Beam and post structures - Principles

STEP lecture E15
K. Schwaner
Arbeitsgemeinschaft Holz

Objective

To set out the principles governing the design of beam and post structures.

Introduction

A continuous cycle of development spanning many centuries precedes the timber-frame construction methods of today. The first attempts to construct shelters were made in prehistoric times. Vertical posts were dug into the ground, then, horizontal planks were placed side by side and joined to form a frame which bore the brunt of the weight. Dividing walls were filled out with wattle and partly coated with clay. In this way, man erected such constructions for the first time, where the load-bearing frame was separate from the non-load-bearing dividing walls.

In the Middle Ages, the classic half-timbered building was developed from above mentioned method of construction. Examples which can still be seen today pay tribute to the very high level of the builders craftsmanship (Figure 1). Towards the end of the 18th century the half-timbered buildings became less significant in comparison with the solid masonry construction methods. This was not least due to the fact that the bourgeoisie, who were gaining more and more influence in society, also developed a new set of values where construction methods were concerned, including, for example, a preference for more "solid" and more "durable" buildings. Timber-frame construction still played a significant role when no particular importance was attached to representative architecture and where buildings had to be erected as cheaply as possible.

Figure 1 The town hall in Frankenberg, Germany

Since the mid 20th century there has been a fundamental change in the attitude towards timber constructions: timber is gaining importance once again as more and more people learn to value its high quality and the numerous things it can be used for. However, due to rising wage costs, the half-timbered constructions built by craftsmen became uneconomic and instead different methods of construction were developed, such as timber-frame construction and modern beam and post structure methods.

Modular construction

A timber-frame structure is a three-dimensional load-bearing construction, erected within a grid, consisting of linear elements which are supplemented by a curtain wall or panels. There is a clear division between the load-carrying construction and the façade elements (Figure 3).

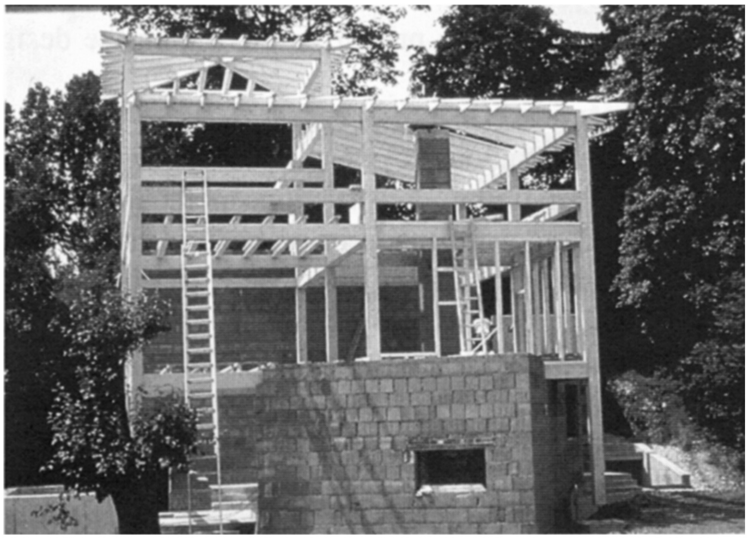

Figure 2 *The skeleton is erected.*

Figure 3 *The house is completed.*

All beam and post structures, whether made from timber, concrete or steel, are based on a basic module. This module ensures that the structure of each beam and post building is standardised and structurally sound. A multiple of the module produces the grid. The module and grid determine the position of the load-bearing columns, the location of the main and secondary beams and often also the way in which the non-load-bearing finishing elements are arranged.

An example of this type of elementary unit is the traditional Japanese home which, in the ground plan and cross and longitudinal section, is built on the basic unit of the Tatami mat (0,91 x 1,82 *m*). The planning of beam and post structures begins with the choice of a ground plan module. Its size, and thereby that of the grid, depends on a wide range of factors and can be given a new and different specification for each building.

Module and grid are governed by

- human dimensions:
  all types of scales drawn up by man such as, for example, Leonardo da Vinci's theory of proportion (Figure 3), Le Corbusier's Modulor, the Japaneses floor mat, the span of a hand, the length of a stride or the height of a step

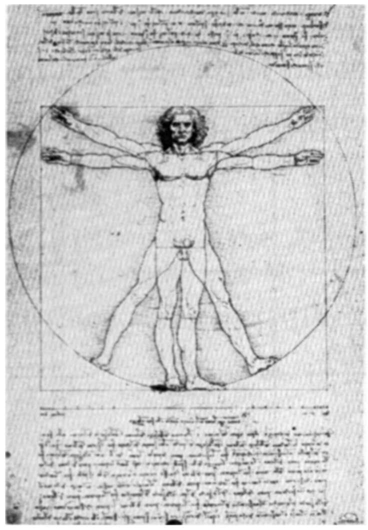

Figure 4 *Leonardo da Vinci's proportion study of 1490. Pen-and-ink drawing, Venetian Academy.*

- architectural design:
  configuration of the building parts, order and arrangement of the inner rooms, size and scale of the rooms, structuring of the façades, specific requirements regarding what the building is to be used for

- structural and material considerations:
  economic beam spans, standardized joints, customary formats of finishing elements, insulating panels, panelling, standard sizes of windows, doors, stairs, spans of load-bearing floor elements

- site conditions:
  geographic position, orientation, size of plot, tree population, vicinity of existing buildings, specifications in the master plan.

There is no one single definitive module size: for example, there is the European module (DIN 8000) = 100 *mm*; the brick size (DIN 41721) = 115 + 10 *mm*; the stair module = 90 *mm* (half height of step); multi-module = 600 *mm*. These produce the customary grid scales of 1,20 by 1,20 *m*, 1,25 by 1,25 *m*, 3,60 by 3,60 *m* or 4,80 by 4,80 *m*.

In addition, the distinction is made between the band grid and the axial grid (Figure 5). The band grid defines the clearance between the parts of the building in a load-bearing construction, the axle grid always refers to the centre lines of the columns or of the load-bearing system.

The number of different possible modules alone illustrates that there is not one universal grid scale. The specification of the respective grid is part of the design process and therefore also constitutes a design criterion. The selected grid is reflected in every part of the building. It can, for example, clearly be seen in the format of the windows, the distances of the load-bearing construction or in the division of the exterior cladding. The effects on the formation of the skeleton are as follows:

- small grid (e.g. 1,20 by 1,20 *m*):
  The structural system is identical to the finishing system; every column is load-bearing; small cross-sections; simple e.g. nailed joints.
- large grid (e.g. 3,60 by 3,60 *m*):
  There is a clear division between primary and secondary system. In this case there are larger cross-sections manufactured, for example, from glued laminated timber; large, open spans and less joints.

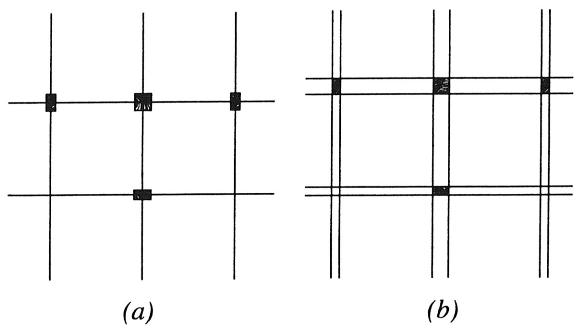

Figure 5 Axis (a) and band (b) grid.

The economy of the building measures undertaken is also dependent on the choice of grid and load-bearing system. As with other timber engineering structures, the number and form of the joints will also greatly influence the overall cost of a beam and post structure.

The most common systems are based on a right-angled ground plan grid. In principle, however, other grid systems (radial grid, triangular grid, etc.).

Load-bearing systems and joints

Almost all beam and post structures can be traced back to a few principal load-bearing systems. Each of these construction forms distinguishes itself from the other by the order and position of the load-bearing elements (columns, main and secondary beams) and by the joints of these building elements. Columns and main suporting beams have single or multiple sections. The secondary supporting beams are flush or stacked (Figure 6). The most important configurations are described below.

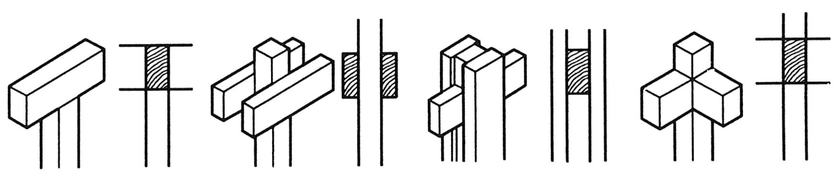

Figure 6 Load-bearing systems in beam and post structures.

System 1: Single section main supporting beam and single section column, single-storey

With this system, the continuous or single span main supporting beam rests directly on the column. The secondary supporting beams can be stacked on the main supporting beams or hung level between them. In the case of a small grid scale, load-bearing boards or wood-based panels can be laid directly on the main supporting beams. Cantilevers in both directions are possible. The load transfer between main supporting beam and column occurs through bearing column ends must be accuratly cut for a good fit. There are simple geometric ratios for the finishing and façade connections. When conneting to main and secondary supporting beams, the different construction heights and other details should be taken into consideration.

Possible connections for supporting beam to column:

These joints are mainly for allocation and eventually against uplift loads:

- tenon joints
- timber or wood-based material exterior or interior butt plate straps
- exterior or interior steel plates
- glued-in bolts
- end-grain joints with Type A connectors according to EN 912
- steel angle brackets
- T-shaped integral fasteners (Figure 8).

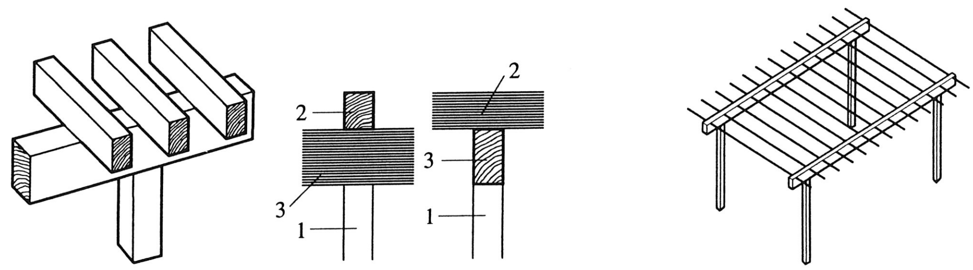

Figure 7 *Single section main supporting beam and single section column, single-storey. (1) Column, (2) secondary beam, (3) main beam.*

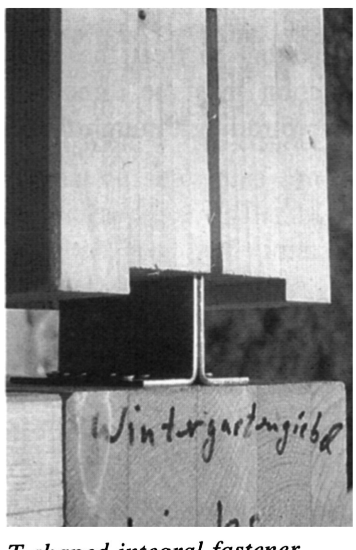

Figure 8 *T-shaped integral fastener.*

System 2: Multiple section main supporting beam and single section multistorey column

This load-bearing system consists of single section multistorey columns and multiple section main supporting beams.

The secondary beams (ceiling beams) normally rest on the main supporting beams to enable the use of the continuity effect for an economic structural design. They can be placed parallel on both sides of the column in the grid axes or be built in as single span beams between the column faces. This system is suitable for two- or multi-storey buildings, in particular for split level floors, since in this case the beams can be fixed to the columns at any chosen level. Cantilevers in both directions are then also possible.

Possible conections for main supporting beam to column:

- dowels or bolts
- toothed-plate connectors, ring and shear-plate connectors
- wooden cleat supports
- steel angle brackets
- column with scarf joint, part of the bearing force as compression
- mixed constructions with these types of joints

The secondary beams are normally laid over the main supporting beam. This stacking method of construction results in relatively high floors. In addition, coupled with the multiple section method of construction, it also creates voids and thereby complex connections from the inner walls and the façade.

The principle of construction is simple, the construction itself and the load-bearing functions are easily recognisable. Characteristic of this type of construction are the protruding ends of the beams, which can normally clearly be seen, with the fastener end distances which often prove necessary. It should, however, be noted that it is almost impossible to avoid penetrating the façade of the building.

The great demands of building physics which are made on modern outer walls (wind tightness, heat loss in joints, thickness of insulation) are particularly difficult to fulfill using this method of construction.

In order to avoid having to treat the timber with preservative, no timber parts within the construction must be directly exposed to the weather. As a result, ends of the beams protruding through the façade should be avoided.

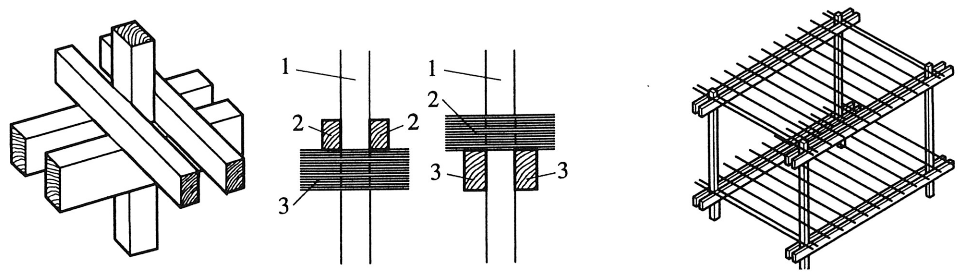

Figure 9 *Multiple-piece main supporting beam and single section multistorey column. (1) Column, (2) secondary beam, (3) main beam.*

System 3: Single section main supporting beam and multiple section multistorey column

This method of construction is often chosen for architectural reasons. The continous main supporting beams are fixed onto the multiple section columns by mechanical timber fasteners. However, due to the slenderness of the columns, additional lining rails or battens often have to be built in as well. Sometimes the main supporting beam can lie directly on top of this batten. Cantilevers in both directions are possible here, too.

The small size of the column cross-sections is problematic where fire design is concerned. The cross-sections often have to be enlarged in order to obtain the required fire resistance. Due to the complexity of this principle of construction, restrictions similar to those of the above-mentioned system apply, regarding finishing and façade element joints.

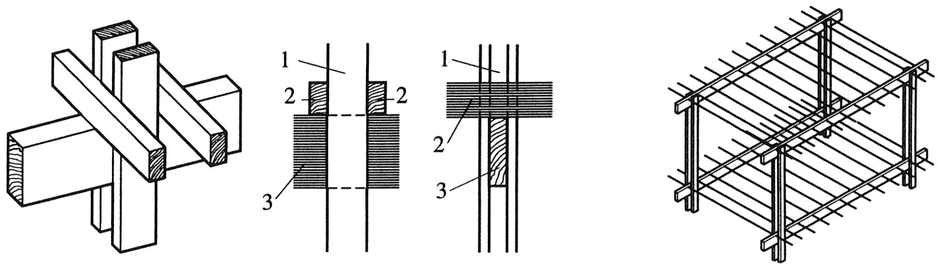

Figure 10 *Single section main supporting beam and multiple-section multistorey column. (1) Column, (2) secondary beam, (3) main beam.*

System 4: Single section main supporting beam and single section multistorey column

The load-bearing skeleton consists of single section multistorey columns. The main supporting beams are then joined to this column as single span beams at any level. Here, the secondary support beams can be laid flush with the main supporting beams or stacked.The advantage of the former construction is that, because the joints are the same level in both directions of the axis, very simple geometries are created for connecting internal and external walls.

If all main supporting beams are lying in one particular alignment and all secondary beams are lying at right-angles to these, an aligned system is produced. A non-aligned system is created when the main supporting beams are arranged at the same height in both directions, but the direction of the secondary beams is changed to a chequered pattern. Thus all main supporting beams are proportionately loaded – the connections are symmetrical and the number of different construction elements and joints can be greatly reduced. This standardisation makes up considerably for the disadvantage of the large number of fasteners and the fact that more timber is used. The system is particularly suitable for prefabrication of the load-bearing elements and the complete finishing components. It enables construction elements to be produced with precision and independent of weather conditions and to be assembled rapidly.

Moreover, the façade of the building can be placed around the building without being affected by wall openings. Only in this way, for example, can a beam and post structure fulfill the high standards expected from a low-energy building. Balconies and canopies are aligned against the façade using independent load-bearing systems.

Possible connections for main supporting beam to column:

- dowelled joints with centre member of welded steel
- T-shaped integral fasteners
- cold-formed steel fasteners, e.g. joist hangers
- wooden cleat supports and steel angle brackets
- contact pressure on specially formed cross-sections of the columns
- proprietary fasteners, e.g. Janebo hook plates (Figure 12), BSB-system (Figure 13)

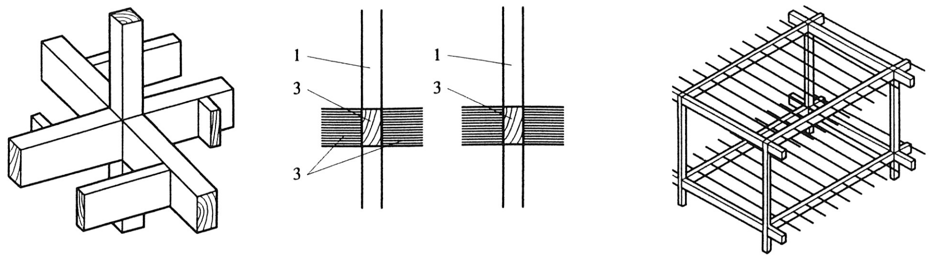

Figure 11 *Single section main supporting beam (level) and single section multistorey column. (1) Column, (3) main beam.*

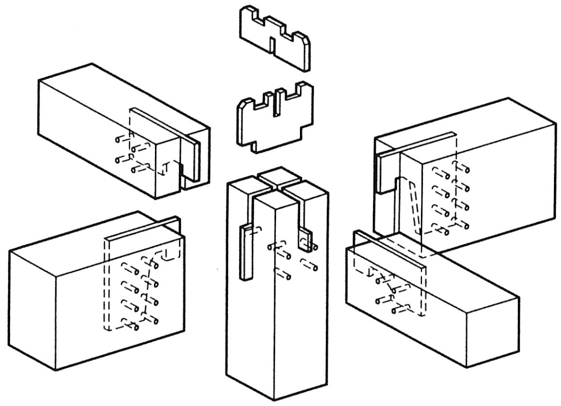

Figure 12 *Proprietary fastener: Janebo-hook-plates.*

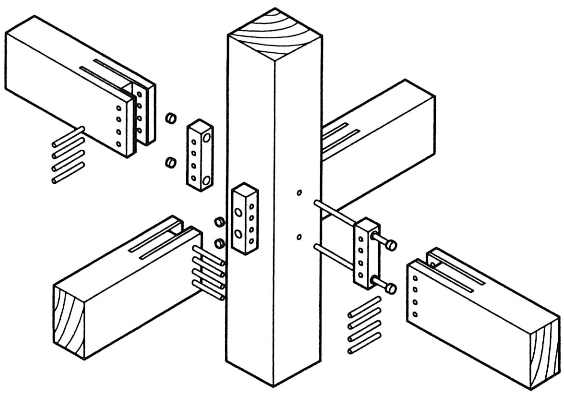

Figure 13 *Proprietary fastener: BSB-system.*

Most of these joints can also be used as a connection at the same height as the main and secondary beams. In addition there are Z-profiles, end-grain joints with ring and shear-plate connectors and supports on load-bearing battens on the main supporting beam. If the timber-frame elements remain visible, the joints must then also fulfil the aesthetic requirements.

The choice of load-bearing system can also be seen as a statement of architectural creativity. A distinction is made between different systems: those which are fully integrated into the wall, partially integrated or non-integrated. In the case of an integrated load-bearing system the skeleton itself is not visible and many different types of materials and surface conditions are possible for both the internal and external panels. In a partly integrated load-bearing system the wall surfaces are arranged flush against the columns in accordance with the grid. Despite structural texture, the whole wall surface is preserved. In a non-integrated load-bearing system the beams protrude and become the main characteristic of the interior design.

Figure 14 *Delivery of complete beam and post structure components to the building site.*

Figure 15 *Assembly of columns and main supporting beam.*

Figure 16 *Assembly, alignment and fixing of the first structure in one axis.*

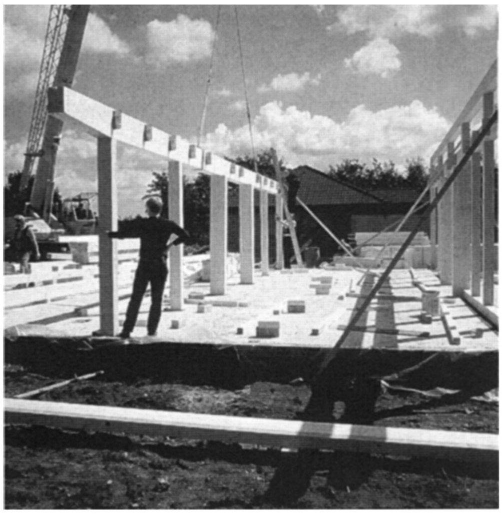

Figure 17 *Aligning the rest of the structure.*

Figure 18 *Placing of the secondary beams.*

Figure 19 *Completed assembly of the ground floor.*

Bracing

In a beam and post structure the functional load-transfer construction is entirely separate from the façade and external wall elements. Only the linear elements (beams and columns) ensure the stability of the building, i.e. the transfer of all vertical and horizontal loads into the ground. In particular, the spatial stability and the bearing and transfer of bracing actions and wind loads must be calculated. Bracing actions are horizontal forces which, for example, are caused by wind, column inclinations and deviations of straightness of the beams due to imperfections in the processes of manufacture and assembly.

Beam and post structures are braced in both horizontal and vertical directions. In certain cases, if enough vertical bracing elements are available, horizontal bracing constructions are not necessary.

Bracing in a horizontal direction is carried out using diaphragms in floor and roof levels. Bracing in a vertical direction is carried out using shear walls, bracing constructions, portal frames, restraint columns or rigid staircases (Figure 20). The diaphragm can be constructed using panelling with wood-based material, aligning bracing struts or by laying floorboards with the tongue and groove in a diagonal direction. It should be noted that a new series of floor systems are currently being developed in which the diaphragm effect is already an integral part. Glulam panels, boxes with webs and panels of wood-based material, laminated veneer lumber, stacks of vertically arranged solid timber planks or boards as well as timber-concrete-composite systems are particularly worth mentioning.

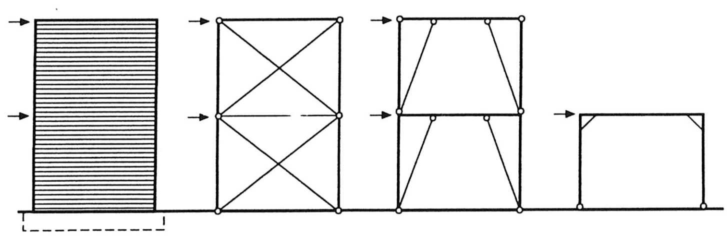

Figure 20 *Vertical bracing elements. (1) Shear walls (timber, brickwork, concrete), (2) crossed diagonals, (3) portal frames, (4) knee-braced frame.*

Vertical linear or planar bracing elements can be aligned to bear the horizontal forces from the floor and roof level diaphragm. The planar elements are shear walls of concrete, brick or timber frame walls with wood based panels. If a structural calculation is carried out to transfer the bracing actions into the joints, brickwork between the columns can then be used for bracing. Bracing can also be carried out by aligning steel or timber bracing struts or aligning crosswise diagonals, or by building portal frames or restraint columns. If the floor and roof level diaphragm is braced to a sufficient extent, a rigid staircase or maintenance shaft can then act as a complete vertical bracing element.

Figure 21 *Gunz house, Keltern, Germany.*

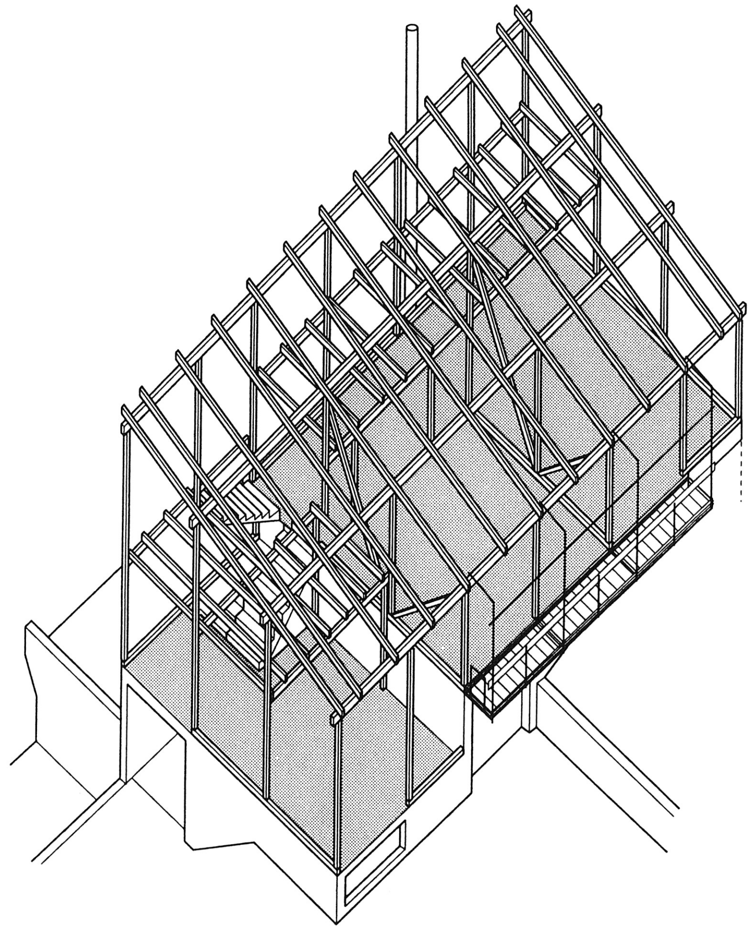

Figure 22 Isometry of the Gunz house.

Conclusion

The changing face of the building industry, with new emphasis being put on construction methods which save costs and protect resources, has led to increased opportunities to make use of building materials and types of construction which on the one hand can meet the individual needs of the customer and on the other are technically advanced, uncomplicated and which can be assembled without difficulty by the local manufacturer. Modern beam and post structures in particular fall into this category (Figures 21,22).

Construction methods developed from past models, new connection techniques and materials ensure that buildings constructed using the beam and post structure method are every bit as stable and durable as buildings constructed using other methods. In addition, they offer such advantages as adaptability, ease of building alteration and extensions, pleasant aesthetic design, exemplary construction physics, ease with which components can be prefabricated, practicability on different technology levels (small workshops, rationalized medium-sized firm, industrial production), easy to transport and assemble. Due to the fact that the customer plays an important contributory role in the construction process, particularly where finishing elements are concerned, it is also possible to reach a marked reduction in building costs. The beam and post method of construction provides a variety of creative design possibilities for a wide range of different buildings and structures. It is employed for housing and office buildings as well as for public buildings – kindergartens, schools, senior citizens' homes, sport and leisure halls. Religious buildings can also be constructed in suitably aesthetic architectural designs using the beam and post structure method.