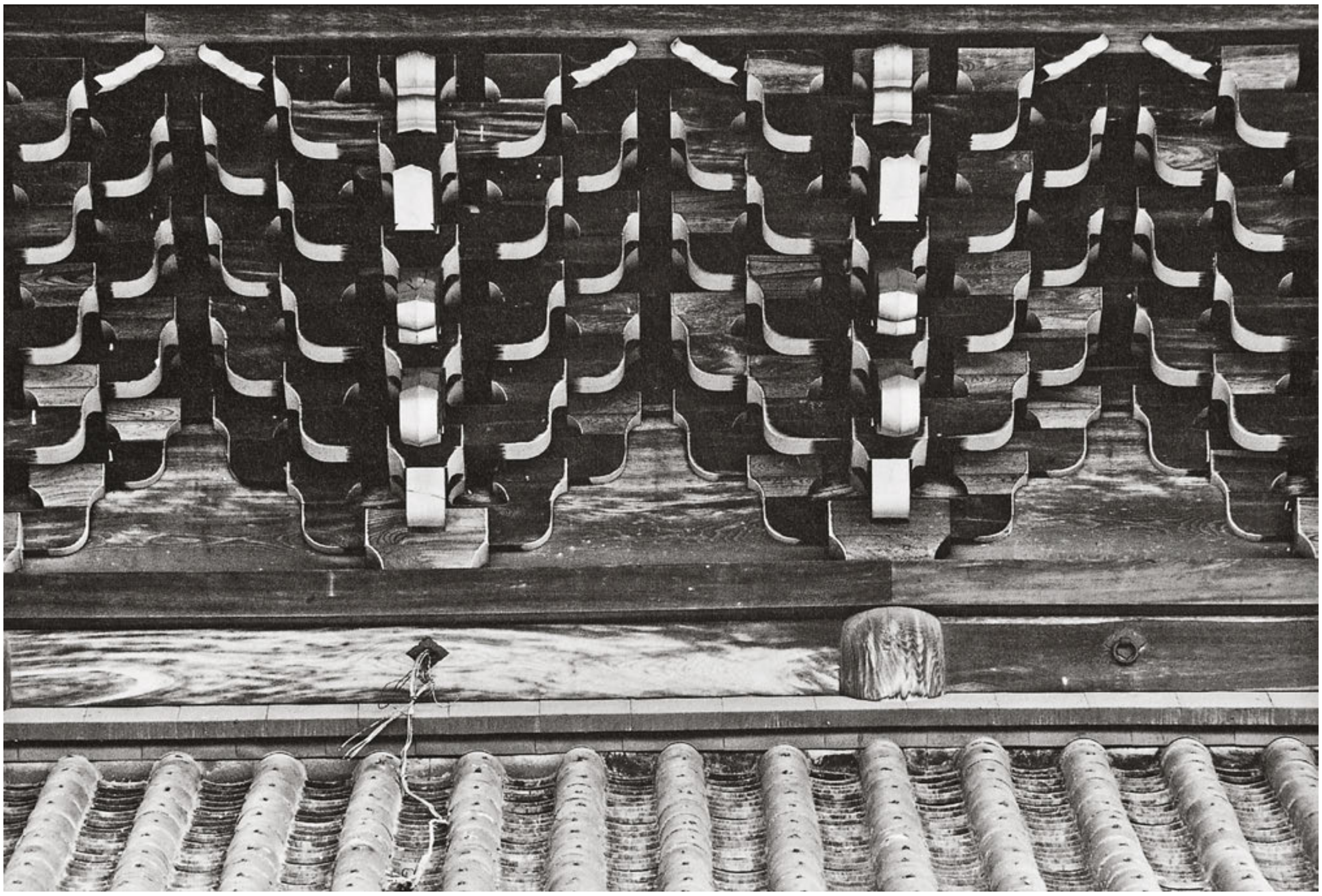
Towards the end of the 12th century Chinese influence once again took hold in Japan, remaining a determining influence for the next few centuries. Besides the short-lived *daibutsuyo*, this enabled the *zenshuyo* to become established. That this latter style, most definitely alien to the Japanese, was able to spread so easily can be attributed to the fact that it was not confined solely to religious spheres; as a way of life it found much favour in 13th-century Japan. The curved forms of the *zenshuyo* "proved as much of a challenge for the Way of the Carpenter as Zen was for the Way of the Warrior".[215] Carpenters were confronted with a constructional and aesthetic concept for which, however, they lacked the fundamental expertise required to implement it. And experience even more so! Consequently, it is not surprising to discover that many early *zenshuyo* designs "are delightfully eclectic in style but decidedly



438 This longitudinal section reveals that all horizontal members – beams and brackets – are connected to the column with through-tenons. (according to: *Bunkazai . . .*, pp. 126/1–128/1)

439 Although the rafters of the Jodo-ji jododo are only arranged in a fan formation at the corners, they do already provide a good idea of what was in store for carpenters in the *zenshuyo*.

440 Eaves corner detail – Todai-ji nandaimon, Nara, Japan



441 The bracket complexes so typical of the *zenshuyo*. – Zuisen-ji taishido, Toyama, Japan

443 Bracket complex – Daisho-in in Miyajima, Hiroshima, Japan

conservative in method of construction".[216] Arising out of this situation, the home-grown wisdom of the carpenter not only rendered possible the development of the hidden roof but indeed caused it. Only when forced to deal with a task for which one does not know the answer will new, unconventional solutions come about.

The history of Japanese building is very strongly characterized by outside influences. "No type of construction really originated in Japan."[217] Parent defines the typical Japanese approach thus: selecting, assimilating and adapting that which appears suitable, or eliminating those things which did not suit Japanese tastes. This led Japanese culture to develop its own, individual style.[218]

In the *daibutsuyo* the carpenter made a great effort with his through-tenoned beams; in the *zenshuyo* the job was made very much easier as the dimensions of timbers in general were cut drastically. To make up for this, even greater emphasis was placed on workmanship. Bracket complexes became smaller but there were more of them. Remarkable was the so very different effect which they had on the viewer. The reason lay in the three-dimensional cantilevering; no longer stacks of three brackets but, on the contrary, up to five, and not only towards the eaves but along the line of the purlins as well. This led to the characteristic dense groups of brackets. (Figs 441 & 442)

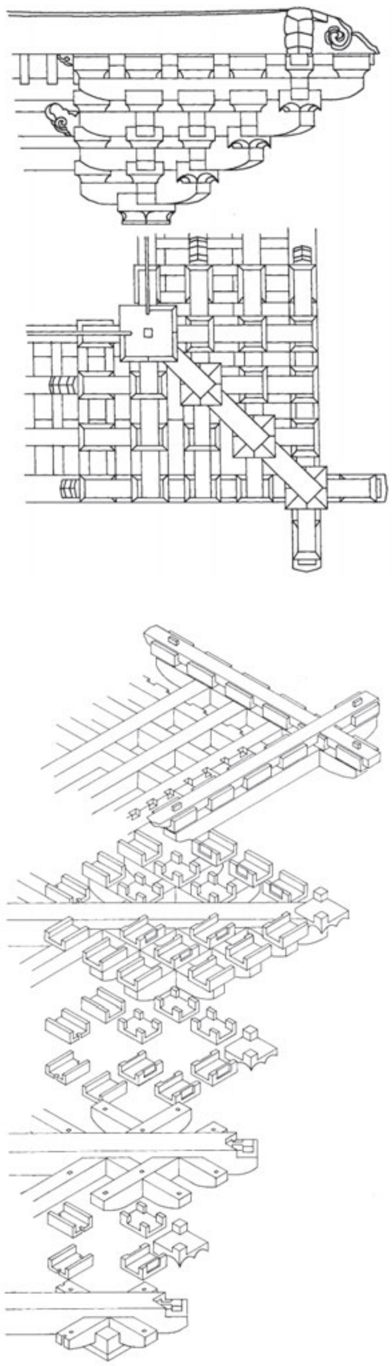
Together with the *otaruki* inclined downwards, the degree of complexity of the assembly reaches such a level, still within the area exposed to the viewer, that we are reminded of a puzzle, completely forgetting the real purpose of the construction. (Fig. 443)

The upward curve of the roof became more pronounced. The carpenters laid the rafters in a fan formation in the *zenshuyo*. On closer inspection we realize that in many cases both types of rafter arrangement could be encountered simultaneously: the parallel rafters in the flatter, lower roof (over *mokoshi*), the fan layout in the steep, raised upper roof (over *moya*). Whereas the layout of the parallel rafters could be spaced out exactly, the timbering due to the curved eaves was already very much more difficult. And the radial arrangement made the task unbelievably complicated; however, the observer usually remains totally unaware of this incredible complexity. (Fig. 445)

The aim was to lay the rafters to match the bracket complexes. In doing so it was realized that the best results were obtained when two rafters were placed over each small block. The spaces between the bracket complexes of course had to be included in these calculations. The raised hip complicated the whole matter further because this did not allow the rafters to be subdivided in the same ratio as the flying rafters. The higher the eaves corner was raised, the more the ratio rafter length to flying-rafter length shifted from the centre of the eaves to the corner of the eaves. (Fig. 444)

The rafters had a supposedly rectangular cross-section. However, in order to preserve this feature optically, their real cross-section could in no way be rectangular![219] (Fig. 446)

Those who are successful in realizing just some of the considerations pointed out here, considerations which carpenters dare not overlook when deciding on the joints for fan-shaped rafter layouts in a *zenshuyo* roof, will understand why the secrets



442 Elevation, view from below and exploded view of one corner of the Kibata jinja romon, Tochigi, Japan. (according to: *Bunkazai* …, p. 302)

444 Eaves corner – Kencho-ji butsuden in Kamakura, Kanagawa, Japan

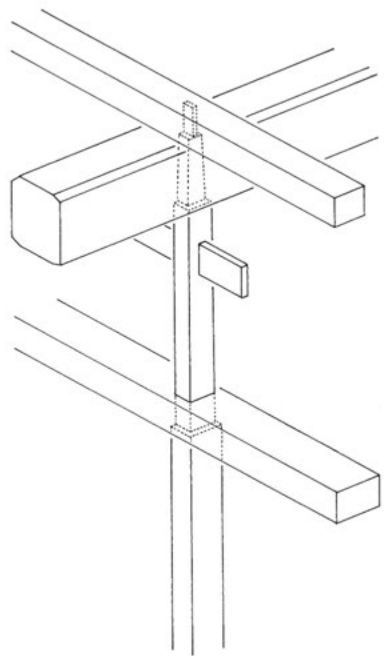
of the *kiwari jutsu* were so jealously guarded. The slightest error in determining the joints would be disastrous for a master. Consciously perceived by the careful observer were not the wonderful solutions to all these problems but, on the contrary, all the unwanted irregularities.[220]

Without wishing to doubt the accomplishments of European carpenters or even belittle them, in a comparison such as this we cannot hold back the growing suspicion that every European carpenter, justly proud of his achievements, especially in the art of "assembling the rafters",[221] would be seized with utter horror faced with the task of his Japanese colleague. Of course, the comparison is inappropriate because developments in Europe followed a different course. The strokes of engineering genius in Europe and the wizadry of Japan's jointing technology were just different answers to the questions posed.

445 The rafters laid parallel cover the *mokoshi* area, the radial ones the *moya*. – Engaku-ji in Kamakura, Kanagawa, Japan

446 The construction problems over the octagonal plan of the Anraku-ji sanjunoto, Nagano, Japan, were fundamentally no different. The difficulty was certainly the fact that polygonal structures were clearly in the minority.

Two brief remarks should prepare the reader for the contents of this chapter.
The conditions encountered in Japan are not met with in Europe in the same way. The traditional Chinese tiled roof, from which the Japanese roof is derived, weighs up to four times that of a modern European roof.[222] The frequent earthquakes and the typhoons with hurricane-like rainfall represent a challenge which could not have been tackled by simply using the unaltered Chinese system. Besides constructional modifications, the Japanese carpenter also decided to adapt the joints.[223] Seen in this light, statements contrasting the most technically advanced and ingenious Japanese joints with those of central Europe, which are weather-resistant and capable of carrying heavy loads, cannot remain undisputed; statements which claim "that conditions such as high load-carrying capacity were occasionally regarded as being of secondary importance [in Japan]".[224] A straightforward comparison is problematic because the conditions are so different.
Kawashima describes very small buildings on the island of Amami Oshima, Japan, whose exposed position has been taken into account in their special construction. Limited by inferior tools, farmers used extremely long tenons of reduced width on their columns, onto which all the horizontal members, provided with corresponding holes, were threaded cross-wise. That this type of construction has proved to be worthwhile might well be attributable to the flexibility of this tenon.[225] (Fig. 447) Comparing these with the through-tenons of keyed tenon joints, which were in fact often assisted by kneebraces but still broke,[226] or the teazle tenons of the columns in the large farmhouses with their haylofts in the roof space *(Haubarg)* of North Friesland, Germany, which could not withstand the thrust of the roof loads,[227] it is interesting to note just how well the builders of such structures had to know their material. The Japanese column tenon was not stronger because it represented a more sophisticated engineering design. Nor was it more durable because the timber chosen was more suitable. For centuries, the *Haubarg* columns carried their loads without complaint, so long as their inclination resisted the thrust of the loads. It was only when this tradition was cast aside and the columns placed vertically that the elasticity of the tenon was overtaxed. The size of its cross-section was based on experience. If individual components of an assembly are altered, whether due to thoughtlessness or lack of expertise, that can lead to apparently inexplicable or wrongly interpreted consequences.[228] The reader should bear this in mind as the role of the climate is discussed in the following pages.
"The original purpose of any building is to protect ourselves, our fires and our possessions against the rigours of the weather (cold, heat, precipitation, wind)."[229] How people react to nature – how they experience sunshine or its absence, the seasons, wind or rain, which answers they find – is reflected in their buildings. The European climate is partly determined by the extent of the continent, from latitudes 38° to 70° north. The comparatively dry and hot climate in the south contrasts with the relatively dry, very cold climate of the far north. In between there is



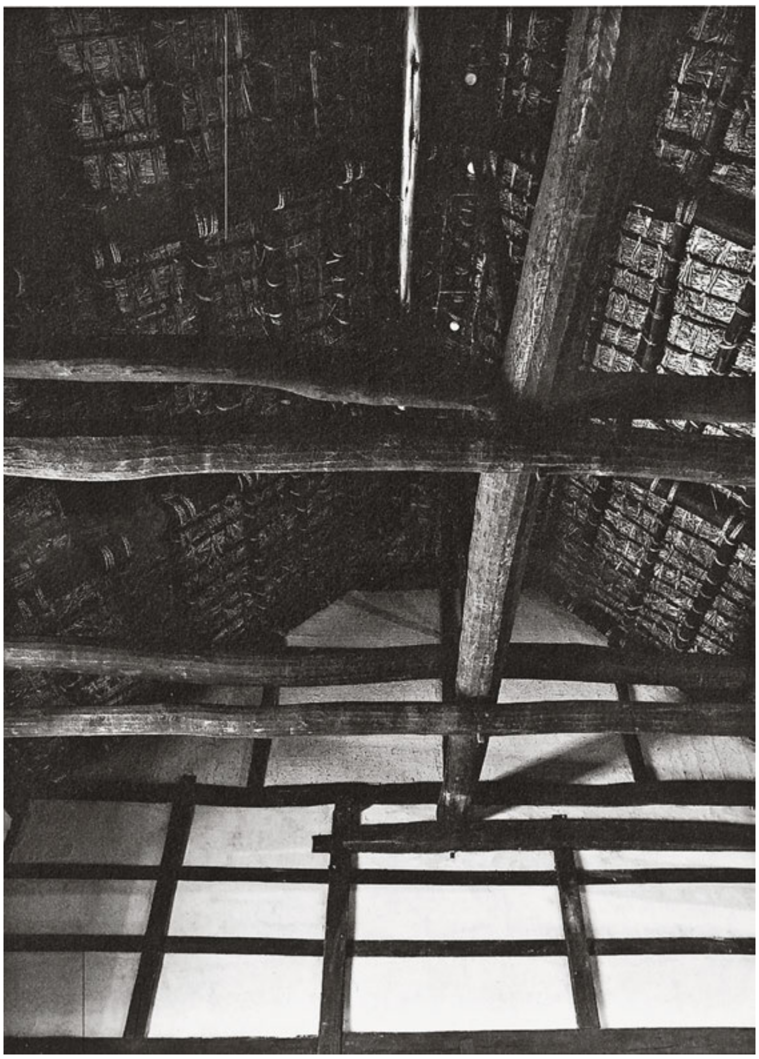
447 ***Koune ke jutaku no otoshi koho*: the principle of the framing in this construction in Koune House, Tokushima, Japan, is based on threading the horizontal members onto the variously tapered end of the loadbearing column. (source: *Tsugi shiguchi kenchiku no kakusareta chie*, 1984, p. 51)**

a complete range of gradations, depending on the geographical location, as well as wet regions on the coasts. These varying climatic conditions are all taken into account in the various decidedly regional building forms. Japan is no stranger to a varied climate; the transition from the hot and humid conditions around latitude 25° north to the dry and cold weather at latitude 45° north are most clearly expressed in the incredible diversification in *minka* construction.[230] While in many areas the European house is matched to the needs of the winter, anybody who cares to try it will find that in Japan the summer was the deciding factor.[231]

In many respects it is the design of a building which reveals the confrontation with the elements: cantilevered roofs, overhanging eaves and gables, roofs extending right down to the ground, porches and verandas. (Fig. 448) All these forms can be found both in Europe and in Japan. Snow loads can be very heavy; however, worse than just the weight for the roof framework is the sometimes extremely varied distribution of this loading, caused by the wind. The "snow truss", a sort of vertical queen-post truss, represents a European answer to this problem.[232] The Japanese, on the other hand, choose to approach the problem by distributing the load rather than directly supporting it.[233] (Fig. 449)

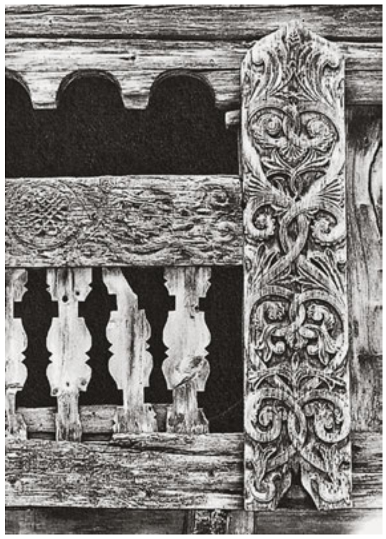
Only very few wood joints can be interpreted as being a direct answer to the issue of how timber can be protected from the

448 Verandas in front of or around log buildings were added, strictly speaking, for protection. – Bîrsana, Maramureş, Romania

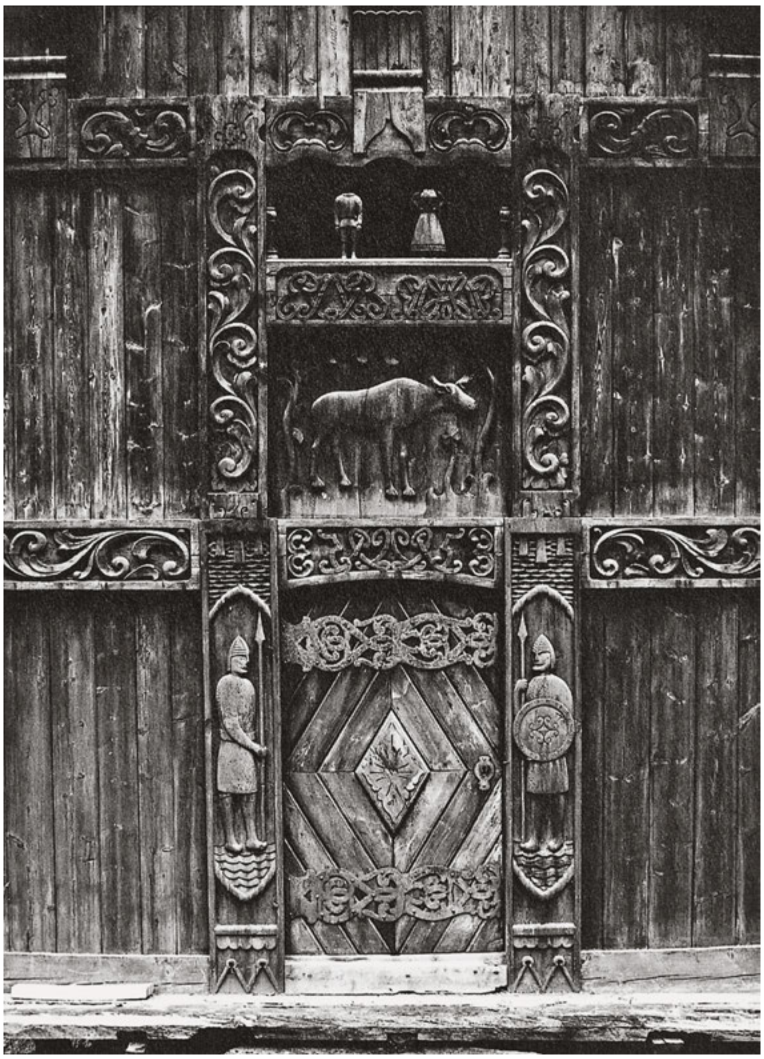


449 The Japanese achieved the required load distribution by way of several layers of interlocking beams. – *minka* in Kitakata, Fukushima, Japan

damaging effects of water. One is the column base half-lap or halved lap with tenon – a stub tenon joint with an additional protective barefaced tenon. Made in a single piece of wood, the overlapping barefaced tenon shields the mortise-and-tenon joint between column and sill beam, sometimes the end grain of the beam below as well. It does not owe its special form to the function of the joint itself but rather to the protective lap, understood totally in the pictorial sense. (Fig. 450)
Since Neolithic man had learned how to produce the mortise-and-tenon, carpenters were constantly confronted with the problem that they created a sort of gutter without a drain. The more accurately the tenon fitted into its mortise, the harder it was for the water to enter. However, the form of construction sometimes required the mortise to be cut larger than the tenon. The columns of some stave churches were simply too large and heavy to be be erected in such a way that the tenons on their bases could be simply dropped into the holes provided for them in the sill beams. Instead, the outer edge of these holes had to be rounded so that the columns could be rotated into position.[234] The ingress of water could not be prevented as long as it was possible for rainwater to reach the interface of the two members to be joined. Water was to be prevented from entering the joint at all costs! The solution was the halved lap with tenon, the usefulness of which corresponded to its extensive usage. (Just how extensive the combination of lap joint and



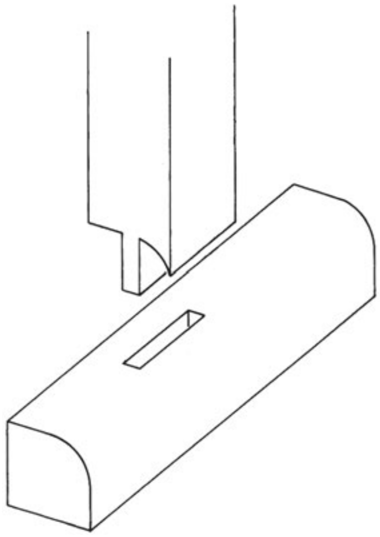
450 Veranda detail – house in Øverbø, Telemark, Norway



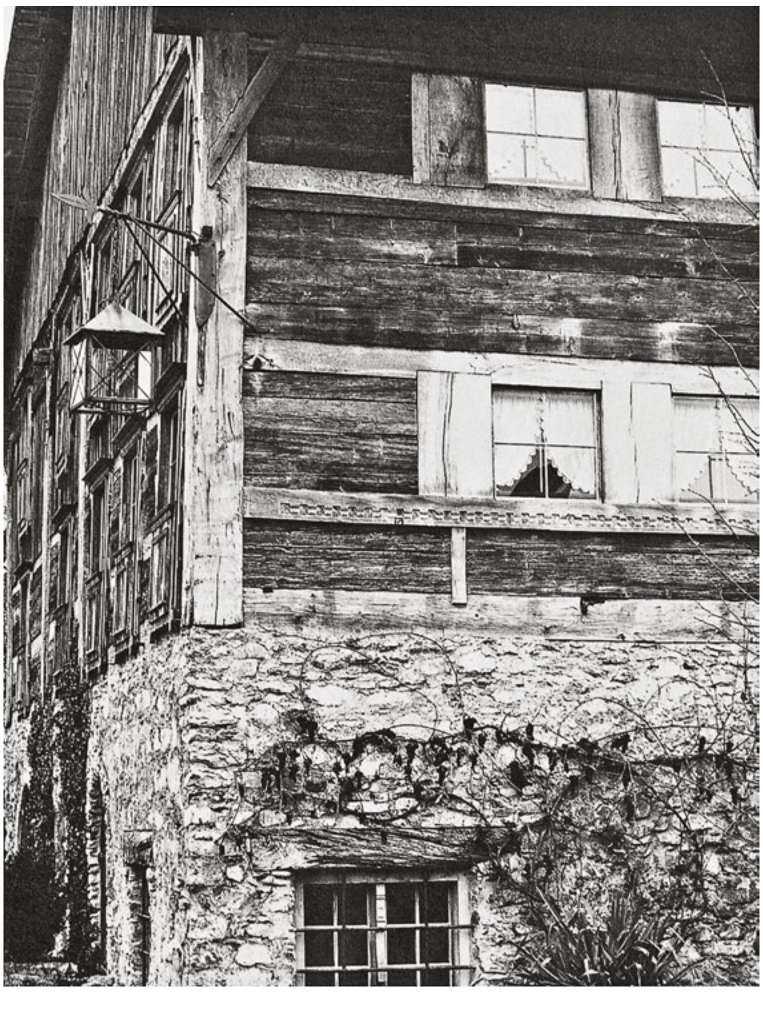
451 Two sentries guard the entrance to this *loft* in Brunkeberg, Telemark, Norway.

tenon really is in each individual case can in many instances only be verified by opening up the joint. [Fig. 451] If Phleps is to believed – and Holan confirms his view[235] –, then some of the Norwegian examples are reversed forked tenon joints, i. e. a slot in the base of the column which fits over the sill beam, without any form of tenon.[236])
The halved lap with tenon as a form of joint designed to provide protection against rainwater is generally regarded as a development stemming from column-and-beam construction. However, builders put its advantages to good use even in regions where only log construction was normally found, for example, to relieve a wall from the weight of the roof. (Fig. 452) Whenever a column stood on a sill beam, the problem of rainwater was the same. (Fig. 453) The halved lap with tenon must have especially proved its worth in the extension of the corner column. (Fig. 454) At this point it was possible to assign the joint further tasks. Firstly, the two incoming sill beams could be joined with the tenon, and this linking of three members brought about a notable stiffening of the assembly in comparison with paired assemblies. (Figs 455) Secondly, the unfortunate problem of the weather-sensitive end grain was eliminated at a stroke. The circular column is particularly common in northern Europe. The corner columns of the *svalgang*, the protective gallery surrounding the main body of the stave church, can be fitted over the sill corners in two ways.
One method is for the crossed slots in the column bases to be fitted over the half-lapped sill beams. Fixing and protection

452 The column tenons of the church in Tročany, Slovakia, are hidden by a lap matching the shape of the sill.



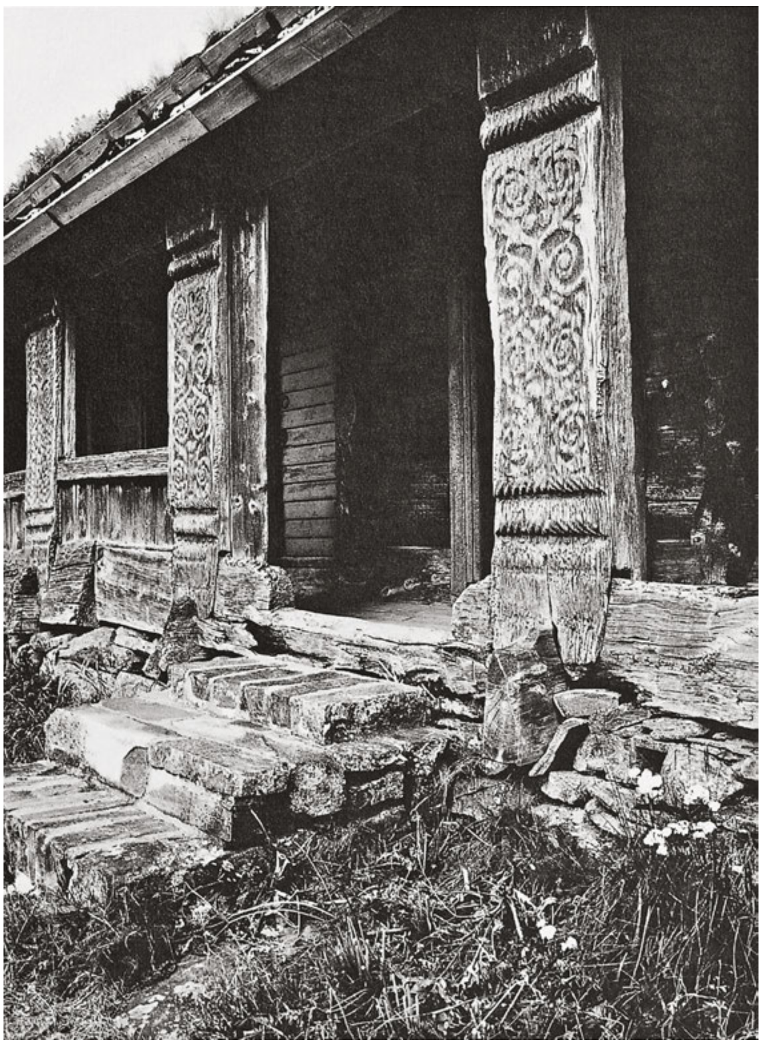
453 Mechanical wood preservation: the overlap screens the mortise and the tenon from rainwater.



454 The corner column of the old courthouse in Sulz, Vorarlberg, Austria, connects and protects the ends of the sill beams.

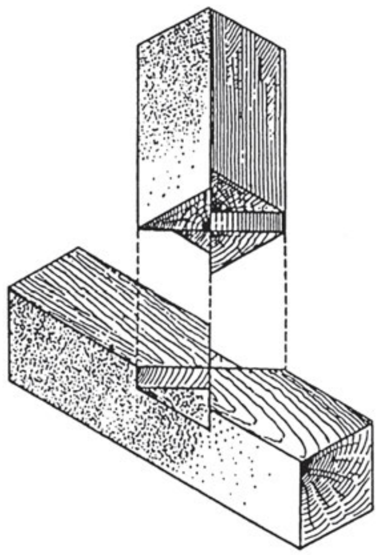
455 Far less effective was the tenon in the column's end grain which only engaged with one sill beam. – Niederneunforn, Thurngau, Switzerland

456 The corner column of the jettied *svalgang* of this *stabbur* in Øverbø, Telemark, Norway, constitutes optimum protection for the L-joint of the sill beams.

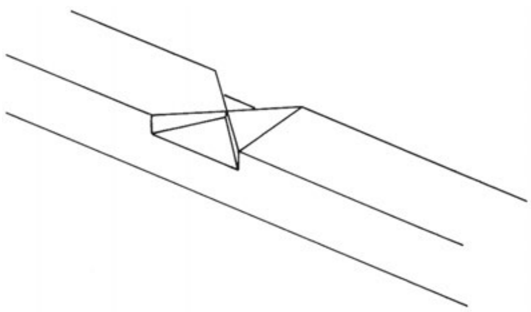


457 In this case the combination of the halved lap with tenon and the column forked over the sill corner creates a new joint. – Veranda in Rauland, Telemark, Norway

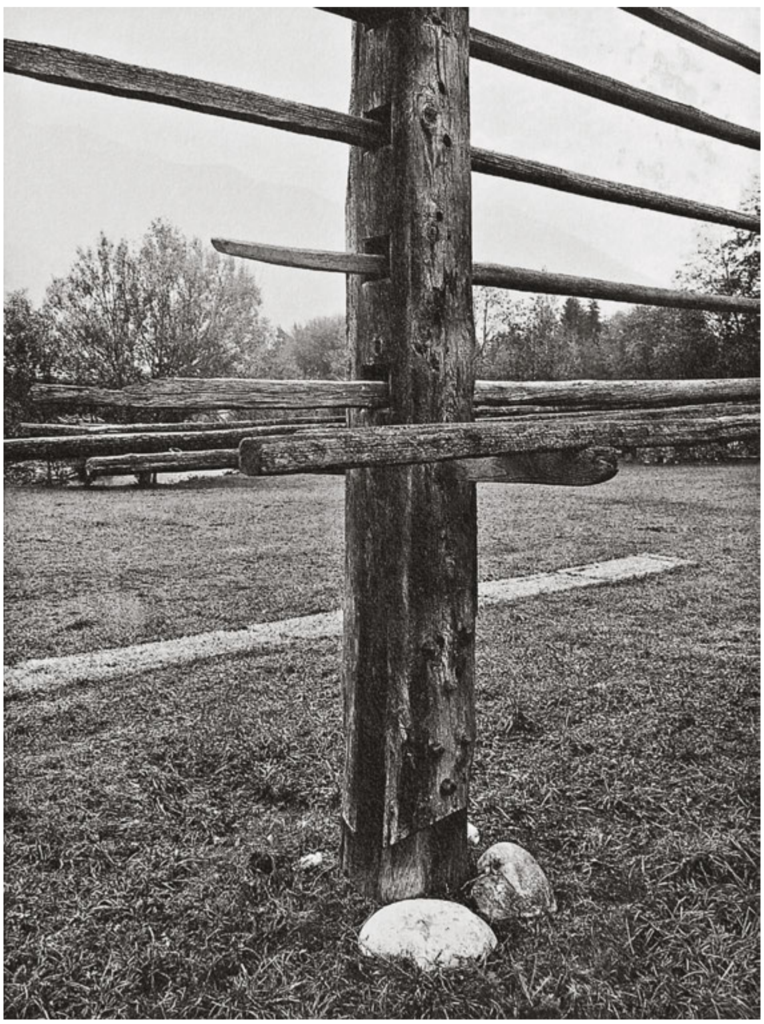
have equal status here since the four "fingers" of the column base provide optimum protection against water entering the joint. This joint was introduced on p. 135f. in connection with storehouses. It involves considerably more work when the sill beams have a trapezoidal cross-section, as is the case with stave churches. The second method is an amazing reminder of the principle of the corner halved lap with tenon. (Fig. 456) It is precisely the fact that two forms of intersection occur which makes the link between the corner of the *svalgang* around stave churches and the corner column of the veranda to the front of the upper storey of the *loft* or *stabbur* so conspicuous.[237] (Fig. 457) Even after this joint was abandoned in the 17th century,[238] the problem did not disappear. Boring through the mortise seemed to offer a neat solution; at least the water not absorbed by the tenon could drain away and the vent hole thus created would allow the timber to dry out again more rapidly. A more elegant answer was the X-shaped tenon. (Fig. 458) The example illustrated by Breymann enables us to understand his explanation that water entering the joint was not trapped but instead drained away;[239] however, it suggests that there was substantially more to be gained from this type of joint. (Fig. 459)
Columns which stand directly on the ground also suffer from the effects of moisture even when a padstone is slipped underneath. Renewal of the column base is required more frequently than any other part of the construction. (Fig. 460) In such cases both European and Japanese carpenters relied on tried-and-



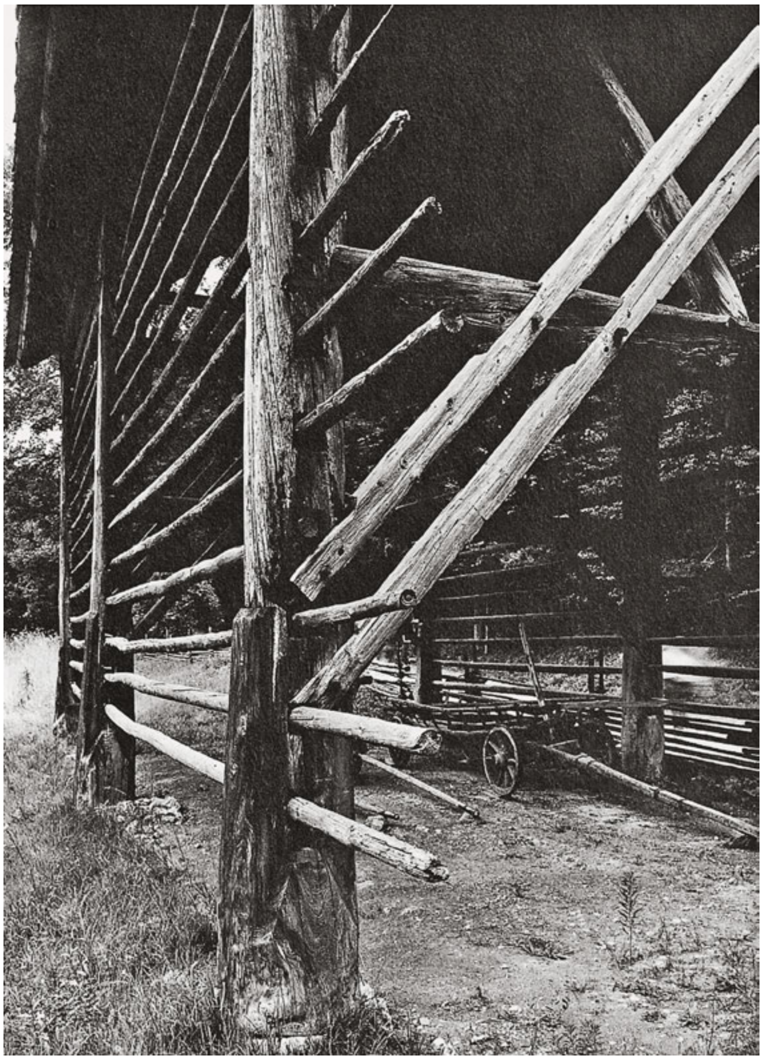
458 X-shaped tenon (source: Breymann, 1900, Fig. 76B)



459 If the recesses cut for the column tenons had been formed with a slope from centre to edge, then the water really could have drained off!



460 Renewing the base of a post to a simple grain-drying shed in Kramsach, Tyrol, Austria.



461 The most diverse well-known splicing joints were employed. – Sasaki House from Nagano in the Nihon minka en

463 The new column base of this grain-drying shed from Carinthia in the Stübing Open-air Museum, Austria, appears primitive by comparison.

tested techniques. (Fig. 461) In contrast, one conspicuous difference between Japanese and European solutions was the complexity of the joint and its implementation. (Figs 462 & 463) Furthermore, the climatic conditions in Japan demanded far more frequent replacements than in Europe. (Fig. 466)

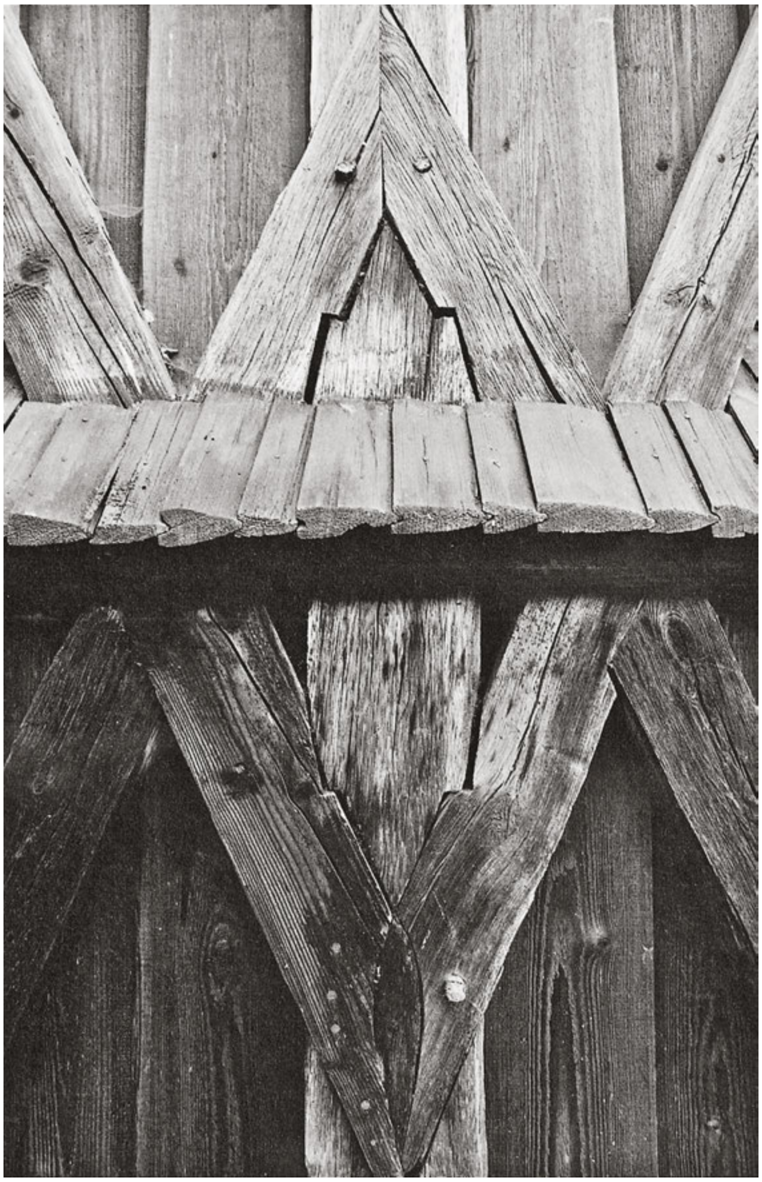
Some wood joints are made unusable by the weather. The angled jointing nail, for example, was both a strong and widely used method of jointing.[240] Nevertheless, it had to give way to the straight nail. One of the reasons for this might be that a nail driven in at an angle from above acted like a funnel, directing all the rain straight into its chiselled hole. (Fig. 467)

Nowhere else does the weather leave its mark more clearly than on the roof. The development of the roof has shown that certain roof pitches correlate with certain roofing materials. The effectiveness and, not least, the durability of the roof covering depend on this. (Fig. 464)

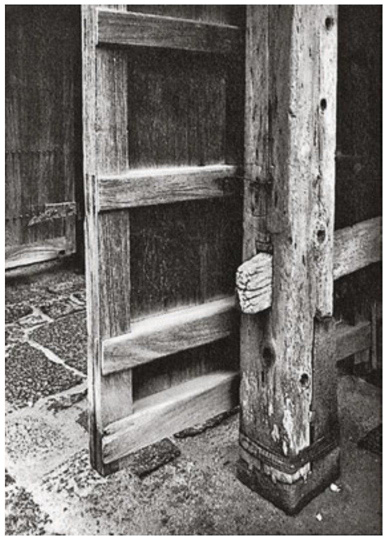
One feature of all roof coverings is their flatness. To produce flat surfaces you need edge-to-edge joints. Roofs composed of wooden shingles were used in both Europe and Japan, but the grooved shingle was probably a European speciality. (Fig. 465) Whether there is an evolutionary connection between the stave wall and the grooved shingle has yet to be investigated; in any case, the shape of their cross-sections is absolutely identical. (Fig. 468) The intention and, as a result, the function of grooved shingles and stave-church walls is the same: the tongue inserted

462 Renewed column base on the Osakajo sakuramon, Osaka, Japan.

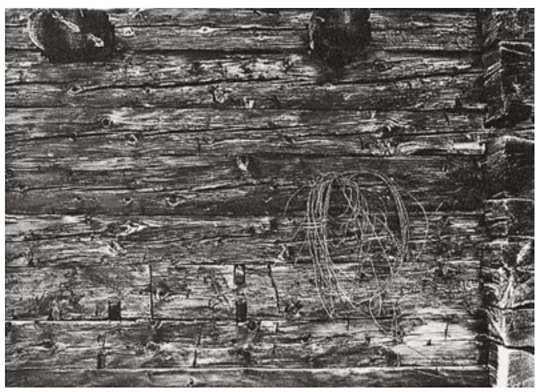
464 Owing to its comparatively short life, the amount of work required and its cost, thatched roofs are also becoming a rarity in Japan. – Hanase, Kyoto, Japan



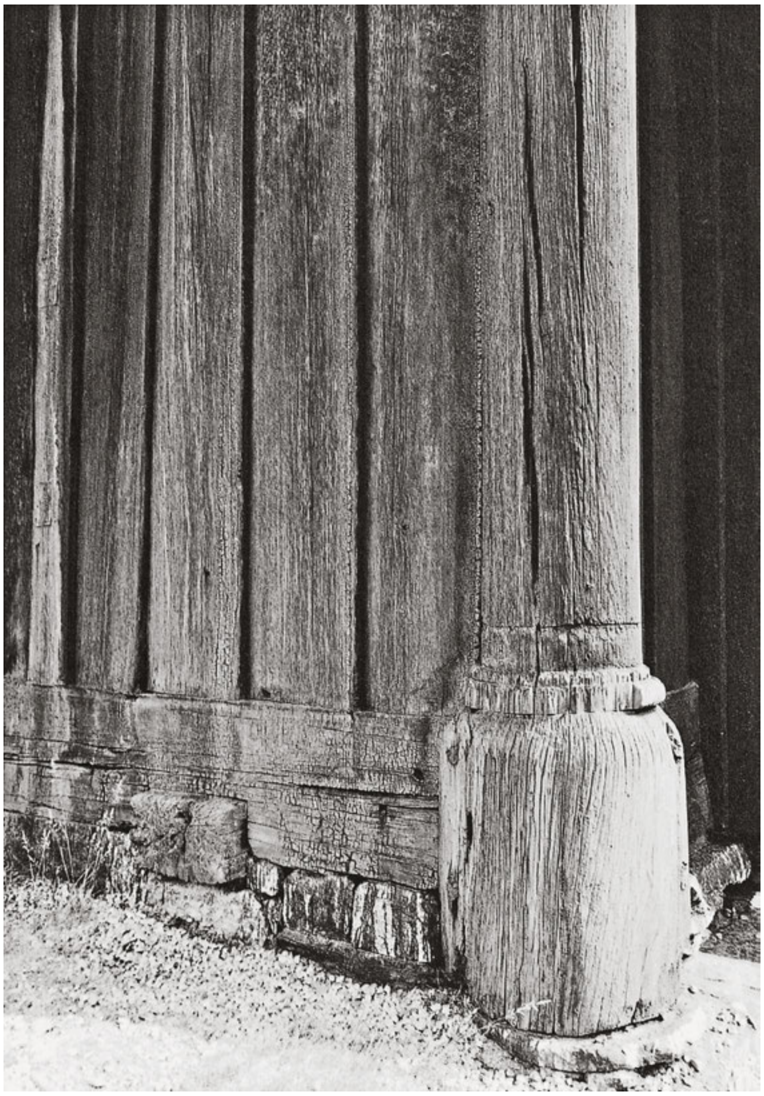
465 Grooved shingles on the church in Hronsek, Slovakia.



466 Does the stone plinth by the temple gate in Hagi, Yamaguchi, Japan, express a sense of weariness or does its shape perfectly matched to the timber reflect a hearty joviality?



467 Angled jointing nails hold the pieced logs in the assembly. – Stall, Carinthia, Austria



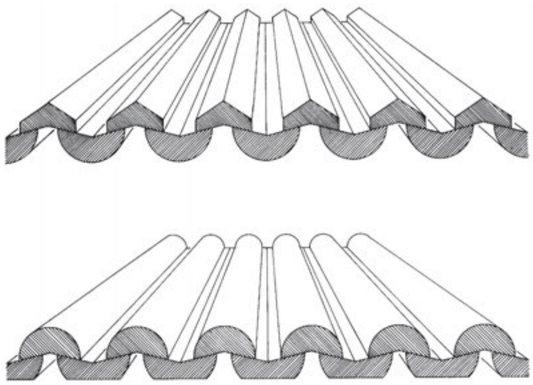
468 The planks of the stave wall to the church in Torpo, Buskerud, Norway, are joined exactly like grooved shingles.

into the groove improves the sealing action which had already been guaranteed by laying the shingles according to the direction of the prevailing wind. In contrast to lay shingle and nail shingle boarding, grooved shingling drains away the water more effectively because the individual pieces cannot twist out of their joints; hence, imperviousness is assured.
Some aspects of Japanese roofing have been approached from an entirely different angle. The smoother the surface of a material, the faster water runs off it. This fact, together with the easily split bamboo, resulted in an ideal roof covering. (Fig. 469) Its poor resistance and durability, as well as its unsuitability for covering large areas, have meant only a few specimens have survived. (Fig. 470) Luckily, this wonderful concept need not be confined to oblivion, for in cultural buildings it has been translated into a language which the Europeans understand better (Figs 472 & 473)
A system very similar to the Japanese one is found in northern Europe.[241] Split half-round pieces were gouged out longitudinally to give them a shallow trough-like cross-section. These pieces were then laid offset in two layers: the bottom layer with the channel facing up, the top layer covering the gaps. The system was identical to that of the bamboo roof but it involved a lot more work. (Fig. 471) Refined versions of this form of roofing essentially involved the change from half-round pieces to planks.

469 Unsurpassed in its lightness, ingeniously simple in its water drainage concept, the bamboo roof nevertheless is burdened by too many disadvantages for it to be a winner in our modern world. – Yokohama, Kanagawa, Japan (photo: Kawashima, Chuji)

470 The decorated gable of the Mudo-ji, Hyogo, Japan, still reminds us of old forms.

471 Examples of Finnish roofing.



472 The roof covering to the Nyakuochi jinja, Hyogo, Japan, formally embodies the essence of the bamboo roof concept in timber.

473 The shaping is perfected on the Horyu-ji gojunoto, Nara, Japan.

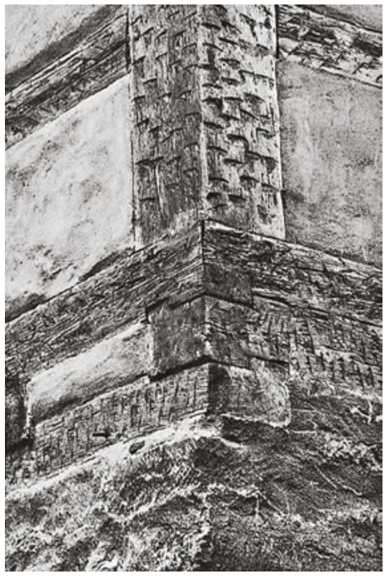
474 Air circulation below the building was at least as important as that within. – Ainokura, Toyama, Japan

The average atmospheric humidity in Japan is approximately 75 %. Therefore, in order to permit building with timber at all, the building had to be raised above the ground, (Fig. 474) for even the opening and sliding screens allowing ventilation via all sides would not have been sufficient; the building also needed under-floor ventilation. (Fig. 476) Throughout Europe, storehouses were encountered which, being placed on stilts or staddles, functioned according to the same principle. (Fig. 475) Although in this case protecting the contents against rising damp was also a valid reason, the main emphasis was on removing the stored goods out of the reach of uninvited guests. In Japan the living quarters were elevated in a similar manner.
The joining of two pieces of timber at right-angles is indeed in the first instance a constructional problem. The more prestigious and durable a building was intended to be, the more its builders had to understand that every form of tenon or half-lap, dowel or wedge could not ride roughshod over certain properties of wood. End grain needed special protection; if boards simply nailed across the ends were considered too rudimentary, then engineering solutions had to be sought which left no end grain exposed. The road to such joints was an extremely arduous one; the structural part of the joint had to make way for a mitre pointing outwards. In Japan the wood preservation aspect of this development included an aesthetic component. The effort expended, unjustified in European terms, and the definitely-not-so-easily-comprehended complexity of wood joints which had been attained over hundreds of years must be attributed to this aesthetic component.[242]
Step by step the Europeans felt their way forward until acceptable results were obtained. (Fig. 478) It was not often that examples were found only exhibiting a mitre-cut on the exterior. (Fig. 479) Looking at the solutions proposed for Japanese structures one cannot fail to gain the impression that in that country, joints on more elementary buildings begin where those of the art of carpentry in Europe end. (Figs 477 & 480) The stopped mortise-and-tenon with mitred corner had already been used by the carpenters who built the Daigo-ji in Kyoto in the 1st millennium![243]

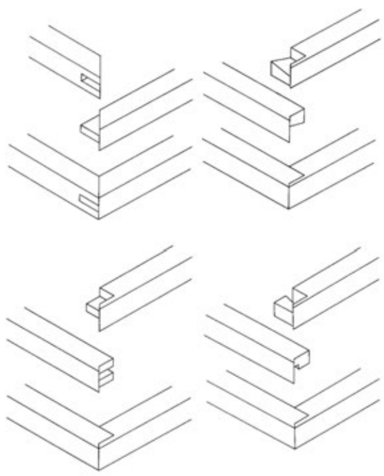
475 Raising European buildings on stilts or staddles may also have been carried out to help with ventilation. The main reason, however, was to protect the stored goods from animals. – Gudbrandsgard, Buskerud, Norway

476 If the gap below floor level was boarded up – which might be done for various reasons –, then ventilation slits still disclosed its function. – Imai cho, Nara, Japan

477 One corner which, apart from the ends of the beams, exhibits no exposed end grain. – Heppenheim, Bavaria, Germany



478 Three-way joint at the corner of a building in Rothenburg, Bavaria, Germany.



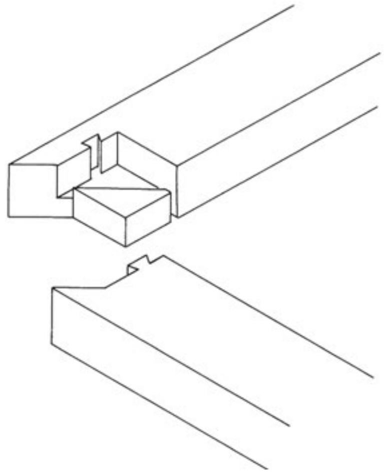
479 Various European corner joints which attempt to take account of the endangered end grain. (according to: Gerner, 1992)

480 Examples such as this one from Tono shi, Iwate, Japan, make it clear that the joint also had an architectural role to play.

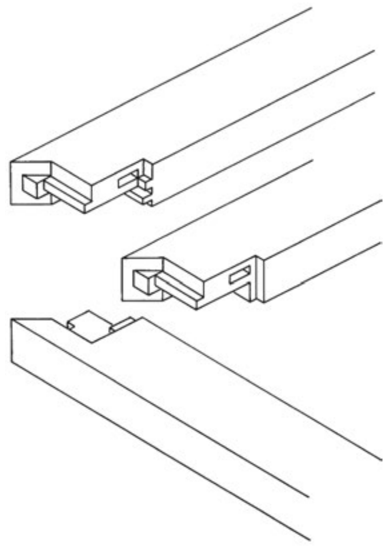
For the five-storey pagoda of the Myoo-in, the carpenter came up with a halved and tabled lap. (Fig. 481) In order to secure both halves of the joint in the same way, to prevent it from separating, the table was incorporated diagonally, in an extension of the mitre. Pressure on the table was to be minimized. Two further precautions were also taken specifically to counteract the lever action of the mitre: the small dovetail and the rebate on the inside edge of the joint.

The five-storey pagoda of the Kaijusen-ji supplies us with two variations on the half-lap joint. (Fig. 482) The task was solved here through multiple rebates and tenons on the faces. Noteworthy

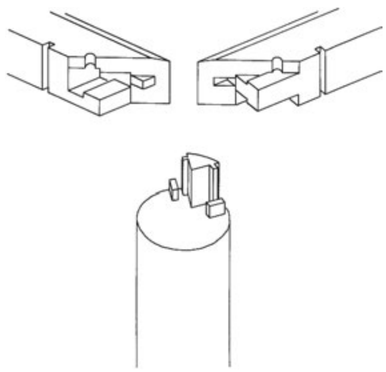
is the very elaborate arrangement on the inner and outer corners of the joint. The reasons for this carved form so alien to the European carpenter is, besides the distribution of the stresses, the attempt to avoid displacing or opening the mitre.
These two examples alone show us that every possibility was consciously exploited in order to serve a very specific engineering aim. The former joint was designed to prevent the parts being separated, the latter to prevent vertical displacement of the two parts. The Japanese carpenter made it his business to not only produce a joint matched to the respective building task but to also try out a combination of experience gained and new ideas in every new building of significance. Just as the names given to some joints allow us to discern the purpose for which they were conceived, the joint receives its final accolade by being built into the structure: in the first case security against vertical displacement, in the second horizontal.
The corner of the header beam in the three-storey pagoda of the Kongorin-ji leaves precious little space for the halved and tabled lap. (Fig. 483) As the mitre was likewise provided on the upper side, the halved and tabled lap had to be made so that it could be assembled from one side. The extremely long mitre included a triangular tenon to prevent twisting. It is not coincidence that placed it in line with the end of the housing; doing this lessens the possible leverage on the table. The column nestles in the angle enclosed by the beams and extends to the top of the header; it prevents the pieces from parting company horizontally by means of its two strong rectangular tenons: in the direction in which the mitre could separate, the dimension of the tenon was almost twice as large as in the other direction. The two tongues left and right of the column extension provide a certain torsional rigidity and, in addition, serve the purpose of preventing a conspicuous gap at the joined faces.
The carpenter of the Tomyo-ji opted for a comparatively simple solution. (Fig. 484) A double tenon is held in place via a *shachisen* driven in diagonally. In order not to overstress this really quite delicate tenon at the intersection of two sill beams, two strong tenons under the column engage with the sills. In this case it is not tongues which conceal the joint but rather the base of the column, which nestles into a recess in the sill beam. So at the one point where one could discern how the joint is put together, the base of the column screens the inside corner of the joint. The, in principle, independence granted to carpenters in the design of joints led them to devise individual solutions for each project. From time to time exploiting this freedom culminated in astoundingly simple solutions – and then again, mental doodlings which left the draughtsman scratching his head! From the outside it is in any case impossible to determine how the carpenter has managed to successfully join highly exposed sill corners in such a way that these do not open. (Fig. 485)



481 Header corner detail – Myoo-in gojunoto, Hiroshima, Japan (according to: *Bunkazai* …, p. 231/2)

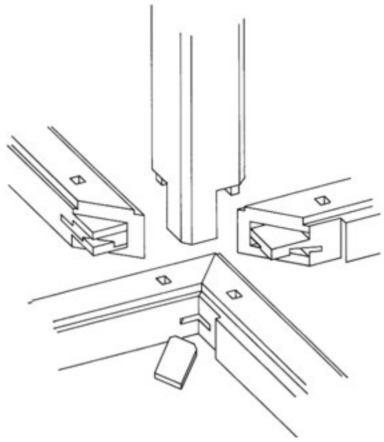


482 Header corner detail – Kaijusen-ji gojunoto, Kyoto, Japan (ibid., p. 153/1)

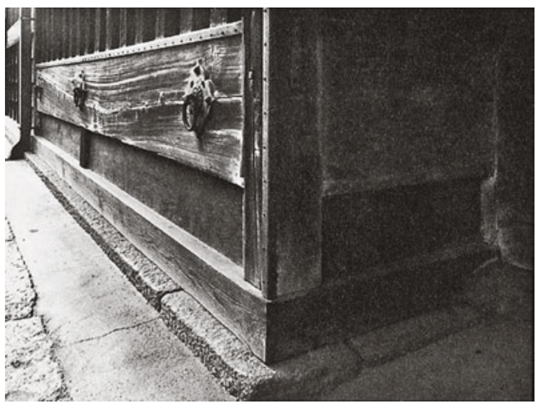


483 Header corner detail – Kongorin-ji sanjunoto, Shiga, Japan (ibid., p. 262/1)

Three considerations are important here: what are the effects of a shortage of timber, what are the effects of a surplus of timber and, my third point, what are the consequences of a decline in the accustomed availability?
It is really quite amazing to discover that timber was also used for construction in places where the resources situation would have led one not to expect it. At the time of its settlement in the 9th century, Iceland, on the northern tree line, already had virtually no timber available for building purposes.[244] However, the migrant peoples arriving from Norway wanted to continue using the building material to which they were accustomed. They had two possibilities: The Gulf Stream supplied astoundingly valuable driftwood from America and the mouths of Siberian rivers in the Arctic Ocean – all they had to do was fish it out![245] The quantity of timber that could be obtained in this way gradually diminished, so the Icelanders were forced to rely increasingly on the more costly imports from Norway.[246] Those who could not afford that hired themselves out as guest workers and asked for payment in wood.[247] Furthermore, the people of Iceland had to be content with very modestly sized pieces.[248] A rich variety of different types of roof construction refutes the allegation that wood was "not used in the structure of a building".[249] Owing to the shortage of timber, the development of new building designs was not practicable; the Icelanders had to make do with the old familiar types, although with skilful modifications.[250]
Archaeological finds provide evidence that the technique of erecting an enclosing wall around rows of freestanding columns supporting a roof was not unknown to the Norwegians. Where the walls consisted of stone or daub back home, they were replaced with grass turfs in Iceland.[251] Unlikely as it may seem, Icelandic builders never abolished this practice, despite the fact that moisture could infiltrate between building structure and turf wall – even though their wood was so valuable to them. It surely would have been a simple matter to have extended the roof over the surrounding walls; it never happened.[252]
The Lapps encountered not dissimilar regional conditions; they too lived beyond the tree line. Their very different way of life forced them to develop portable housing which had to be of a very light design that could be rapidly erected and dismantled. It would perhaps have been less troublesome to procure the necessary wood at each camp-site, but as this material was not to be found the Lapps, compelled by the circumstances in which they found themselves, devised an ingenious, simple form of shelter which, as such, was complete in itself and could not be developed further. (Fig. 487) Two "gable poles" were set up in a scissor arrangement. At the junction, a ridge pole was passed through one of the prebored holes; this ridge pole fixed the scissors which leaned inwards. To be able to adapt this portable frame to any ground, the tops of each of the four gable poles were provided with several holes. This adjustable joint also had another benefit: as the Lapps carried their tents between camp-sites, the bottoms of the poles dragged along the ground; therefore, thanks to its several holes the joint took this gradual shortening into account.[253]



484 Sill corner detail – Tomyo-ji hondo, Kanagawa, Japan (according to: ibid., p. 255/1)



485 Only the grain of the wood and the knowledge that it would not otherwise be possible tell us that this sill corner conceals a wood joint. – Toyoda House in Imai cho, Nara, Japan

The lack of timber in Spain led to a totally different development there in the 12th and 13th centuries under the influence of the Moors. In order to realize the dome-like top, which already characterized the Kirghiz tent, in a rigid wooden form, the carpenters[254] of the time developed a very unconventional construction employing boards and small blocks. (Fig. 486) The result thereby obtained is extraordinarily impressive, the method of jointing, on the other hand, one which has not changed since.[255] "We generally have a false impression of the art of timber construction in earlier periods of history. We happily present a picture of crudeness; but we learn that it is a finer picture once we are introduced to the reality."[256]

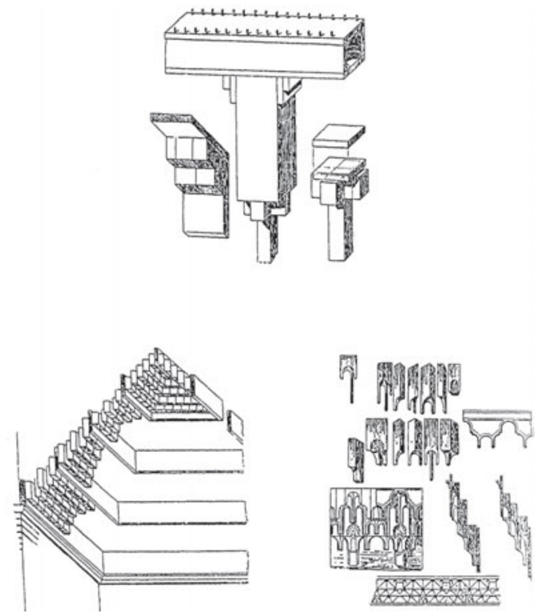
In Italy too, timber found only partial favour as a building material. The reason for this is not so much the shortage of wood but rather deep-rooted traditions.[257] Timber buildings are especially rare in the countryside "and can only be found in a few mountainous districts".[258]

The situation – in terms of development – was reversed in the Erz Mountains and the Sudetenland. It was precisely because of the abundance of the necessary resources[259] and the adoption of the traditional method of building – log construction – that the population had to develop a new approach; the German settlers of the Middle Ages had been accustomed to timber-frame construction.[260] There must have been very compelling reasons which forced them to relinquish this method of building. On the other hand, this knowledge of timber-frame construction suggests that the specific form of support in the *Umgebinde* could have evolved from this. The quality of the timber found in this region did not match that found in the neighbouring Bohemian Forest, where it was quite usual to construct multistorey log buildings. The trees in this region grew with such a pronounced taper that a well-sealed joint could not be achieved. Apart from that, the compressive strength of the timber was lower.[261] In their search for a solution to relieve the load on the logs, they developed the *Umgebinde* form. (Fig. 488)

In those areas of Romania in which building timber in larger sizes was not available, the use of wattlework persisted; (Fig. 489) and not only for housing – places of worship were also built in this way.[262] "There are innumerable churches which only owe their name to their function; the architectural features of all of them are those of houses." Some were never even given a tower.[263]

The situation presented itself very differently in those regions and periods in history in which a shortage of wood was hardly imaginable. It was precisely this abundance of the material which led to this wood-based engineering.[264]

In Europe there are only a few isolated examples which can match the impressiveness of Japanese specimens. The date of the incorporation of a 42.5-m-long head beam in the wheat barn in Cressing Temple, Essex, England, has been proved to be 1260. It must have been one of the tallest oaks of all time.[265] If, generally, the inclusion of extremely long timbers can be taken as an indication of an early completion date (because such pieces became more and more difficult to obtain), we cannot fail to be awestruck by the dimensions of the tie beams in St Paul's Cathedral, London, England: it took years to find and



486 The combination of boards and wooden blocks to produce any three-dimensional form. (source: Uhde, 1903, Vol. II, Figs 126, 127, 138)

487 The framework of a Lapp tent. (source: Sirelius, 1906, Fig. 25)

procure the 50 tie beams, each over 16 m long, which finally arrived on site in 1696.[266]
Large temples needed trees with a very large girth which had grown in particularly dense forests. The pagoda of the Horyu-ji and the eastern pagoda of the Yakushi-ji incorporated such trees which were between 2000 and 2600 years old. The columns of these temples are also made from such species.[267] And Taiwanese trees up to 2000 years old have been used in the newly erected western pagoda.[268] Columns fabricated from half-round trunks as standard was a luxury which could no longer be afforded. Today, the Todai-ji is the largest timber structure in the world. (Fig. 490) Originally, the *Daibutsuden* (Great Buddha Hall) measured approximately 86 x 50 x 50 m high, with the height of the two flanking pagodas exceeding 100 m.[269] Japan is still a country rich in woodlands, but forests which could provide such giant trees have long been a thing of the past, as is the case for the countries of Europe. (Fig. 491) The *Jomon-sugi* on Yakushima Island, Kagoshima, Japan, remind us of such specimens; it is not for nothing that they derive their name from Japan's Neolithic Age (10,000–300 BC).
The straight-grained oaks used for the keel of one Viking ship had to be at least 25 m long. In restoring this ship the Norwegians had to import timber from Canada.[270] They were confronted with the same problem as the Japanese, who these days have to go searching in Vietnam and Laos now that sources in Taiwan have dried up.[271] During the reconstruction of Viking forts it was established that 50 large, old and flawless oak trees were needed per project. The radially split trunks provided planks up to 500 mm wide![272] In stave churches the four main loadbearing corner columns located over the intersections of the interior sill beams exhibited a base girth of up to 2 m.[273] Linking stave structures with scarcity of timber, as some authors have done, seems incomprehensible.[274] It can only have been the availability of first-class material[275] (which we all know can only be selected where sufficient quantities are to be found) which led to the building of such magnificent structures for which, basically, amazingly simple jointing techniques sufficed.
Similar indications of generous volumes of old timber can be found in many European countries. In Romania sill beams almost 1 m wide were used until fairly recently.[276] There is no doubt in Panoiu's mind when he says that "the abundance of timber rendered possible the retention and continuation of traditional building methods".[277] The wooden churches of Slovakia which still stand near the border with the Ukraine indeed include members with a width in excess of 500 mm. Some of Norway's old farmhouses incorporate logs 11 m in length,[278] some of those in Sweden and Finland have floorboards 1 m wide.[279] In Russia log buildings made with logs up to 12 m long and a crown diameter exceeding 500 mm could still be built in the 17th century.[280] The sill beams of the Church of the Assumption of the Virgin in Kondopoga, Karelia, Russia, measure 700 mm.[281] In northern Switzerland ridge-supporting columns up to 16 m high were still being incorporated in houses until up to nearly 100 years ago.[282] For the Church of St John the Baptist in Freising, Bavaria, Germany, dating from the early 14th century, the carpenters of the time thought nothing of cutting away

488 Relieving columns (which exploit the considerably greater compressive strength of the material parallel with the grain) were placed in front of the ground-floor log construction in order to carry the load of the roof or even an upper storey. – Jonsdorf, Saxony, Germany

489 This house near Cicîrlău, Maramureş, Romania, is still wholly in wattlework. The walls are covered with daub.

490 Even in its modern scaled-down version, the Todai-ji daibutsuden, Nara, Japan, is still an imposing edifice.

491 *Gassho-zukuri* houses embedded in a pure forest landscape. – Shirakawa mura, Gifu, Japan

87 % of the cross-section for the suspension of the 500-mm-diameter oak king post![283] The structure to the roof of St Stephan's Cathedral in Vienna, Austria, was built from 2,889 main trunks.[284]
Places whose names reveal that they were once covered by forests[285] can be equally well be taken as indicating the abundance of timber as can vested rights permitting the felling of building timber on common or magisterial land either free of charge or for a low nominal fee.[286] In really remote regions it is still possible to adhere to traditions which in other areas would be regarded as criminal: the "timber-devouring fence" is just one example.[287] (Fig. 492) However, where such fences would have had to be renewed annually,[288] this practice was in most cases abandoned long ago, even in densely wooded areas. And some buildings in the Tatra Mountains bear witness to the fact that builders were never compelled to budget with the material. (Fig. 493)
Mind you, a profusion of timber did not necessarily mean that it would have been available for all to use. At the foot of the Riesen and Adler mountain ranges in the Czech Republic, the socially weaker classes of the population in the 19th century were forced to build so-called *Scheitholzhäuser* (billet-wood houses).[289] (Fig. 493) One example of a quasi-commercial use of a plentiful supply of timber can be found in the Carpathian Mountains. Romanian farmers who had become quite talented carpenters formed themselves into groups, village by village, fabricated small wooden houses and offered them to interested buyers, who then transported them home. "Off-the-shelf" houses were built in this way according to fixed layouts, but individual requests could also be incorporated because the buyer normally chose a particular carpenter whose name had reached him by word of mouth. Originally also produced for more remote areas of Romania and Hungary, after World War 2 the markets became confined to the immediate district. Apparently, churches too were built to order and delivered. So the inscription "Built on this spot – here in Börveli" (today Berveni, Transylvania, Romania) is not as strange as it may appear at first sight.[290]
We are accustomed to expressing values in terms of comparative figures. Towards the end of the 16th century "a decent house" cost 20 roubles "even in areas where forests were not so extensive".[291] At the end of the 15th century the price for a wooden church was estimated at one or two bulls.[292]
Under such Utopian conditions, the way this valuable material was handled must occasionally be quite simply referred to as scandalous.[293] When barns with a plan size of 57 x 15 m have nothing more to support apart from the roof, but still require the felling of 25 oaks 200 years old and 100 pines 120 years old, this can only be described as "irresponsible".[294]
It is hardly surprising that a surplus of material did not inspire economy of usage. And it is equally unsurprising that jointing techniques developed under these circumstances never underwent any changes. "For instance, in Italy it was the normal custom to deal with the problems which a large roof structure posed by employing a simple design but with timbers of massive dimensions."[295] In medieval Italy builders were still applying the "law of relative scale".[296] The dimensions of the members and not the type of construction varied according to the

492 The large quantity of timber contributes to the massive appearance of this fence. – Obernberg, Tyrol, Austria

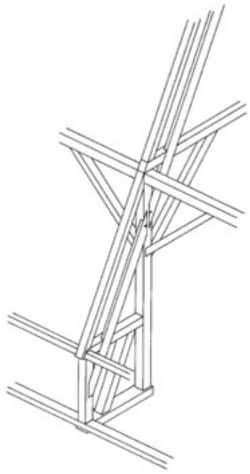
size of the structure. The clear span of the tie beams in Messina Cathedral, Sicily, Italy, was an impressive 14 m; their cross-section was correspondingly large: 800 x 450 mm.[297]
It was only the growing realization of dwindling material resources that forced a rethink of traditional strategies. However, laws and prohibitions,[298] issued by ruling authorities who saw a threat to their economic interests, were not sufficient. Whereas in the past virtually any lengths could be incorporated, (Fig. 494) carpenters were now forced to devise new joints in order to produce the desired lengths artificially. Of course, the actual date varies. In England this process took place around 1300.[299] All roofs above a certain size had to have at least their spars assembled from two pieces. In roofs over both churches and large barns it proved relatively easy to incorporate supports for the joints. (Figs 495 & 496) Japan faced this predicament around 1100. The reconstruction of the Todai-ji one hundred years later brought this problem harshly to light: owing to a lack of the usual building timber and a lack of knowledge of how to combat this situation, the Japanese were forced to shelve the project for several years. While at that time the problem could be bypassed by simply waiting, the more recent restoration at the start of the 20th century had to rely on the help of steel to preserve the accustomed appearance of the temple for future generations.[300]
New problems demanded new ideas. Straight-grained timber had to be replaced with pieces which were becoming less and less straight, easily split species by those split less easily or only with difficulty, nice long growths by ever shorter pieces. In order

493 The short *Holzscheite* (billets of wood) used to build the walls led to such houses being called *Scheitholzhäuser*. – Vitanov, Slovakia

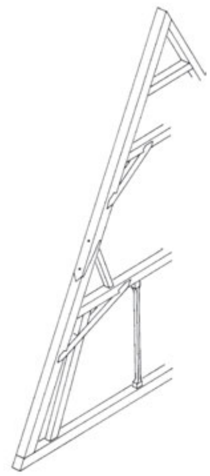
494 A "Cathedral of Timber Construction": The barley barn at Cressing Temple, Essex, England, dates from the beginning of the 13th century.

to maintain the balance between material and labour costs, diminishing resources were offset by more complicated joints.[301] Besides new joints, this also led to a surge in tool development.[302] As long as nails, screws, metal straps, etc. remained too expensive,[303] the intuition of the carpenter was in demand. Even before declining reserves forced the splicing together of short pieces to obtain the required lengths, carpenters had been faced with the problem of devising lengthening joints, at least for the central columns of the pagodas. Splicing joints have a very low compressive strength. Therefore, they were often secured by iron straps when it was felt that the building's importance warranted this.[304] The huge central columns of the pagodas were required to do nothing more than support the apex of the pagoda. It would seem though that not even the *kai-no-kuchi* joint was considered sufficiently capable of withstanding all the possible load combinations that could occur. (Figs 497 & 498) This joint was also known, but without tongues, in France[305] and in Germany, where it obviously did not enjoy unanimous support: "The X-shaped stub tenon, as it is designated in all textbooks, is a perfect example of a poor joint."[306] The need for a lengthening joint may also have been quite simply a result of the carpenters not being able to handle the often gigantic trunks in one piece. Although the early pagoda columns were all allegedly made from a single piece of timber, those for the Horyu-ji, Hoki-ji and Horin-ji were all fabricated from two.[307] And this problem was not only confined to Japan. As the carpenters working on the Freiburg Minster, Baden-Württemberg, Germany, could not tenon the king post of the bell-tower into its position as was normally the case, they had to invent a joint to deal with this one-off situation. (Fig. 499) However, European splicing joints were seldom as impressive as Japanese versions. When a carpenter in Europe went out of his way to design a new joint, in the 19th century he had to accept being ridiculed.[308]

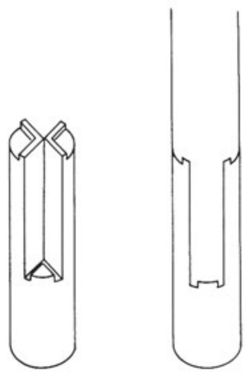
However, a problem which carpenters encountered far more frequently than that of how to extend a vertical element was



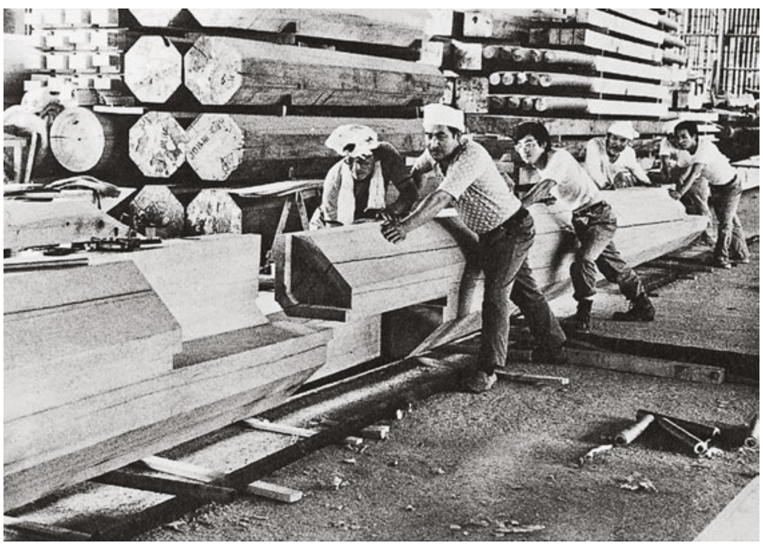
495 In the wheat barn at Cressing Temple, Essex, England, both spars and secondary spars were made from two pieces. (according to: Hewett, 1980, Fig. 90)



496 In Lincoln Cathedral, Lincolnshire, England, the spar splices over the Angel Choir were supported by suitable struts. (according to: ibid., Fig. 101)

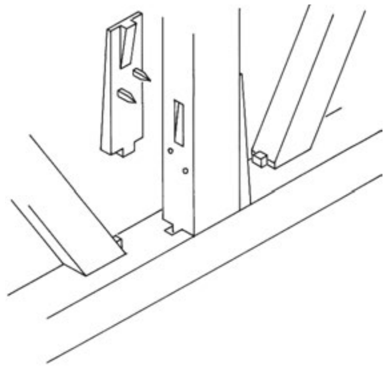


497 *Kai-no-kuchi-tsugi* (joint like the mouth of a shellfish)



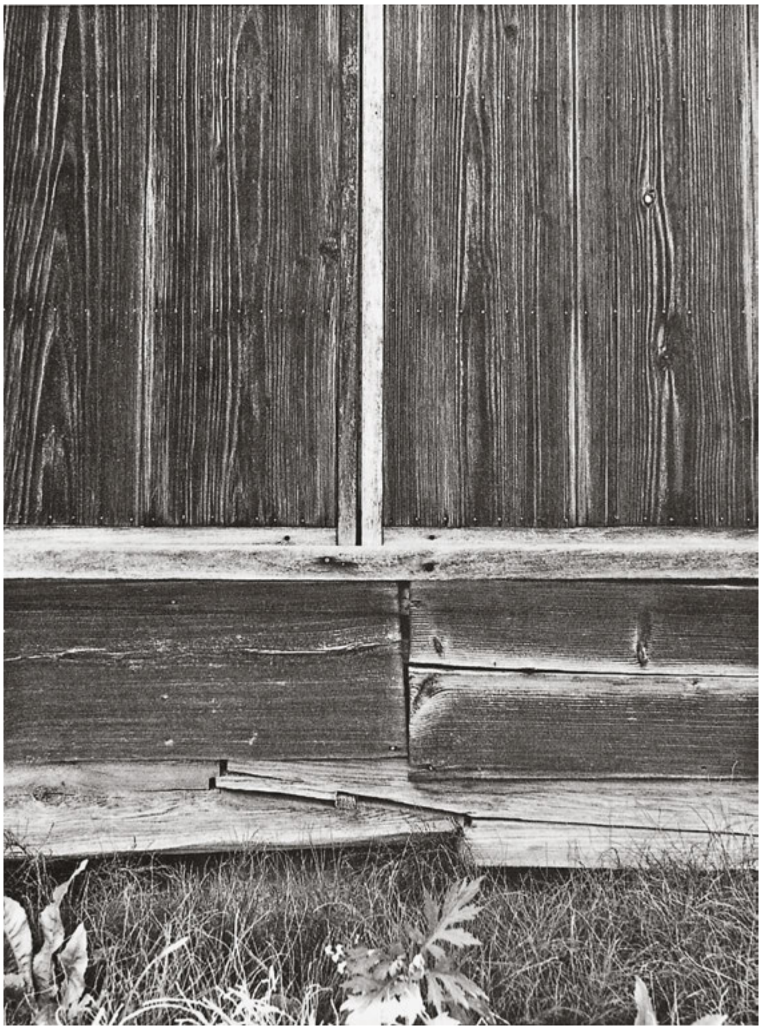
498 Assembling two pieces of the central column of the re-erected Yakushi-ji Pagoda, Nara, Japan. (photo: Teraoka, Fusao; in: Nishioka et al., Soshisya, 1981)

the matter of splicing horizontal members when pieces of sufficient length were not available. The task of the joint in this case is totally different to that in vertical members. A column splice is very seldom subjected to tensile forces and can, in principle, be installed wherever necessary. The joints in horizontal members have to be devised very differently in line with the nature of the supports. There are many places at which they cannot be incorporated at all. Although the splayed-and-tabled scarf was a widespread form which was very popular because it was easily produced, it was not capable of resisting much tension, despite its table; and the sort of applications where this joint was employed did not need to exploit its compressive strength. A bridled abutment was useful in preventing lateral buckling. (Fig. 504) In the Japanese language there is no difference between such a joint with or without a table; both versions are called *daimochi-tsugi*.
The splayed-and-tabled scarf with tongue is capable of taking a certain amount of tension. One of the many variations on this joint again includes a bridled abutment to prevent lateral buckling, this time also possible in the middle of the tongue. (Fig. 501) The joint only becomes worthwhile with the addition of the key. In many cases two "folding" wedges, when driven against each other, force the two tongues firmly into their respective rebates. Not common in Europe was the edge-halved scarf secured by means of a *shachisen* inserted at an angle. (Fig. 502) As the two halves of the joint do not include a table in this case, the chance of obtaining really tight wedging has been missed. These two examples demonstrate how the material properties make this joint relatively susceptible to vertical twisting. The latter joint, but with table, is often referred to as a *Französisches Schloß* (splayed, tabled and keyed scarf with tongue as well as bridled and squared abutments – Figs 505 & 506). This very distinctive name already suggests the value which

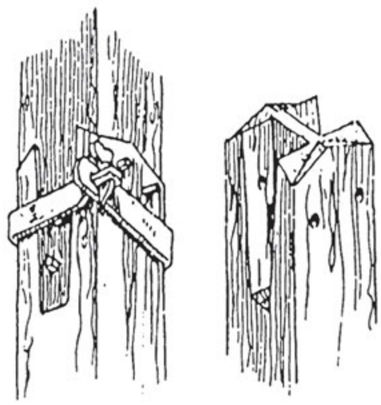


499 In order to set up the almost 18-m-high bell-tower of the Freiburg Minster, Baden-Württemberg, Germany, the mortise had to be made such a size that the support's tenon could be rotated into place. Tenoned wooden fishplates filled in the oversized hole. (according to: Phleps, 1967, Fig. 174)

500 Every support of the Rinshun kaku in the Sankeien, Kanagawa, Japan, has a new base. The horizontal members which brace the construction are in each case spliced at the point where they intersect the support.



501 A *kanawa-tsugi* in a sill beam. – Iwate Futsukamachi, Iwate, Japan



503 A splice in the tower of St John the Baptist's Church, Lüneburg, Lower Saxony, Germany. (source: Ostendorf, 1908, Fig. 318g)

502 The bridled abutment prevents lateral buckling. – Iwate Futsukamachi, Iwate, Japan

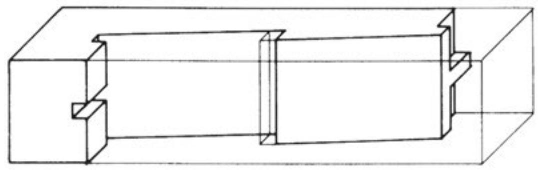
504 A beam from the old roof truss of the Natural History Museum in Vienna, Austria.

carpenters attached to this joint. In Europe the only disadvantage with which it is credited is the great effort required to produce it.[309] A very similar example was the *Jupiterschnitt*, a splayed-and-tabled keyed scarf with sallied vertical abutments. (Fig. 507)

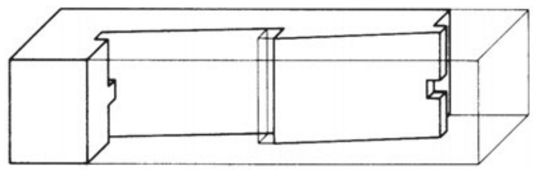
To ease the amount of work involved, carpenters in Germany happily substituted a sallied abutment for the bridled version.[310] It fulfils the same function and, at least on one side, can be produced by just two saw-cuts. In the examples from England it is noticeable that the English carpenters did not hesitate to combine the two versions. (Fig. 508) In chronological terms it was a short step from the joint which relied on numerous wooden nails for its shear strength (Fig. 509) to the joint which Hewett says he found in the head beam of Place House in Ware, Hertfordshire, England, (1295) and which he calls the "apogee of English scarfing".[311] (Fig. 510) But here too, our attention is immediately drawn to the use of so many wooden nails. Regardless of how the carpenter shaped his joint, he did not want to forego the safety which the traditional method of nailing promised. In some cases one feels reminded of nailing plates: up to 12 wooden nails were driven into scarf joints with just oblique shoulders.[312] The speciality of the header joint in Place House lies in the tenons which reinforce the effect of the sallied abutment. In each case they run towards the table in order not to weaken the other half too much. Therefore, the joint would be designed for tension taken on the table, compression from above and below taken by the under-squinted abutments and, last but not least, lateral pressure taken by sallied abutments and tenons. Every one of these functions is backed up by at least one wooden nail.

A comparison of two head beams from Kent, England, proves particularly interesting in the issue of which matters carpenters explored. (Fig. 511) At first sight it appears that the directions of the angles of the abutments are due to a whim of the creator; and, astonishingly, Hewett attributes the differences to exactly that reason.[313] Looked at from a purely engineering point of view, the use of so many wooden nails may well make the two versions identical. However, if one visualizes the loads acting on the assembly and, step by step, builds up a picture of a joint which satisfies the criteria, a suspicion arises that an inattentive apprentice had erred in marking out the second version.

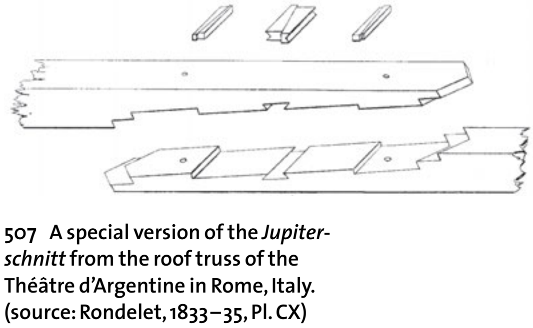
A further development of the splicing joint which took place in England is represented by its rotation through 90° .[314] Neither Graubner nor Gerner can provide evidence of one single example to prove that this development also took place in Germany. However, this form of the joint is very much in evidence in Japan. *Okkake-daisen* (splayed-and-tabled scarf with tongue) joints are, logically, no longer secured with *shachisen*, for the wedge(s) would then lie vertically and would be stressed in an extremely disadvantageous manner. The joint was once again secured horizontally by the *daisen* (large peg) from whence the joint takes its name. Actually, this rotation of the joint only became sensible as carpenters also adapted its shape. The bridled abutment was no longer useful, the tongue alone proving adequate. As the two halves of the joint were now no longer pressed together by *shachisen*, the tables of the two scarfs had



505 The *Französisches Schloß*, in Japan known as the *kanawa-tsugi*. The shape of this joint differs in detail between Europe and Japan. The Japanese abutments and rebates are considerably narrower than the European ones. (source: *Uchida yoshichika*, 1993, Fig. 4–6–3)

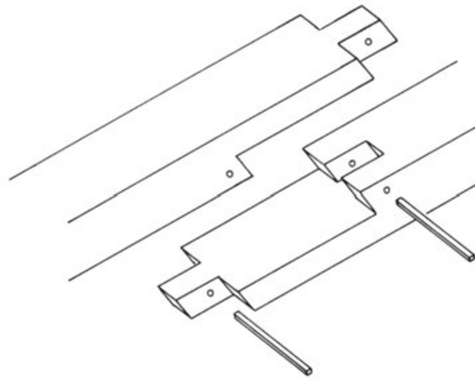


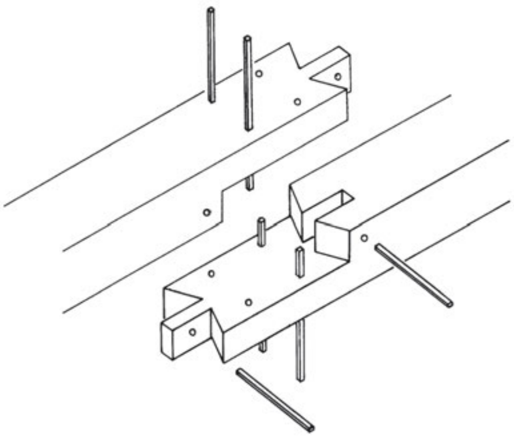
506 *Shiribasami-tsugi* is the name given to the same joint but with the bridled abutment concealed on the inside (for use in exposed positions). (source: ibid., Fig. 4–7–3)



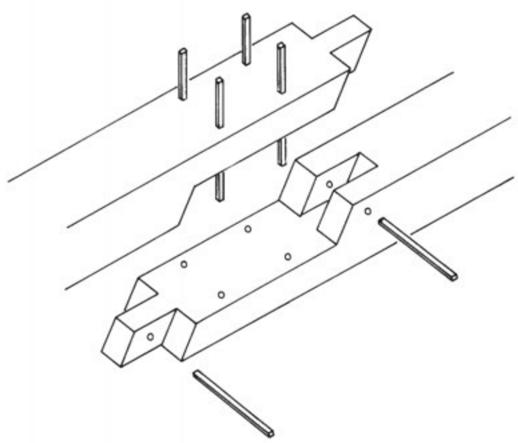
507 A special version of the *Jupiterschnitt* from the roof truss of the Théâtre d'Argentine in Rome, Italy. (source: Rondelet, 1833–35, Pl. CX)

to match exactly. Therefore, the damaging frictional resistance generated when assembling the pieces could only be avoided by cutting the tables at a slight angle. This prudence, which despite a perfect fit (according to human judgement) still allows the pieces to be easily assembled, is a distinct speciality of Japanese carpenters. It manifests itself in many other joints, e. g. the gooseneck tenon *(kama-tsugi)*, the end of which tapers conically towards the centre of the joint.[315]
A description of Japanese joints cannot overlook the *kama-tsugi*. It is no stranger to Europeans. (Fig. 512) but its importance in Japan is immeasurably greater; this is best assessed in terms of its frequency. It was even used as a spline joint, the *chigiri-tsugi*.[316] Far superior to the dovetail in terms of tensile strength, its primary problem was the long neck. A whole series of modi-

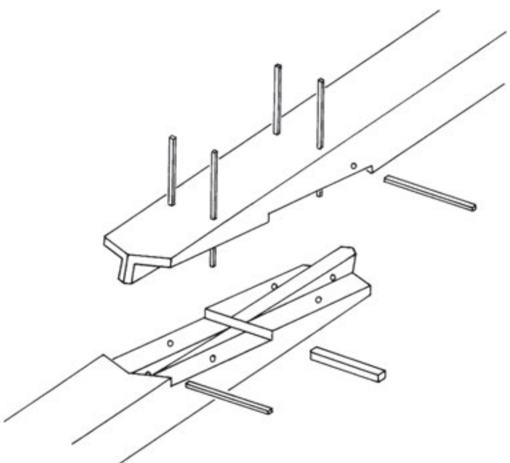




508 A joint used on barns in Essex, England. (according to: Hewett, 1980, Fig. 264)

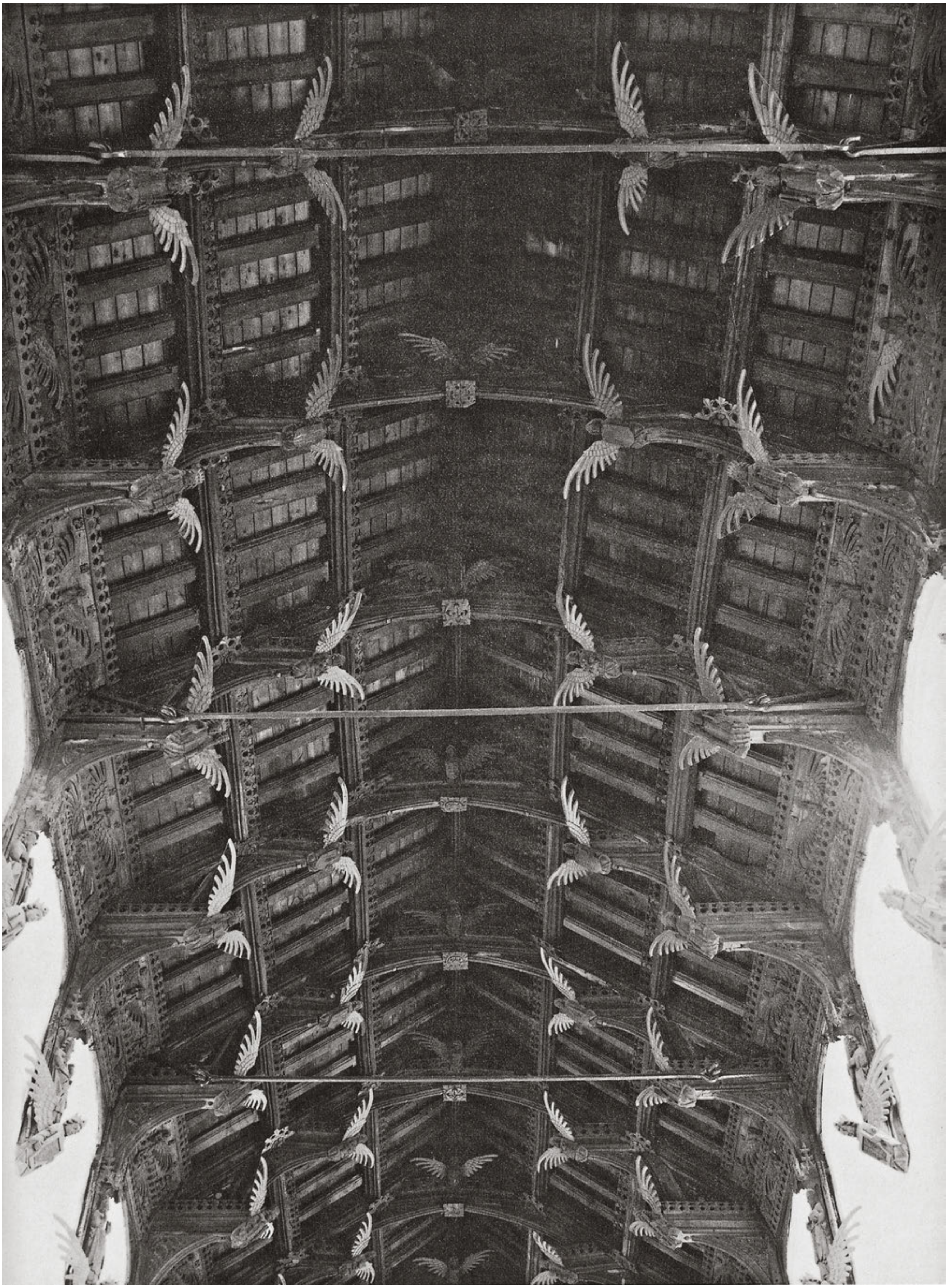


511 Splicing in the Old Vicarage in Headcorn, Kent, England. (according to: ibid., Figs 266, 267)



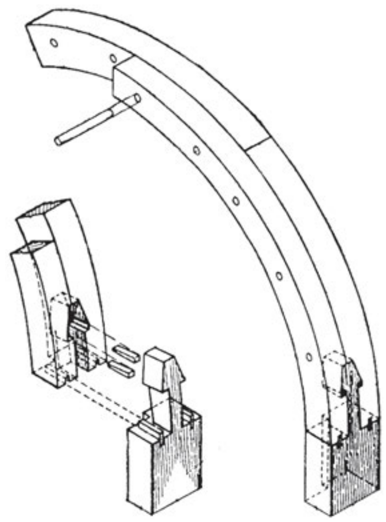
510 The conspicuous rarity of this joint in Place House, Ware, Hertfordshire, England, corresponds to its costly fabrication. (Hewett, 1980, p. 271) It is wholly understandable why the joints of later periods were simpler. (according to: ibid., Fig. 252)

509 Splicing joint in the head beam of the barn in Grönloh, Lower Saxony, Germany, in the Cloppenburg Open-air Museum.

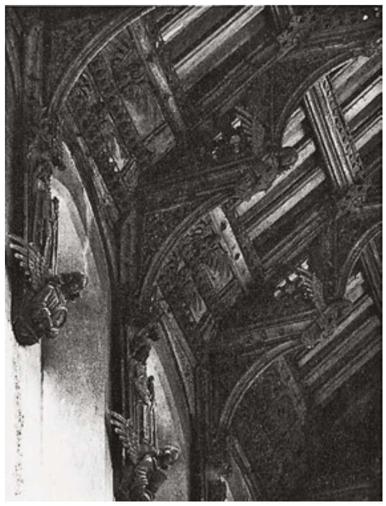


514 Iron tie-rods are essential in the hammer beam roof at St Wendreda in March, Cambridgeshire, England.

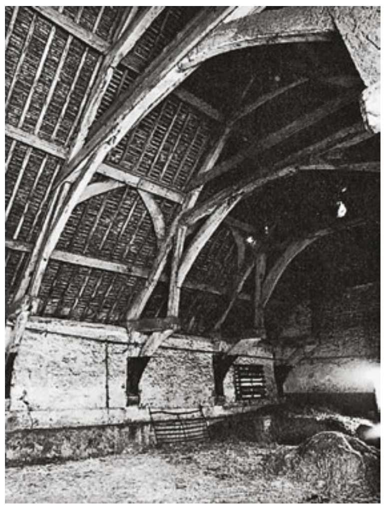
fications remedied this defect, including half-laps, bridled abutments and tongues.
Joints of greater complexity were more expensive to produce. The value of wood in 17th-century England is described by Brunskill[317]: "Bark was much in demand by tanners and could be worth as much as the growing timber itself … [and] would more than pay for the felling, … the thinner and otherwise useless branches, when sold, would pay … for carriage as far as twenty miles, the chips resulting from trimming would pay for the cost of the trimming and, if the timber was to be squared, the slabs of rounded section would pay for the sawing." Consequently, the timber required was made available "free of charge" and so material costs did not need to be added to the costs of the carpenter, by now increasingly in demand.[318]
Only in exceptional cases were clients prepared and able to pay for the wood required to be transported over long distances. The Schaffhausen bridge (Switzerland) was considered important enough to have 400 fir trees felled in the Bregenz Forest (Austria).[319] In Russia the difficulties associated with transportation over long distances were likewise only tolerated in very special individual cases, "for the building of very important structures".[320] Japanese builders were prepared to ship the main columns well over 50 km as long ago as the construction of the Todai-ji; and for the restoration 300 years later they moved the massive trunks several hundred kilometres from the west coast of Honshu to Nara.[321]
If in view of these difficulties people were, in principle, not prepared to refrain from building with wood, the mental agility of the carpenter was indispensable. The development of the *Bundwerk* was, in its early stages as an economic form of timber construction, besides new joints, another answer to the question of "What next?" Emergency measures introduced only disclosed their effects generations later. Japan was the first.[322] And in Norway too it is said that a number of foresighted masters recognized the danger looming and planted their own pine forests to guarantee an adequate supply of wood for stave churches.[323] However, an untouched man-made forest would be a contradiction in itself – such a thing is not possible.
"The earlier a civilization experienced a Golden Age of timber architecture in its history, the sooner it lost its forests."[324] The building boom of the Middle Ages took its toll in Japan[325] just as it did in Europe. The establishment of the *zenshuyo* in Japan also falls within this period. This new style of timber architecture, with its use of shorter and smaller-sized members, was ideally suited to countering the emerging crisis. In Europe the transition to Gothic architecture, whose stylistic and constructional demands exceeded what was feasible in wood, should have represented a noticeable easing of the situation.[326] However, the demand for and consumption of material was not determined by the very elaborate but, compared with the total volume of building, diminishing proportion of prestige buildings such as churches and temples. It was an ever-decreasing circle: exploding populations, expanding towns and cities, which increased the transport problems of the necessary building material. Further forest clearances and, not least, disastrous wars enabled the shortages to be felt more and more keenly. During World War 2 the plundering of timber reserves in Japan



512 A haunched gooseneck tenon *(mechigai-kama-tsugi)* – McKay calls it a "hammerheaded key tenon" – was used by English cabinetmakers for door frames. (source: McKay, 1946, Fig. 77)



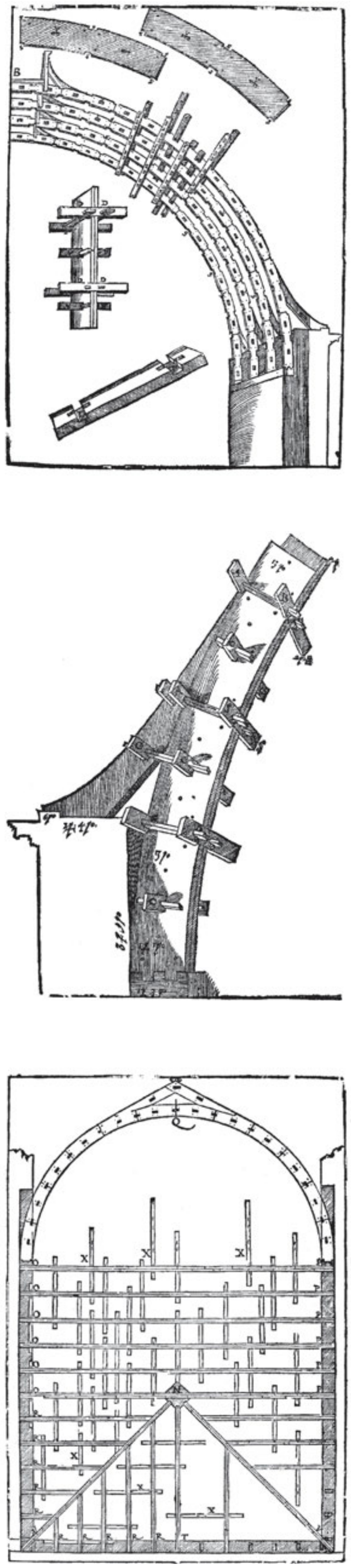
513 Detail of the hammer beam roof over the Church in Woolpit, Suffolk, England.



515 This form of construction can be studied at close quarters in this cowshed in Tarrant Crawford, Dorset, England.

was so extensive that there was no longer enough bark available to carry out essential roof repairs. It was during this period that sheet roof coverings started to appear.[327]
As mentioned above, one important aspect of timber construction was the possibility of using relatively short pieces. The hammer beam roof, introduced during the 14th century,[328] was a truly virtuosic treatment of short pieces of wood. (Fig. 513) However, the most impressive specimens reveal the weaknesses of this type of roof construction: the greater the span, the less effective the collar, which has to be located higher and higher. (Fig. 514) At the point where spar, hammer beam, post and purlin-like longitudinal bracing members meet, the construction is seriously impaired by the three-dimensional intersection. Further, the wide opening at the base of the roof is to some extent negated by the hammer beam at the top of the wall. (Fig. 515)
Exciting in its foresightedness is the invention[329] which Philibert de l'Orme demonstrated in 1626.[330] By breaking with tradition, he developed, almost prophetically, a form of construction which is even more closely linked with traditional carpentry than today's laminated beams because it does not utilize any form of adhesive. (Fig. 516) According to the inventor the advantages were: the use of short pieces of wood and freshly felled timber, the much cheaper form of construction (lower material and labour costs), the easy replacement of defective pieces and, last but not least, the relative independence from other trades. Roof constructions can be erected on masonry walls which would not normally be adequate to withstand the forces present in conventional roof designs.[331] This radical approach is probably the reason why this development was never used in de l'Orme's home country, France. Even a poem written by the inventor was not sufficient to entice willing builders:

> … Small timbers I wonder at thee who with the acumen
> of the artist
> Join together to form mighty towers;
> Thick beams and spars will now and for ever
> Be banished from their burdened houses.
> Soon we will build with a thrifty hand the illustrious edifice
> That otherwise consumes princely treasures.[332]

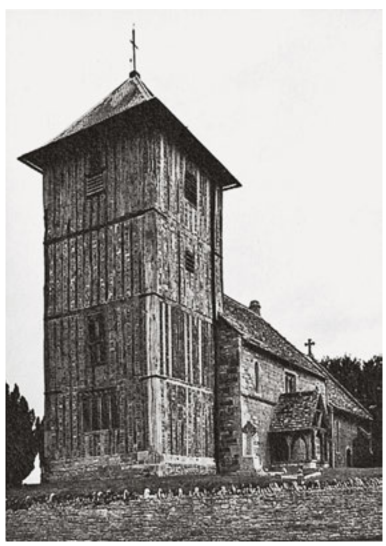


516 (source: De l'Orme, 1626, Vol. X, *Nouvelles inventions pour bien bastir*)

The same applies to wood as to many other things in life which are unattainable or rare and which awaken desires and become status symbols. King Henry VIII of England had the floor of his ballroom in Leeds Castle, Kent, England, made from ebony. Katsura Rikyu is sometimes still defined by the inclusion of only the very finest types of wood. The columns in English and French timber-framed buildings cannot be packed tightly enough,[333] (Fig. 518) and in Germany property owners used the gables of their houses to parade their wealth. (Fig. 517) In the course of transferring the Wehlburg farmstead to the Cloppenburg Open-air Museum, Germany, the continuing rivalry between this and the neighbouring Wohnunger farm, also built in 1750, was verified. After this had been built, the concept started for the gable end only as a pretence – six columns and triple rails left and right of the entrance – was changed to the victorious eight columns and six-fold rails![334] And Swedish country mansions were given a storey which could not be used at all in winter because it was virtually impossible to heat.[335]
Of course, Japan did not remain immune to such vanity. The thicker and larger, the rarer the species of wood, the more suitable was the *daikoku-bashira* or the *toko-bashira* for signifying the wealth of its owner. Innovative accomplishments were, admittedly, not linked to such excessive expressions of grandeur.

517 Quatmann farmhouse from Elsten, Lower Saxony, Germany, in the Cloppenburg Open-air Museum.

518 The panels between the columns are no wider than the columns themselves! – Upleadon. Gloucestershire, England



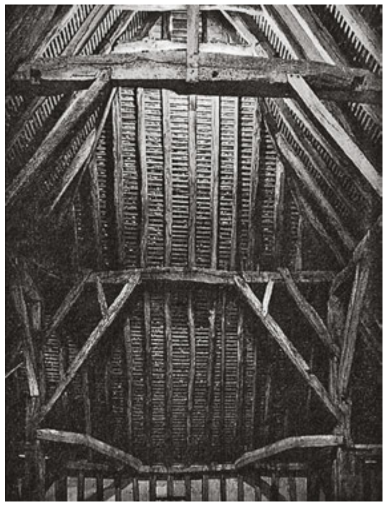
1 Graubner, 1986, p. 40
2 Schier, 1951, p. 6
3 Sirelius, 1906–09
4 Ahrens, 1990, p. 126
5 Florin, 1937, p. 24
6 Schier, 1951, p. 15; Schulz, 1964, p. 10; Meringer, 1898, p. 185
7 Petrescu, 1974, p. 10; Blaser, 1975, Fig. 172; Meringer, 1900, p. 7; Schier, 1966, p. 87 f.
8 Ibid., p. 17
9 Ibid., pp. 344, 357
10 Ahrens, 1981, p. 130 f.
11 Moser, 1992, p. 42; Erixon, 1953, p. 341
12 Foltyn, 1960, p. 36
13 Conrad, 1990, p. 200 f.
14 Kawashima, 1990, p. 38 ff.
15 Phleps, 1958, p. 15; Reinerth, 1937, p. 79
16 Zippelius, 1954, p. 27; Phleps, 1914, p. 19 f.
17 Erixon, 1925A, 1925B
18 This period, corresponding to the European Neolithic Age, owes its name to the characteristic rope pattern with which the pottery of the period was decorated. (Itoh, 1982, p. 127)
19 Coaldrake, 1990, p. 94; Seike, 1981, p. 8
20 Soper, 1990, p. 278
21 Soper claims that Stone-Age hunters and fishermen never knew of the existence of stone tools. (ibid., p. 275)
22 Coaldrake, ibid., p. 92 ff.
23 For Gerner, forked branches are the first "true joints". (Gerner, 1992, p. 14)
24 Gschwend, 1988, p. 11
25 Ibid.
26 Phleps, 1935, p. 25 f.
27 Schier, 1951, p. 17; Moser, 1990, pp. 43, 151; Zippelius, 1954, p. 12
28 Oelmann, 1907, p. 6
29 Ahrens, 1990, p. 85
30 Gschwend, 1988, p. 11
31 Radig, 1937, p. 58
32 Zippelius, 1958, p. 13
33 Ibid., p. 14 f.
34 Ibid., p. 17
35 Gerner, 1992, p. 11
36 Reinerth, 1929, p. 131 ff.; Ahrens, 1990, p. 94; Lissenko, 1989, p. 30; Zippelius, 1954, p. 31
37 Sirelius, 1909, p. 63
38 Itoh, 1973, p. 23
39 Nishi, Hozumi, 1985, p. 54
40 Watanabe, ibid., p. 110
41 Zippelius, 1954, p. 34 f., Fig. 10c
42 Ibid., Figs 10a, b
43 Muramatsu, 1992, p. 22
44 Schadwinkel et al., 1986, p. 207
45 Schier, 1966, p. 104; Riedl, 1953, p. 28; Ando et al., 1995, p. 136
46 Muramatsu, ibid., p. 21 f.
47 Gerner, 1986, p. 25. Klöckner sets this date one hundred years earlier. (Klöckner, 1978, p. 11)
48 Exhibition catalogue *Holzbaukunst in Vorarlberg*, 1990, p. 7
49 Coaldrake, 1990, p. 107
50 Ibid., p. 111
51 *Nihon kenchiku gakai*, 1992, p. 99, Fig. 1; Coaldrake, ibid., Fig. 120; *INAX* 4/3, 1984, p. 24
52 *Bunkazai …*, 1986
53 Coaldrake, 1990, p. 107
54 Schadwinkel, ibid., p. 140
55 Fletcher, Spokes, 1964, p. 117
56 Schier, 1937, p. 25
57 Schier, 1966, p. 100 f.
58 We must attribute it to the unquestioning loyalty to tradition that collar beams in trussed spar roofs are still provided with dovetailed laps – not particularly difficult to produce but, nevertheless, requiring more effort. This type of connection is really only useful for the rafter roof.
59 Carstensen, 1937, p. 45 ff.
60 Holan, 1990, p. 147; Werner, 1978, p. 204 ff.; Phleps, 1939, p. 103 f.; Bünker, 1897, pp. 169, 177, 186 f.
61 Ibid., p. 187; Moser, 1985, p. 121 f.
62 Bergenhus, 1991, p. 15 f.; Berg, 1981, p. 356
63 Erixon, 1937A, p. 11; ibid., 1937B, pp. 20, 25
64 Ibid., p. 15, Fig. 3, p. 20
65 Nakahara, 1990, p. 58
66 Phleps, 1958, p. 44, Fig. 92; Seesselberg, 1891, p. 69
67 Ahrens, 1981, p. 176 f., Figs 112, 118, 121
68 Ahrens describes a permanent shelter dating from 6500 BC (Ahrens, 1990, p. 79 f.)
69 Coaldrake, 1990, p. 96
70 Breymann, 1900, p. 3
71 Lissenko, 1989, p. 217 ff.
72 Schepers, 1985, p. 17. According to Schepers (ibid.) the term motte-tower is derived from the French "la motte" (mound, knoll).
73 Hirai, 1980, p. 9
74 Brunskill, 1985, p. 40
75 Schier, 1966, p. 345
76 Moser, 1992, p. 122; Norberg-Schulz, 1979, p. 17
77 Hauglid, 1992, p. 13; Laws, 1992, p. 15
78 Phleps, 1939, p. 93. Phleps' quote is incorrect (cf. Dietrichson, Munthe, 1893, p. 107).
79 Research into housing has not yet clearly established the actual reason for the covering with daub. Schier presents this uncertainty to us indirectly: in the chapter on wattling he describes the daub covering on log construction as a continuation of the old wattle-and-daub technique, whereas in the chapter on the storehouse he specifies better fire protection as the reason for the covering with daub. (Schier, 1966, pp. 91, 361) And when Mayer lists protection against moisture alongside fire protection, we only need to take one look at the examples in Japan to throw this into a doubtful light. (Mayer, 1986, p. 40)
80 Dietrichson, Munthe, 1893, p. 119; Holan, 1990, p. 89 f. Some authors specify this date as being as late as the 18th century. (Bresson, 1981, p. 92; Bugge, Norberg-Schulz, 1969, p. 19)
81 Keim, 1976, p. 167; Coaldrake, 1990, p. 96; Itoh, 1973, p. 23. The view that this development originated in northern regions (cf. e. g. Phleps, 1940, text to Pl. 32; Phleps, 1942, p. 171) is also given a detailed rejection by Keim. (ibid., p. 166 ff.)
82 Schweizer Ing. und Arch.-Verein, 1902–04, p. 24; Uhde, 1903, Fig. 370; Sirelius, 1908, p. 23; Laws, 1992, p. 14; Blomstedt, Sucksdorff, 1902, p. 78 f., Pl. 18/3
83 Ibid., p. 41, Fig. 11
84 Keim, 1976, p. 66 f., Fig. 9
85 Ibid., p. 63
86 Christie, 1974, p. 43, Fig. 31
87 Ahrens, 1981, p. 127; Christie, 1976, p. 18
88 Ueda, 1990, pp. 85, 90
89 The Yayoi came from the mainland and, thanks to their superior culture, dominated the Japanese archipelago during the Bronze and Iron Ages.
90 Itoh, 1973, p. 25
91 Schier, 1966, p. 345 f.
92 One predecessor of the present shrine is said to have been bigger than the Todai-ji. It collapsed several times because, owing to its height, the rotting of the upper parts of the columns quite simply went unnoticed. (Horiguchi, 1961/3, pp. 10, 13)
93 For a typology of the *kura* see Itoh, 1973.
94 Ueda, ibid., p. 37
95 Itoh, 1973, p. 32

96 Ibid., p. 44
97 Schier, 1966, p. 89 f.
98 Petrescu, 1974, p. 57; Stepan, Va$r$eka, 1991, pp. 301, 304
99 Mayer has pointed out in detail the divergent opinions of art historians and ethnologists. (Mayer, 1986, p. 108, note 96)
100 Nishi, Hozumi, 1985, p. 54
101 Keim, 1976, p. 87; Thiede, 1937, p. 82
102 Sirelius, 1908, 1909; Schmidt, 1950, p. 107; Haberlandt, 1934, p. 19 f., Pl. I, Figs 1, 4, 5a, 5b
103 Panoiu, 1967/68, p. 99
104 Ibid., p. 98; Wolf, 1979, p. 33, Fig. 4
105 Blomstedt, Sucksdorff, 1902, p. 139; Opolownikow, 1986, p. 27, Fig. 18; Lissenko, 1989, p. 71
106 Ibid.; Faensen, Iwanow, 1972, p. 509
107 Gerner, 1992, p. 155
108 Faensen, Iwanow, ibid., p. 502
109 Sirelius, 1909, p. 70 f.; Lissenko, 1989, p. 29
110 Blomstedt, Sucksdorff, 1902, Fig. 52; Sirelius, 1908, Figs 104, 105
111 In many regions this practice was never discarded.
112 In south-eastern Sweden right-angled jointing notches were common. (Erixon, 1937B, Figs 17, 18, 20)
113 Berg, 1981, p. 358
114 Ibid.; Berg, 1994, p. 56
115 Two suggestions have been put forward as reasons for this twin-track approach: independent development (Christie, 1976, p. 38 ff.) versus imitations of stone churches (Ahrens, 1981, p. 188).
116 For the not inconsiderable number of other forms see: Lissenko, 1989, p. 34; Schulz, 1964, p. 221, Figs 7, 12; Erixon, 1937B, Fig. 3
117 Norberg-Schulz, 1979, p. 11
118 Mayer, 1989, p. 39; Dâncu$s$, 1995, p. 26
119 Bedal, K., 1975B, p. 40
120 Bedal, K., 1975A, p. 29
121 Murashige, 1991, Figs 1, 34, 38, pp. 77–79
122 Asano, 1959/1, 2, p. 70
123 Bugge, Norberg-Schulz, 1969, p. 58
124 Phleps, 1942, p. 69
125 Phleps, ibid., p. 66 ff.; Keim, 1976, p. 85
126 Gschwend, 1969/6, p. 5, 1988, p. 277; Phleps, 1942, p. 71
127 Sirelius, 1908, p. 32
128 Lissenko, 1989, pp. 76, 134; Blomstedt, Sucksdorff, 1902, p. 124; Blaser, 1975, p. 49
129 Sirelius, 1909, p. 72; Uhde, 1903, p. 315, Fig. 370
130 Gschwend, 1972/10, p. 9, 1988, p. 186
131 Murashige, 1991, p. 33
132 Christie, 1976, Figs 27A, C; Holan, 1990, p. 159; Berg, 1981, p. 361
133 cf. "The Properties of Wood"
134 Phleps has studied in great detail the various types of sliding joints which took account of the differing shrinkage behaviour of the material with and across the grain, and which ultimately enabled the inclusion of doors and windows simultaneously with the log wall. (Phleps, 1942, pp. 158–223) Care should be exercised with respect to his conclusions regarding the chronological order of the various joints. (cf. Keim, 1976, p. 138, Fig. 28c)
135 Phleps, ibid., p. 70/1
136 Moser, 1955, p. 529 ff.
137 Strzygowski, 1940, p. 38 f.; Ahrens, ibid., p. 193 ff., Figs 134-136
138 Lissenko, 1989, p. 148
139 Strzygowski, ibid., p. 39
140 Faensen, Iwanow, 1972, pp. 40, 48 f., 506
141 Blaser, 1975, p. 135; Petrescu, 1974, Fig. 146, p. 40
142 Horiguchi, 1961/3, pp. 10, 13
143 Watanabe, 1974, p. 158 ff.
144 Ibid., folded enc. 3. We come closer to understanding these doubts when we compare Fukuyama Toshio's older restoration drawings with his updated versions. (ibid., p. 89, folded enc. 3; Horiguchi, ibid., p. 10) Only in these later revisions does he take account of the fact that, during the period in question, joining horizontal members to columns by means of through-tenons was not yet possible.
145 Schepers, 1985, p. 18
146 Franke, 1936, p. 39
146A A *Bundwerk* is a braced column-and beam construction which has boards nailed to its inside face to form a solid wall. Over the course of time this, initially, low-budget form of construction was given far more diagonal bracing than was necessary in a decorative arrangement, as well as decorated lap joints to the bracing, thus turning it increasingly into an expression of the owner's prosperity.
147 Knesch, 1991, p. 7
148 Hanftmann, 1907, p. 112
149 Bedal, A. & K., 1975, p. 169; Bedal, A., 1985, p. 272
150 Fletcher, Spokes, 1964, p. 157
151 Eitzen, 1963, p. 28
152 Bedal, A., 1985, p. 278
153 Gerner, ibid., p. 29
154 Exhibition catalogue *Holzbaukunst in Vorarlberg*, 1990, p. 23
155 Asano, 1985, p. 4
156 The *daibutsuyo* (great Buddha style) owes its name to the Todai-ji and Jodo-ji, two gigantic structures which contain large statues of Buddha.
157 Christie, 1981, p. 371; Dietrichson, Munthe, 1893, p. 36
158 Ahrens, 1981, p. 159 ff., Figs 106-108
159 In 1199 there was still timber available with which a hall larger than 50 x 50 m could be roofed over in one clear span supported on just four corner columns!
160 Kawashima, 1990, p. 83
161 Eitzen, 1954, pp. 37–76; Ostendorf, 1908, p. 4
162 Klöckner, 1978, p. 22; Kaiser, Ottenjann, 1988, p. 111 f.; Gerner, 1979, p. 40
163 Hewett, 1980, Figs 275, 276
164 Klöckner, ibid.
165 Eitzen, ibid., p. 67
166 Großmann, ibid., p. 132
167 Kawashima, ibid., p. 77
168 Parent, 1985
169 *Bunkazai* …, 1986
170 Kawashima, ibid., p. 82
171 For the importance of the ridge-supporting post or column see: Schier, 1966, p. 27 f., *Lex Alamannorum* 94/1, *Lex Baiuvariorum* 10
172 Kurata, 1958/5, p. 69
173 A *shachisen* is a key of rectangular cross-section which is normally employed as the retainer in the keyed mortise and tenon joint. Exactly like our dowelled beams, it is placed perpendicular to the direction of tension.
174 cf. p. 92
175 A *warikusabi* is a wedge which is driven into the end grain of a tenon (foxtail wedging). The wedges jam the tenon against the sides of the mortise and thus hold the joint tight. At the same time, the sides of the slot prevent the tenon from splitting in case the wedges should be driven in too forcefully.
176 A *daisen* is a tapered dowel, usually square in section. It is used to secure various splicing joints, above all in scarfs. In contrast to the *shachisen*, the *daisen*, like our wooden nail, is employed perpendicular to the grain and the joint.
177 Itoh, 1973, p. 50
178 Omori, 1966/5, p. 86 ff.
179 Klöckner, ibid., p. 18 f.; Eitzen, ibid., p. 75
180 Phleps, 1951, p. 6
181 Brunskill, 1985, p. 59 f.

182 Binding et al., 1989, p. 191
183 Ahrens, 1981, p. 137
184 Coaldrake, 1990, p. 122. Besides *daibutsuyo*, the other new style imported from Korea or China which is meant here is *zenshuyo*, which also arrived in Japan towards the end of the 12th century. For further details see p. 203 ff.
185 Eitzen, 1963, pp. 1–38
186 Schier, 1966, p. 41 ff.; Gschwend, 1988, p. 99
187 Kawashima, 1990
188 Instead of *shinzuka*, the name *odachi* is common in some areas (Kyoto-Osaka/Kinki region). (Itoh, 1982, pp. 72, 84)
189 Seike calls the *wagoya-gumi* roof the *kyoro-gumi*.
190 Another designation is *yojiro-gumi*. (Itoh, ibid., p. 72)
191 To be able to utilize the roof space more effectively, from time to time builders extended the masonry walling supporting the base of the roof slope above the floor level. The resulting section between the attic floor level and the top of the masonry is called a jamb wall.
192 Binding, 1991, p. 159 ff.
193 Deinhard, 1962, p. 8
194 Winter, 1961, p. 267
195 Eitzen, 1963, p. 23 ff.
196 In England roofs were known as single-framed or double-framed, depending on whether they had longitudinal bracing or not.
197 Ostendorf, 1908, p. 24. It was only later that it became possible (or perhaps necessary due to the size of the roof) to also place the longitudinal bracing directly under the spars.
198 Fletcher, Spokes, 1964, p. 156 ff.
199 Brunskill, 1985, p. 148 f.
200 Deinhard, ibid., p. 6 f.; Ostendorf, 1908. The post truss was known as long ago as the 4th century, when it was used for very shallow-pitched roofs (approx. 26°) in the traditon of the roofs of the ancients. (Conrad, 1990, p. 204) However, the introduction of the truss posts in the steep spar roofs of the Middle Ages does not appear to be a deliberate continuation, as the "uncertain manner of the wood joints … adequately proves". (ibid., p. 208)
201 Deinhard, ibid.
202 Ostendorf, ibid., p. 17
203 Called *Hängebänder* (hanging ties) by Ostendorf and Schnell.
204 Dienwiebel, 1938, p. 111, Fig. 51
205 Binding, ibid., p. 191
206 Soper, 1990, p. 307
207 cf. p. 96
208 Note the term "rafter" in the context of Japanese roof construction. As this book attempts to identify various forms of construction in linguistic terms as well, wherever possible, the term "spar" cannot be applied here.
209 The flying rafters are in this case *hiendaruki*. Parent calls them "flying rafters" too and distinguishes them from the "fly rafters" *(shigai daruki)* which we would call "flying spars". (Parent, 1985) This problem with names is inescapable. Masuda's translator uses the term "secondary spar" (Masuda, 1969, p. 132) which, unfortunately, has already been assigned in this book to the spars parallel to the main spars in large roof constructions and introduced to stabilize the frame. (cf. p. 191, Fig. 403) The introduction of the term "secondary rafter" would be logical, but not necessarily helpful.
210 Kawashima, 1990, p. 177 ff.; Parent, ibid., p. 22
211 Ibid., p. 239
212 Ibid., p. 22
213 Nishi, Hozumi, 1985, p. 36 ff.
214 Parent, ibid., p. 101
215 Coaldrake, 1990, p. 120
216 Ibid., p. 122
217 Soper, 1990, p. 277
218 Parent, ibid., p. 158
219 Masuda, 1969, p. 132 ff.
220 Seike, 1981, p. 97
221 "Assembling the rafters" includes the jointing of inclined roof members in valleys and on hips. These are more complicated than most other joints because the real lengths cannot be depicted in two dimensions. To produce them our carpenter must possess a keen three-dimensional perception. The term *Hexenschnitte* ("witch's cut") (e. g. for joining the rafters at the intersection of the inferior purlin of a hipped roof) reflects in linguistic terms the anxiety and respect of carpenters.
222 Graubner, 1986, p. 35
223 Asano, 1981, p. 2
224 Gerner, 1992, p. 26
225 Kawashima, 1990, p. 167 ff.
226 Baumgarten, 1961, p. 86
227 Saeftel, 1931, p. 28
228 Ibid., p. 55, note 96
229 Oelmann, 1927, p. 3
230 Kawashima, 1990; Baba, 1978/7, p. 5; Itoh, 1961/5, p. 8
231 *Japan Architect*, 1960/6, p. 90; Taut, 1958, p. 100
232 Moser, 1992, p. 53 ff.
233 Kawashima, ibid., p. 83 ff.
234 Lindholm, 1968, p. 34; Dietrichson, Munthe, 1893, p. 35
235 Holan, 1990, p. 171, Fig. 4.43
236 Phleps, 1967, Fig. 14.3, in contrast to Figs 14.5 & 14.6
237 Phleps, 1958, p. 45 ff. A *loft* is understood to be a (generally) two-storey storehouse which supposedly originated in Germany. If it is placed on stilts then it is called a *bur*. (cf. Holan, 1990, p. 89 f.)
238 Clausnitzer, 1990, p. 137
239 Breymann, 1900, p. 28
240 Phleps, 1935
241 Lissenko, 1989, p. 72; Blomstedt, Sucksdorff, 1902, Figs 60–62; Norberg-Schulz, 1979, p. 234
242 cf. p. 250 ff. and 257
243 *Bunkazai* …, 1986, p. 93
244 Sacher, 1938, p. 1
245 Ibid., p. 3
246 Ahrens, 1990, p. 159
247 Sacher, ibid., p. 3
248 The largest cross-section among those examples described by Sacher measures 180 x 180 mm. (Sacher, ibid., Pl. IV/8)
249 Ibid., p. 9. Ahrens especially highlights the "high standard of carpentry in medieval Iceland". (Ahrens, 1990, p. 158)
250 Sacher, ibid., Pl. III
251 Bugge, Norberg-Schulz, 1969, p. 7
252 Ahrens, ibid., p. 129
253 Sirelius, 1906, pp. 123 ff., 146
254 These were Moorish carpenters. It is, therefore, understandable why this example exists in complete isolation.
255 Uhde, 1903, p. 95 ff.
256 Phleps, 1951, p. 4
257 Castellano, 1986, p. 83
258 Ibid.
259 Bernert speaks of *Umgebinde* columns with a size of up to 470 x 470 mm. (Bernert, 1988, p. 83)
260 Helmigk, 1937, p. 17
261 Franke, 1936, p. 33
262 Petrescu, 1974, p. 53 f.
263 Ibid.
264 Seike, 1981, p. 11; Burger, 1978, p. 21
265 Hewett, 1980, p. 105
266 Hewett, 1985, p. 68
267 Brown, 1989, p. 28 f.

268 Ibid., p. 60
269 Coaldrake, 1990, pp. 93, 113
270 Sjovold, 1985, p. 63
271 Information given personally by Ohashi Yoshimitsu.
272 Ahrens, 1990, p. 151 f.
273 Dietrichson, Munthe, 1893, p. 6
274 Bresson, 1981, p. 100
275 Ahrens, 1981, pp. 131, 139 f.
276 Petrescu, 1974, p. 20
277 Panoiu, 1967/68, p. 89
278 Bugge, Norberg-Schulz, 1969, p. 89
279 Bresson, T. & J.-M., 1981, p. 160. The authors talk of a *length* of one metre. From the context however, we must assume that this is a mistake.
280 Lissenko, 1989, p. 52
281 Ibid., p. 56
282 Gschwend, 1968/11, pp. 8, 11
283 Haas, 1983, p. 28 ff.
284 Perger, 1970, p. 94
285 Strzygowski, 1927, p. 35 f.
286 Blaser, 1983, p. 80; Österr. Ing.- und Arch. Verein, 1906, p. 92; Strzygowski, 1927, p. 36
287 Eysn, 1898, p. 277 f.
288 Swoboda, 1967, p. 15
289 Stepan, Va$r$eka, 1991, pp. 48, 346
290 Gunda, 1986, pp. 84 ff., 89
291 Lissenko, 1989, p. 36. Even when this comparison does not mean very much to us, it could not have been a large sum as attention is especially drawn to it.
292 Balogh, 1941, p. 19 f.
293 Brunskill, 1985, p. 24. Vienna Anthropological Society, 1895, p. 95 ("not very careful"); Klöckner, 1978, p. 45 ("waste of material was … accepted without question"); Baumgarten, 1961, p. 164 (" … in some building work towards the end of the 18th century the relationship between task at hand and timbering used was carried to absurdity.")
294 Ibid., p. 165
295 Ostendorf, 1908, p. 71
296 Ibid., p. 1
297 Ibid., p. 90 f.
298 Gerner, 1986, p. 21; cf. p. 60
299 Essex County Council, 1990, p. 13
300 Coaldrake, 1990, pp. 127, 153
301 Hewett, 1980, App. 1
302 Seike, ibid., p. 11; Coaldrake, 1990, p. 127
303 Brunskill, ibid., p. 38
304 Parent, 1977/5, p. 80; Ostendorf, ibid., p. 223
305 Nakahara, 1990, p. 30
306 Böhm, 1911, p. 33
307 Parent, ibid.
308 Breymann, 1900, p. 19
309 Gerner, 1992, p. 90; Graubner, 1986, p. 80. Not even in this case does the nomenclature appear to be unambiguous. For Graubner a *Französisches Schloß* is also a *Druckblatt*, i. e. a scarf joint or a halved lap joint, the faces of both of which are cut at an angle in both directions like the dovetailed pectination of log construction. (Graubner, ibid., p. 124)
310 Gerner, ibid., p. 90 ff. Graubner calls a *Brüstungszapfen* (bridled abutment) a *Nutzapfen* and the coincidence of the *Nutzapfen* with a tongue (as is the case with the *Französisches Schloß*) a *Kreuzzapfen* (X-shaped stub tenon) owing to its shape. (Graubner, ibid., p. 80) The reader who takes a moment to reflect on the X-shaped stub tenon *(juji-mechigai-tsugi)* will sense the ambiguities. Incidentally, Graubner also illustrates the latter. The Japanese joint name *jyumon-ji-tsugi-te* seems to suggest that Tanaka Fumio built this X-shaped stub tenon into a Jyumon temple. (ibid., p. 63)
311 Hewett, ibid., p. 265
312 Ibid., Fig. 245
313 Ibid., p. 268
314 Ibid., p. 271
315 One-tenth of the joint depth is specified as a standard value for the taper. (Nakahara, ibid., p. 19)
316 A *chigiri* is a spline joint. *Kusabi-tsugi* is another name for the same joint. (Nakahara, 1990, p. 35)
317 Brunskill, ibid., p. 28
318 Ibid., p. 28
319 Killer, 1941, p. 24
320 Lissenko, 1989, p. 50
321 Coaldrake, 1990, p. 127. Coaldrake gives the distance as being ten times as far. That must be a mistake; the distance from Nara to the Kobe region is no more than 500 km, neither by land nor by water.
322 Seike, ibid., p. 12
323 Holan, 1990, p. 179
324 Ohta, 1992, p. 34
325 The start of the Kamakura era (1185–1333) coincides with the beginning of the Shogunate. Transferring the court to Kamakura turned the city into a religious centre. A wealth of temple facilities still remains to bear witness to this.
326 Mayer, 1986, p. 15
327 Kawashima, 1990, p. 30 ff.
328 Ostendorf, 1908, p. 117
329 The roofs of the city halls of Padua and Vicenza dating from the 15th century are said to have anticipated de l'Orme's design. If Ostendorf is to be believed, then this method has certainly found its fans in northern Italy. (cf. Ostendorf, ibid., p. 157)
330 Conrad points out that the domes of San Marco in Venice, Italy, dating from the 13th century, as well as the Dome of the Rock in Jerusalem, Israel, dating from the 7th and 11th centuries, are built identically. (Conrad, 1990, note 224)
331 Gilly, 1797, pp. 22–28
332 Ibid., p. 7
333 Brunskill, ibid., p. 49
334 Kaiser, Ottenjann, 1988, p. 95 f.
335 Bresson, 1981, p. 160

Wood joints were devised because they had a function to fulfil. As long as experience was lacking, aesthetic criteria played a secondary role in the shaping of joints. When a larger construction than usual was required, builders resorted to tried-and-tested methods, testing their suitability for larger projects. If the carpenter felt unsure about a bracing element, then he braced the bracing. (Fig. 519) At first nobody took offence at such botched efforts. It was only as carpenters began to understand the structural principles properly, as the "How?" of a structure was no longer a subject for debate, that form became the decisive factor.[1] To give an element of a construction its due importance must have inspired the craftsmen of the time. Nevertheless, beauty was not an end in itself. "For the people of the Middle Ages a work of art was an object which had the task of being useful for a certain purpose."[2] In fact, Yanagi goes so far as to claim that without a purpose the hand-crafted article was not beautiful.[3] Beauty took second place to function. Thomas von Aquin's comparison of the glass and the iron saw expresses this unmistakably. The saw made from glass, although more attractive to the eye, does not fulfil its purpose, i. e. to saw. Such beauty without a corresponding purpose severed the bond between the category of the beautiful and the category of the useful.



519 The lower up brace was so long that it itself was braced top and bottom. – Barley barn in Cressing Temple, Essex, England

Placed in such a relation, beauty can be evaluated.[4] It was very strongly characterized by the raw material itself. The sum of its properties could be employed either aesthetically or incorrectly. The differences between any two pieces of wood are measured by the differences in their properties. The more considerate our carpenter was in taking account of the individual nature of the material to be worked, the more outstanding were the workpieces in terms of their diversity as well. It is no coincidence that the Masters of the Tea Ceremony say: "Beauty loses its power when it is repeated."[5] No inorganic material can do justice to this definition of beauty; and – increasingly robbed of its organic characteristics – neither can wood, which is seemingly only called such to satisfy tradition.

Joints, as the smallest architectural component, are one of the most visible indicators of the perpetually changing concepts of the definition of beauty; for the definition of usefulness also underwent such changes. In their role as engineered components, wood joints offered unimagined possibilities to break away from the (often) rigid, prescribed or hereditary straightjacket of traditional forms of construction, the chance to utilize these principles as a means of expression on a much broader scale than the structure as such would normally have allowed.

Wood joints are also an expression of the high regard for the worked material. (Fig. 520) It is not up to mankind to pass judgement on the transitoriness of the material, at least that is the Japanese view. Mankind has intervened in the natural lifecycle by felling the tree. Now mankind must do its utmost to handle the material as carefully as possible and do its utmost to preserve it.

520 The esteem for the material was obviously more important than the economics of labour costs on this simple gateway in Hagi, Yamaguchi, Japan.

We are accustomed to placing economic criteria in the foreground. Solid wood in selected quality has become a status sym-

bol, both in Europe and in Japan. The use of a certain vocabulary is sufficient to suggest values, the basis of which the modern consumer is no longer in the position to appreciate. As the gulf between living with the natural world and living *within* the natural world grows wider, so it will become increasingly easier to pass off a fake as the real article. Perhaps the most glaring example of this is the business with the *tokonoma*, the alcove, (see p. 41, note 70) in Japan. What could better express the shift in the value attributed to the material? However, as long as resources were in plentiful supply, structural problems were resolved in line with experience and an aesthetic judgement which was determined by tradition. (Fig. 521)
Wood joints became the vehicle for artistic notions, a means of expressing subjective and objective values. These were not only not independent of each other but, frankly, were mutually dependent. The influences which shaped the wood joint of the individual carpenter were dependent on the "objective" aesthetic ideal to the same extent as the general concept of beauty was influenced and developed by the "subjective" notion of beauty of the individual craftsman, albeit in very small steps. "Craftsmen tend to be conservative when it comes to technical matters."[6] The average craftsman in the Middle Ages hardly had any opportunity to travel beyond his immediate district and hence broaden his horizons. Primarily therefore, mental inspiration had to be encouraged through new tasks. "Like a pearl [grows] in an oyster",[7] like flowers germinate in complete isolation – the example of Japan in the Edo period can be likened to these two expressions.
There are many wood joints in Europe and Japan which are identical in appearance and have the same function. However, the intention of this chapter is to finally lay to rest the idea that such seemingly identical joints are indeed identical. An evaluation in this respect depends, among other things, on the weight given to the different methods of production, the different attitudes to timber, the different tools and the different building tasks. Values are characterized by so many components that their formative influences such as history, culture, etc. exclude identity from the outset.
By means of three comparisons the intention is to demonstrate that a purely technical/functional study of wood joints is simply inadequate as a basis for a comparison, and that besides the similarities and disparities of Japanese and European examples shown hitherto, there are other unrelated aspects which have to be investigated. Once the observer is ready to accept this viewpoint, then he will also begin to understand that there are hardly any cases where is it possible to speak of Japanese joints and European joints being identical. Two identical species of tree cannot grow from two dissimilar varieties of seed.

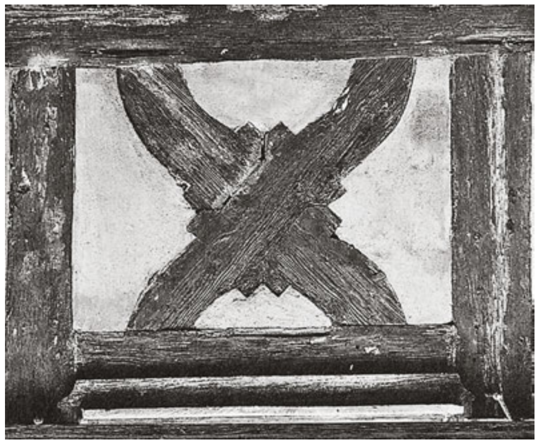
The visible and the invisible

Dovetails or notches are intended to prevent the lap from being pulled out of its housing. The functional concept, so readily visible in this type of joint, inspired European carpenters to experiment with this form. By way of multiple stopped dovetails and notches they realized what fun could be had once they also departed from straight lines. (Fig. 522) As very large

521 This giant bolster under a beam conveys especially clearly, via its function, the value of aesthetic impressions as opposed to economic considerations. – Kirchberg, Tyrol, Austria

522 In extreme cases the visual appeal strived for was no longer the shape of the lap itself but rather the figures created by the laps. – Town hall in Esslingen, Baden-Württemberg, Germany

structures demanded very large timber members, the joints took on correspondingly monstrous proportions which made the craft of the carpenter appear cruder than it actually was. Therefore, it seemed obvious to start where the intervention was visible and, at the same time however, did not impair the construction. This progression in the development of joints was sensible and feasible only if the carpenter exploited the apparent straightness of the material. Only in this way did the laborious fine work gain any recognition at all.
Inevitably, the standardization of building timber went hand in hand with urban expansion. However, as the decorative aspect of the crooked timbers used in the past had not been forgotten, they were now produced artificially. (Fig. 523) Apart from that, the "fraying" on the lap joint ends could also be transferred to the wood parallel with the grain by means of a trick, and without weakening this seriously. (Fig. 524) By combining the organic character of "crooked" braces with the alienation now overriding their functional purpose, an apparently vast number of variations became possible. I say "apparently" because these untamed outbursts very quickly started to be channelled into orderly paths. The desire for regularity and certainty was reflected in the strict, geometrical forms which were cut more and more according to clichés.[8]
This context probably includes all those forms of ornamentation[9] which decorated the overlap of every bracing and rail on timber-framed buildings, i. e. the parallelogram formed by the cross-lap joint. The visible arrangement of bracings and rails which already questions the constructional relationship is altogether alienated by this embellishment. The formal resolution of the legibility of the construction is further enhanced by the selective accentuation provided by wooden nails; owing to their differing colouration they become visible decoration.
One phenomenon in log construction, which emphasizes the joint in excess of its function, could be interpreted similarly.[10] In Romania we still encounter log buildings whose walls are covered in daub and, as a rule, a coloured limewash. Only the ends of the logs, irrespective of whether at the corners or due to projecting partition walls, were left without plaster and limewash. Two reasons for this can be put forward. As the end grain is far more susceptible than the rest of the log, it may have been that builders wanted to give it the chance to dry out rapidly after it had become wet, i. e. better to leave the ends unplastered. On the other hand, there are enough examples where log ends are also protected with daub. Therefore, it seems obvious that artistic enterprise as a motive for highlighting the joint should at least be considered.
A fundamentally different, principal stipulation of Japanese timber construction was to incorporate the joints in such a way that, wherever possible, they remained undetectable. This condition evolved at a time when structures were still open and there was no ceiling to bar the view up into the roofspace. The "finished, completed, undisguised appearance" was the aesthetics specification which the carpenter had to fulfil.[11] Depending on the style of architecture, this can leave the viewer with an impression of great simplicity. A purely formal analysis misled Bruno Taut into erroneously believing in the simplicity of the Ise-jingu.[12] That such a competent observer was so fooled



523 St Andrew's cross in Calw, Baden-Württemberg, Germany.

524 The desired ornament was cut out of the solid wood just as deep as was necessary to apply a durable coat of plaster. – Michelstadt, Hessen, Germany

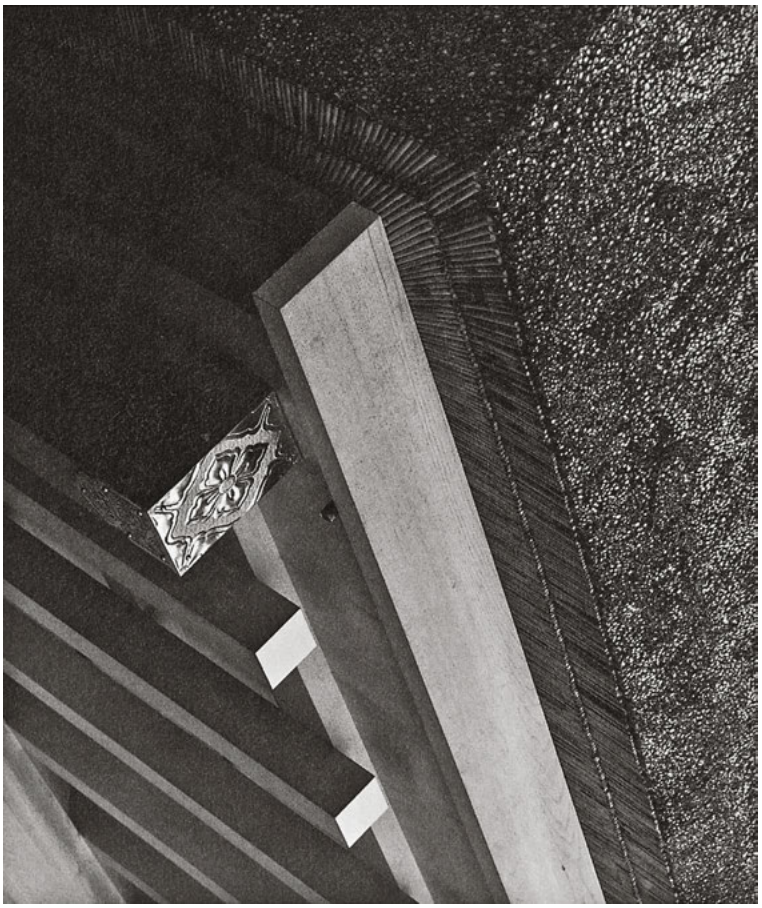
must be attributed to the absolutely flawless workmanship. (Fig. 525)

Without their masking a great number of details would be exposed: chamfering one corner of the eaves purlin for the visual transition of the purlin cross-section to the angle of the roof slope, considering the pattern of the grain on the bargeboard, the shaping of the underside of the thatching. (Fig. 526) Just how intrinsic the task of concealing the position of the joint was to the carpenter's way of thinking can be seen in joints whose line was no longer hidden owing to the pursuit of a new aim.[13]

The principle of invisibility was especially difficult to realize in the case of vertical splices. The structural requirement "that the axes of the pieces to be connected meet in a straight line, that both pieces make contact over the largest possible surface area, and that splitting and splintering be avoided"[14] also caused difficulties. The task was made easier when one or more sides of the joint were covered by other parts of the construction. In the ideal case only a single line revealed the position of the joint to the viewer. (Fig. 527) The awareness of this artistry seems to have been increasingly lost as Western building technology was adopted more and more. How else are we to explain why in the old rice store of the Takayama-jinya the exhibition architect removed just the one column of a partition wall which was intended to cover a joint.

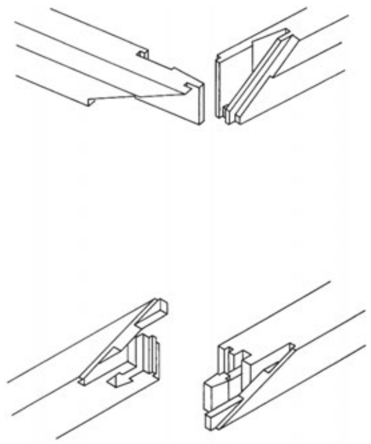
525 The appearance of unperturbed simplicity, as is so irrefutably evident in the Ise-jingu, is based on the centuries-old concept which specifies each and every detail.

527 Above the column of the *kakezukuri* construction the viewer is only aware of the line of the seam of the joint between two beams. – Ishiyama-dera hondo, Shiga, Japan

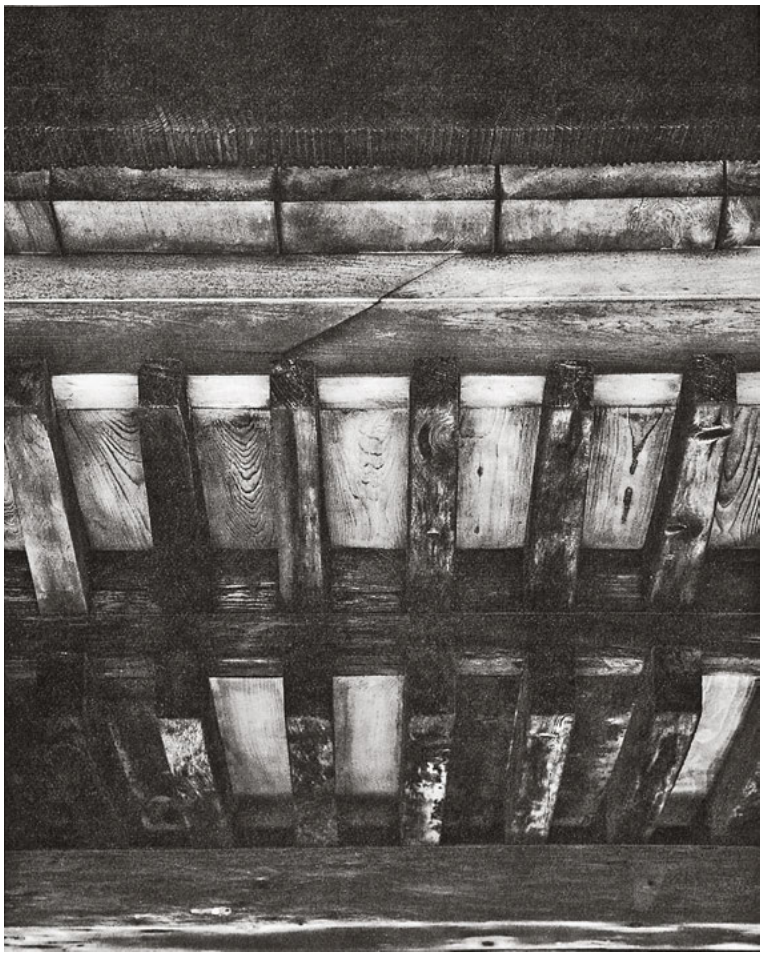


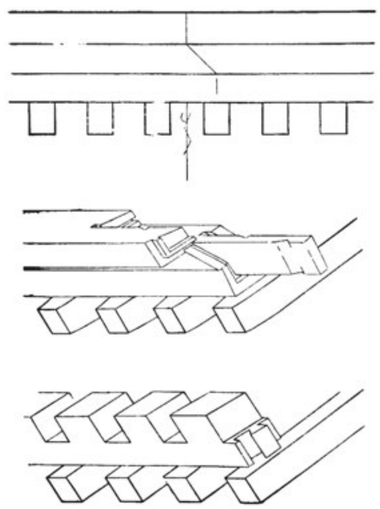
526 Two staggered layers of straw form the eaves termination. Piece by piece each straw is placed in a sleeve closed at the front and then sewn together into mats each approx. 20 cm wide.

The splicing joint underwent a further improvement when the direction of the seam between the joined members more or less followed the direction of the grain. Consequently, the joint had to fulfil two functions which were expressed in its realization: for the viewer the carpenter had to meet the aesthetic demand for invisibility (Fig. 528), and for the structural engineer the joint had to be capable of withstanding the loads to which it was subjected. The outcome was that the carpenter divided the available cross-section of the piece of wood into two sections. The visible part was shaped in such a way that, as far as possible, it did not reveal that there was a joint at this position at all. The functional part of the joint was arranged inside or on the non-exposed rear face of the wood. (Fig. 529) New joints did not have to be invented; the existing repertoire was sufficient to provide a multitude of combinations to suit the tasks at hand. (Fig. 530) What is fascinating is how all the necessary functions were integrated within the restricted cross-section. Especially noteworthy are the precautions taken to prevent the joint opening up under lateral forces, in particular on the horizontal members on the eaves side which were subjected to the load of the rafters.
Individual aspects of these decidedly Japanese joints can also be found in Europe. Gerner presents us with two examples of divided joints which owe their form to the carpenter's attempts to find the best way of preventing moisture entering the joint.[15] In England lap joints with hidden notches were found which, despite being more expensive to produce, had replaced the notched lap joint to a large extent.[16] And in Wells Cathedral, Somerset,



530 Divided splice joints on the Enkyo-ji jogyodo, Hyogo, and the Kyuan-ji romon, Osaka, Japan. (according to: *Bunkazai* …, p. 288/2, 320/3)

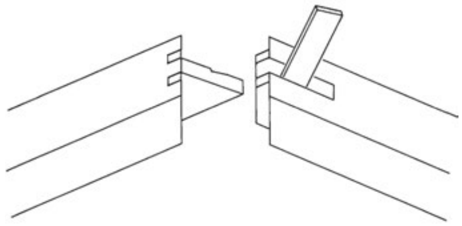




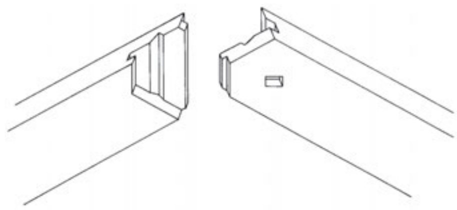
529 A drawing illustrating one possible joint. (source: Suzuki, 1847)

528 Beam splices: splayed scarf above flying rafters; apparently butt-jointed between base rafters and flying rafters. – Ishiyama-dera tahoto, Osaka, Japan

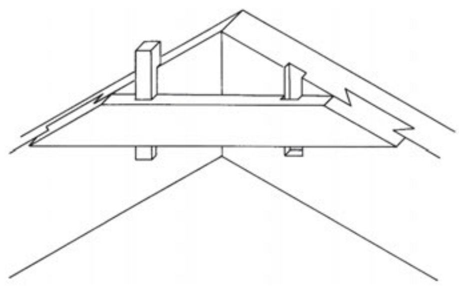
England, there are secret dovetails too.[17] If you believe Brunskill, then in England the notion of concealing the connection was a prime factor in the design of these types of joints. This form of "secret jointing" is said to have been really quite common.[18]
In addition to the fundamental differences in the attitudes, a proviso in a German textbook adequately explains why divided joints like those of the Japanese could never have evolved in Europe: you cannot look inside a "secret joint"; therefore, the carpenter would never have known whether his joint had been cut accurately enough to fulfil its task.[19]
The widespread use of divided joints in Japan has already been mentioned elsewhere in this book, albeit under another heading. As in discussing the corner joints of sill beams, where protecting the wood had been our foremost consideration,[20] the basic premise represented here is that functional aspects were the prime movers in the development of joints. The coupling of engineering needs and clarity of execution was the catalyst for further refinements in terms of aesthetics, the climax of which was the inviolability of the pattern of the grain.
One logical consequence of this was, for example, the connection between the bargeboards at the ridge which, firstly, had to function as a joint, and, secondly, had to take into account the special vulnerability of the end grain. This synthesis resulted in a form which, also taking account of aesthetics, left only a mitre-cut showing on the outside. (Figs 531, 532 & 533) The special problems of this joint owing to the successive increase in the roof load during construction have already been pointed out.[21] (Fig. 534)
The joints of this family which are most difficult for the viewer to detect are those which connect very delicate fillets in interior work. Here, occasional *shachisen* already tend to be more leftovers from other joints rather than functional components. The workmanship reminds the European more of the ebonist than the cabinetmaker – and certainly not the carpenter!
A totally separate category of joints developed with the ideal of beauty in mind was the *isuka-tsugi*.[22] (Fig. 535) Graubner calls them *Schäftungen* (edge and face halved obliqued scarfs).[23] In their simplest form they were not capable of carrying tension loads. Virtually the only condition they had to fulfil was that of appearance. The line of the joint in the pieces to be joined was made according to how many sides were to remain exposed. The crowning achievement in this group of joints is the *Miyajima-tsugi*, named after the place where it was discovered (Miyajima, Hiroshima, Japan). The idea behind this unique joint was never passed on further by its creator – it is not found anywhere else.
The cultural significance of the *isuka-tsugi* still exerts its influence on today's carpenters. Tanaka Fumio took this form and, entirely in the tradition of the Edo period, delightfully reshaped it to lend it a new importance. (Fig. 536)



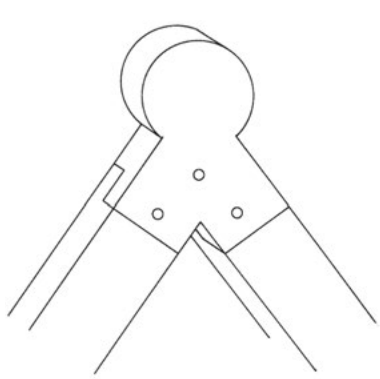
531 Bargeboard joint (according to: Graubner, 1986, p. 115)



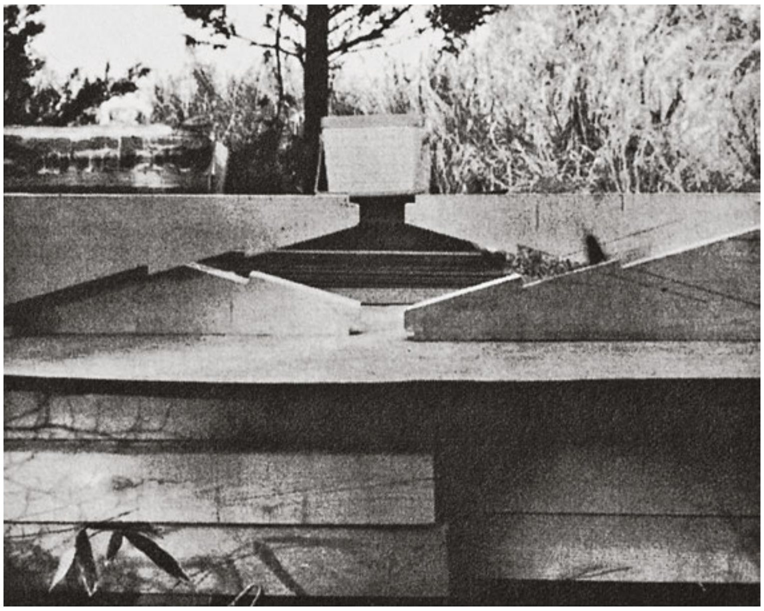
532 Rear view of bargeboard joint (according to: Nakahara, 1990, p. 203)

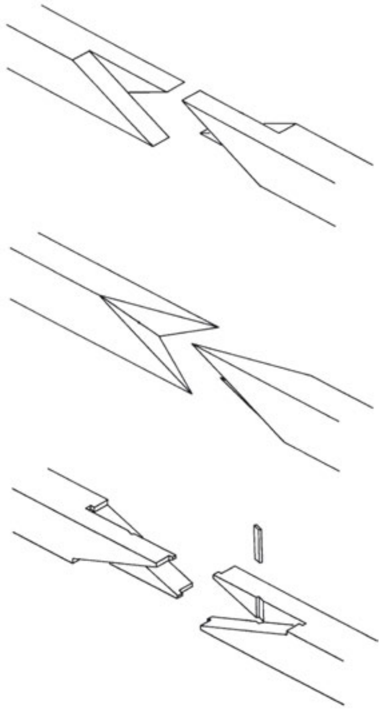


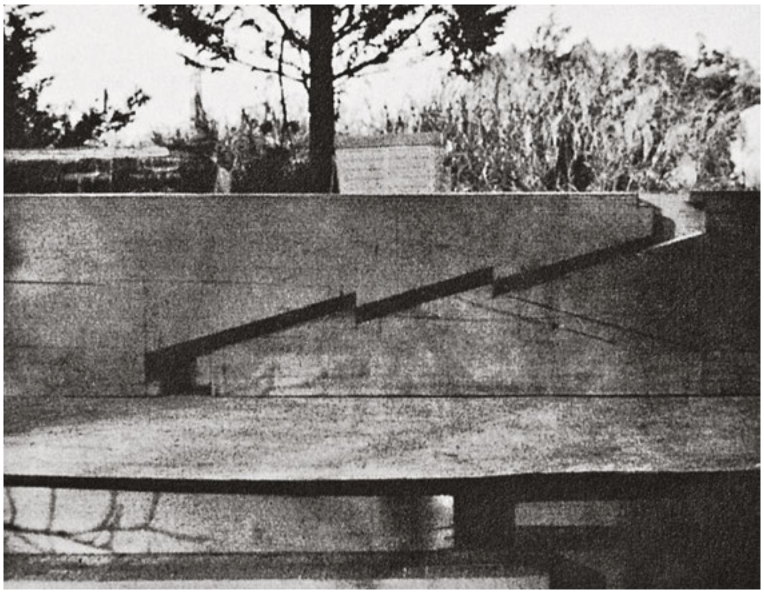
533 (according to: Uchida Yoshichika, 1993, Fig. 4.33.5)



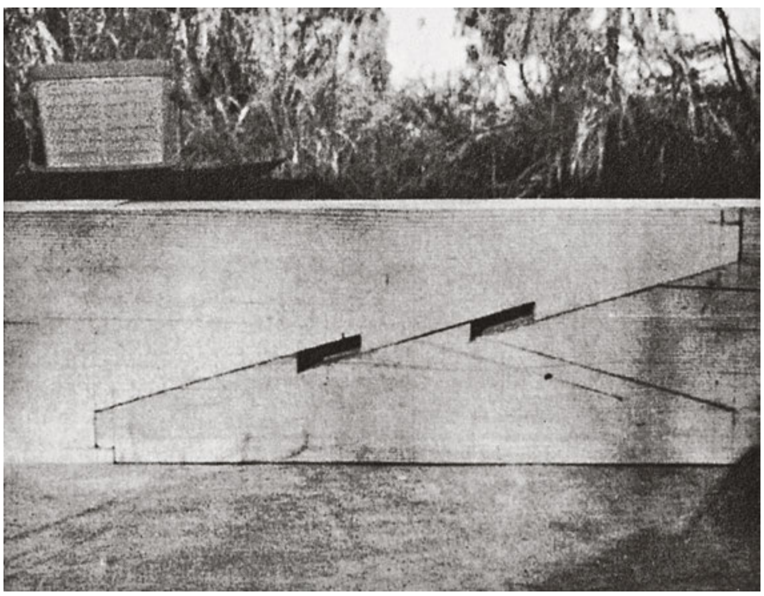
534 Compared with the European standard solution the idiosyncrasies of the Japanese design catch the eye. (source: Opderbecke, 1909, Pl. 11)







535 *Isuka-tsugi, sumi-isuka-tsugi* and *sumikiri-isuka-tsugi*. (The Japanese word *isuka* consists of three characters meaning "overlapping crossed beak". The *sumi-isuka-tsugi* is used when aesthetics demands could not be satisfied by the *isuka-tsugi*. The *sumikiri-isuka-tsugi* – in terms of function identical to the *Miyajima-tsugi* – even withstands a little tension.)



536 *Ima-no-nakabiki-no-tsugite* by Tanaka Fumio: joint parallel with the ridge in the beam placed directly beneath the ridge over the living room. (source: Jutaku kenchiku, 1985/1, p. 161)

European timber construction without wooden nails (dowels) would be unthinkable. Every scarf, lap or tenon had to be secured to prevent one part pulling away from its mate. The wooden dowel, although normally hidden from view, was important in log construction too, but not to the same extent as in column-and-beam frameworks. In column-and-beam construction the wooden nail had to be incorporated in such a way that, if necessary, it could be rehammered at a later date, which in turn meant that a significant length had to protrude above the surface. Wooden nails provide an unmistakable clue to the form of construction. How could we have avoided exploiting their decorative function? If adorning the construction started to play too great a role in the mind of the carpenter, there was a danger that the actual construction would take a back seat or be forgotten entirely. In favourable cases the carpenter did no worse than overdo things somewhat.

Was it the shadow on the wall cast by the wooden nails lit from the side? Whatever it was, from the moment when the wooden nails caught the eye of the observer it was only a question of time before the first carpenter lent them an importance which exceeded their purpose. (Fig. 538) The carpenter now had the chance to prove his worth as a woodcarver.[24] (Fig. 539) In the light of such shapes, it does not come as a surprise to hear that wooden nails were also turned.[25]

For the carpenter wooden nails originally had a purely technical function. Not every species of timber could be used for making wooden nails. The wooden nail had to be drier than the wood it had to fix. When it was driven in the edges suffered through the careless hammer blows. In extreme cases the end grain was splayed out into a fan shape. This was tantamount to wilful vandalism as, owing to its exposed position, this damage made the nail very vulnerable to the effects of the weather. The end which was driven into the timber was given a point to minimize frictional resistance, so the damaged head of the wooden nail was trimmed similarly.

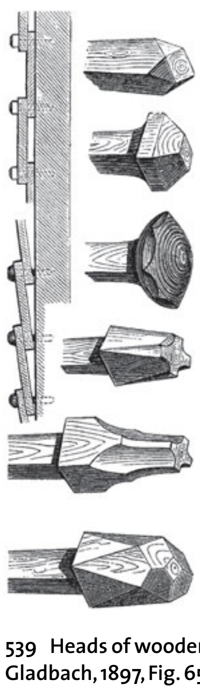
In log construction the carpenter had many more opportunities to fashion the end grain. Every log had two ends which offered themselves for special treatment. Above all, new or unusual designs could grab the attention from further away. And in log construction it was also initially pragmatic reasons which drew attention to the log ends: to preserve the timber it was customary to coat them with limewash.[26] A few isolated buildings remain to show us how evolution might have progressed. (Fig. 540)

Even pectination with dovetail joint shapes had not been easy owing to the dovetail needing to be cut in three dimensions. However, if the carpenter had learned how to visualize the joint in his mind's eye, it did not require any magic to double the dovetail, although producing the joint was considerably more involved. Nevertheless, the decorative value must have provided a sufficient incentive, for even rural occasional carpenters dared to try their hand at such joints.

Even more complicated was the production of the *Klingschrot*;[27] none of its faces were flat.[28] One needed to set aside plenty of time in order to erect a storehouse assembled with *Klingschrot*

537 The wooden nail enables us to see immediately whether overlapping members are connected by way of a lap joint or a mortise and tenon. – Cloppenburg Open-air Museum

538 The base of the wall to the town hall in Esslingen, Baden-Württemberg, Germany



539 Heads of wooden nails (source: Gladbach, 1897, Fig. 65)

joints. It is said that four men took one day to complete just two rings of logs.[29] If carpenters claim that the justification for the *Klingschrot* taking them twice as long to produce compared with dovetail-shaped joint faces was the fact that the result lasted twice as long,[30] then this can only be seen as part of the reason for choosing this joint. Just the simple fact that such elaborate joints were used exclusively on dwellings and storehouses makes it very clear that prestige was at stake here. (Fig. 541) What farmer would not have been equally pleased had his cowshed also lasted twice as long!

Another joint used in log construction was the *Kugelschrot*, which, in a logical progression of this trend, only appears to have come about as a result of the desire to create an eccentric joint which had never been thought of before.[31] (Fig. 544) Looking at the end of the member, the designation *H-Schrot* would have been far more appropriate.

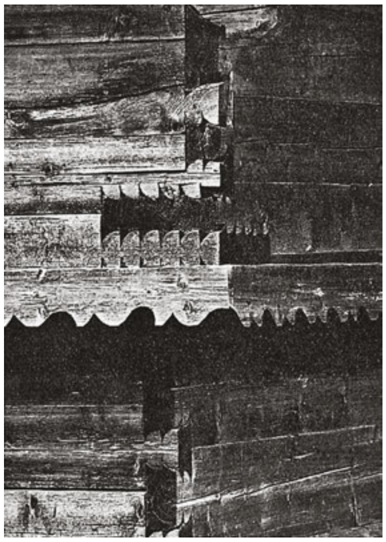
Perhaps even more decorative than the end grain at the corners was that on integral partition walls. Nowhere near as important for the construction as the corner joints, it nevertheless seemed obvious to simply copy these. Even with more complicated forms, adaptation was normally easily accomplished. (Fig. 542) However, as soon as the carpenter specifically assigned the joints of the partition wall the subordinate role which was actually appropriate to them, the barrier of functionality was demolished. (Fig. 543) In the euphoria of design, every shape which could be produced in wood was tried out. In some cases our carpenter gives us a totally uninhibited demonstration of the fact that all reminiscences of the constructional requirements had been left far behind.

The *Malschrot*, "which for small structures represents the very boldest element to which timber architecture has ever given birth",[32] had to be arranged in such a way that the stacking assembly could be built up vertically member upon member. Whereas the cross atop a circle – a very popular motif – had to be inserted horizontally, other decorative shapes cropped up which could only be finished off from the outside after integrating the logs of the intermediate wall.[33] (Fig. 546) In this case too, the unrestrained passion for embellishment broke all records for insensitive treatment of material and type of construction. In contrast to the case of the corner joint, exaggerated attempts at carpentry expressionism can also be found on the partition walls of utility buildings.[34]

The terms *Zierschrot* (*Zier* = ornament) or even *Figurenschrot* (*Figur* = figure) are not out of place when one considers some joint shapes.[35] (Fig. 547) In Upper Bavaria, Germany, an example has survived which combines the two methods of emphasizing the end grain which have been outlined; there, the figures carved in the end grain are further highlighted by painting, or rather they are embedded in an artistic design which is completely at odds with the nature of the construction.[36] (Figs 545 & 548)

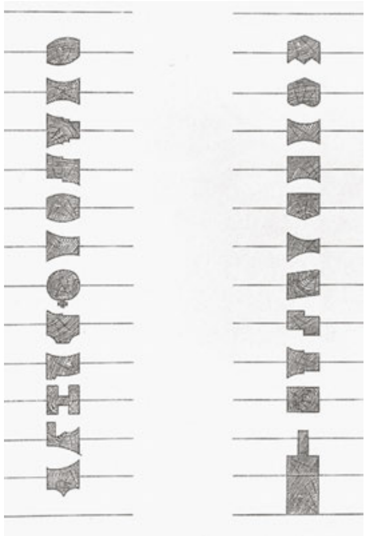
The fantastic carvings to which the decoration of log ends gave rise – from very elementary versions[37] (Fig. 549) up to their culmination in true masterpieces[38] – are well known. It is the complaint of every craftsman that the most difficult part of his work is often not recognizable to the layperson. The selflessness, to remain modestly in the shadow of his work, can only

540 Five domino-like contrasting spots have been painted on the end grain of each log. – Ždiar, Slovakia



541 A six-fold *Klingschrot* on a granary from Saureggen, Carinthia, Austria, in the Stübing Open-air Museum.

542 A partition wall integrated by means of double *Klingschrot* joints. – Hasleiten, NE Austria



543 A compilation of various decorative forms of *Schrot* joints on a utility building in Ellmau, Tyrol, Austria. (source: Deininger, 1903, Pt 1, Bk 7)

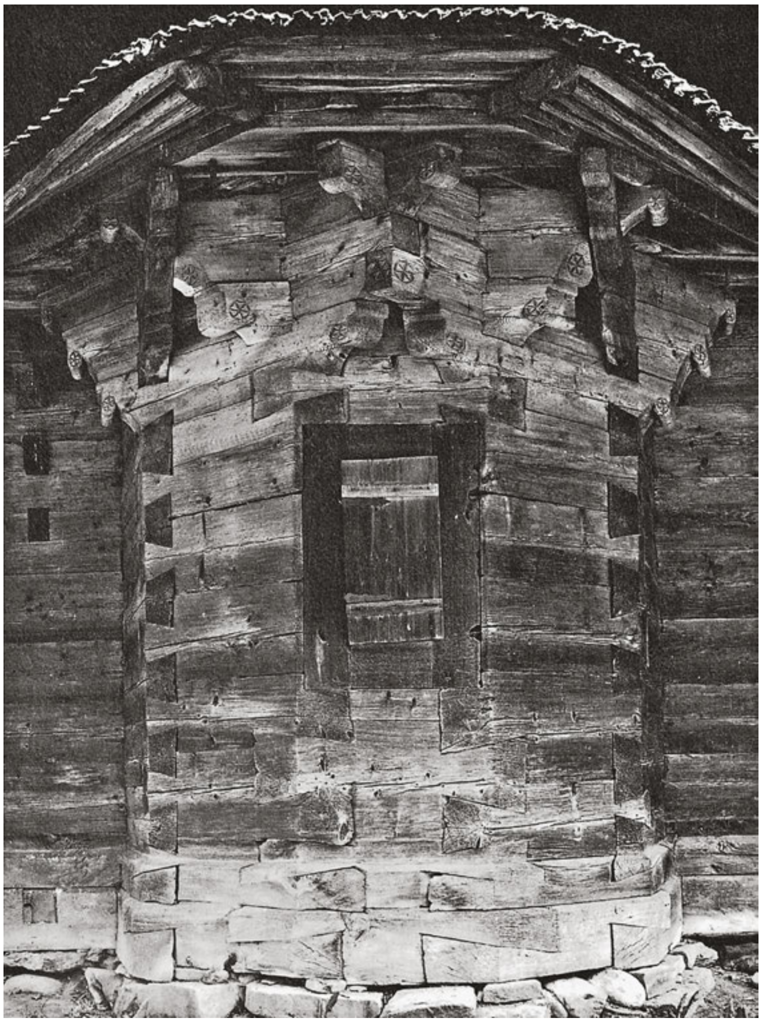
544 Why the *Kugelschrot* (*Kugel* = sphere) should be so named is really not at all clear; parallel with the grain it is a half-cylinder, on the end grain a semicircle. – Grafenbach, Carinthia, Austria

545 Painted *Zierschrot* – Surheim, Bavaria, Germany

546 Even shapes as these were legitimate game for some carpenters, paying no respect to the nature of the material. – Oberaurach, Tyrol, Austria

547 This specimen is a strong reminder of the inlay work of the cabinetmaker. – Trautenfels, Steiermark, Austria

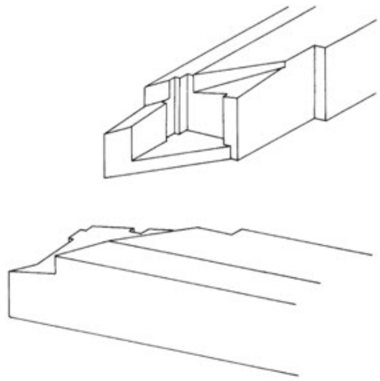
548 A very frequent symbol was the cat. However, the painted form was very rare. – Haus, Steiermark, Austria



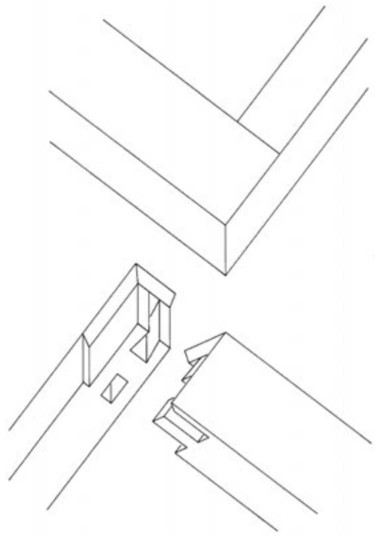
549 The cantilevering brackets of this church terminate in the shape of stylized horses' heads. – Călineşti, Maramureş, Romania

550 Behind the expressively shaped interrupted tie beam, the carved dragon's head symbolizes, inimitably, the task of the tie beam, namely to restrain the feet of roof slopes which are trying to spread apart. – St Nicholas' Church in Beaune, Burgundy, France

be credited to a few. Only in isolated cases was a carpenter able to break free from such a suspicion of self-portrayal by conveying, in pictorial fashion, the constructional context in the assembly to the uninitiated as well through an appropriate shaping of the joint. (Fig. 550)
In his system of ethics the Japanese carpenter must bear a moral guilt upon the felling of the tree, a crime which can only be atoned through a system of building which guarantees the continued existence of the tree.[39] The part most at risk as a result of the process was the end grain. Should the above examples from Europe have given the reader the impression that the, admittedly for timber, far less damaging climatic conditions in Europe would have left the end grain on structures undamaged, then that would certainly be false, for here too the same problems had to be faced. In juxtaposing Japanese solutions, the very different artistic attitude of the European is proved by the dilettantish and often seemingly makeshift nature of protective measures on buildings. An analysis of such examples conveys very clearly the view that joints were only treated lovingly by the European carpenter when they were designed to impress and astonish the viewer.
In comparison with those of their Japanese colleagues, the practical solutions devised by European carpenters for protecting sill-beam corners can at best be considered as first attempts.[40] Over the course of time the Japanese turned the technical requirements into artistic ones and raised them to the level of a standard. End grain had to be hidden. Unattractive things are hidden. Therefore, the fate of the exposed end grain was sealed. What had been relatively easy to solve in the joining of bargeboards, i. e. denying the presence of any constructional problems, became an increasingly tantalizing challenge for the Japanese carpenter as exposed surfaces multiplied. Specifying the aesthetic value of not countenancing any visible end grain demanded even more refined designs on the eaves corners than it did on the sill corners, a large proportion of which were normally screened by a column. (Fig. 551) At the eaves at least two sides were always completely visible, so joints here were only permitted to exhibit a mitre seam after assembly. The solutions devised would have done the very highest credit to any European cabinetmaker. (Fig. 552)
But this form goes one better still. The long, peaceful Edo period gave rise to the flowering of an artistic creativity which, in its constant search for new opportunities for expression, broke through all the known and conceivable barriers of the otherwise strict, regimented building codes. What had provided a reliable source of income for carpenters in other periods, namely the rapid reconstruction work necessary following military conflicts, was no longer available to them. If a carpenter of the Edo period wanted to improve his finances, he had to stand out from the run-of-the-mill woodworker. If a building required no major repairs, then, out of necessity, the emphasis had to be shifted to the interior. The main target was the *tokonoma*. One of the primary elements of this alcove was the column defining one corner, the *toko-bashira*. Shelves which seem to float are one aspect of this search for the incomparable; the column no longer attached to the floor is another. As the Japanese sat on the floor, their posture meant that they could not



551 Eaves corner detail – Enjo-ji hondo, Nara, Japan (according to: *Bunkazai* …, 1986, p. 348/1)



552 Eaves corner detail on a hipped roof (according to: Graubner, 1986, p. 132)

553 Model of a *koguchi-kakoshi* joint in the Nihon minka en.

avoid seeing the underside of the truncated *toko-bashira*. The solution which the carpenters devised to hide the end grain here as well can only be classed as one peak in the Japanese carpenter's art. The *koguchi-kakoshi* (hidden end grain) is, when all is said and done, a very simple joint, the creation of which, however, must have demanded a truly unsurpassed ability. (Fig. 553)

Construction and Decoration

Increasing confidence in the construction itself permitted more licence in the realm of decoration. It gradually became more and more difficult to distinguish purely ornamental features from parts essential to the construction. The beauty of a building was enhanced by the successful blurring of its recognizable constructional elements. (Fig. 554) And for this people were prepared to sacrifice considerable quantities of a material which, it must be said, really was no longer in abundant supply.

In covering up the constructional assembly, every possibility which seemed legitimate to the carpenter was employed in the design of the façade. No member was spared this treatment – structural members and others alike. (Figs. 555 & 556) For example, panel infills which would have been far more economical when made from one single board seem to want forget their genetic origins through the, thanks to their regular structure, bearable restlessness of the constantly changing direction of the grain.

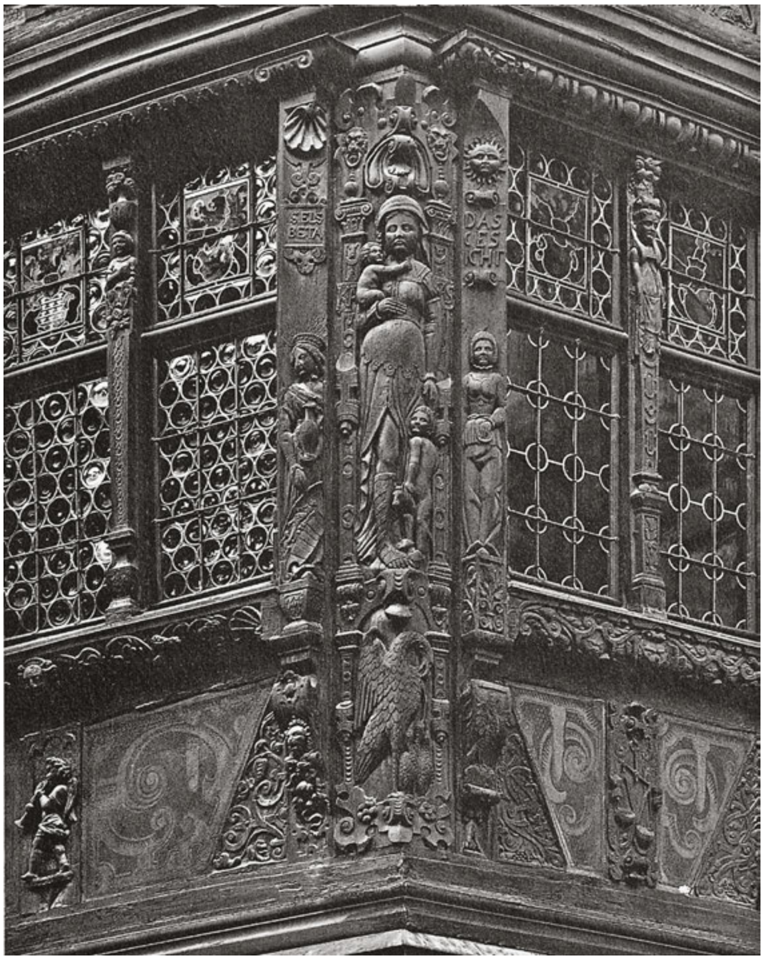
Having already encountered such developments in the countryside, we expect to find them even more prevalent in the towns. (Fig. 557) Questioning the possible feasibility of accurate wood joints becomes a farce when the accuracy itself becomes the prerequisite for the desired effect. For instance, if the benefits of the mortise and tenon in comparison with the lap joint are considered justifiable because the lap demands more accurate working, or the multiple step joint is considered superseded as it cannot be cut sufficiently accurately, and on the other hand though, the overlaps of diversely shaped decorative bracings on the façades of timber-framed buildings bear witness to the accuracy to which carpenters could work, then we begin to suspect that work was performed primarily for show. Examples of such ornamental bracing have angered no other author more so than Phleps who writes that they "announce the demise of timber architecture".[41]

In any case they cleared the way for the devaluation of wood joints, even if in my opinion they were not the root cause. The joint had in many instances more or less lost its original function. It had degenerated into a mere toy on the carpenter's playing field of expressive possibilities, serving, at best, as a reminder of earlier tasks.

No opportunity was missed to enlarge the surfaces on which artistic woodcarvers could set to work. Carved panels which were also intended to be visible from a distance could not be allowed to be interrupted by the surface texture of other materials because otherwise their effect would have been lost. The contrast between timber frame and panel infill, likewise the contrast between alternating grain patterns, had suffocated the carvings. Even the rosette showed a deliberate disregard

554 Structure and decoration can still be discerned here. – Coburg, Bavaria, Germany

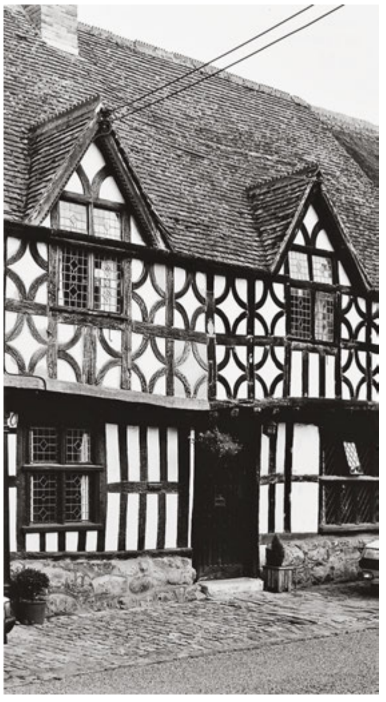
555 The Deutsche House in Dinkelsbühl, Bavaria, Germany, is a perfect example of how rich townsfolk felt the urge to display their position.



556 On the Kammerzell House in Strasbourg, Alsace, France, absolutely no piece of wood remains uncarved. Even the few plaster wall infills are richly decorated.

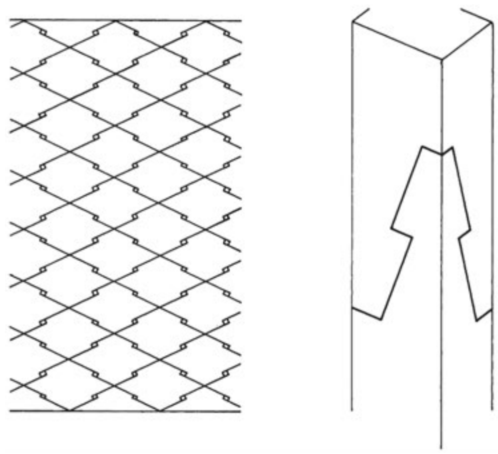
558 The rosette, in this case carved in the triangle formed by posts and down braces, was a very discreet form of constructional cover-up. – Brümmer farm from the Lüneburg Heath, Lower Saxony, Germany, in the Hösseringen Open-air Museum

557 The plastered surfaces were only for show; they conceal flat panel infills. – Strasbourg, Alsace, France

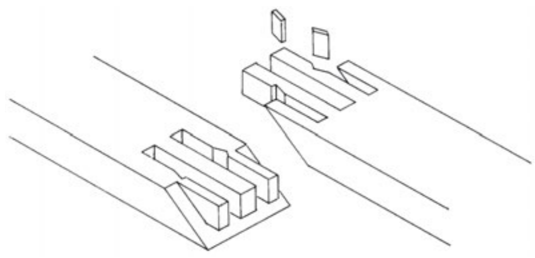


559 In the light of such panel infills, who thinks of sober triangulation? – Potterne, Wiltshire, England

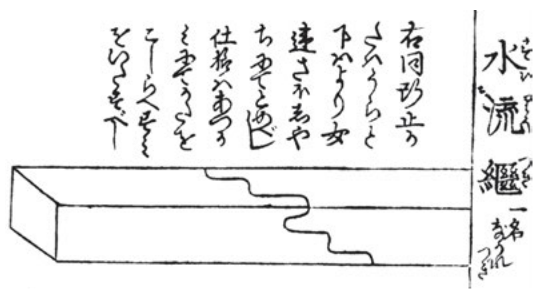
for the construction.[42] (Fig. 558) However, only an artist could really make the most out of the freedom in creativity thereby gained, an artist who was not only willing to throw off old conventions but, on the contrary, was never even aware of these.
With braces stabilizing angles in particular, the shape suggests the irrelevance of their cross-section and hence, basically, the manner of their integration. (Fig. 559) Whether, for example, a down brace was expanded to fill the enclosed triangle or an up brace trimmed back to virtually nothing was a question of the desired appearance, not structural necessity. Which forms of step joints were not developed in order to weaken as little as possible those members linked by up braces? Such structural engineering or materials technology considerations appear to have been deliberately negated to an increasing extent.
In Japan too, there was a movement which questioned the constructional character of the joint. And like with the preceding examples, in this case as well, statements regarding the supposed parallel nature of European and Japanese specimens could not be more dissimilar. In both Europe and Japan, a dearth of new challenges in a period of inertia forced the carpenter to adjust his field of activity. The focus on creativity shifted appreciably towards decoration – quite differently in Japan owing to the aesthetic criteria which differed from those in Europe. The products of this shift in emphasis are judged all too easily as "nonsense" by Europeans with their modern sense of values. And even in Japan there are not very many people today who are prepared to give this phenomenon a fair appraisal by considering the values applicable at the time.
The aforementioned self-decreed isolation of the Japanese nation by the Tokugawa from 1603 to 1868 was stony ground for the seeds of new momentum. "The art of this period … appears to be heading for a dead end."[43] The absence of external stimuli coupled with the suppression of new ideas internally forced the carpenter to express himself in ways which at first sight appear strange.
With the development of, what are still today, exemplary designs in the Sukiya style, e. g. for decorating the *shoji* and *fusuma* (sliding screens) or the *ranma* (a panel between door lintel and ceiling joists),[44] and their implementation carried out during the Edo period, also in the shaping of wood joints, carpenters appeared to have found a niche which allowed them to circumvent the long-standing law requiring them to conceal the position of the joint. (Fig. 560) Frivolities not really comprehensible to Western minds, such as the doubling of traditional joint forms, may have been a prelude to this. (Fig. 561) After a carpenter had demonstrated that nothing was impossible, even *ryusui-tsugi*, (Fig. 562) and *unka-tsugi* (Fig. 563) would have strayed into the realm of the conceivable.[45] If the reader recalls that definition of a wood joint which speaks of "permanently and securely" (cf. p. 99), he cannot overrate the flights of artistic fancy of an artisan who attempts to restrain dynamism in a static form.
The renewal of the bases of columns probably made up the bulk of the Japanese carpenter's workload. This gave him the chance to express his individuality on a daily basis. (Fig. 564) The viewer is forced to reflect on the comparison with the European examples of joints, the functions of which have been left



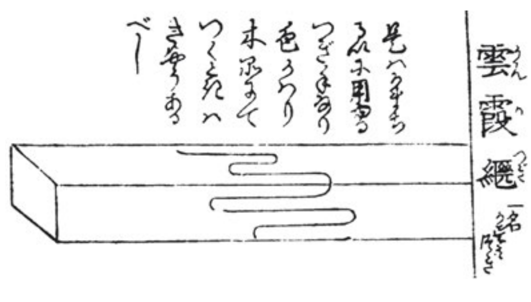
560 A detail of a window in the Sumiya, Kyoto, Japan, and the sort of formally derived *shiho-matsu-kawa* joint.



561 A sophisticated type of keyed haunched mortise and tenon joint in the Fumon-ji hojo, Osaka, Japan. (according to: *Bunkazai* …, p. 501/2)



562 The *ryusui-tsugi* – joint portraying the image of running water – betrays in its name and its appearance a desire or dream of the carpenter. (source: Suzuki, 1847)

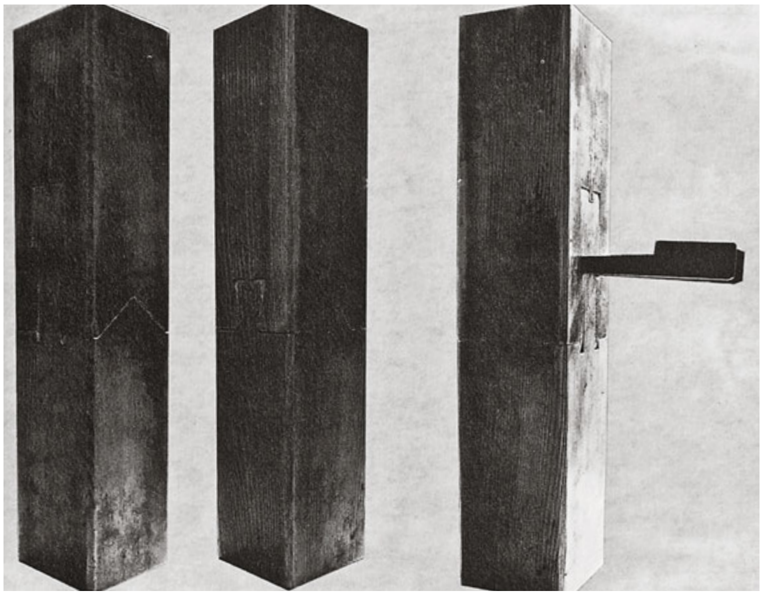


563 The *unka-tsugi* – cloud or nebula joint – likewise bears witness to desires which know no frontiers.

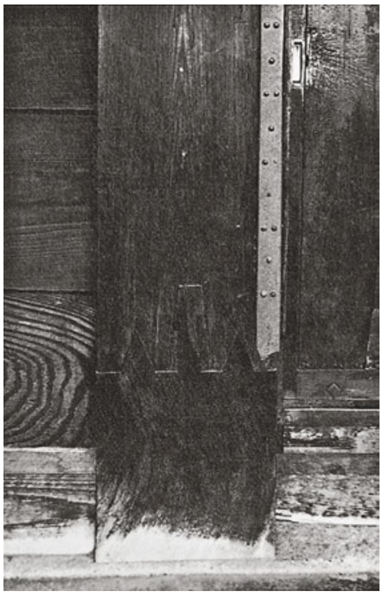
further and further behind. The age of the frivolous increasingly takes centre stage. (Fig. 565)
The carpenter tries to compensate for the lack of new constructional challenges independently. Nothing could illustrate his dilemma more clearly than joints which suddenly appeared to show more than was allowed. In the quest to distinguish himself from his colleagues, to cut a leading figure among the competition, a decorative line became an eye-catcher.[46] A focus of attention like so many examples from Europe, but not for its own sake in this case. While in Europe the carpenter proudly displayed his wares, in Japan the carpenter compelled the viewer to look more closely. (Fig. 567) Following the line of the joint around all sides, we become aware that the carpenter has connected the pieces in a way which, at first sight, appears impossible. (Fig. 566) And that is exactly the effect desired by the joint's creator. His attention having been captured, the observer is normally at a loss to explain the mystery; even colleagues are puzzled by the seemingly inexplicable. (Fig. 628) In this way they achieve a vague justification for their insubordination with regard to the first rule of aesthetics, i. e. that the position of the joint should remain hidden from view.
Such puzzles were not unknown in Europe. So-called *Meisterwitze* ("master's pranks") are "impossible" joints. What makes them possible is, on the one hand, knowledge of the material's properties and, on the other, the ability to break free from the chains of conventional ways of thinking. In these respects they remind us of the trains of thought of Japanese carpenters. However, such examples always remained limited to cabinetmakers' models.
What began just above the ground became even more noticeable once placed at eye level, even for the Japanese, despite their very different relationship with the ground compared to the people of Europe. (Fig. 568) Of course, it was now important to be able to view the joint from all sides; only by circling around the column could you be sure that you were looking at the impossible made possible! An X-ray was necessary to facilitate the non-destructive renewal of the column bases of the Himeji-jo otemon.[47] The ingenious design of this unique joint lies in its simplicity. (Fig. 569)
The underlying principle of these "puzzle joints" is the overcoming of customary compartmentalized thinking about the way in which two pieces of timber can be connected. This approach is to be found in the *shiho* joints, albeit in a simplified form. (Fig. 570) They appear to be unopenable from any of the four sides. They remain a mystery as long as the viewer remains unaware of the fact that every one of this family of joints has to be separated diagonally. Of course, the trick of opening them only works in one direction, i. e. the joint is so precisely cut that it has an imperceptible conical taper towards one side.
A dovetail on all four sides, the *shiho-ari*, is just one of a countless series of these puzzles. In principle, each of the basic forms can be tested for its suitability as a *shiho* joint. Even when their interconnection was not intended to remain a secret for long, the demands that the perfect fabrication of such a joint placed on the abilities of the carpenter were obviously sufficient excuse to experiment with a multitude of variations. (Fig. 571)
The *shiho-matsu-kawa* joint is an excellent illustration of the

564 Column-base joint on the Imanishi House in Imai cho, Nara, Japan.

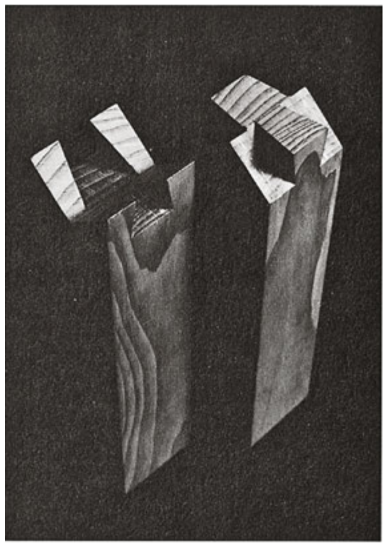
565 Decorative joints on the Sumiya, Kyoto.



566 A decorative joint which requires lateral thinking to solve the puzzle. – Model of the *Takenaka-daiku-dogu-kan* in Kobe, Japan



567 Transferring the functional parts of a joint to the inside was in no way abandoned with the coming of the exclusively decorative features on the surface. – Sumiya, Kyoto

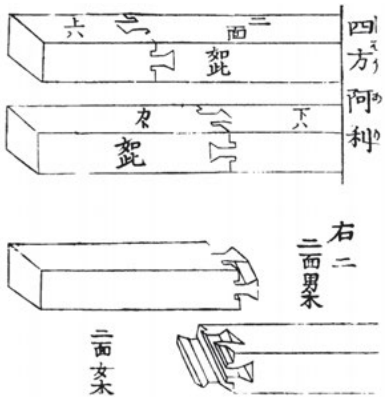


569 A model of this joint, separated for clarity.

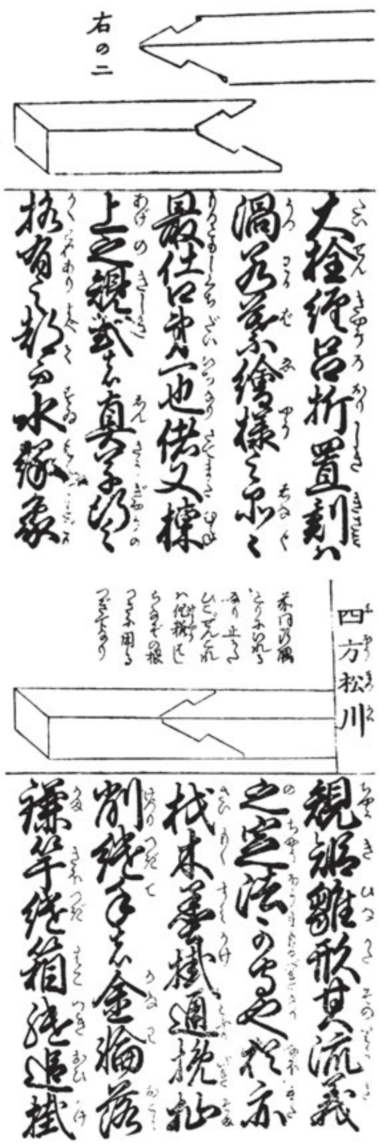
568 The other two sides of this gatepost are identical to their visible counterparts. – Osaka-jo otemon, Osaka, Japan

570 *Shiho-ari* joint on the gateway to the Honmon-ji in Tokyo, Japan.

571 *Shiho-ari* (source: Suzuki, 1847)



fact that the development of this type of joint did not come out of the blue either. (Fig. 572) Its formal relationship to the design language of the Edo period has already been shown above.[48] Another way of approaching the formal shaping of this joint is through a linguistic analysis. *Matsu* is the pine tree common all over Japan. *Kawa* can be written in one of two ways, from which two meanings may be derived; one of these is bark. With a little fantasy the shape of the joint can certainly be associated with the pictorial representation of pine bark.[49] However, the symbol on the illustration can be read as *kawa*, here meaning river. Then the joint were to be understood as an artistic interpretation of pine and river. Only at first does this latter interpretation appear to be more far-fetched than the former. In reality it sounds much more poetical to the Japanese ear. (Fig. 573)
Finally, a third variation offers itself as a possible answer. Matsukawa could have been the name of a carpenter who wished to break the bonds of anonymity.[50] If this interpretation is correct, then this example would show us once again what our journey through the developments and types of wood joints has proved time and again: that the whole vitality and the special appeal of the culturally influenced handling of wood by mankind grows out of the unity between the functional and the personal.



572 ***Shiho-matsu-kawa*** **(source: ibid.)**

573 In Japanese art there are countless examples in which the content revolves around the synthesis of pine tree and water: painted screen in Nagoya-jo, Aichi, Japan.

1 cf. Dietrichson, Munthe, 1893, p. 35, note
2 Assunto, 1987, p. 24
3 Yanagi, 1989, p. 197
4 bid., p. 111
5 Taut, 1958, p. 215
6 Smith, 1965, p. 126
7 Masuda, 1969, p. 5
8 Opderbecke, 1909, Pl. 14
9 Schier, 1937, pp. 22, 24, Figs 13, 14; Frolec, Vařeka, 1983, p. 187
10 Panoiu, no year, p. 60 f.
11 *Bunkazai …*, 1986, p. 587
12 Taut, 1958, p. 145 f.
13 cf. p. 258 ff.
14 Breymann, 1900, p. 19 f.
15 Gerner, 1992, p. 94 f.
16 Quiney, 1990, p. 51; Essex County Council, 1990, p. 14 f.; Hewett, 1980, p. 91
17 Hewett, 1985, p. 12
18 Brunskill, 1986, p. 37
19 Breymann, ibid., pp. 26, 30 f.
20 cf. p. 221 ff.
21 cf. p. 62
22 Nakahara, 1990, p. 26 f.; Sumiyoshi, Matsui, 1991, p. 24 ff.
23 Graubner, 1986, p. 53 ff.
24 Ostendorf, 1908, p. 9, note 2
25 Bernert, 1988, p. 103
26 Romstorfer, 1892, p. 202
27 Moser, 1985, p. 121 f. *Glockenschrot* is also a term which is met with. (Pöttler, 1984, p. 47)
28 Phleps, 1942, p. 62 f.
29 Ibid.
30 Bünker, 1897, p. 187
31 Moser, 1985, p. 126; Moser, 1992, p. 39
32 Phleps, ibid., p. 64. For the term *Malschrot* and its differentiation which has been partly undertaken in the literature, see Werner, 1978, p. 209, note 6.
33 Haiding, 1980, p. 150; Phleps, ibid.
34 Haiding, ibid.
35 Ibid.
36 Werner, 1978, p. 206 ff.
37 Gschwend, 1969/6, p. 4, Fig. 5
38 Gschwend, 1988, p. 31, Fig. 81, p. 179; Phleps, ibid., p. 26
39 Brown, 1989, p. 21
40 cf. p. 223
41 Phleps, 1951, p. 42
42 Gerner criticises the view that only decoration is behind such designs by pointing out the historical origins of the forms of embellishment used. (Gerner, 1985, Introduction to the reprint of Issel, 1900) The deeply rooted pagan symbolism evident in the forms has not yet been questioned because it has not been expressly highlighted. It merely demonstrates that Christianity had not yet been around long enough to suppress people's desires to create images. The real issue addressed by Issel (and condemned by Phleps) is the crossing of the boundaries for ornamental adornment as prescribed by the construction. (Issel, 1900, p. 100 f.; Phleps, ibid., p. 9 f.)
43 Ienaga, 1979, p. 151
44 Japan Architect, 1960/4, pp. 73–75; Nishi, Hozumi, 1985, p. 131
45 *INAX*, Vol. 4, No. 3, 1984, p. 38
46 Zwerger, 1994, pp. 287–89
47 *INAX*, ibid., p. 56 f.; Sumiyoshi, Matsui, 1991, p. 44
48 cf. Fig. 560
49 The author is grateful for information given personally by Dr Minamoto concerning this interpretation of the name.
50 This case would not be unique. (Sumiyoshi, Matsui, ibid., p. 57)

Structural Timber Construction in China

574 The Chengling Pagoda at the Linji si temple in Zhengding, Hebei, was constructed during the Jin dynasty (1125–1234).

"The Chinese building is a highly 'organic' structure. It is an indigenous growth that was conceived and born in the remote prehistoric past, reached its 'adolescence' in the Han dynasty (around the beginning of the Christian era), matured into full glory and vigour in the T'ang dynasty (seventh and eighth centuries), mellowed with grace and elegance in the Sung dynasty (eleventh and twelfth centuries), then started to show signs of old age, feebleness, and rigidity, from the beginning of the Ming dynasty (fifteenth century)." [1] Liang Sicheng, a pioneer in the field of research into traditional Chinese architecture and the father of Chinese architectural historiography, used these words to summarise his findings in 1946 after many years of research in the field. His albeit rather subjective description could similarly paint the picture of an ambitious carpenter who at first courageously tries until, after several attempts, he finds a workable solution, which he then perfects over time before external conditions begin to force him to abandon his individuality so that in the end, he unquestioningly does what is asked of him in a routine, distanced and emotionless fashion. The description and interpretation of the constructional aspects of Chinese timber construction that follows shows that this is a pattern that recurs time and again and offers an opportunity to trace its origins.
Unlike in Japan, Chinese constructions made use of all manner of materials depending on their local availability. The Chinese had already begun erecting buildings made of stone thousands of years ago with a technical prowess no less refined than that of the Greeks and Romans. Indeed, it is the durability of stone that is to thank for providing us with invaluable traces of building forms made of wood, which would otherwise not have been evident. (Fig. 574) Wars, fires, the so-called persecution of the Buddhists and, more recently, the Cultural Revolution have destroyed countless monuments of inestimable worth for tracing the historical development of construction. Some gaps in the history of the development of traditional Chinese architecture can be filled with the help of buildings in Japan that have survived there. Perhaps this can, at least, be interpreted as a late – if unintentional – advantage of China's one-time cultural influence in Japan.
In China, fired bricks were already being produced in the 5th century BC.[2] For much of the population, however, domestic dwellings were made of unfired earth. Below ground, dwellings were dug out of the loess soil with correspondingly fascinating ecological properties.[3] Above ground, buildings were made of earth blocks or rammed earth walls. Nevertheless, wood was still the dominant building material. "No Chinese house could be a proper dwelling for the living, or a proper place of worship for the gods, unless it were built in wood."[4] Where its availability was widespread, one had grown used to its advantages: unlike other building materials, it was relatively straightforward to obtain; wood constructions were simple to construct; they were easy to extend; and they could be built on difficult terrain in mountainous regions.[5] Even rock faces were not impossible. (Fig. 575) Wood as a building material also had further significant advantages: buildings that were no longer needed were easy to dismantle; the ability to form openings such as doors and windows was almost unlimited; the division of the building into bays of-

575 The Hanging Monastery in Hunyuan, Shanxi, built in the 6th century.

fered all manner of variations; and, last but not least, the earthquake-resistant properties of the material are impressive.
To properly understand what follows, it is first necessary to explain the concept of a bay. This is the volume described by four adjacent columns arranged in a rectangle. The dimensions of a Chinese building are not given as an absolute measure but are instead denoted by the number of column intervals along the long side (usually oriented west–east) multiplied by the intervals along the depth of the building. The size of the bay depends on the size of the building and can also vary within a building. The number of supports visible on a façade can in any case be taken as a clear indication of the – typically uneven – number of intercolumnar bays. On the north–south orientation, the bays are arranged symmetrically to the left and right of the central axis, and are of the same size. The columns in the interior, which are not visible from outside, do not necessarily have to follow the column grid suggested by the external columns. As a consequence, the bay intervals in the interior can change.
Incidentally, the Chinese nomenclature for the individual building elements is somewhat complicated by the fact that functionally identical elements are given different names depending on where they are used. For the craftsmen, this had the significant advantage of clearly differentiating between, for example, a head beam between columns that defines the perimeter of the building and a head beam that spans between internal columns and all the short columns of a *tailiang* construction. Furthermore, over the course of time some elements were given new names. The *dou* with intersecting grooves were called *dou*, but those with one groove were known during the Qing period as *sheng*, while the *gong* parallel to the wall were called *qiau*, and those perpendicular to the wall *gong*.[6] Liang Sicheng, one of the first 20th-century scholars to analyse the *Yingzao fashi* (Treatise on Architectural Methods) published in 1103, was driven almost to despair by the apparent contradictions in the so promising, logical structure of the "building standards" and the unfathomable technical terms it contained: "In the course of my own work, what proved most difficult and time consuming was to differentiate, memorize and understand the terms and forms of those complicated structural parts."[7] He resolved the problem for himself with the realisation that "the only reliable sources of information are the buildings themselves and the only available teachers are the craftsmen".[8] At the time he wrote this in the 1930s, it was, of course, still possible to consult craftsmen schooled in the traditional techniques.[9]

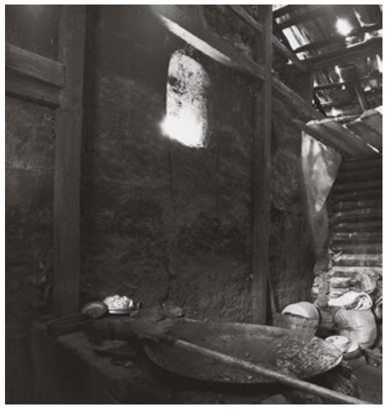
576 The four-sided courtyards of the Mosuo consist of a single-storey. "Grandmother's room" on one side and two-storey buildings on the other three sides. – Lijiazui, Sichuan

In China, as in Europe and Japan, one finds both log-cabin buildings and column-and-beam constructions. While log construction also spread across large areas of China, it did not attain even a comparable level of the technical elaboration found elsewhere. Examples of single-cell, single-storey log constructions can be found in the provinces of Xinjiang[10] and Tibet,[11] and larger two-storey buildings in Yunnan and Sichuan. (Fig. 576) As these areas were only later incorporated into the Chinese Empire, the minorities who lived there were able to retain their independent cultural traditions, to which log construction belongs, for a long time. To the Han Chinese who settled there, albeit not altogether voluntarily, these traditions were foreign, but they quickly realised that in order to cope with the climatic and topographic conditions as well as the availability of resources they would have to adapt, or even dispense with, their own building methods.

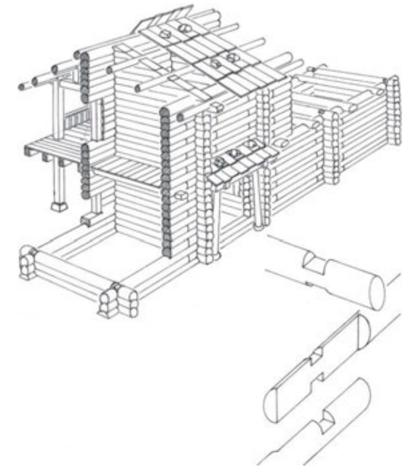
Two fundamental prerequisites influenced the development of log construction: first and foremost, the abundance of dense coniferous woodland (Fig. 577), and secondly a comparatively dry climate. Log construction developed in regions where it was necessary to shelter against very cold climates and contain warmth. By contrast, the flooding and humidity in regions affected by the annual monsoon would be fatal for log buildings. This explains, for example, why log construction did not develop in the settlement area of the Dong minority in the border regions of the provinces Guizhou, Guangxi and Hunan, despite the plentiful supply of timber in these regions.

In the animistic religions of many of the minority peoples there was little need for sizeable places of worship of the kind required for Buddhism or Taoism. Their primary need was for dwellings, sheds, stables and barns in dimensions appropriate to small-scale agriculture. The buildings and their construction were, therefore, correspondingly simple. Beams with a diameter rarely exceeding 15 cm were lengthened by the simplest means if they were too short. (Fig. 578) These primitive connections were secured by incorporating them into a junction with a dividing wall. (Fig. 579) The roof construction likewise testifies to the residents' lack of interest in searching for ways to improve the construction. They either remained simple constructions of the kind familiar from European log construction, (see Fig. 578) or employed a technique borrowed from skeleton construction.[12] (Fig. 580) Small wonder then that log construction earns little more than a passing description in the literature.[13] A very different picture becomes apparent when one takes a closer look at the construction and structure of more diverse kinds of buildings, as is undertaken below by way of example in the section "The construction and structure of temple buildings".

The dominant form of timber construction in China is column-and-beam construction, usually in a rectangular configuration. There are two principal different construction methods, *chaundou* and *tailiang,* both of which are post-and-truss constructions: trusses arranged parallel to the gables are erected behind one another along the longitudinal axis, connected and held in place by beams and purlins, making it possible to extend the building in a longitudinal direction.



577 Widespread deforestation meant that residents in regions where buildings were traditionally made of wood increasingly began to erect walls out of earth. - Zepo, Yunnan



578 According to: Xiao, 1999, vol. 2, figs. 14–21.

579 Intersecting cross-wall in a log wall construction in Lijiazui.

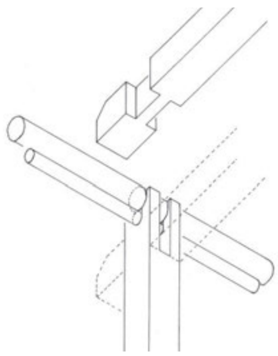
580 The purlins in the roof of this "Grandmother's room" in Zepo, are borne in part by columns that stand on the ground and in part by columns interlocked with several logs of the wall construction via reversed forked tenon joints.

Chuandou construction is typically described in English-language literature as "post-and-tie" or "through-jointed type" construction. (Fig. 581) Both terms are unsatisfactory in that they communicate no idea whatsoever of the construction, despite the fact that the construction exhibits quite clear characteristics through which it can be described. Vertical elements, posts or columns bearing purlins at their upper ends, play a visually dominant role. In its basic form, each purlin is born by a column standing on the ground. The columns are connected with one another by through-jointed beams to form a truss. Ideally, a single such anchor beam passes through all the columns. Where the anchor beams were too short, they were spliced together in the column. The columns grow longer with the roof pitch from the eaves to the ridge. The principal attraction of this construction lies in the ability to use timber elements with a very slender cross-section. The drawback is that the floor plan is rigidly determined. This led to various derivations that in essence take the same approach: instead of placing all the purlin-supporting columns on the ground, some are connected via reversed forked tenon joints into horizontal anchor beams arranged at different heights. This has the added benefit of reducing the quantity of wood required. In some cases these horizontal beams also served to prevent the mortised columns from breaking apart. (Fig. 582)

The *chuandou* construction method is most widespread in the Chang Jiang (Yangtze) Basin and the regions south of the river. The buildings of the Dong minority offer a good example of such construction.[14] The Dong constructed their dwellings with up to four, but typically three, storeys. The ground floor was dictated by the pattern of columns and was often closed off with wall-like panelling and subdivided by wooden partitions. These housed pens for small livestock, the closet, storage areas for tools and firewood sheltered from the weather and sometimes also small workshops. The floor above was for living in. The central room was the kitchen with an open fire that served as a communicative space for the family in the cold season. In the warm months, this function was transferred to a veranda that was open on one or more sides. The third floor contained sleeping areas for the children and storerooms for food. (Fig. 583)

The buildings of the Dong, like those of many other minority peoples in the south, were therefore raised off the ground on stilts. These so-called *ganlan* houses can be found throughout the subtropical regions of Southeast Asia where there is intense sunlight and high precipitation and where the air is hot and humid, particularly during the rainy season. During this period, the rivers can swell to become torrents. The *ganlan* houses offer protection against moisture and flooding, as well as reptiles and all kinds of mosquitoes, whose habitat is apparently confined to heights beneath that of the living area. In addition, the elevated buildings ensure sufficient ventilation for the timber construction and also, due to their specific, very open construction, optimal ventilation for the inhabited floors.[15] With their outwardly open construction these dwellings differed significantly from the courtyard houses of the Han Chinese. As a result, these houses can in theory be extended in all directions.

581 The unfinished skeletal timber framework shows clearly how precisely the rough-cut pine trunks have been worked with an adze in order to connect as many columns as possible with a horizontal beam. - Pingpu, Guangxi



582 Using a system that recalls early raised header construction the transverse beams were worked in such a way that they could be set into the slotted columns. For better anchorage, the projecting section retained its full cross-section. These beams served not only as anchor beams but also prevented the shoulders of the purlin recess at the top of the column from breaking off.

583 The many open and permeable sections of external wall show how important ventilation was. – Pingliu, Guangxi

A special variant of these is the *diaojiaolou,* or so-called "overhanging floor" house. (Fig. 584) Wherever possible, the Dong preferred to settle along rivers, which served as an important, and during the rainy season often the only, transport route and moreover ensured a permanent supply of water. Flowing water cools the air in the immediate vicinity and the closer the dwellings were to the water, the more they were able to benefit from this. By extending the living floor over the river (Fig. 585), the space beneath could also be protected from both sun and rain. This was achieved by allowing the horizontal beams that separate the ground floor from the first floor to project out beyond the building's perimeter. The cantilevered ends of the beams are recessed to slot as tenons into corresponding holes cut into the "hanging posts" of the overhanging floor, a construction that resembles that of European medieval timber-frame houses. Over time, the Dong were successively displaced from the easy-to-settle valley locations to increasingly remote higher-lying regions by the Han Chinese who settled in ever more outlying areas. While these regions afforded them a safe retreat, they had to significantly modify their cultivation techniques. For wet rice cultivation in such mountainous terrain, it was necessary to create terraces, artificial level surfaces that were reserved without exception for agricultural use. The dwellings were therefore erected primarily on sloping terrain. This is a further reason why log buildings were never contemplated, despite the immense abundance of Chinese fir *(Cunninghamia lanceolata),* a wood that is well suited for log construction. If the slopes themselves were too steep for column-and-beam constructions, retaining walls made of stacked pieces of rock from riverbeds were erected as a base.

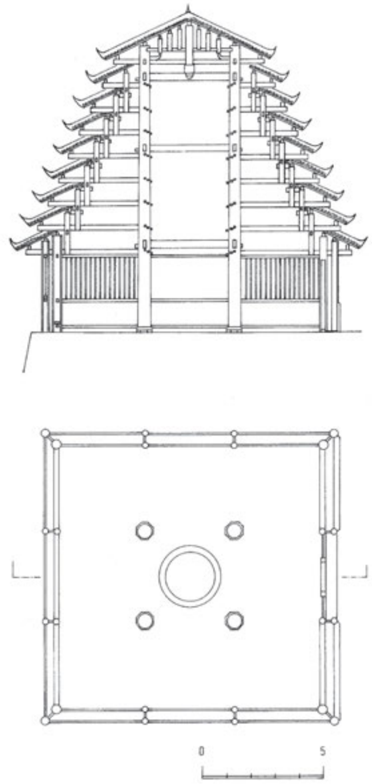
A particularly spectacular variant of *chuandou* construction can be seen in the drum towers of the Dong. (Fig. 586) These served as a communication and meeting centre for each village, and the number of towers announced far and wide the number of clans living in a village. Their cultural importance was reflected in their architectural elaboration, both in terms of construction and decoration. The clans competed with one another according to clearly defined rules to create the most impressive tower in the village. The very best, most carefully selected tree trunks were reserved for the main supporting construction. Four columns typically defined a floor plan in the shape of a rectangle, six columns that of a regular hexagon, eight columns that of a regular octagon. (Fig. 587) There are also examples of drum towers with a rectangular floor plan and just two storeys, and very occasionally carpenters attempt to pull off a "one-legged" drum tower, a particularly demanding task with just one central loadbearing column into which all the struts must be mortised from all sides. The main columns, connected to each other by horizontal beams, are supplemented by an outer ring of columns. The crown ends of these outer columns bear purlins that support the lowermost monopitched tier of roofing. The inferior purlin rests on the outer end of the beam that connects the main column with the outer column. The logic of this construction cannot accommodate a roof that would extend far enough to effectively protect the columns. For this reason, a series of stepped tiers of monopitched roofs was chosen: it affords optimum protection for the timber members

584 The overhanging columns of the cantilevered upper storey lend the construction its name: *diaojiaolou*. – Pingqiu, Guangxi

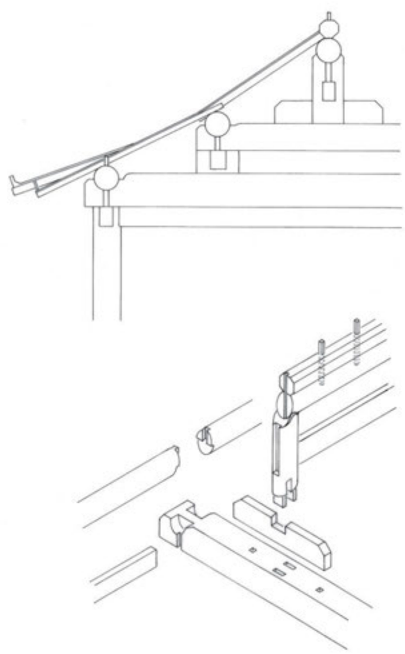
585 Waterside settlements had many advantages. Gaozeng, Guizhou

586 Despite its rather squat dimensions, the drum tower in Mapang, Guangxi is one of the largest of its kind.

by shielding against driving rain and allowing wind to pass between the tiers of roofs, reducing the level of moisture in the wood, caused by extreme humidity during the monsoon period, to a tolerable level. The upper tiers of monopitched roofs are borne by columns, which in classical *chuandou* manner rest on the horizontal connecting beams. The resulting load acting on the connecting beam is borne by tenons inserted into the main column, and on the outside by the next column one tier further down, with which the beam is connected by means of a through-tenon.
The planning and realisation of the drum towers was entrusted to experienced carpenters. While the structural timbers of a dwelling were pre-cut to size by travelling groups of carpenters so that the villagers could assemble the shell of the house themselves within the space of a day, the drum towers were not only cut but also constructed by the carpenters. Traditionally, there was neither a drawing nor a model. Instead, the responsible master carpenter had more or less free hand in how to achieve the required size and height. It is indeed fascinating that one never comes across two identical constructions.
The term *tailiang* construction, literally "raised beam" or "terraced beam" construction, draws its name from a constellation of pairs of corresponding columns that each bear a horizontal beam with recesses at each end to receive the purlins. On these beams, further short posts are placed to the left and right, offset inwards to the required degree. These are anchored with one or two tenons to the beam. (Fig. 588) These pairs of posts in turn support a second horizontal beam. This pattern is continued until only a single post remains in the centre to support the ridge purlin. The lengths of the posts in the roof construction determine the pitch of the roof. While it is immediately evident that, compared with *chuandou* construction, this method is capable of covering a large volume uninterrupted by columns, the dimensions of the columns, and even more so of the beams, reflect the load they must support. The Chinese refer to these beams according to their length as four-, five- or six-rafter beams, referring to the number of inclined roofing members required to span from the ridge purlin, over the intermediate purlins to the inferior purlin.
The Chinese carpenters developed different constructional variants for the posts that bore the transverse beams in the roof construction. They experimented in detail with the possibilities known to them from log and column-and-beam construction. The figures (Fig. 595, Fig. 597 and Fig. 600) show three possibilities for achieving a construction that raises the transverse beam to the desired height. In the first example, the mid-level four-rafter beam rests on a series of tiered beams, in the second, a four- and a six-rafter beam rest on camel's-hump-shaped braces and in the third, a two- and a four-rafter beam rest on slender columns.
The *tailiang* construction was most prevalent north of the Chang Jiang (Yangtze). However, its truly outstanding importance lay in its use for large prestige buildings. In the halls of temples, freedom of movement around the statues of Buddha together with an uninterrupted view of them was paramount. Palaces likewise presented carpenters with the task of constructing spaces as large as possible but without columns. The



587 The section through the drum tower in Mapang shows a simple but highly effective construction that can be made with simple tools.

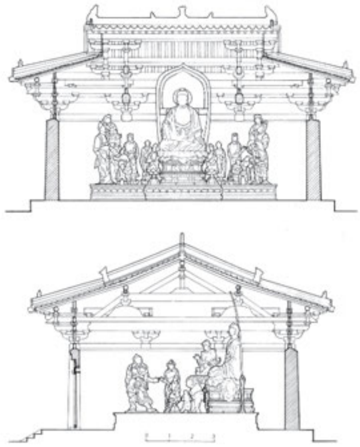


588 According to: Zhong, Chen, 1986, p. 158, fig. 5-9-46

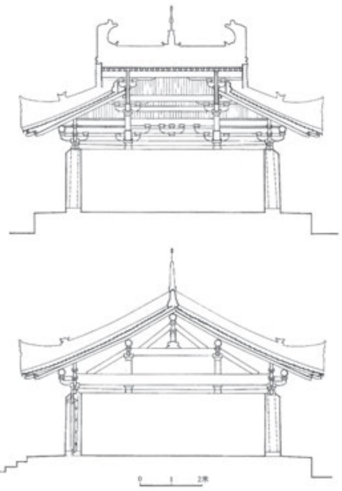
oldest known temple in China today, the Nanchan si, built in 782, (Fig. 589) escaped destruction during the persecution of the Buddhists only due to its exceptionally remote location in the Wutai Mountains and its apparent lesser importance. Twelve columns divide the floor plan and enclose a space of 3 by 3 *jian* (bays). (Fig. 590) Various characteristics point to the building's origins in the Tang period (617-907): the entasis of the columns, the increasing length of the columns from the centre of the building to its corners as well as two camel's-hump-shaped braces above a supporting beam that lies directly on the massive transverse beam. What suggests that the Nanchan si was probably of secondary importance is the total lack of columns in the interior and the absence of bracket complexes between the columns.

A comparison with another very small temple, likewise spared from the ravages of the time, the Tiantai'an in Pingshun, shows an interesting variant that in its details reveals a certain constructional uncertainty. (Fig. 591) Although Tiantai'an also exhibits a 3 by 3 *jian* arrangement, at 7 x 7 m it is much smaller than Nanchan si, which measures approximately 11 x 10 m. Nevertheless, it was given intermediate bracketing at the eaves over the door. The gable opening between the ridge purlin and the two-rafter beam was then closed in with walling. Over time, however, the weight of the walling seems to have subjected the transverse beam to excessive load, requiring that it receive an additional support. Now three posts rest on the four-rafter beam below, in turn necessitating that it too be strengthened.

589 The Nanchan si is the oldest known temple in China.



590 According to: Zhong, Chen, 1986, p. 76, fig. 5-4-3c and d



593 According to: Fu, 2001, vol. 2, p. 501, fig. 3-7-24 and 25

591 The Tiantai'an was built in the Tang period.

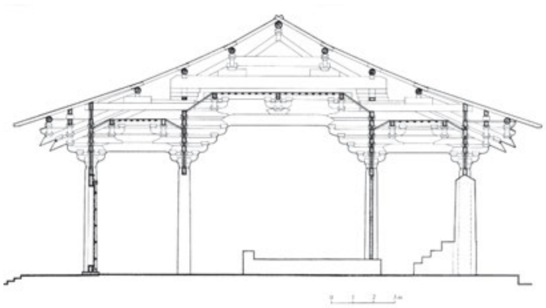
592 The interior almost certainly has more columns than were originally intended.

The three relieving beams now dominate what was originally conceived as a column-free interior. (Fig. 593) The columns beneath the intermediate purlins are proper columns, unlike the voluminous camel's-hump-shaped braces in Nanchan si built only slightly earlier.

The east hall *(Dong da dian)* of the Foguang si, built in 857, creates an entirely different impression. Although this temple, which measures 34 x 17.70 m, is regarded as a medium-sized temple, its construction and articulation is among the most exquisite of its kind from the Tang period. (Fig. 594) Here the four central columns of the 7 by 4 *jian* column grid have once again been omitted to make space for the altar. (Fig. 595) In the cross-section, one can see that the inner and outer rings of columns are of equal height. The towering bracket complexes arranged over the columns reach unparalleled dimensions. Although the brackets supporting the eaves between the columns are more modest than those above the columns, their independent form and size point to the importance they were accorded. The specific details of the *tailiang* construction are concealed in the main hall by suspended ceilings. The ridge purlin is supported in this case not by individual posts as is usual, but only by the diagonal struts.[16]

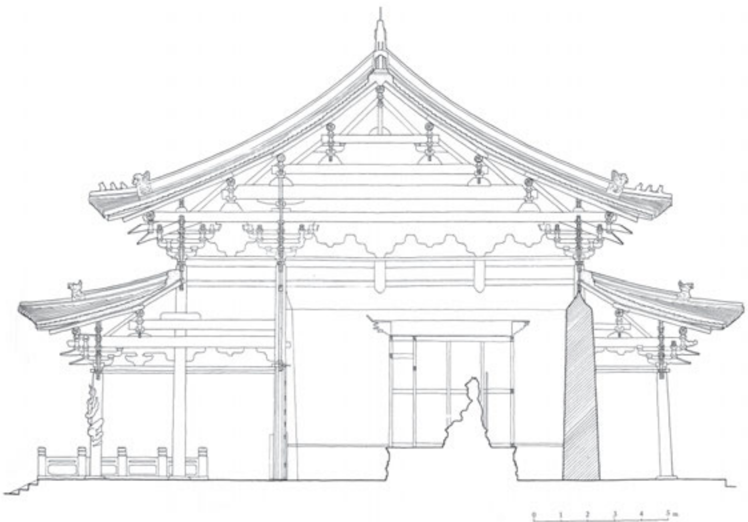
The Shengmu dian hall of the Jinci ancestral temple in Taiyuan originates in its current form from the Song dynasty (960-1279). (Fig. 596) It takes a very liberal approach to the positioning of the columns. In this case, very tall columns support two levels of eaves, one above the other. The front quarter of the quadripartite section of the temple hall is separated from the rearward section by a row of columns. (Fig. 597) This row of columns makes it possible to divide the transverse tie beam above the columns into a two-rafter beam and a six-rafter beam. While at the back, a row of low columns bears the weight of the monopitch roof, the main façade is connected in a rather unconventional manner with the main hall: the low columns of the main façade, entwined with dragons, align directly with the aforementioned inner row of columns. The absence of a row of columns beneath the upper eaves creates sufficient space for a very deep veranda that also incorporates the adjoining gallery within the construction. The interior is still clearly separated by the massive wall, but a look at the roof construction shows very

594 That the Foguang si survived the persecution of the Buddhists during the Tang period is probably due to its remote location.



595 According to: Zhong, Chen, 1986, p. 79, fig. 5-4-7

596 Jinci Shengmu dian.



597 Cross-section through the main axis of Jinci Shengmu dian. (according to: Zhong, Chen, 1986, p. 103, fig. 5-6-12)

clearly the principle of *tailiang* construction and the possibilities it affords to overcome significant height differences. (Fig. 598)

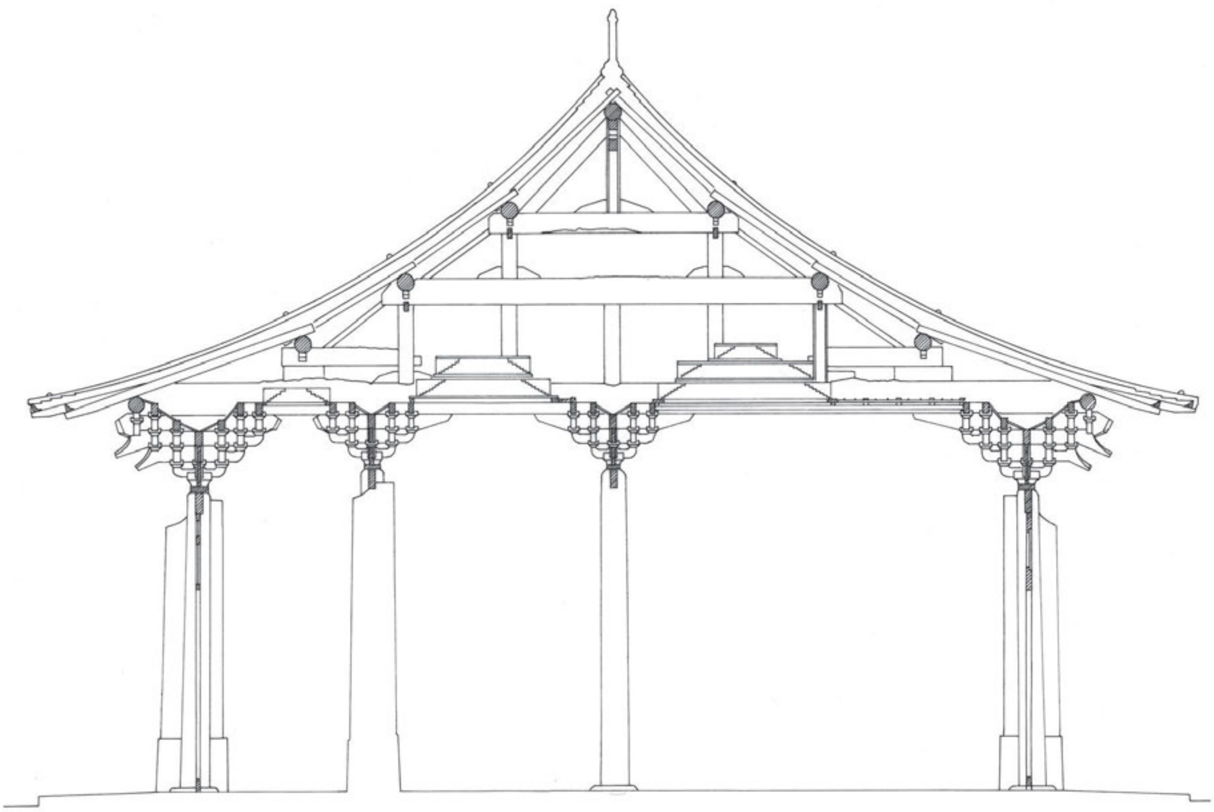
During the Yuan rule, the Sanqing dian hall of the Taoist temple Yongle gong was erected in 1262 in Ruicheng. (Fig. 599) It is striking to see just how much the bracket complexes beneath the eaves have shrunk compared with those in the Foguang si (see p. 273) (Fig. 600) In addition, the roof pitch is much steeper: an aesthetic innovation, but one that had little serious implications for the structure as all it entails is the extension of the vertical posts beneath the cross-beams that support the purlins (see also Fig. 588). There are, however, a number of significant details that illustrate the continuing development of the construction. While the inner and outer columns differ only slightly in height, their length has increased enormously. Until then, it was standard practice that the length of the columns did not exceed the distance between them. The inward inclination of the outer columns likewise increased, as did the gradual lengthening of the columns from the centre to the corners, an important aspect for the structural stability as we will see later (see pp. 279–280). In this context, the large diameter of the corner columns compared with that of the others is also of importance:[17] the load resting on the corner columns is larger due to the construction of the corner of the roof and its resulting weight.

For all of the above, it is important to note that many of the constructions cannot always be clearly attributed to one or the other system.[18] Transverse beams that lie above one another, connected to each other by dowels and moreover interlocking with longitudinal beams, are much more resistant to the frequent earthquakes in the Yunnan region. In prestige buildings,

598 Looking upwards from below, one can identify which parts of the construction of the main façade carry which set of eaves.

599 Yongle gong Sanqing dian.

600 Cross-section through the Sanqing dian of the Yongle gong. (according to: Zhong, Chen, 1986, p. 116, fig. 5-8-3)



suspended ceiling constructions often obstruct one's view of the roof construction. In domestic dwellings, this was only rarely the case. But where the structural beams were visible they were often given decorative treatment. (Fig. 601) Very often it is necessary to take a closer look: the placing of the inferior purlin directly on the column seems at first glance to indicate *chuandou* construction, but on closer inspection one can see that the purlin rests on a head beam directly beneath it that acts as a tie beam between the columns – a detail characteristic of *tailiang* construction.

601 The roof construction of this old house in Baisha San Yuan Cun, Yunnan, here without roof covering, shows the care that has gone into shaping the ends of the beams that give the roof its form.

Structural wood preservation: raised platform and cantilevered roof

Large Chinese temple and palace buildings exhibit a clear horizontal zoning. A grid of columns stands atop a platform and in turn support a colossal roof. (Fig. 602) Two structural elements are particularly conspicuous: the raised platform and the wide cantilevered roof. Both elements are a product of the need to protect an extremely costly and labour-intensive timber construction against the sometimes destructive forces of nature. The platform and the sailing roof are a response to the predictable influence of sun, wind and rain; the unpredictable forces of earthquakes will be discussed later (see pp. 292–293).

602 The Meridian Gate (Wumen) is the south entrance to the Imperial Palace in Beijing.

Timber columns should not stand on the ground if they are to be protected against the effects of water. While a stone slab can be used as a base for the column, it still does not provide adequate protection against splashing water. The solution used by the Chinese is to raise the entire building on a platform, an act that simultaneously heightened the grandeur of an important building. In accordance with its importance as the foundation of a building, the platform construction underwent constant development.[19] To a certain degree, this is also linked with developments in society. In Erlitou in the province of Henan, the former capital city of China, archaeologists found an 80 cm thick platform measuring 108 x 100 m made of rammed earth. Erected more than 3000 years ago, the construction can only have been made by slaves, who would have been forced to ram layer after layer of earth, each between 4 and 10 cm thick, with the aid only of a stone or wood tamper with a head measuring 3 to 6 cm in diameter. The intensive compaction of the earth closes the capillary channels in the earth with the aim of making the platform impervious to water.[20] On top of this was a further platform measuring 36 x 25 m with a thickness totalling 3.10 m. This was probably the foundation of the main hall. As if this were not enough, the columns were given additional support. At a depth of 50 to 70 cm beneath the surface of the foundation, archaeologists found a massive stone or a few individual stone blocks embedded in the foundation as a base for each column.[21]

The durability of a wood construction is dependent on the quality of the platform on which it stands. Archaeological finds reveal the workmen's ongoing search for the best possible platform: a variety of materials aimed at improving the stability of the platform were found beneath the surface, ranging from gravel, to rubble to pieces of charcoal. Rather than using them as aggregate in the earth mixture, they were embedded and rammed in alternating layers with the earth. For the platform for the Zhuanlungzang hall of the Longxing si in Zhending, each column had its own foundation. This can be seen in the alternating layers of earth and crushed brick, which varied in number and depth from column to column.[22] During the restoration of Nanchan si, it transpired that a different approach had been taken. Here the platform has been given a gradient of 3 ‰ from the centre to the edges.[23] Precisely when such attempts to improve the stability of the ground first began has as yet not been ascertained.

The aforementioned Sanqing hall stands on a platform 2.39 m high. The foundations beneath the corner columns are 3 m deep, those beneath the outer columns 2.47 m, while the foundations for the perimeter wall are 2.13 m deep. This means that the foundations for the columns were all bedded in the ground beneath the platform, although those between the columns were not. The assumption is that this was an attempt to prevent frost damage.[24] And indeed, some 750 years later the foundations are still intact.

In the Ming period (1368-1644) builders began mixing the earth used for the foundations with a measure of lime according to two different mixing proportions depending on the size of the tamper used. During the Qing period (1644-1911) this working process was set down in increasingly greater detail, resulting in foundations of a strength far in excess of what was needed.[25]

The timber columns transferred the load resting on them to the foundation via a stone padstone. (Fig. 603) The stone padstone served to distribute the weight as evenly as possible to the foundation, to protect the wood against rising damp from the ground, and as a datum point for the construction of the structural frame and the execution of the floor. The degree of care taken by the carpenters is demonstrated by the insertion of a wooden base plate between the outer timber columns and the padstone: should rot begin to set in at the base of the column, this wooden base plate, into which the column was mortised, could easily be replaced.[26]

The timbers of the walls and the columns were also protected against excessive moisture to a differing degree by roofs with different forms. In the case of hipped roofs, the eaves around the perimeter sheltered the wall beneath; hipped and gabled roofs, although more expressive in appearance, offered a similarly effective shelter to hipped roofs. Hipped roof forms were, however, reserved for the nobility.[27] As a result, most domestic dwellings had pitched roofs. The dwellings were either arranged so close to each other that they sheltered each other or alternatively, one or more monopitched roofs were added to the gable ends. (Fig. 583) To provide any degree of protection, pitched roofs would have to be extended far beyond the end walls. For this reason, one finds very few temples with pitched roofs where the end wall columns are not concealed up to a certain height within a protective layer of earth or brick facing. (Fig. 604) However massive these walls appeared to be, they served no loadbearing function and, like other forms of protective cladding such as boarding or shingles, could in theory be replaced when worn (which, of course, happened very seldom because the interior surface of many temple walls had been covered with murals of immeasurable cultural and historical

603 Stone column footing from the Kaiyuan si Zhonglou built in the Tang period. - Zhengding, Hebei

604 Only the *dougong* in the Tian Wang dian of the Zhenguo si in Pingyao, Shanxi, project out of the walled masonry enclosing the loadbearing columns. The temple was built during the Period of Five Dynasties.

value). This enveloping of the column, however, contradicts a fundamental rule of timber preservation by preventing adequate ventilation. In Nanchan si the columns along the eaves are, therefore, only partially embedded in masonry and in the Imperial Palace in Beijing, the columns are protected at the points where they project out of the enveloping masonry by perforated bricks which provide the necessary ventilation.[28]

Most people associate a historical Chinese roof with a concave curve and an eaves line, and sometimes ridge line, that arcs upwards at its ends. And for the roofs of large prestige buildings, this is in fact largely the case. Without doubt, this distinctive silhouette plays an important role in their aesthetic perception. But the underlying functional reason, and the origin of its form, is to be found elsewhere entirely: in the need to protect the timber structure and the need for illumination.

This is best described by contrasting it with the roofs of simple dwellings, whose roof inclines are planar in China too, or at the most exhibit a barely perceivable concave form.[29] Courtyard houses, a very common form of dwelling, are oriented inwards. Daily life takes place in the courtyard, and the outwardly almost hermetically sealed buildings that housed the majority of the Chinese population at that time, are by contrast very open to the interior. (Fig. 605) Whether in the house of a civil servant or that of a simple farmer, it was always necessary to protect all walls with door and window openings against both sun and rain. The simplest way of achieving this was to use a projecting roof. A farmer with a four-sided courtyard might wish to have a sheltered work area or a covered walkway between adjacent rooms. (Fig. 606) The so-called grandmother's room, a somewhat primitive centre of the family compound of the Mosuo minority,[30] often looked like a skeleton construction within the interior of the courtyard. (Fig. 607) Aside from housing an open fire, it also served as the grandmother's sleeping quarters. The roof projects so far beyond the face of the log construction that it has to be supported by a row of columns, resulting in a corridor. (Fig. 608) For climatic reasons, and with respect to the special sense of warmth and security of the grandmother's room, the row of columns was usually closed off with a wall such that holes in the roof covering were sometimes the only source of light when the fire was not lit.

Temple or palace buildings are, however, much higher than domestic dwellings. As a consequence the roof has to project that much further out to protect the wall beneath it as well as to shelter crowds of worshippers. The eaves of the earlier Nanchan si temple were not given flying rafters, but those of the later Foguang si temple extend more than 4 m beyond the row of columns in the façade. At the same time, temple buildings are very often open to the south and only a few also have an additional, comparatively small opening on the north side. The longer the roof extends out and downwards on the south side, the more it prevents light from reaching the interior of the temple where the worshippers go to see the statues or magnificent wall murals. The builders of the time therefore had to find a solution that ensured the safe dispersal of rainwater from the roof while allowing sufficient light to illuminate the interior. The solution lay in the use of short rafters that run only from purlin to purlin. When the inclined roof members no longer ex-

605 View from the upper floor of one of the many courtyards of the Wang Family Compound in Jingsheng, Shanxi. This residence from the Qing period covers an area of 4.5 hectares.

606 View from a "Grandmother's room" of an interior courtyard formed by four buildings in Dacun, Yunnan.

607 The "Grandmother's room" itself was always a single-storey construction. - Dazui, Sichuan

608 A protective wall in front of the log construction creates a wide corridor in front of the "Grandmother's room". The entrances in each wall are always arranged offset to one another. - Luoshui, Yunnan

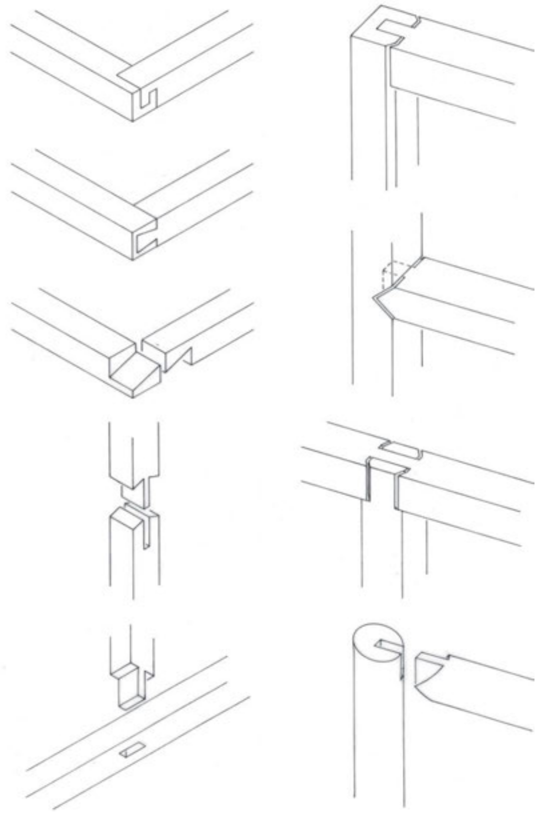
tend from the ridge right down to the eaves, the purlins can be arranged freely at the height necessary to achieve the desired contour of the roof. (Fig. 609) The changing taste in roof profiles over time can be seen in the guidelines given in the respective building manuals of the day, the *Yingzao fashi* from the Song period and the *Gongbu gongcheng zuofa* published in 1734 in the Qing period.[31] The curving roof surface not only reduced the overall height of the roof but also had the structural advantage of reducing lateral wind loads – a very significant benefit because the columns only rested on padstones and were not additionally held in place by a connecting sill beam.[32]

In the case of buildings with multiple storeys, however, it was not possible to provide adequate protection against the weather, regardless of how far the roof projected. The solution that arose also explains the initially confusing incompatibility of its perception and construction: pagodas and towers are termed two-, three-, or five-storey buildings according to the number of roofs. This is, however, not always what one can see on the surface! Yakushi-ji sanjunoto is a three-storey building but has six tiers of roofs. Dule si Guanyin ge appears to be a two-storey building but actually has three storeys. Yingxian muta has six roofs but consists of ten structural units. The answer to the riddle lies in the need to protect the façade between the structural roofs as best possible, in some cases through the insertion of additional monopitch roofs, in others by attaching balconies, with the result that the building's appearance no longer corresponds to the structure of the construction.

609 This model of Yongle gong Sanqing dian shows how the rafters are laid from purlin to purlin, how the hip ridge is formed as well as the wedge-shaped beams on the inferior purlin to elevate the eaves at the corners.

Choice of materials

A major factor contributing to the lasting durability of a construction is the quality of the materials out of which it is built. Certain kinds of wood have specific qualities. Carpenters were aware of this and passed on their knowledge over generations. Pine, for example, was noted in the Jin period as being "especially well suited for the making of boats and coffins".[33] In terms of examples of material qualities, the Imperial Palace in Beijing proves to be a real treasure trove. Nanmu,[34] for example, is not only very durable but also exhibits an especially attractive play of colours ranging from olive-brown to red-brown. Teak and pine from northeast China were used predominantly for the columns, Chinese fir[35] for the purlins, rafters and for the roofing boards that bear the earthen mass in which the roof tiles are bedded. For making corner beams as well as door and window frames, carpenters turned to the wood of the camphor tree. In Lu Ban jing, documents also describe its use for making water wheels for irrigation purposes.[36] In early 1877, the *Peking Gazette* reported on the steep rise in the price of camphor wood. The fact that camphor trees were often revered in their place of growth as *feng shui* trees contrasted sharply with their intended use as timber for shipbuilding. Newspaper articles soon followed deriding such superstitious practice.[37] Cypress was the wood of choice for structural members directly beneath the ridge purlin. Through experience gathered over hundreds of years, it became clear that, under normal conditions, Chinese fir was more capable of delaying the onset of the rotting process than any other kind of wood. Only where wood was to be em-

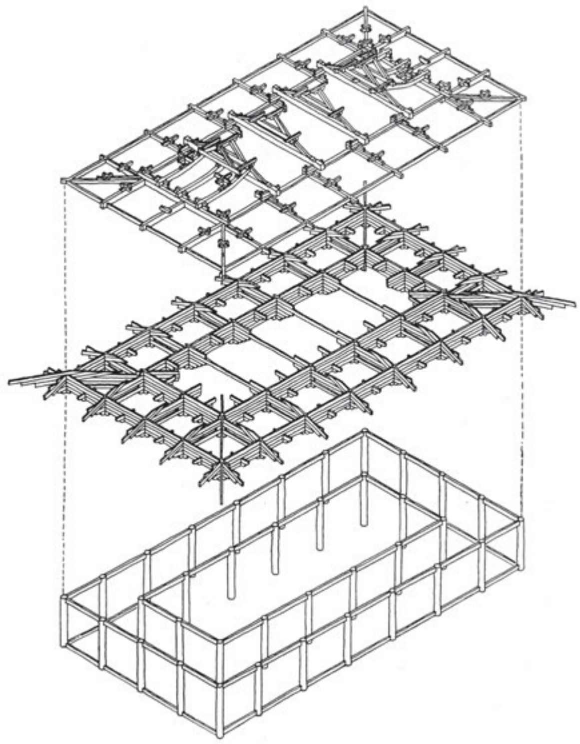


610 The Chinese carpenters developed various methods of marrying the need to protect joints against moisture with aesthetic considerations. The following measures were taken to enable water to disperse rapidly: where possible the end grain was always covered; halved scarf joints were bevelled and tenons were through-jointed. Joints were cut bevelled on facing surfaces to avoid unsightly gaps forming as a result of drying shrinkage. (according to: Wei, 1999, fig. 6.33-40)

bedded in moist earth, did carpenters prefer to use cypress, Korean pine or willow.[38] But in the north of the country, carpenters could not be quite so choosy: *"Trees that inhabitants in the south would never use, such as the mulberry tree, willow, robinia and pine, were used indiscriminately in the north. As a result the beams and purlins of their houses are often misshapen and their tools and wooden utensils cracked..."*[39]

Stone and bronze plinths were already used beneath wooden columns as far back as the Shang dynasty (1600-1100 BC).[40] In the Ming and Qing palaces, tung oil was used to protect the ends of beams and purlins that rested on walls, and for the connections between beams and columns, as well as for the bottom steps of staircases. The Dong minority, in whose settlement area the tung tree[41] grew, also made use of its especially resistant properties.[42]

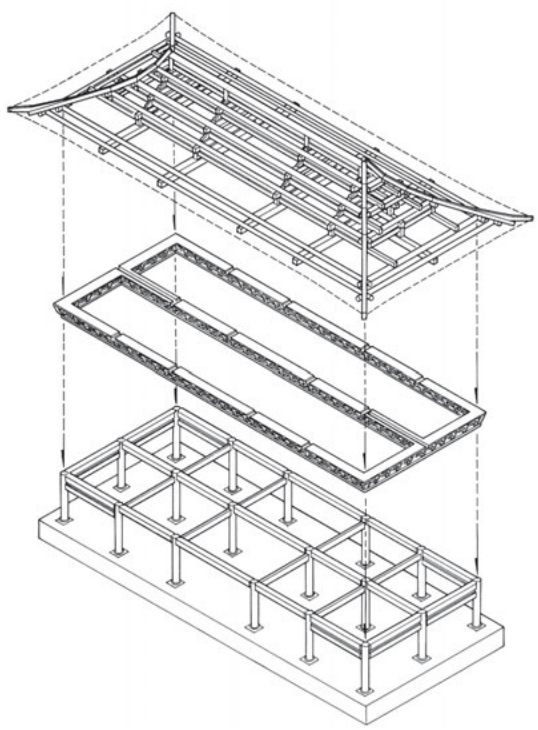
Despite all of the above, two aspects were of key importance for the long-term preservation of the timber structure: the incorporation of ventilation openings into the structure and the design and elaboration of the wood joints themselves. The capacity of the material to adjust its moisture content in response to its environment means that it swells and shrinks. Should two connected timber elements shrink, this can in certain circumstances affect the quality of the joint as well as look unsightly. The carpenters of the day devoted an inordinate amount of attention to this problem, reconfiguring many wood joints so that drying cracks would not, as far as was possible, be visible. The solutions they developed had the added benefit of concealing the outward-facing parts of the jointed members by diagonally cutting the functional part of the connection, so that the end grain is protected. (Fig. 610)



611 Exploded axonometric of the tripartite structure of a temple from the Tang period. (according to: Guo, 1995, p. 69, fig. 35)

The structure and construction of temple buildings

The complex sets of brackets (*dougong*) that feature prominently in Chinese architecture are particularly fascinating, not least because nothing of the kind developed in Western construction. As a structural element, they connect the columns with the roof. Their primary function was initially to transfer loads from the horizontal beams that bear the weight of the roof to the columns while simultaneously enabling the eaves to cantilever outwards as far as possible. (Fig. 611) While the columns were fixed to one another by means of a ring of tie beams at their crown ends, the *dougong* connected the inner and outer ring of columns through their layered criss-cross of beams, which are reminiscent of the structure of intersecting beams in log constructions. This created a horizontal sheet effect, enabling the carpenters to use more slender timber members for the roof construction. In the Ming period, and even more so during the Qing period, the *dougong* remained a characteristic intermediary element between the column and roof, but they no longer served as a connecting element. (Fig. 612) Instead, the loadbearing columns were more strongly connected to one another in the transverse axis. The dimensions of the horizontal beams of the roof structure became so large that the beams themselves were able to support the roof cantilever. The *dougong* still transferred the load of the roof to the columns, but they no longer stiffened the construction.

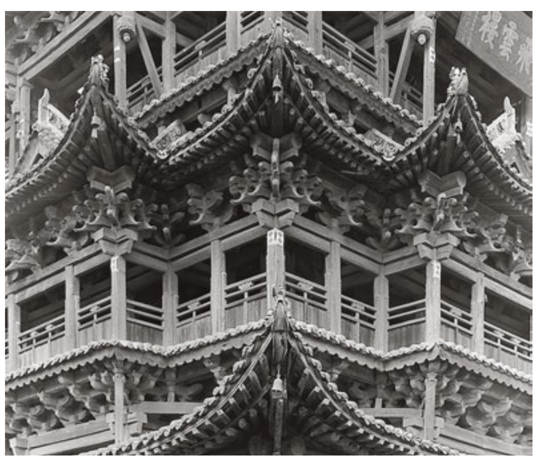


612 By way of comparison, a similar drawing of a temple from the Ming-Qing period. (according to: Fu, 1984, p. 23, pl. 1.8)

Western observers are often quick to note that Chinese temples rarely exhibit any diagonal stiffening elements. This is made possible by a series of structural measures. The columns of the outer ring of columns are inclined slightly inwards and gradually increase in length from the centre to the edges so that the overall weight of the roof is directed towards the centre of the building. This is even more apparent in multi-storey buildings. Consequently, the floor area decreases the higher up one is in the building. As a result of these measures, buildings with a roof load of up to 400 kg/m² [43] have been able to withstand hundreds of years of heavy storms and even earthquakes. This enormous weight can be attributed to the fact that the glazed ceramic roof tiles are laid in a thick bed of earth mortar that smoothens over the kinks in the roof, a product of the rafters, to form a continuous curved roof surface.

A further, not inconsiderable contribution to the vertical stiffness of the building can be attributed to the wall infill between the columns. Where a colonnaded walkway surrounded the building, the upper ring of beams was augmented by a second, lower-lying beam that served as the inner bearing for the monopitched roof over the colonnaded walkway. An additional ring of beams also increased the stability of the skeleton frame. The decorative design or visual emphasis of essential functional aspects of the construction often had a corresponding structural justification. On the other hand, they were also designed to lighten the perceived weight of the structure where it was most apparent. Two particularly successful and highly visible measures underline this principle. Along the eaves, there was always an even number of columns to emphasise the importance of the central axis. With the exception of the buildings of the Liao, who for cultural and historical reasons oriented their buildings eastward,[44] most main buildings faced south. This orientation allows the winter sun to shine deep into the interior while providing shade during the summer, but the actual reason is another: "North was deemed to be the most superior direction. The most important part of the building lay directly behind the central bay. In a temple, this central area was reserved for the supreme deity, in a palace for the ruler's throne, and in a government building for the seat of the council eldest."[45] From the Song period onwards, the central bay was always the widest and the bays at the corner correspondingly the narrowest. (see Fig. 596) In the centre of the altar, opposite the main gate, it was deemed appropriate to space the columns as far apart as possible. The corners, by contrast, were subject to the greatest weight of the roof and it therefore made sense to space the columns closer together.

The second measure concerns the line of the roof. Aesthetically, the contour of the roof appears to be conditioned by the columns that grow taller towards the edges of the building. In actual fact, however, constructional aspects need to be considered. The descending ridge of the roof hip is supported by the hip rafter. This is the line where two roof surfaces meet. The degree of their respective concave curvature follows predefined proportions, and to ensure that they meet as uniformly as possible the rafters were successively raised using wedge-shaped supports.[46] The result is that the rafters at the eaves grew higher towards the corners of the building. This so characteristic arc of the roof, which makes the roof appear visually lighter precisely where it is heaviest, took on

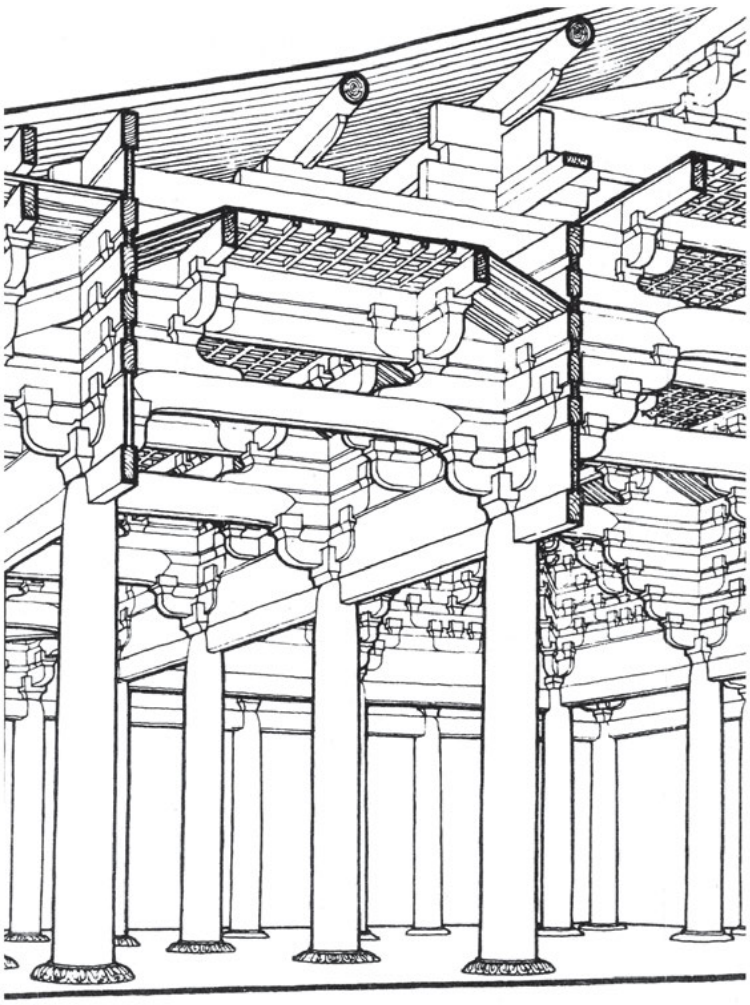


613 Eaves detail of the Dongyue miao Feiyun lou in Wanrong, Shanxi.

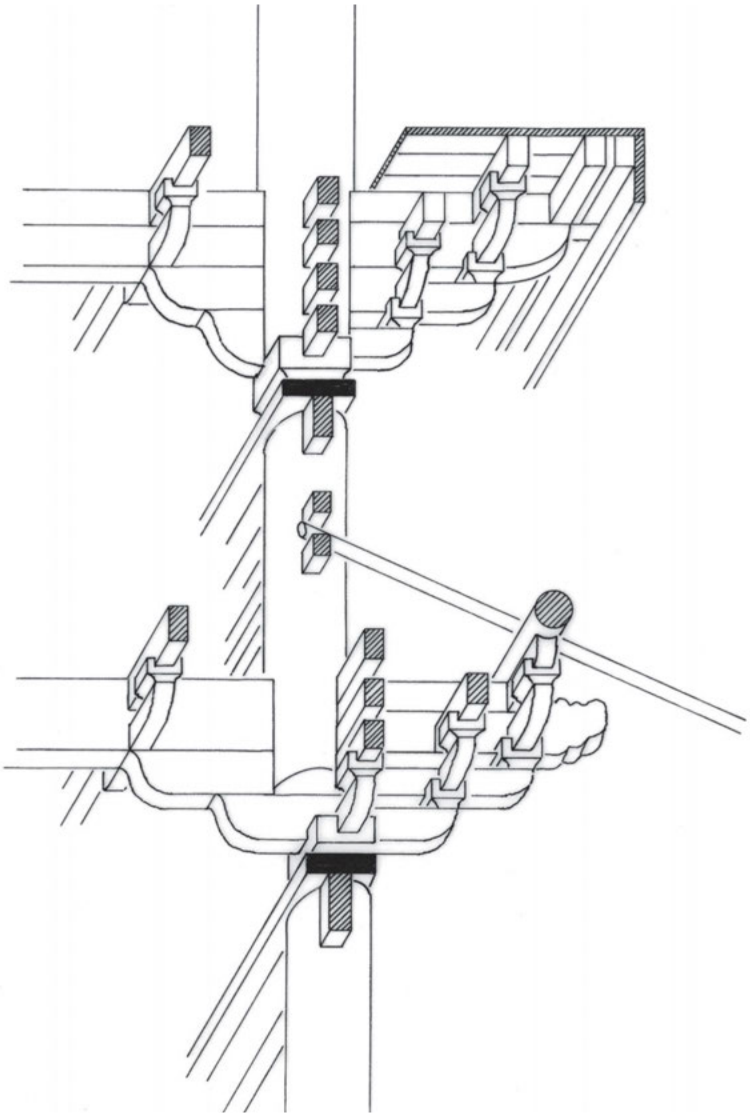
quite expressive forms. (Fig. 613) It is quite incredible just how many aspects come together in this one construction detail to form a harmonious whole: the construction task, the structural conditions, aesthetic considerations and illusionistic image. In Japan there were three different ways of laying rafters: parallel, fanned out or in *daibutsuyo* formation, that is parallel with a fanning arrangement in the corners only. In China the parallel arrangement was preferred, but in practice the latter method seems to have been used most commonly. (Fig. 614)

Increasing technological knowledge, or rather knowledge of the mechanical properties of wood led to visible improvements in construction technology. In the Sui period (581-618), the load-bearing vertical timber members were still buried in the ground and even in the later Tang epoch there is evidence of post-and-beam construction,[47] although this comparatively "primitive" construction method is not indicative of the general state of development of architecture in the Tang period: Linde dian, the Kylin Virtue Hall, was built in just two years despite its vast dimensions of 222 x 127 m. The Dabei Pavilion of the Longxing si in Zhengding from the later Song period exhibits a bay width in excess of 7 m and a much freer arrangement of columns. (see also Fig. 596) The outer columns no longer dictated the distribution of columns in the interior and they were often shifted into the northern part to provide more space for worshippers and their rituals in front of the altar. Wood jointing technology also made a great leap forward in the Song period. During the Sui and Tang periods,

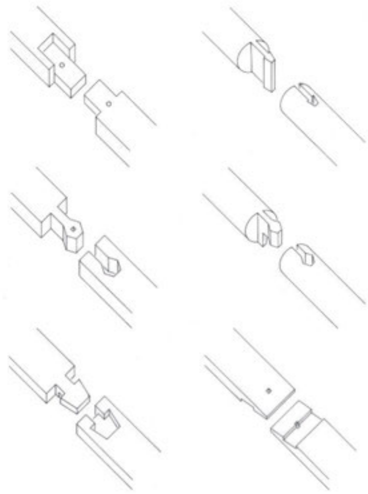
614 Both eaves of the Dule si Guanyin ge show how the rafters fan out at the corner. To make that possible they are cut to a wedge shape at their inner ends.



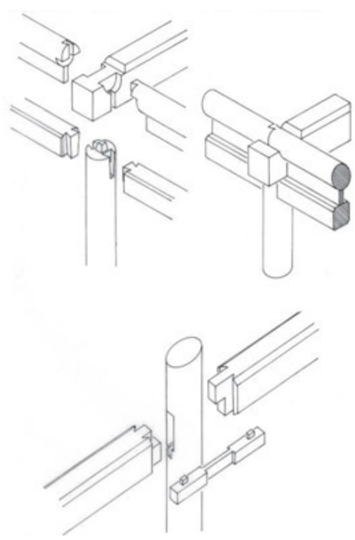
615 In the East Hall of Foguang si there are no bracing sill beams. (detail taken from: Liu, 2005, fig. 86-6)



616 This detail of a multi-storey construction shows that each storey is borne by an own ring of columns. The shallow rectangular beams beneath the large blocks, an innovation of the Song dynasty, are highlighted. (according to: Zhong, Chen, 1986, p. 108, fig. 5-6-23)



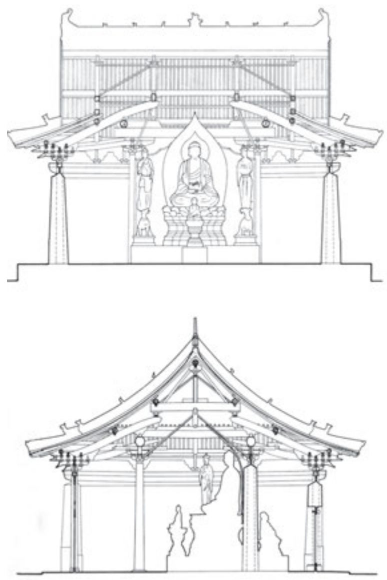
617 Different variants of longitudinal beam joints from the Song and Yuan period. (according to: Zhong, Chen, 1986, p. 106, fig. 5-6-19; Guo, 2002, p. 39; Guo, 2002, p. 77; Zhong, Chen, 1986, p. 106, fig. 5-8-33)



618 Purlin connections above a column with reinforcement to prevent sagging and beam connections passing through a column with additional locking piece to secure the joint. (according to: Ma Bingjian, 2003, p. 122, fig. 3-4 and p. 124, fig. 3-9)

columns were interconnected exclusively by sill beams and by tie beams at their upper ends, into which they were mortised. In some cases there were also intermediate beams. These joints offered only limited resistance to the force of storms. (Fig. 615) Columns that were not restrained at their base were held in place only through the weight of the roof.[48] In the Song period, the carpenters began to incorporate rings of beams with a shallow rectangular cross-section directly above the columns. (Fig. 616) Each of these beams spanned only from bay to bay, but they were connected to one another by sometimes quite complex connections. (Fig. 617) The crown ends of the columns now extended right through the ring of beams and were firmly fixed to the base blocks of the bracketing above. Instead of being mortised, the tie beams were now through-jointed: the tenons were inserted from either side into the column and extended far enough to be joined together with a straight or oblique halved and tabled joint,[49] or another form of connection (Fig. 618) able to withstand tensile forces.
The buildings of the Jin dynasty (1115-1234) replaced the camel's-hump-shaped braces over the purlin-supporting columns with supporting members. (see Fig. 588) This reduced the weight acting on the transverse beams.
While few new fundamental innovations followed during the period of Mongol rule until 1368 in the Yuan dynasty proclaimed

by Kublai Khan in 1271, ongoing attempts to simplify the building process and orient it towards more practical considerations led to a clearer articulation of prior innovations. For example, the column arrangement in the interior became much freer, no longer following the dictate of the regular grid of beams but rather the placement of the statues. To be able to omit or reposition columns, the upper tie beams over the remaining columns sometimes needed to be quite massive. Both the Guangsheng si in Hongdong as well as the Yongle gong in Ruicheng (see Fig. 600) are excellent examples of this. The front hall of the Guangsheng si also exhibits a further construction detail that impressively demonstrates the advancements in timber construction technology: the slanting beam. This represents an improvement of the lever arm constructions that were already widely used in the constructions of the Song and Liao to balance the weight of the eaves against that of a higher-level purlin. (Fig. 619) The slanting beam can also be interpreted as a further development of the *tuojiao* – the diagonal struts that supported the purlins against the beam below. At its lower end, the slanting beam rests on the bracketing above the outer columns, at its upper end against the inner tie beam. Its function was to carry the rafters in a particular section of the roof. While the lever arm served to distribute loads at certain points and the *tuojiao* contributed to vertical stiffness, the slanting beams united and extended these functions by providing two-dimensional load distribution vertically and horizontally.
In buildings with hipped-and-gabled roofs, the carpenters of the Yuan period employed diagonally placed beams. (Fig. 620) This horizontal stiffening of the four corners of a roof contributed a hitherto unknown degree of flexural rigidity to the stability of the entire construction.
Another innovation can also be attributed to attempts to simplify construction: before the Yuan period, multi-storey constructions were typically assembled storey for storey. The columns of a new storey stood on the beams of the storey below. This meant that the construction had to be precisely executed and also weakened the building's overall stability. Continuous columns, as were used in the Ciyun ge in Dingxing, completely changed the construction system typically used during the Liao and Song periods.
Two absolutely outstanding building constructions from the Liao period (907-1125) not only exhibit the above construction elements but also serve to disprove the widely held cliché that

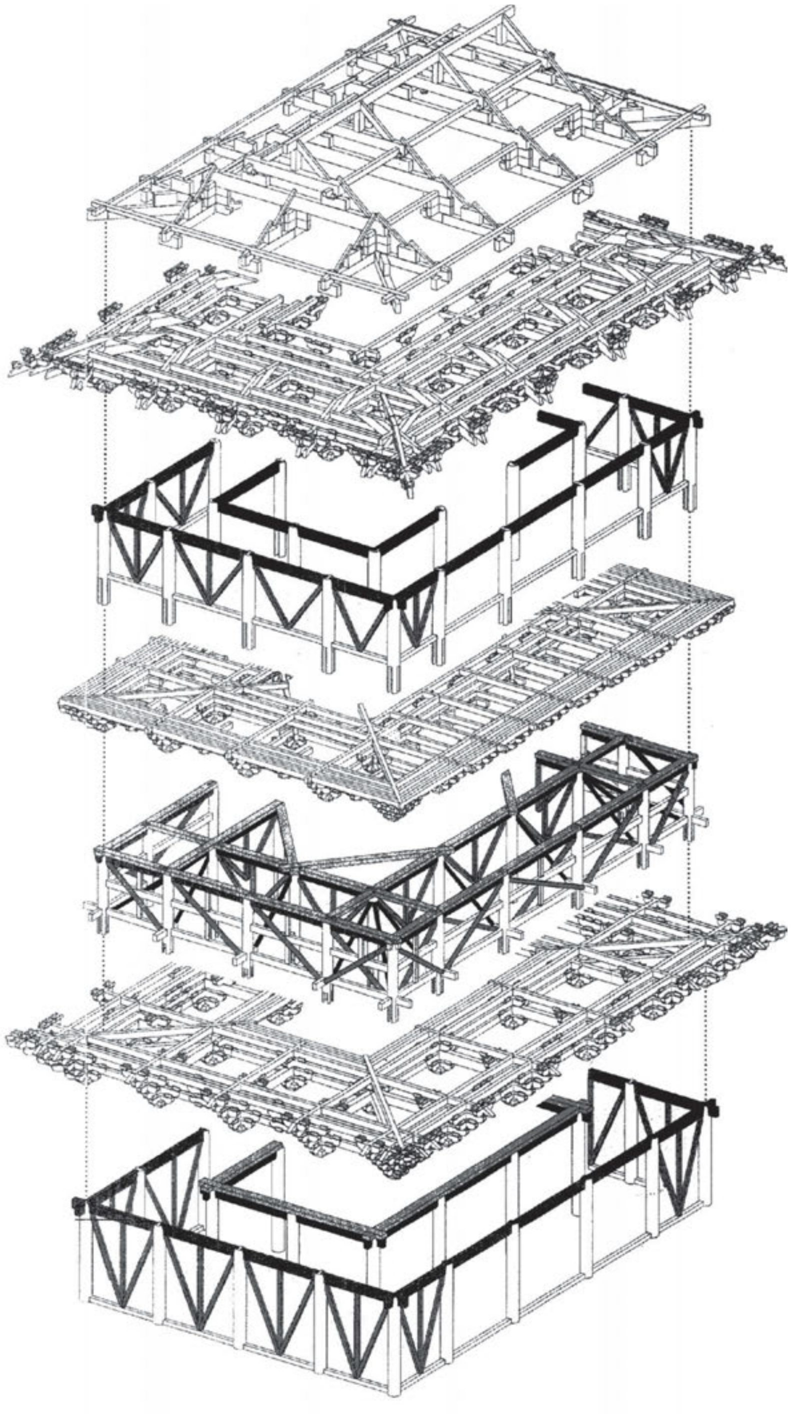


619 The sections through the Amithaba Hall of the upper Guangsheng si in Hongdong, Shanxi, show the position and purpose of slanting beams in the structure. (according to: Zhong, Chen, 1986, p. 123, fig. 5-8-17 and 18)

620 View of the underside of the roof construction of the Xia si Shanmen in the Lower Guangsheng si complex.

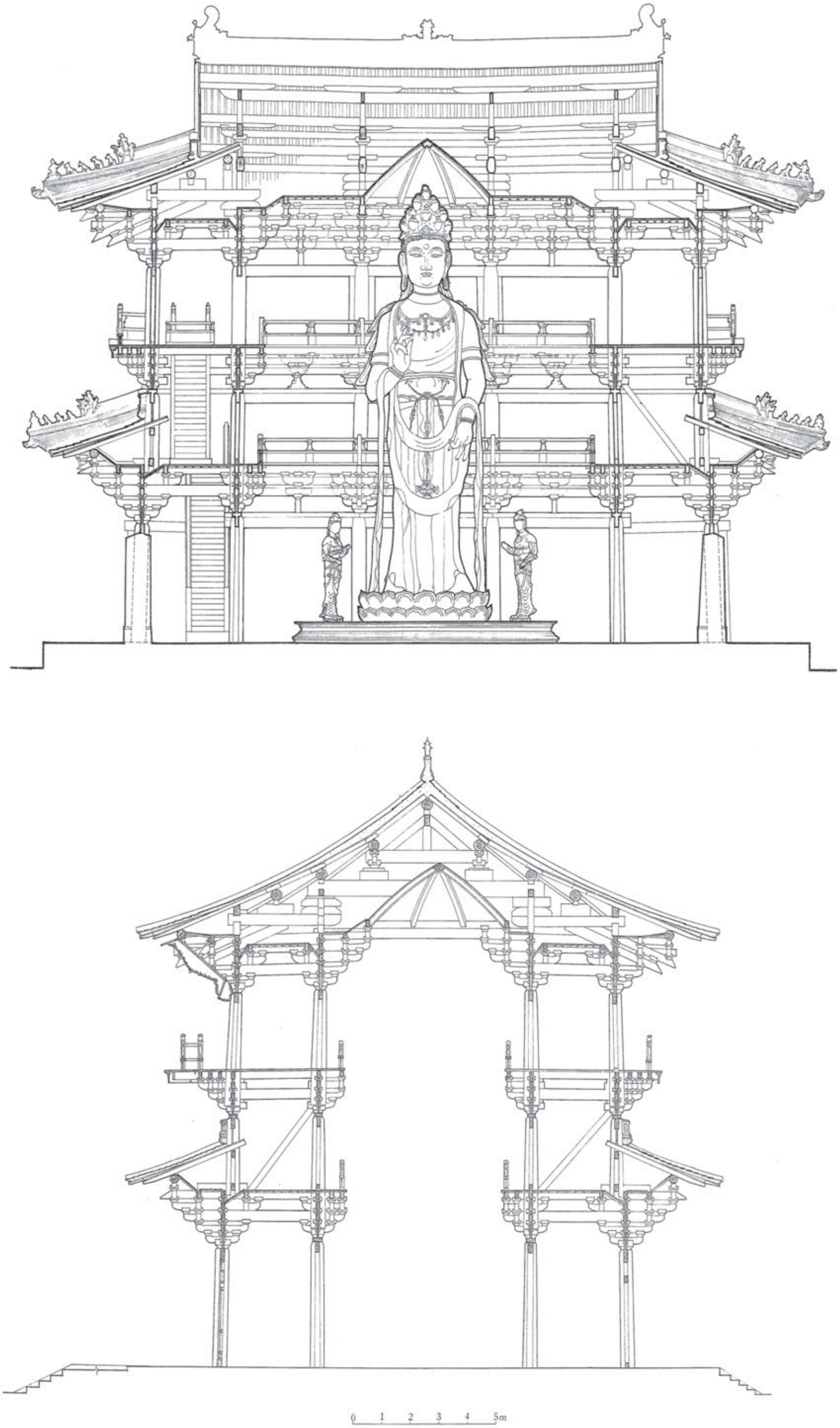
621 Dule si Guanyin ge seen from the Shanmen.

622 Constructed to house a monumental statue of Buddha the three-storey pavilion is an exceptional work of architecture.



623 An exploded view of the construction of the Dule si Guanyin ge separated into layers reveals an unexpectedly dense and thorough system of diagonal bracing. (source: Yang, 2007, p. 39, fig. 15)

East Asian architectural constructions lack the concept of diagonal bracing. The Dule si Guanyin ge in Laiyuan is the older of two surviving multi-storey building constructions from this period. (Fig. 621) Chinese hall constructions are typically single-storey constructions. Their status is demonstrated through their spaciousness in the horizontal dimension; at that time building high was interpreted as an indication of a lack of space. In this respect the architecture of the Liao can already be regarded as exceptional.[50] The Avalokitesvara Pavilion is itself over 22 m high and contains a 16 m high statue of Avalokitesvara, hence its name. Its three storeys are not readily legible from outside as the second is concealed behind the veranda and only visible from within. (Fig. 622) The storeys have each been assembled individually and are connected with one another via sets of brackets. Improving on the measures used to stabilise the construction already described, the outer columns of the



624 Section through Dule si Guanyin ge. (according to: Zhong, Chen, 1986, p. 90, fig. 5-5-14, p. 91, fig. 5-5-15)

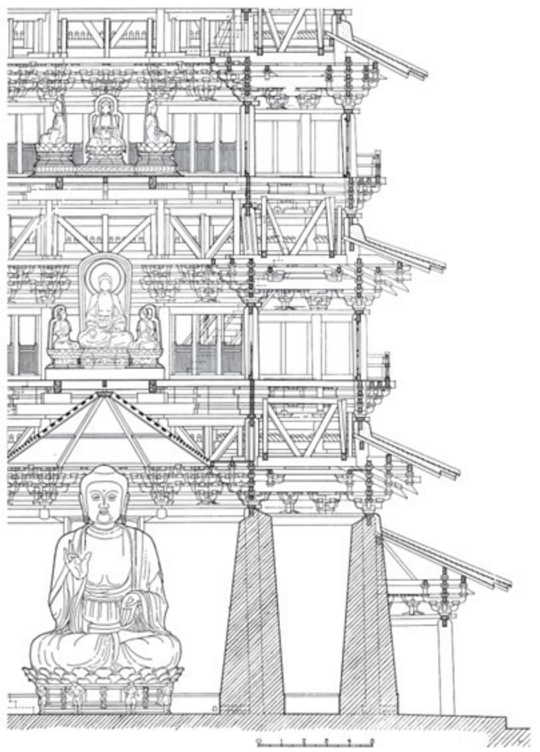
second and third storeys were offset inwards by the thickness of the column, and those that were embedded in an earth housing were additionally stiffened with concealed diagonal braces.[51] (Fig. 623) Further diagonal braces were added to the roof construction which is likewise hidden from view. (Fig. 624) However, all these measures were still not sufficient to compensate for the aforementioned fundamental weakness of storey-for-storey construction. A particularly problematic aspect was the lack of horizontal stiffness in the intermediate layer between the first and second storeys. This layer had been opened up to such a large degree that the grid of layered beams (intersecting in a manner reminiscent of log construction) that normally resists horizontal loads was not able to properly fulfil its intended function. During restoration works in 1753 it became necessary to insert storey-high diagonal braces as stiffening elements between the inner and outer rows of columns in the "invisible" second story.[52] As part of these works additional posts were also inserted beneath the eaves.[53] In light of what we know about these later developments, it is in retrospect hard to understand why the inner columns, which lie exactly over one another in each storey, were not originally constructed out of single pieces of wood. The increased stability would have been incomparably greater, despite the ring-shaped construction of the individual storeys around the statue. As it happens, in the upper ceiling opening the carpenters closed off the corners of the four right angles to form a hexagon, an intervention so unusual as to be conspicuous. Had they perhaps anticipated the problems that were to come?

Due to its age, due to its considerable height of 67.31 m and not least due to its construction, the Shakyamuni Pagoda at Fogong si in Yingxian is one of the most fascinating timber constructions in the history of Chinese architecture. (Fig. 625) The Yingxian muta, as it is also known, is believed to have been built in the period between 1056 to 1093 or 1095.[54] Two concentric rings of columns define its basic structure. Eight columns describe the inner octagon, 24 the outer. The diameter of the pagoda at its base is a vast 35.47 m and the columns of the ground-level storey disappear into incredibly thick walls. To protect this against the weather, a monopitch roof runs around the perimeter of the ground floor supported by 24 further columns. The space enclosed by the inner ring of columns is used for the placement of Buddhist statues. (Fig. 626) The space between the inner and outer ring of columns forms a corridor which also provides access to the veranda that runs the perimeter of the pagoda.

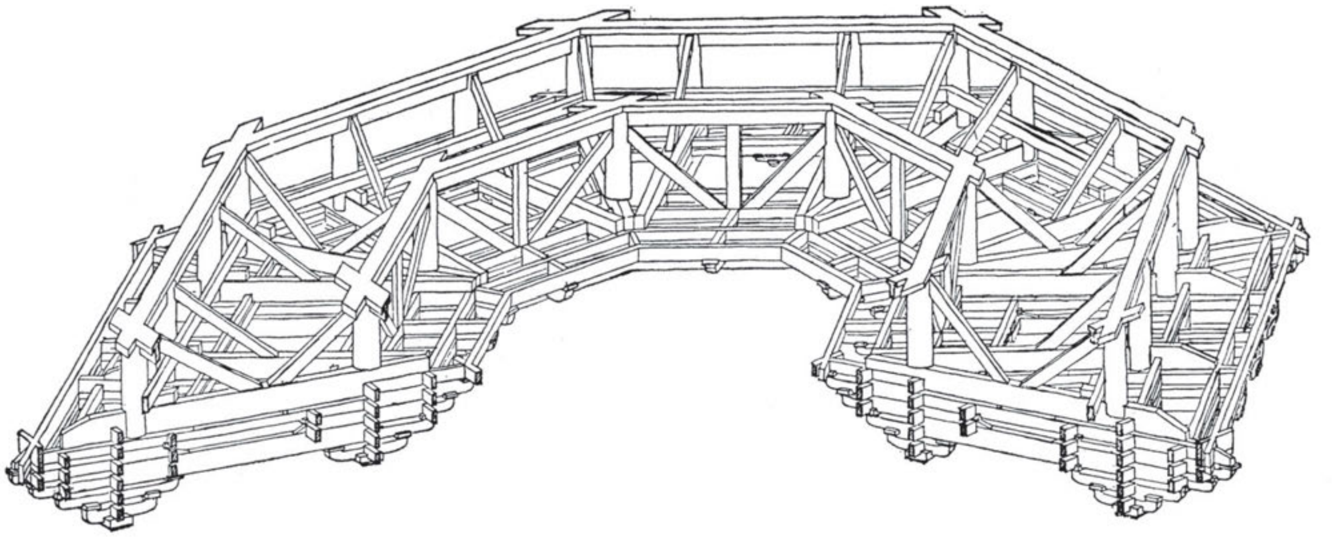
Seen from outside, Yingxian muta appears to have five storeys, but as with Dule si Guanyin ge there is a hidden floor between every outwardly visible storey. Here too, each storey has been assembled individually. The columns of each ring of columns are connected at their base by a sill beam and at their crown end by an upright tie beam, with a second shallow rectangular beam as reinforcement above it. Radial tie beams and bracket complexes connect the inner and outer rings of columns to one another. The columns exhibit a marked inward incline. The external columns of each outwardly visible storey lie directly above the axes of those in the hidden intermediate storeys, but to achieve the structurally desirable tapering form of the

625 Fogong si Shijia ta in Yingxian, Shanxi.

626 Statues can be viewed on the accessible floors of pagoda.



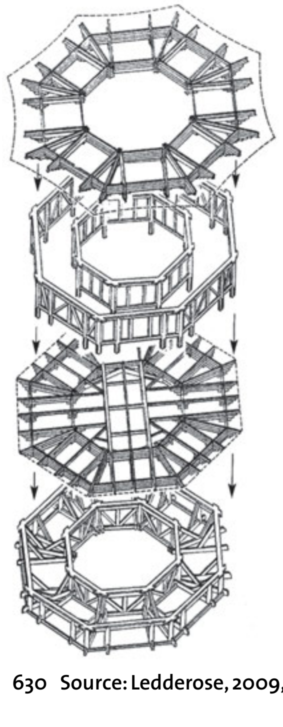
627 This portion of a section shows the complexity of the construction. (detail taken from: Chen, 2001; plate 16)



pagoda, the columns of each intermediate storey are shifted inwards by the width of half a column. They are fixed in the underlying bracket complexes via reversed forked tenon joints, which in turn connect with the respective column beneath. (Fig. 627) In earlier epochs, carpenters built pagodas on a square floor plan and employed a construction dominated by a central column that rose in one piece from the ground to the top. The improvements realised in Yingxian muta are extremely complex but also effective. The switch from a square plan to an octagon is better able to withstand and redistribute lateral forces. The use of an inner ring of columns instead of a single central column significantly increases the stiffness of the construction. Given the height of the pagoda, continuous columns were not an option, and the painful lack of stiffening offered by storey-wise columns, as seen in Dule si Guanyin ge, has been counteracted here by a series of specific and carefully considered measures. Additional braces have been introduced in all storeys. In the 'invisible' storeys (which are also not immediately perceivable from within the pagoda), storey-high diagonal bracing is used in both vertical directions, that is, tangential in the plane of the ring of columns and radial from the inner to the outer ring of columns. (Fig. 628) Some of the bracing timbers have been left rough-hewn and some of the invisible carpentry work is similarly lacking in finesse: the timber members have simply been cut to a point at their ends and then "mortised" into prepared receiving openings in the beams.[55] In the levels that are hidden from view, the space that corresponds to the corridor in the visible storeys is more akin to an obstacle course. The carpenters also inserted additional structural reinforcements in the regular storeys. On both sides of the inner columns, supporting columns were placed beneath the bracket complexes on the second to fifth storeys. Likewise, from the second to the fourth storey an additional rectangular supporting column was arranged beneath the bracketing on the inner face of the external columns. (Fig. 629) What at first sight looks like a subsequent emergency measure from a later date has been proven, with the aid of radiocarbon dating, to date from the same time as the construction of the pagoda.[56]
Horizontal stiffening in Yingxian muta is provided on each level by a horizontal network of interconnected bracketing com-

628 The inaccessible intermediate storeys serve as structural stiffening layers for the respective accessible storeys, and ultimately for the entire pagoda. (source: Chen, 2001, p. 49, fig. 25)

629 In the open storeys one can see additional columns placed to the left and right of the walkways. Occasional openings in the ceiling reveal a view of the structure of the intermediate inaccessible storeys.



630 Source: Ledderose, 2009, p. 41, fig. 49

plexes. (Fig. 630) They form a specific configuration of two rings of stacked beams which are held together by radial stacks of interlocking beams. The advantage of this construction lies in the comparative rigidity of the assembly compared with that of rectangular buildings with perpendicular pectinated joints. While rectangular log construction joints also create a sheet effect, their resistance to lateral distortion is largely a product of the large number of overlapping joints which absorb most of the lateral loads. The series of structural ring constructions stacked one above the other in Yingxian muta has rightly been compared to the remarkable construction of the spinal column of mammals, which through a combination of vertebra and intervertebral disc manage to unite robustness with flexibility while minimising weight and material usage.[57]

The sheer multitude of structural stabilisation measures employed in Yingxian muta, explains its incredible longevity. And yet it is quite extraordinary to think that between its construction and the end of the 16th century, the pagoda had already survived seven earthquakes intact. In the earthquake that occurred during the reign of Emperor Shundi (1333-1368), the earth is reported to have shaken continually for seven days. The pagoda was clearly able to withstand this and remained standing.[58] Its survival can be attributed in no small part to the bracket complexes, which we shall now examine in greater detail.

The construction principles of bracket complexes

The technique of layering orthogonal arrangements of horizontal beams creates a loadbearing support for loads from above, for example from a roof over a log cabin construction. The loadbearing capacity depends on several components, such as the number of tiered beams, the quality of the wood, the kind of connection or the possible fixing methods other than at their ends. The principle of this construction involves stacking layers of beams up to a desired height where, when subjected to vertical loads, they are also able to resist lateral forces. The capacity of wood to sustain both compression and tensile forces makes it ideal for cantilevered applications. This property we have discussed previously in the context of various log wall constructions. In those cases, functional reasons meant that there was no other option but to extend the higher-lying beam at the junction between two walls beyond the plane of the wall, in the process creating a bracket-like support. A typical situation might be for a bridge pier. (Fig. 631)

In the case of a bridge pier, a further property of this construction becomes apparent: the possibility of using cross-beams. Lateral force acting on an arrangement of interlocking beams can easily push these out of position. The more layers there are, the heavier the weight acting on them and the better the interlocking system is able to resist lateral forces; but only for as long as the layering of beams does not bring about another effect: their increasing tendency to displace under the applied weight. For the interlocking brackets over the bridge piers of cantilevered bridges (Fig. 632) beams as wide as the bridge are laid next to each other, perpendicular to the flow direction, and then joined together. One by one, so as not to exceed the cantilever,

631 Layered logs form a primitive but resilient form for a bridge pier. Lijiazui, Sichuan

632 Bridge pier of a cantilevered bridge in Zhengyang, Guangxi.

layer after layer of beams of increasing length are laid on top of one another until the available trunks are able to span between the bridge piers. To fix them in position they are connected in a kind of permeable interlocking arrangement: beams as wide as the bridge-width laid in the direction of water flow hold the cantilevered beams in place. These short cross-beams ensure that the construction is adequately ventilated and can accommodate differences in the thickness of the beams. The distance between them is determined by the optimal distribution of tension and compression forces within the beams lying in the direction of the bridge.

The brackets that result from this construction project left and right according to a predetermined breadth – in the example above, the width of the bridge. A conceivable variant of this principle derives from the idea that the lowest beam layer need not necessarily have the same width as the load that will ultimately be applied. In theory, a single beam from which all other beams extend in all four orthogonal directions should be sufficient to have the same effect. For a bridge this will obviously not work, because the slightest gust of wind will knock the system off balance. But for the *dougong,* the bracket complexes that sit on the plane of the wall and support balanced loads from either side of the wall, this principle functions very well.

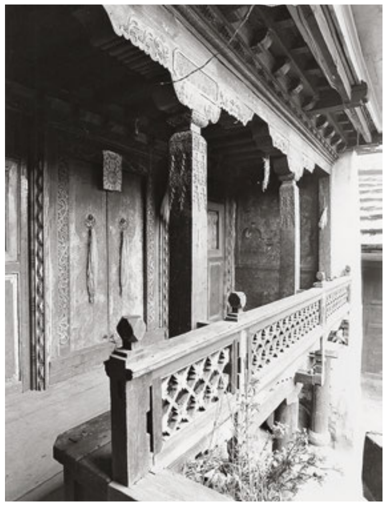
Dougong

The most dominant aspect of Chinese timber buildings when seen from afar is the roof, at least where prestige buildings are concerned. From close up it is the *dougong*,[59] complex sets of brackets, that are most apparent. Regarded as a status symbol, their use was restricted to buildings for the imperial family, official state buildings, large temples and the residences of high-ranking officials.[60]

Short load-distributing beams, as connection pieces between columns and beams, can be found in the simplest of buildings. (Fig. 633) These rest on beams that extend as transverse stiffening tie beams out the wall and through their anchorage in the wall column, transfer the weight of the projecting eaves into the column. Through the introduction of such brackets it became possible to splice together shorter lengths of beams and to shorten the bearing distances as far as was possible for the respective applied load. (Fig. 634) These very simple examples illustrate clearly the thought processes that motivated the development of the *dougong*.[61]

The earliest evidence of *dougong* exists in burial objects from the Eastern Han period (25-220). Models of houses made of fired ceramics show single- and multi-storey buildings whose eaves and balconies are borne by beams that project from the wall. To better distribute the load, wooden blocks (*dou*) positioned at the outer ends of the projecting beams bear short beams (*gong*) arranged parallel to the eaves, i.e. perpendicular to the projecting beams. These in turn carry the eaves purlin or the sill ring beam of the cantilevered floor above. Alternatively, they can serve as a support for two or three wood blocks, thereby extending the bearing surface for the loaded beam ever upwards in stepped tiers, in order to distribute the load more effectively. (Fig. 635) Despite the lack of archaeological evidence, re-

633 To support the eaves purlin, a supporting beam is laid beneath it, similar to in a temple, which is in turn supported by a short bolster. - Dazui, Sichuan



634 The columns of the veranda in this farmhouse in Lijiazui are richly decorated in front of the entrance to the house's altar. The columns bear a large block as well as a short and a longer bolster.

635 The ceramic model from the Han period, which can be seen in the Metropolitan Museum in New York, shows two variants of *dougong*.

searchers believe that the first blocks to be placed on top of columns to distribute loads date back to the West Zhou dynasty (11th century-771 BC).[62] The *dougong* of the Han period existed in all manner of sizes and manifestations. At that time their development as a load-distributing element of the construction was still in its infancy. Such constructions are most clearly seen at the corners of buildings where the load of the projecting roof is at its greatest. We only need think of the Horyu-ji in Japan (see p. 175) or the Dule si Guanyin ge (see p. 283): the weight of their (excessively) cantilevered roof had to be supported by supplementary columns at the corners. The burial objects from the Han period reveal how the carpenters had sought to find an appropriate solution. Four entirely different approaches can be identified in the models from the Museum of Henan.

A four-storey model of a dwelling with storehouse resolves the support of the corner in the uppermost storey as follows: a beam anchored to the wall construction extends diagonally out of the corner of the building. On top of this rests a block that in turn serves as a base for a *gong* that is bent at precisely this point so that to the left and right it runs parallel to the eaves. This provides a bearing for three small blocks, one at each end of the bracket and one in the middle. On these rest a second and a third set of further cantilevered beams that follow the same pattern. In the second, the distance between the middle and each of the end blocks is larger; in the third there are five small blocks. These then bear the eaves purlin. The ceramic model gives no indication of how the 90° elbows of the *gong* are formed.[63]

A second model, also of a dwelling with storehouse, this time with four storeys and an accessible lantern on the roof offers a more readily identifiable solution. In the third storey, beams extend as before from the corners of the building, each with a large block resting on its end. In this case, the first *gong* is placed orthogonal to the projecting beam, i.e. at 45° to the walls. Now, however, the *dou* blocks, placed at each end of this *gong* are rotated so that they are parallel to the walls. On these rest two short *gong* arranged parallel to the walls, each with further *dou* blocks at each end in turn supporting longer *gong,* each with three *dou* blocks. The lowest *gong* arranged at 45° to the walls is long enough for the uppermost *dou* to be distributed regularly without overlapping at the corner.[64]

A third model shows a two-storey storehouse. Above the upper storey, five beams along the eaves and two at each gable project out of the wall at regular intervals. The distance from the outermost beam to the corner is half of that from beam to beam. On blocks resting on these beams lie *gong* arranged parallel to the wall, each of which support three small blocks which in turn support an unusually massive ring of beams that runs the perimeter of the building. This by comparison much simpler *dougong* construction is surprising in that it would seem to be for a hipped or hipped-and-gabled roof but actually bears a pitched roof.[65]

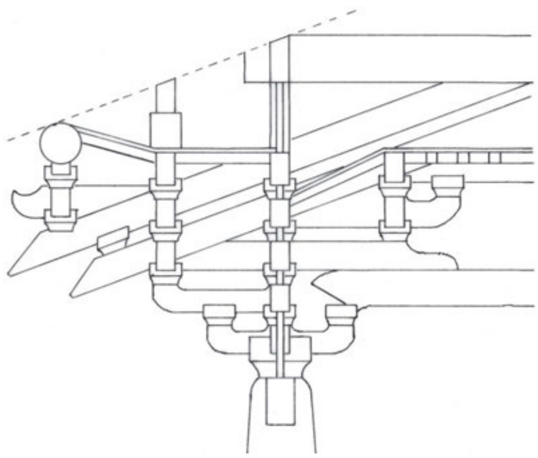
In the last of the models discussed here – a temple from the Sui period – the beams no longer project out of an unidentifiable wall construction. Twelve columns define the outline of the building: four corner columns each with two columns between them along the eaves and gable ends. A ring of beams connects the columns at their crown ends. The wall columns are significantly shorter than the corner columns and stand on large decorative footing blocks, which in turn rest on a foundation sill beam. At their upper ends they bear a minute load-distributing arm parallel to the wall with three small blocks. The corner columns are mortised at their base into the foundation sill beam. The crown ends of the corner columns appear to directly support the connections between the sections of the ring of beams. In the extended axis of each column, a complex of stacked *gong* cantilever out of the wall, from the corner columns in the axis of the diagonal of the temple. At the end of each *gong* rests a block as a support for the next bracket arm. The cantilevered bracketing extends only in one direction, with four tiers above the wall columns and, amazingly, only three tiers above the corner columns even though the eaves appear to rise at the corners. The massive bracket arms over the corners bear the majority of the load, their size a product of the smaller number of brackets and the height of the tiers.[66]

The examples above demonstrate two aspects. Firstly, that the solutions where the *dougong* are entirely separate of the wall appear to have been rather weak. The task of transferring the enormous load of the roof to the projecting beams via such freely stacked and themselves structurally instable *dougong* cannot have been satisfactorily resolved. On the other hand, the fact that such sets of brackets consisted of multiple pieces made it possible to replace elements that were broken or worm-infested. The individual pieces were notched, sometimes additionally secured with concealed dowel pins.[67] Whether actual buildings constructed according to the principles shown in these models were able to withstand the force of earthquakes, we do not know.

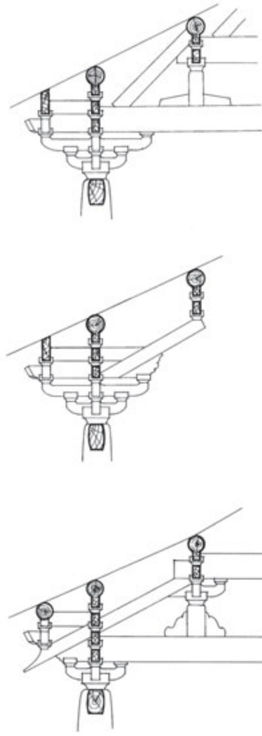
During the Tang period, a great developmental leap took place. The weaknesses in the construction of the *dougong* of the Han period were completely resolved. (Fig. 636) The large block was now recessed with a cross-shaped mortise to receive the two lowest *gong*, which crossed one another at right angles with a half-lapped joint. This created cantilevers in all four directions, two in the plane of the wall, one outwards and one inwards. At their ends, these *gong* held small blocks, fixed in place with dowels, which were likewise notched but only in one direction to hold a single *gong*. The *gong* in the second tier, which extended out further than those beneath them, were likewise half-lapped at their centres. By repeating this pattern, the structure could be extended. The intention behind this construction was to extend the cantilevered *gong* as far out as the desired eaves overhang. The weight acting at the eaves was balanced by the corresponding counterweight applied on the inner side, with the large block acting as the fulcrum. The overlapping perpendicular *gong* in the plane of the wall played an important contribution to stabilising the *dougong*.

The introduction of cantilever arms, the *ang,* heralded a further significant improvement to the bracket complexes. (Fig. 637) If we recall the *tuojiao,* the diagonal struts in the roof constructions that served as vertical stiffening in the transverse axis (see p. 283), and then, instead of seating them in the lower transverse tie beam, extend them further out into the *dougong* over the wall columns, we are a first step towards the development

636 Eaves detail showing two variants of *dougong* in the wall plane of the East Hall of Foguang si, one above the columns and one between them.



637 *dougong* above a wall column in the Foguang si Dongda dian. (source: Pan, 2004, vol. 1, p. 19, fig. 12)



638 *dougong* from the Kaihua si in Gaoping, Shanxi, from Longxing si Moni dian in Zhengding and from Yongshou si in Yuci, Shanxi. (source: Pan, He, 2005, p. 89, fig. 3-15 and 3-16)

of the *ang*. The second step is to extend them right through the *dougong* so that they project outwards. (Fig. 638) This development took place between the 6th and the 10th century.[68] This can be seen quite clearly in the roof construction of the Zhuanlunzang dian in the Longxing si in Zhengding from the Northern Song dynasty (960-1127).[69] In contrast to the Japanese *otaruki,* which are sliced off at a right angle, the ends of the Chinese *ang* are all formed into a so-called bird's beak.

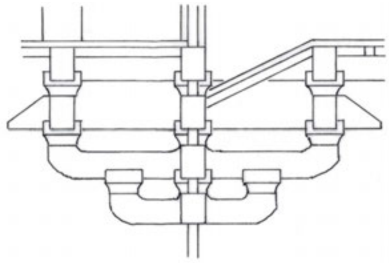
The *ang* has been described as the "climax of bracketing science".[70] It functioned as a lever arm: the load of the eaves is transferred via the lever arm and presses against the underside of a transverse beam or is counterbalanced by an intermediate purlin. Its constructional contribution lies in the stiffening effect it has on the horizontal layers of interlocking *gong*. Its functional contribution lies in the fact that the eaves line of the roof no longer needs to arc upwards as much as was previously necessary with solely horizontal *gong*. As a consequence, the curve of the roof contour became less pronounced.

The number of sets of *gong* or *ang* varied between one and five.[71] The carpenters developed *dougong* for three parts of the construction: above the wall columns, above the corner columns and as additional support between the wall columns, the latter often smaller and differently articulated to those over the columns, as can be seen, for example, in Foguang si. (Fig. 639) The relatively small Chuzu an, erected in the Song dynasty on the site of the Shaolin si in Henan, is an example of the opposite case where the proportions are reversed: (Fig. 640) although all the *dougong* of the Chuzu an look identical, the intermediate *dougong* are in fact considerably larger. Their *ang* support an intermediate purlin inside the building, whereas the supposed *ang* of the bracket complexes over the wall columns are, in fact, just decoration. The rather one-sided outward orientation of the bracket complex of the intermediate *dougong* is counterbalanced by a transverse tie beam.

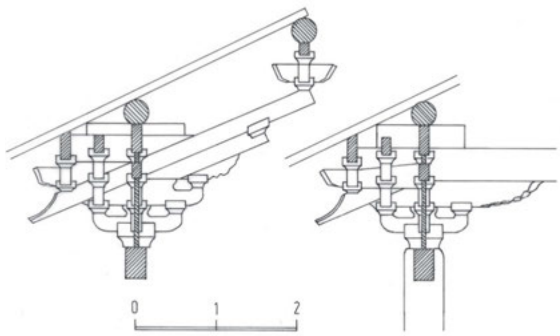
The intermediate *dougong* served an important function. Thanks to the additional support they provided, the dimensions of the eaves purlin could be reduced. As, like all *dougong*, they were connected with the wall plane by one or more horizontal beams, they helped stiffen the eaves considerably.

While the *dougong* over the wall columns and those in-between could look identical, at least on their outer face – as later developments were to show – the *dougong* over the corner columns are a special case, not least due to their bi-directional orientation. Their construction shows very clearly that their development took a different path to that proposed in the model of the Sui temple. In the latter, the number of tiered bracket sets in the *dougong* over the corner columns was less than those over the wall columns. The bracketing over the corner columns of Foguang si, by contrast, present the opposite situation: (Fig. 641) to support the larger load, an additional *gong* lies on the large block between the orthogonal, half-lapped *gong,* precisely in the diagonal axis of the corner. The number of sets above this exceeds that of the *gong* over the wall columns, not least in order to achieve the aesthetically motivated heightening of the roof contour at the corners of the building.

To get a better idea of the earthquake resistance of these extremely carefully constructed, flexibly jointed and often



639 ***dougong*** **between the wall columns of the Foguang si Dongda dian. (according to: Pan, 2004, vol. 1, p. 22, fig. 15)**

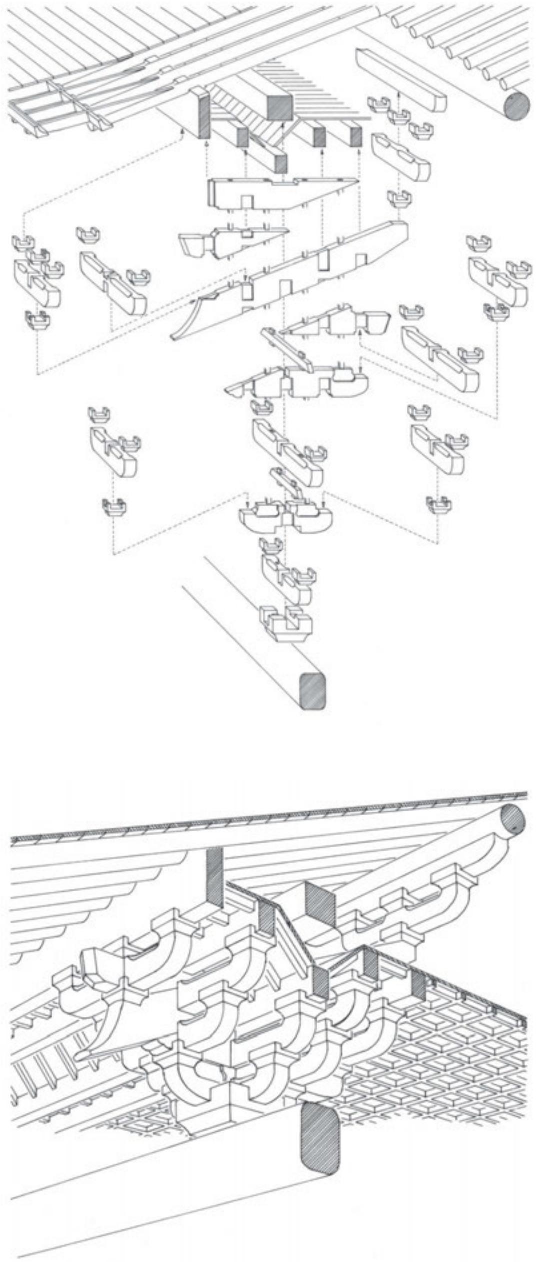


640 The ***dougong*** **of the Chuzu'an are exceptional in two respects: they look different only on their inner face and the intermediate dougong are larger than those over the columns. (according to: Liang, 1984, p. 89, fig. 40c)**

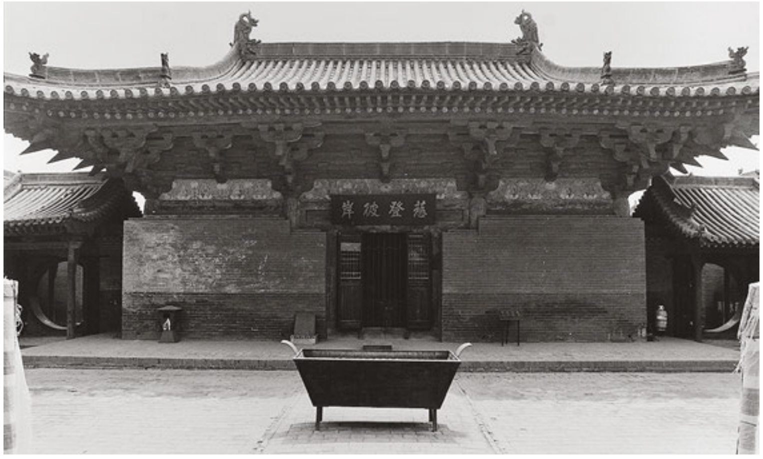
641 The ***dougong*** **above the corner columns are much larger than the others due to the increased weight and larger roof overhang at the corners. Foguang si Dongda dian**

colossal buildings, it is necessary to disassemble and examine the individual parts of a bracket complex in one's head. (Fig. 642) To date, this phenomenon has not been conclusively researched scientifically.[72] This is due not least to the fact that computerised earthquake simulations can only approximately model the behaviour of the hand-made carpentry connections and structure of the *dougong*. Tests undertaken using models are also of limited applicability due to the fact that a scale model performs differently: in the most elaborate tests to date, a 1:5 scale model was built by carpenters using the same material as the original – but given that the material concerned is organic in nature, it is questionable whether the performance of a fivefold cross-section can really be assessed using a simple conversion factor from the scale model. Tests conducted on individual construction elements should likewise be viewed critically. As interesting as they may be, it should be clear from the above how difficult it is to draw conclusions from these for the entire structure. If a wood joint is to fulfil its function, namely the lossless distribution of a load acting on it, the joint must be constructed to engage perfectly. Notched, half-lapped and dowel connections are technically easy to construct. To avoid the risk of asymmetrical settlement, the carpenters of the age needed to work with awe-inspiring precision. They also employed additional securing measures: some *dougong* were held in place with long dowels that penetrated multiple layers of horizontal elements.[73] Ultimately, however, the load of the roof prevented the occurrence of lateral displacement. Nevertheless, if each *dougong* needed to look identical to the next, the carpenters were required to work with almost unbelievable precision, a feat of craftsmanship that is hard to replicate.

In 1679 a force 8 earthquake shook the earth in the immediate vicinity of the Dule si Pavilion, and again in 1976 with a magnitude of 7.8. A number of other temples in the vicinity collapsed, but not the Dule si Pavilion.[74] The supposition is that the comparative flexibility of the connections allows them to give during a seismic shock and that the multitude of connections immediately reduces the severity of the shock. The seismic vibrations are neither confronted by an absolutely rigid construction, nor are they allowed to spread unhindered in a particular direction. The numerous changes of direction in the different parts of the assembly from layer to layer as well as the diagonal bracing and not least the elastic resilience of wood as a material, contribute to dissipating the energy of the shockwave. Certainly, the bracket complexes are not the sole reason for the earthquake resistance of the structure – many temples and palaces from the Ming and Qing periods whose *dougong* no longer offered much in the way of structural stabilisation have likewise survived many earthquakes. Rather it is the cumulative contribution of ongoing adaptations of the construction, such as the aforementioned inclination of the columns (in Yingxian muta the inclination increases with each storey) or the stiffening sheet action of the wooden floor as a horizontal separation between the ground and upper floor. These adaptations are the product of experience and knowledge handed down from generation to generation, which in turn respond to changing requirements and fashions or are enriched by new knowledge. That the storey-for-storey construction of the multi-storey



642 Schematic drawing of an intermediate *dougong* as built and disassembled as an exploded axonometric. (according to: Glahn, 1981, p. 138 and 139)



643 The characteristically monumental dimensions of the *dougong* of the Tang period continued to have a formative influence for many years. Zhenguo si Wanfo dian

buildings from the Liao period has proven to be resistant to earthquakes is most certainly not a product of their non-continuous columns. A single column that rises through all storeys results in an incomparably more stable structure. But the carpenters of the day had always gradually pushed forward the construction methods of their time with a degree of caution, only pursuing directions that proved successful. For contemporary researchers, a particular problem is the fact that the craftsmen never gave particular thought to which measures were specifically aimed at improving earthquake resistance. Consequently, it is no surprise that there are no written records concerning this aspect. That notwithstanding, there were still practical approaches, but these were simply regarded as general knowledge.[75] While it was never wrong to follow such principles during construction, they cannot provide us with scientific explanations.

Let us examine the further development of *dougong*. The temples of the Tang dynasty as well as those from the time of the Five Dynasties (907-960) are characterised by extreme top-heaviness. (Fig. 643) The proportion of the height of the column with respect to that of the *dougong* lent the latter considerable weight. That began to change during the Song period. For example, the Jinci Shengmu dian (see Fig. 596) shows that the size of the *dougong* had begun to shrink in relation to the height of the columns. Less apparent, however, is that their attempts to make the *dougong* more decorative brought about an alignment in the appearance of the *dougong* over and between the wall columns. Indeed, in the bracket complexes between the columns, the *ang* were replaced by so-called *false ang* which no longer served as diagonal cantilevers. (see Fig. 597)

The buildings of the Liao generally exhibited greater innovation. The "bracket sets of the Liao period were more complex than any that had preceded them and more diverse than any that would follow."[76] Dule si Guanyin ge had 24 different *dougong*. (Fig. 644) Conspicuous for buildings of this period are the angular cantilever arms projecting out of the wall, thus creating fan-shaped backet sets. Various types of angular *gong* were developed: those that extend at an angle of 30° left and right of the main axis, those at an angle of 45°[77] and those at 67.5° for the *dougong* at the corners of an octagonal pagoda such as the Yingxian muta.[78] During the Jin dynasty (1115-1234), the *dougong* became perhaps even more expressive. This is especially apparent in the case of the *dougong* between the wall

644 From even a cursory glance at the eaves of the Yingxian muta, it is clear that it has a large number of different *dougong*.

645 An intermediate *dougong* of the Shanhua si in Datong, Shanxi.

columns of the Shanhua si Sansheng dian. (Fig. 645) Under Jurchen rule, the angular cantilevered beams became more of a fashion accessory. The idea was that the segmentation of the *dougong* provides additional support for the eaves purlin. Sansheng dian illustrates clearly how this development rapidly began to exceed necessity: the outermost *gong* had grown so long that they were no longer suitable for supporting loads.

In the Yuan period, the manifestation of a further development finally robbed the *dougong* entirely of its former importance. A not inconsiderable part in this development was played by the introduction of horizontally laid braces in the corners of the buildings. (Fig. 646) These significantly improved the stiffness of the corners, and therefore of the entire building. As a result the *dougong* became ever smaller, and the *ang* were almost entirely replaced by *false ang*. The true *ang* were only used for the intermediate *dougong* between the columns. Over time the loadbearing capacity of the *dougong* as a whole decreased considerably and the *dougong* began increasingly to serve only as decoration. Overall, the construction became much simpler, but also more stable. This process was further supported by the introduction of additional horizontal bracing between the columns, connected to these by means of through-tenons.

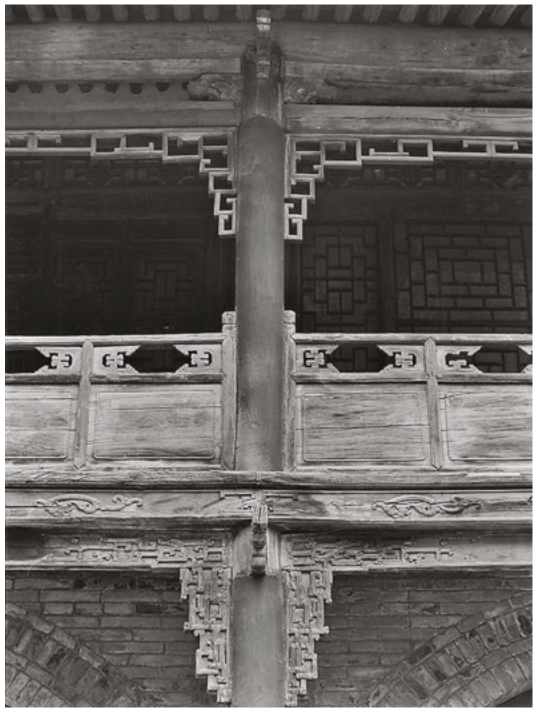
As cited at the beginning of the chapter, Liang Sicheng viewed the Ming period as the beginning of a period of rigidity. There followed a distinctive break with the building traditions of the Song and Yuan periods. "The change is [...] as if some overwhelming force had turned the minds of the builders toward an entirely new sense of proportion."[79] In Dule si Guanyin ge the ratio of proportions was 2:1 – two units of column to one unit *dougong*. This proportion now shifted to 5:1. Where in the past a maximum of two *dougong* were placed between the columns, this number now rose to up to eight. (Fig. 647) Where once they served to lessen the load acting on the columns, the reverse was now the case. They had become weighty constructions for the beams that supported them. As a consequence, the head beams, which previously served primarily as tie beams between the columns, acquired ever larger dimensions. The purlins were

646 In the Xia si Shanmen in the Lower Guangsheng si, the diagonal braces at the corners exhibit an arrangement characteristic of the Yuan period.

647 A section of the façade of the Gate of Great Harmony (Taihe men) in the Forbidden City illustrates the primary decorative function of the later *dougong*. The eight intermediate *dougong* are almost impossible to differentiate from those over the columns.

648 Ceiling of a garden pavilion in the Forbidden City.

no longer borne by the *dougong* but directly by massive beams, the ridge purlin by massive ridge columns. The *tuojiao* disappeared entirely. As a stiffening measure, they were no longer required to stiffen a structural system that increasingly drew its rigidity from the enlarged cross-section of its beams and the doubling of the number of beams. The *dougong* themselves lost their structural function and became decoration. (Fig. 648) Fu Xinian was even more unequivocal in his characterisation of the age of the Ming and Qing dynasties: *"From maturity, [the architecture] fell into patterns and finally became standardized. The style progressed from expansiveness and freedom to refinement, care and precision; from emphasis on total effect to tendency toward overdecoration. The framework deteriorated, from being light and flexible and built of appropriate materials to rigid and clumsy."* [80] (Fig. 649)



649 The Wang Family Compound in Jingsheng is a goldmine for the study of some of the best wood craftsmanship of its kind.

The economics of construction

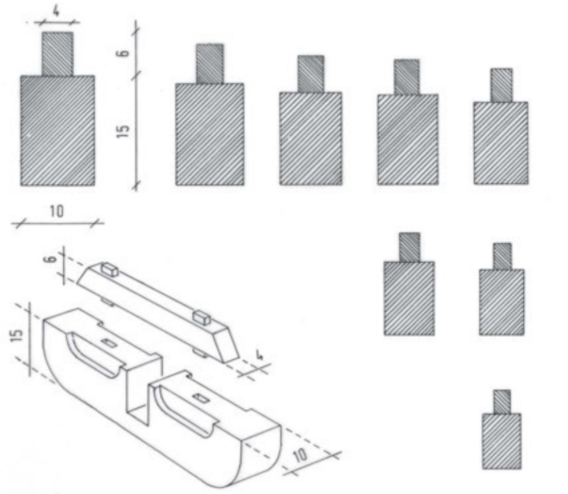
The *dougong*, or rather the *doukou,*[81] the mouth of the block, provided a base dimension from which the size of all other building elements could be calculated: their cross-section dimensions, the distances between individual components as well as their lengths. This construction detail describes the width of the mortise cut into the base block that receives the lowest *gong*, a dimension that in turn matches that of the width of the cross-section of the lowest *gong*. Through this common denominator it was possible to develop the entire structural system based on the bay dimension, the column height or the column cross-section:[82] the column cross-section, for example, was defined as the sixfold dimension of the *doukou.*[83] None of the components have absolute dimensions. The Chinese building system is based on ratios of proportions. It draws on thousands of years of observations on which dimensional proportions were structurally suitable and practical, coupled with a growing understanding of which proportions were aesthetically pleasing. The *Yingzao fashi* (Treatise on Architectural Methods), published in 1103 by Li Jie, is the oldest surviving written document that details such a system of proportions as a basis for building. In compiling his treatise, Li Jie sifted through numerous relevant documents and consulted intensively with master carpenters.[84] The motivation behind the publication of this work was driven by economic interests. By compiling this body of knowledge, the intention was to improve the speed at which the workmen could work. It was not concerned with improving their earnings but to make building faster and more cost-efficient.

Time and again, far-sighted officials and scholars had warned their ruler of the dangers of unbridled excesses in building. During the Song period, Hong Mai described the conditions when building the palaces for the Sui Emperor Yangdi. Due to a lack of appropriate timber in the neighbouring mountainous region, tree trunks had to be procured from regions far away. 2000 men were reportedly needed to pull a single column. The manufacture and repair of wooden wheels for transport purposes, whose iron axles were constantly overheating, required such an immense amount of manpower that the number of workmen per column could easily have totalled several hundred thousand.[85] During the reforms implemented during the Northern Song dynasty, Wang Anshi (1021-1086), the advisor to

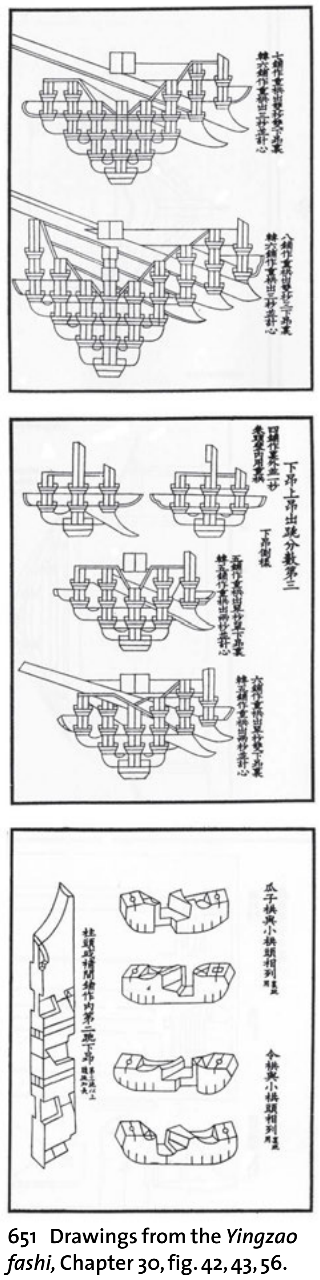
Emperor Shenzong, did not shy away from any taboos. Despite massive resistance from conservative sections of society, the old system of conscripting a workforce for public building projects or pay in kind was replaced by the introduction of taxes. Through such means it was possible to employ professional carpenters with state money and the farmers no longer had to abandon their work. Wang could well have been behind the first edition of the *Yingzao fashi*. [86]

The treatise was not written for the construction workers; they knew how to build. Instead, the detailed descriptions covering how to calculate the material and manpower requirements were aimed to show officials in the state apparatus how to calculate building costs reliably. One of Wang's aforementioned reforms involved counteracting corruption and blackmail among the lowest officials by providing better pay. In the fourth chapter of the *Yingzao fashi,* all public buildings are arranged according to size into eight categories. Li Jie stated precise dimensions for the individual building elements. They were given in *cai* (an absolute unit) and *fen* (a modular interval), where 15 *fen* equalled 1 *cai*. The author describes their practical application using a *gong* and corresponding stiffener. (Fig. 650) The height and width of the elements in all building categories have a ratio of 3:2. A *gong* with a width of 10 *fen* therefore has a height of 15 *fen*. The same ratio is applied to the stiffener. The height of a gong corresponds to 1 cai, a simple unit, while the sum of the height of a bracket arm and a stiffener is called a full unit. To convert this system of proportions into concrete numerical dimensions, the cross-section of a bracket arm of a category 1 building – the largest building with ten to twelve columns along its east-west axis – is given as 9 x 6 inches, while a *fen* of the smallest category measures 4.5 x 3 inches (where an inch during the Song dynasty equalled approximately 3.2 cm). The declaration of dimensions in *cai* and *fen* meant that this could be applied to all buildings regardless of their size or function. The *Yingzao fashi* gives no explanation for the use of 3:2 as a ratio for the dimensions of building elements. Guo Qinghua gave this some consideration and came to the conclusion that in terms of bending strength, the optimum proportion of a beam sawn out of a tree trunk is $\sqrt{2}:1$. The ratio 3:2 is not bad as an approximation of this and is easier to remember, easier to calculate and the results look correct. In Sweden, carpenters cut beams for log constructions with a cross-section ratio of 14:10, which is a little bit closer to the ideal dimensions.[87]

In the Chinese building manuals we can discern two different categories. One is strictly technical – it concerns primarily public and prestige buildings; the other mixes technical aspects with rituals, geomancy and prophecy – these concerned mostly buildings for the people. The *Yingzao fashi* and the *Gongbu gongcheng zuofa* from 1734 belong to the first group. The latter paid special attention to cost-effectiveness and financing.[88] In the Qing period, standardisation had progressed significantly, making large-scale prefabrication possible. Standardised building elements could be combined and assembled to construct different types of buildings.[89] The artistic and technical qualities were clearly defined and building constructions exhibited a high degree of uniformity and homogeneity. Technological knowledge was handed down in the form of recitable



650 A simple *gong* was the base unit from which all other dimensions of a building could be derived. Buildings were divided into eight different categories according to size, whose dimensions could be determined by a series of interrelated units and sections. (according to: Glahn, 2009, p. 15)



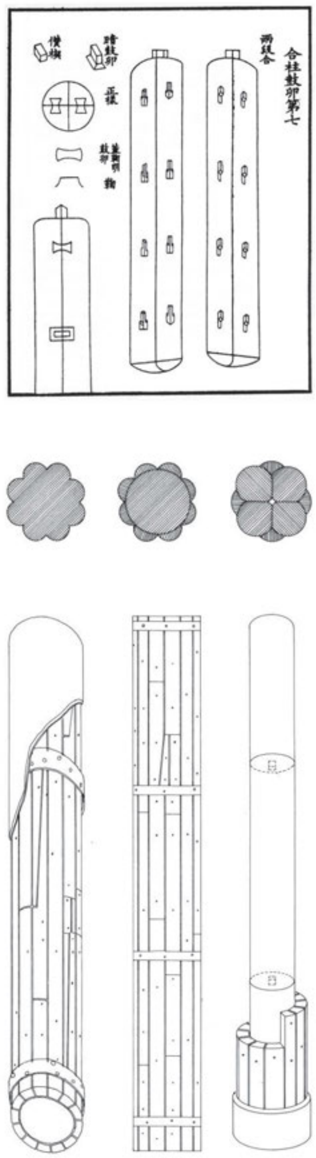
651 Drawings from the *Yingzao fashi,* Chapter 30, fig. 42, 43, 56. (source: Guo, 1995; p. 251, 255)

rhymed construction "recipes". Once the length of the building's axis and the *doukou* had been determined, a building could even be constructed without drawings.[90] The *Yingzao fashi* is practically bursting at the seams with explanatory drawings, (Fig. 651) whereas the *Gongbu gongcheng zuofa* contains just 27 sections of different buildings, without any explanations of the details at all.

The second, broader category of building manuals includes the *Lu Ban jing* (the classic work by Lu Ban) published in the 15th century. Lu Ban was a legendary master carpenter from the 5th century BC, who is still revered today as the patron saint of carpenters. This manual dealt with more modest buildings: simple dwellings, storehouses, stables and even a family shrine, and was written for carpenters and construction workmen. It is doubtful, however, that they actually studied it. Most workmen learnt their trade from a master craftsman through observation and imitation. The *Lu Ban jing* is a compendium of the knowledge of carpenters. It documents the precise details of even the small elements. In I-78, even the length of a tenon of a beam is specified exactly, as one would expect in *cai* and *fen*.[91]

In the Ming period, as the feudal system began to disintegrate, the rulers tried more than ever to mount a display of status intended to divert the people from their problems. This included architectural buildings whose monumentality recalled that of much earlier times. To realise such projects, timber had to be sourced from distant provinces such as Yunnan and Sichuan.[92] The lack of appropriate wood and the enormous cost involved made it necessary to find ever stricter ways of economising the building process. The use of less than ideal timber can be seen directly on some less prominent buildings, (Fig. 652) but for prestige buildings such as temples, palaces and residences, the use of skewed beams was not an option. For the columns, however, optical tricks were not an option. During the Tang dynasty carpenters already used such tricks, to reduce material usage on the one hand and to fulfil certain aesthetic requirements on the other: in Foguang si, the sill and lintel beams are formed out of 6 to 8 cm thick planks assembled to form hollow box sections that look like beams and whose dimensions are appropriate to the column thickness and the enormous *dougong*.[93] Columns, however, have to support the weight of the roof and its construction as well as that of the *dougong* construction that collects, bundles and redistributes the load from the horizontal to the vertical, before transferring it to the foundation. Optical illusions could not be used here. If wood of a sufficient size could not be obtained, the necessary cross-section had to be constructed artificially. (Fig. 653) The *Yingzao fashi* already detailed how in earlier times columns were fashioned out of two, three or four parts held together with the aid of butterfly splines. The main hall of the Baoguo si in Zhejiang is one such example from the Southern Song dynasty. Such composite column constructions first became standard practice in the Ming and Qing periods. Where columns were embedded in the gable walls, the carpenters took the shortcut of joining together two or three sections of column above one another with tenons and did not even need to work them any further. Another method involved cladding a continuous core with smaller sections of wood. This was particularly laborious to realise because the surfaces of the

652 The small Youxian si temple in Gaoping uses beams with irregular dimensions and forms that must have presented the carpenters with a challenge. Noteworthy is the unconventional extension of the intermediate *dougong* in the central axis, which display a remarkable economy of means.



653 Columns made of several pieces from the *Yingzao fashi*, Chapter 30, fig. 62 (according to: Guo, 1995, p. 256), in Baoguo si (according to: Zhong, Chen, 1986, p. 107, fig. 5-6-21) and from the Ming and Qing periods (According to: Zhong, Chen, 1986, p. 135, fig. 5-9-5a)

sections of wood nailed to the core had to be made to fit perfectly. These were additionally secured with iron straps.[94] Where columns were particularly long, they also needed to be suitably thick. In such cases, a combination of both methods was employed. While these columns were compression-resistant, they were comparatively weak in terms of bending strength.

A very similar approach was employed for beams with a mostly rectangular cross-section. Here too, two different methods were used: either several shorter lengths of beam spliced together or a single long beam core clad with many smaller sections of wood. In the case of horizontal beams, the use of iron straps as fixings was essential. To protect these new surfaces of important loadbearing and hard-to-replace parts of the construction against the effects of weather, suitable coverings needed to be developed. In addition, no one would want to leave such inhomogeneous surfaces exposed. The product of this development was to wrap the loadbearing structure with several layers of hemp fabric fixed with a special grouting or mortar that created a smooth surface. This surface was then sealed with a varnish and painted with rich decorations.

This measure was just one possible means of economising. In the roof construction of the Longhu Hall of the Yongle gong in Ruicheng, one can see that other ideas were also being experimented with as far back as 1294, which later became standard practice in the Ming and Qing periods. By placing a row of columns centrally down the longitudinal axis, the 6-rafter transverse beams could be replaced by two 3-rafter transverse beams. (Fig. 654) On closer inspection, one can see that the beams have been trimmed rather coarsely and that each is very slightly different. In the Yuan dynasty, it seems the carpenters were less worried about concealing obvious economisation measures in areas accessible to the visitor. Later generations of master builders learnt from this. The use of smaller construction elements made it possible for carpenters to work in smaller dimensions and shorter lengths, and meant that smaller trees could be felled and that significantly less wastage resulted. Smaller elements were also not as heavy, which in turn had a positive effect on the dimensioning of the loadbearing structural members. As a consequence of all of the above, the master builders of the later dynasties were able to build more and larger buildings with the same amount of timber. Increasing standardisation and prefabrication compensated for the additional labour required for the production of the much larger number of components.

The economics of construction is likewise influenced by the use of tools. As described in the preceding discussion on Europe and Japan, in China too the earliest joints were simply tied together using stone tools. Although they were surprisingly precise, the kinds of buildings we have come to associate with Chinese architecture would not have been possible, regardless of the time invested. Building at that time may have been ecological, but it was not economical.

An intermediary form in the development from the tied and knotted joints of the early days of China (5000 BC and earlier) to the mortise-and-tenon joints from the Warring States Period (475-221 BC)[94a] are bronze objects that date back to the end of the Spring and Autumn Period (6th-5th century BC) and joined

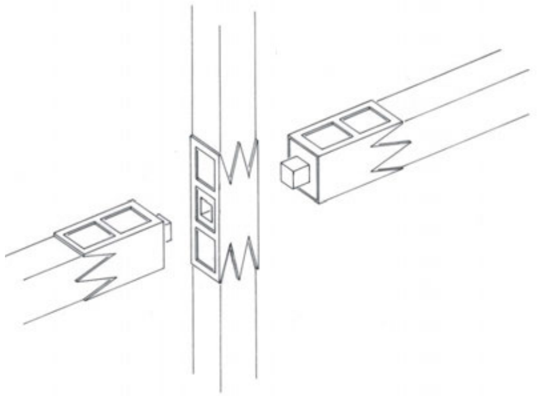
654 Many details of the roof construction of the Longhu dian gateway building to the Yongle gong exhibit an increasing tendency towards more slender cross-sections.

together wooden beams. The motor for this development is believed to be the transition from the use of straw roofing to ceramic tile roof coverings during the Western Zhou period. The greater weight of the roof made it necessary to strengthen the wood construction.[95] It is conceivable that bronze sleeves were employed as means of securing weak joints, but a supposition of this kind would seem more logical when the metal piece connected two or more construction elements, in a manner similar to that shown in an archaeological find from Yaojiagang (Shaanxi).[96] A reconstructed drawing shows several straight bronze sleeves. (Fig. 655) Individual beam ends were fitted into two of them so that only the rebated tenon protrudes. Another bronze sleeve slid over a column with spared holes into which the two horizontal beams are mortised. The drawing shows quite clearly that the sleeves could not have fulfilled their designated task. On the contrary, the sleeve slid over the column does not provide a bearing surface for the tenons, and the tenons of the horizontal beams are subjected to greater stress due to the increased weight of the beams. It also seems equally unlikely that there have been no advancements in timber construction since the Hemudu Culture (5000-4000 BC), from which evidence of both square-cut wood as well as various kinds of tenon joints have survived,[97] while in the same period both ceramics and metalworking underwent the most fascinating developments.

A key to understanding this construction lies in the observation that the bronze finds are worked in a most unconventional manner. The outward-facing side of the sleeve covers the full surface of the beam with a plate that is richly decorated. The other three sides enclose the beam with a framework of metal bands that are as thin as can be. Two explanations can follow from this: firstly, that the carpenters were not yet aware that a massive metal sleeve could damage the wooden core it encloses. The largest metal surface faces in precisely the direction where the difference in thermal conductivity of the wood and metal creates the largest temperature gradient, thereby causing the maximum amount of condensation. The second explanation picks up what has been noted elsewhere in the context of other examples, namely that the sleeves serve to highlight the joints as key elements of the construction. One can see unmistakable parallels with the ever more elaborate decoration of the structural elements in the later dynasties. (Fig. 656)[98]

The ability to work bronze had, therefore, not really made a real contribution to the development of jointing technology. At least, this is the only conclusion one can draw from the examples. In terms of the development of tools, however, advances in this field were much more relevant. Tools fashioned in iron were much more effective than their bronze predecessors. Their improved efficiency simultaneously inspired the development of more specialised tools.[99] Like with other technological developments mentioned previously, progress was made through exploration and trial and error. The typical presentation of historical development as a linear pattern, where one improvement follows the next, is misleading. On the contrary, many development processes have given rise to unexpectedly useful by-products and spin-off solutions.

The first evidence of multi-storey constructions appears in the Han period. This represented a major technological advance



655 According to: Ledderose, Schlombs, 1990, p. 156, fig. 115

656 The painted treatment of a corner detail from the Forbidden City is so vibrant that one does not at first notice the individual elements of the construction. Only on closer inspection can one discern details that are surprisingly reminiscent of the aforementioned metal sleeves or of protective metal plates that were nailed to the end of rafters.

and an essential part of this was the development of the first simple *dougong*. In order to properly distribute loads they had to be made very precisely. The reconstruction drawings from the temple complexes in Xi'an, the capital of Shaanxi, which are from the Han period, exhibited a special detail: the doubling of all corner columns. One may recall that this is where the load of the roof is especially great. Interestingly, however, pairs of columns were also used for inward-facing corners and at these points, the weight argument does not apply. A possible explanation may be that at that time it was only possible to mortise one beam to the left and one beam to the right at the same height into a column.[100] At points such as corners, where two mortise holes had to be cut at 90° to one another, the tools available were apparently not of sufficient quality to enable the carpenters to realise such a task.
The carpenter's tools used in China are not new to us. Particularly apparent is the large variety of different saws. Archaeological finds from the Neolithic Age show saws made of bone, stone and seashells.[101] Frame saws, which look like our crosscut saws, are used to the present day. In China they were available with bi-directional saw teeth so that they could be used by two sawyers to cut tree trunks. They were sometimes so long that they needed two tensioning winding rods.[102] But in general, saw blades with teeth pointing outwards in each direction from the centre were used. This meant that the sawyers at each end worked with the same effort, a particularly strenuous task as the pit-saw "is a totally unbalanced tool."[103] It is worth noting how this contrasts with Europe as well as Japan. In Japan a tree trunk was cut by one man who stood underneath the supported log. In Europe, the so-called top-notcher guided the saw while the strenuous work was undertaken by the partner in the saw pit. The term "top-notch" has become synonymous for someone who is particularly experienced.[104]
The one-man saws cut with a thrusting action. Only small handsaws such as our grooving saws, fret saws or veneer saws cut on the pull stroke. Along with Buddhism, Japan also imported building techniques from China and the active cultural exchange between China and Japan that followed for a while also concerned working methods. The Japanese knew about all the Chinese tools, although, surprisingly, they changed the use of some of them.
Highly developed tools were a prerequisite for the development of through-jointed beams, making it possible to cut ever more slots and holes of ever greater complexity into beams with an ever smaller cross-section. That was necessary, as we have seen, to produce ever more and larger constructions out of less and less material.
The *Yingzao fashi* differentiated for the first time between *xiao muzuo* (fine carpentry work) and *da muzuo* (large-scale carpentry work).[105] The Chinese language did not, however, differentiate between the trades of the carpenter and joiner; they were all simply woodworkers *(mu jiang)*.[106] *Xiao muzuo* focuses on the small parts of carpentry: doors, windows, balcony balustrading and so on. These are elements that are seen from close-up. Their connections are not terribly complex, but they are carefully considered. Furniture and cabinet making is a direct offshoot of *xiao muzuo*. The simple elegance of the furni-

657 Source: Lu Ban jing, in: Ruitenbeek, 1996; 2/15b

ture, visible in the slenderness of their cross-sections and the unassuming perfection of their joints, would be unthinkable without the reciprocal influence of *da muzuo*. The precision with which they were able to work is tellingly illustrated by a minute peculiarity of the small Chinese handsaws: the carpenters of the day had their saws made with the last three to five teeth arranged in the opposite direction.[107]

A particularly impressive example of this reciprocal effect is the four-poster bed or alcove. These “can be completely enclosed to create a private world within a room.”[108] (Fig. 657) Handler called these beds “a miniature house where sons are conceived.”[109] The sons represented the continued existence of the family, the continuance of tradition but also the transitory nature of life. Transience is a central pillar of Buddhism. The inhabitants of a house reflect the transitoriness of the protective built enclosure. Fatalism, however, was not the consequence; as the examples have shown, their actions were guided by a desire to achieve perfection within the respective possibilities of the day.

1 Liang, 1984, p.3. Sung is a now outdated way of writing Song.
2 Zhong, Chen, 1986, p. 61
3 Golany, 1992, p. 123-125; Knapp, 1986, p. 30, 36; Sibert, Loubes, 2003, p. 116-117
4 Needham, 2006 (1971), p. 65. Buildings for the dead were made of stone.
5 Zhong, Chen, 1986, p. 62
6 Wei, 1999, p. 150-151. The term *dougong* is explained in a section of its own (see p. 290)
7 Liang, 1948, foreword, p. 2, after Thilo, 1977, p. 56
8 Liang, 1984, p. XV
9 Glahn, 1982, p. 27
10 Knapp, 1986, p. 64, fig. 3_24; p. 67
11 Ma, Li, 2002, fig. 736-796
12 cf. Xiao, 1999, Vol. 1, p. 133, fig. 1_32, 1_33 and 1_34
13 In Xiao's (1999) history of Chinese architecture, only one single page out of a total of 1260 pages concerns log construction. While log buildings were only erected in the easternmost part of Tibet (see Ma, Li, 2002, ibid.), it is nevertheless conspicuous that there is no mention of them at all in Xu, 2004. Liang Sicheng does, at least, present an informative drawing. (Liang, 1984, p. 121, fig. 62).
14 For further information on the architecture of the Dong minority, see Zwerger, 2006.
15 Si, 1992, p. 154
16 Liang Sicheng cites a few comparative examples of this old Chinese construction method. The most prominent of these, because it is present at a scale of 1:1, is the roof construction of the corridor around the central precinct of the Horyu-ji in Nara (J). (Liang, 1984, p. 43)
17 Zhong, Chen, 1986, p. 117, and Steinhardt, 1984, p. 134 quote different dimensions for the diameter of the columns.
18 cf. Sun, 2004, p. 326-330
19 Zhong, Chen, 1986, p. 170-172
20 Wickede, 1990, p. 151
21 ibid.
22 Zhong, Chen, 1986, p. 170
23 Steinhardt, 1984, p. 104
24 Zhong, Chen, 1986, p. 170-171
25 ibid., p. 171
26 Glahn, 1981, p. 138
27 Hipped roofs were already widespread before the Song period, but their use only gradually became a distinctive characteristic during the Ming and Qing periods. Their restricted use for other purposes was, however, only enforceable in the capital city. In the areas outside of imperial control, such as those areas occupied by minority groups, hipped-and-gabled roofs were used widely. (cf. Knapp, 2000, p. 140)
28 Zhong, Chen, 1986, p. 304
29 cf. Sun, 2004, p. 335
30 The Mosuo are a matrilinear minority not officially recognised by the state that live in the extreme northwest of Yunnan province and the neighbouring Sichuan.
31 Liang, 1984, p. 16, 19
32 Needham, 2006, p. 102
33 Zhong, Chen, 1986, p. 303
34 Nanmu (lat. Phoebe zhennan), endemic in southwest China, is an evergreen tree and a member of the Lauraceae family that grows very straight and can reach a height of 30 m.
35 Cunninghamia lanceolata
36 Ruitenbeek, 1996, p. 14
37 Feuchtwang, 1974, p. 128
38 Zhong, Chen, 1986, ibid.
39 Xie, 1935, vol. 2, p. 60, cited in: Ruitenbeek, 1996, ibid.
40 Liu, 1980, p. 46
41 Vernicia fordii. The seeds of other trees are also suitable for pressing to extract tung oil.
42 Zhong, Chen, 1986, p. 303-304
43 Glahn, 1981, p. 132
44 The nomadic Qidan people oriented their yurts eastward because they worshipped the first morning of each lunar month. Likewise, when they met for gatherings, they sat facing east. As the Liao dynasty, they ruled from 907-1125 over part of northeast China. For further information on the eastward orientation of many, though not all Liao buildings see also Steinhardt, 1997, p. 139-140.
45 Glahn, 1981, p. 138
46 Fu, 1984, p. 13
47 Zhong, Chen, 1986, p. 73
48 Glahn, 1981, p. 132
49 Zhong, Chen, 1986, p. 106
50 Steinhardt, 1997, p. 42
51 Liang, 1982, p. 76, fig. 26
52 cf. Liang, 1982, p. 99, fig. 51
53 ibid., p. 43
54 Ledderose, 2009, p. 39
55 cf. Chen, 2001, photo 106.
56 Zhong, Chen, 1986, p. 97
57 Ledderose, 2009, p. 40
58 Steinhardt, 1997, p. 112
59 *Dougong* is a term that originates from the Qing period. In literature from the Song period, the name *puzuo* bears the same meaning.
60 Thilo, 1977, p. 58
61 cf. Needham, 2006, p. 95
62 According to motifs seen on bronze vessels. De Bisscop, 2007, p. 71
63 ibid., p. 50, cat. 35
64 ibid., p. 70, cat. 37
65 ibid., p. 136, cat. 91
66 ibid., p. 234, cat. 159
67 ibid., p. 72
68 Guo, 1995, p. 54
69 cf. Liang, 1982, p. 129
70 Soper, 1942, p. 100
71 Liang, 1984, p. 15
72 Fujita Kaori made this assertion in a lecture given at Tokyo University on 20 April 2010. Although this referred specifically to Japanese pagodas, in my opinion this is generally applicable for all large historical buildings.
73 Wei, 1999, p. 152
74 Zhong, Chen, 1986, p. 311
75 ibid., p. 317
76 Steinhardt, 1997, p. 173
77 Pan, 2004, p. 41, fig. 34
78 Chen, 2001; pl. 6, 8-15 ff.
79 Liang, 1984, p. 103
80 Fu, 1984, p. 33
81 There is also a parallel term from the Song period for this term from the Qing period. (cf. Guo, 2002, p. 21, 33.)
82 cf. Guo, 1995, p. 11
83 Fu, 1984, p. 32
84 Guo, 1995, p. 30
85 Thilo, 1977, p. 213
86 Glahn, 2009, p. 14
87 Guo, 1995, p. 60
88 Ruitenbeek, 1996, p. 27-28
89 Wei, 1999, p. 15
90 Fu, ibid.
91 Ruitenbeek, 1996, p. 193
92 Zhong, Chen, 1986, p. 133
93 ibid., p. 164
94 Zhong and Chen mention iron straps (ibid., p. 135), Wei mentions steel straps (Wei, 1999, p. 123).
94a cf. Liu, 1981

95 Wickede, 1990, p. 156-157
96 ibid., p. 157, fig. 116. See also the figure on Plate CXXXVI in Needham, 2007 (1965), p. 70, fig. 376b.
97 Li, 2004, p. 23, fig. 1-6
98 Barbara von Wickede also notes this point. Wickede, 1990, p. 158. Yang Hongxun's opinion that the bronze parts from the Spring and Autumn Period had already relinquished some of their functional purpose in favour of decorative treatment would also seem to contradict the plausibility of their use as reinforcement for the wood construction.
99 Zhong, Chen, 1986, p. 40
100 Thilo, 1977, p. 121
101 Li, 2004, p. 80, fig. 3_12
102 ibid., p. 111, fig. 3_32
103 Hommel, 1969, p. 227
104 Noble, 2007, p. 117
105 Ruitenbeek, 1996, p. 76.
106 Eberhard, 1966, p. 41
107 cf. Hommel, 1969, p. 238, fig. 347
108 Handler, 2005, p. 63
109 ibid., p. 67

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