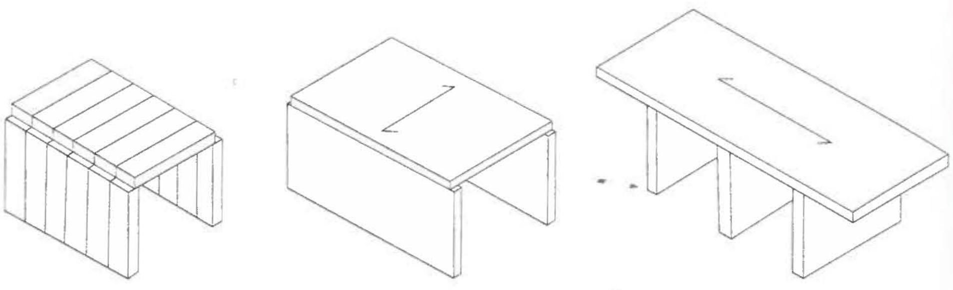


C 3.1

Panel systems

In panel constructions the structural systems consist of planar wall and slab elements, which simultaneously form an enclosed space. The panels can be constructed of steel, timber construction materials, concrete or masonry. Both small, narrow panels and large, room-sized panels are self-supporting elements.
Panel construction methods are differentiated according to three construction principles:

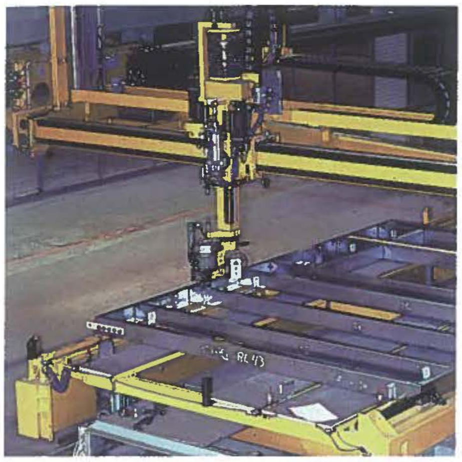
Small panel construction
Today, small panel construction is only used in low-level, multi-storey buildings. In this system, the walls are constructed of narrow, storey-high panels, between which slender slab elements are spanned. The wall and slab elements are constructed in widths of 60 to 120 cm. Small-format panels allow more individual design processes than the larger-format panels; however, the number of joints is considerably greater and should be considered when planning. Although small elements are more easily assembled using simpler hoisting equipment, they require more time for assembly.

Large-panel construction
The structural system of large-panel construction consists of floor slabs supported on four edges by the longitudinal and transverse walls below. If the slab span is limited to 6 m, it is possible to support it on only two axes; that is, in either the longitudinal or transverse direction. Should the slab be supported in the transverse direction by the longitudinal walls, the non-load-bearing transverse walls only act as bracing and partitioning elements.

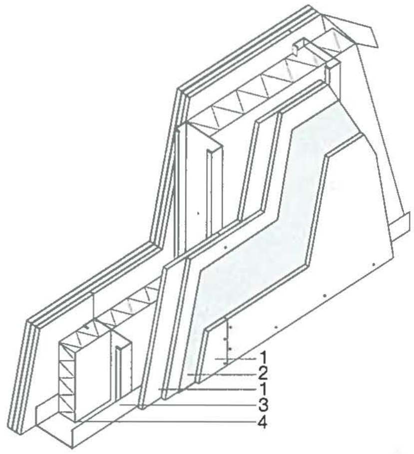
Crosswall construction
The structural system for crosswall constructions consists of transverse walls as arranged parallel to act as supports for the floor slabs above. As the direction of span of the slabs is longitudinal, the slab can be constructed continuously across a number of fields. The economical moment situation allows a slab construction of minimal static depth, which leads to a saving of construction materials. Bracing is provided by longitudinal walls or stairwells. As the facades on the shorter ends of the compartments do not carry any loads, they can be enclosed with lightweight partitioning elements (fig. C 3.1).

Generally, external wall elements must fulfil all the necessary requirements of building physics and, subsequent to assembly, be absolutely tight at all junctions. They must be light enough to ensure ease of transport and assembly, even when thermally and acoustically insulated to the required levels.

The dimensions of the panels are dependent upon material selection, transport conditions and constructional grid dimensions; panel height is equivalent to storey height. The panels are connected using standard methods; the choice of technique is influenced by both the wall panel material and overall construction system.
The supporting consoles are the load-transferring construction elements; the connections must transfer all forces of compression, tension and shear from the load-bearing members.



C 3.2



C 3.3

C 3.1 Construction principles of panel systems
a Small-panel construction
b Large-panel construction
c Crosswall construction
C 3.2 Manufacture of a steel frame construction in a factory
C 3.3 Steel frame wall construction
1 12.5 mm plasterboard cladding
2 0.38 mm metal panel
3 C-section (416 mm centre distance)
4 insulating fibreboard
C 3.4 Isometric representation of steel-frame construction; intermediate floor connection and footing connection
C 3.5 Construction principles of steel-frame construction
a Platform building method
b Balloon frame building method

Building with steel panels

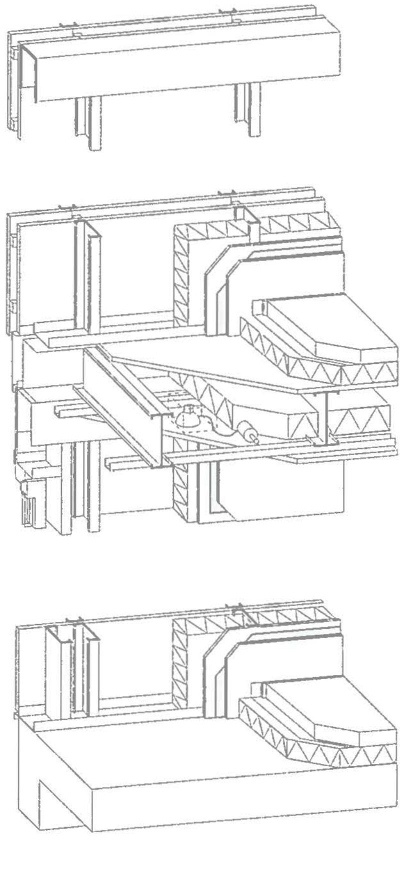
Steel panel building methods

Framework construction is the basic principle employed when building with steel panels. The differences, however, are that the loads are transferred via the columns in the skeleton in timber framework construction, whereas, in conjunction with the cladding, the steel frame acts as a plate. The steel frames and cross ribs are manufactured in the factory and the panels are delivered to the site either as framework or complete with cladding, depending on the level of prefabrication.

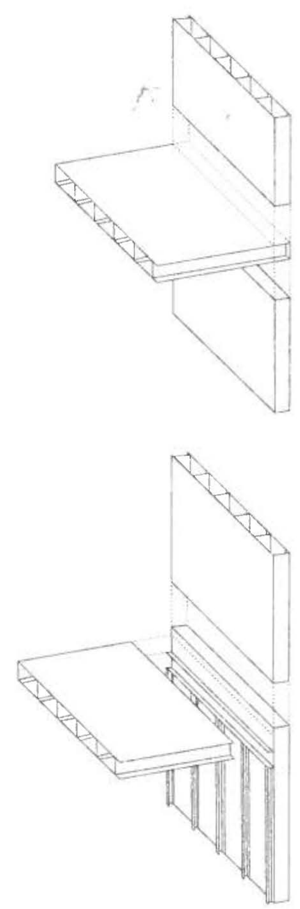
Steel framework construction
In this form of construction, the load-bearing panel elements are constructed out of cold rolled-steel sections as rough building elements for walls, slabs and roofs (fig. C 3.2). The advantages of this building method are the low weight and high load-bearing capacity of the construction elements. The metal frames are constructed of vertical standing sections (studs), arranged at intervals of 40 to 80 cm, which are connected at the top and bottom by U-profile channel sections. The connections are either welded or screwed. The construction owes its stability to the double-sided cladding of various materials. A wall is produced that acts either as a panel or slab and transfers all applied loads to the adjacent building elements. The cavities between the studs are insulated according to thermal and acoustic requirements (figs. C 3.3 and C 3.4). In order to minimise the thermal bridging effects of the metal studs, the elements can be equipped with an additional insulation layer. It is possible to produce the finished elements complete with installations and finished surfaces. Site assembly connection of the prefabricated panels is carried out by screwed and bolted fixings using simple hand or electric tools. Planning and construction grids are based on the axial grid principle. Analogous to timber framework construction, there are two different approaches to the assembly:

Platform construction systems
Buildings constructed using platform building methods are erected storey by storey. The floor slabs rest on the storey-high wall units (fig. C 3.5a).

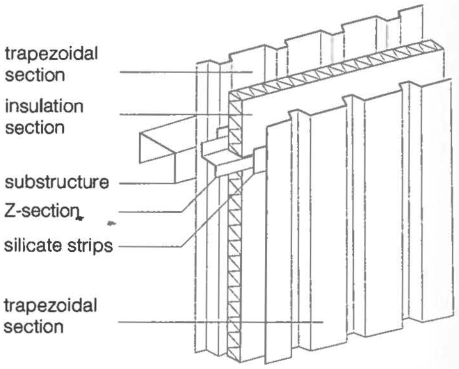
Balloon frame construction systems
In balloon frame construction systems, the external walls stretch over the full height of the buildings. The floor slabs are not connected to the wall construction, but to console elements that are welded to the stud sections (fig. C 3.5b, p. 111).



C 3.4



C 3.5



C 3.6

The weight savings of steel, compared with timber, framework constructions is approximately 30 % and about 66 % compared with solid wall constructions.
This building method is widely used for prefabricated homes in Japan, but has also broken into the housing markets in the USA, Canada and Australia. In Germany, however, this "new" building method has not gained acceptance and only about 1 % of housing construction is carried out using these techniques. Here, they are predominantly used in industrial construction for halls and warehouses.
Both large and small panels can be used in steel framework construction systems. Small-size wall panels have the advantage that they are adaptable to a great variety of different building forms. Large panels are manufactured as wall units with widths of up to 12.5 m and slab elements with span dimensions of up to 14 m.

▸ Cocoon Transformer
(Cocoon Systemleichtbau AG)

This steel frame construction is most suitable for new buildings, extensions and the addition of one or more storeys. The wall units are manufactured, fully finished, in the plant and are ready for assembly on site (fig. C 3.8). The cladding and insulation are coordinated with the individual wishes of the client. These system elements are particularly appropriate for wide spanning wall and slab constructions. They can be extended and added to in both vertical and horizontal directions as desired.
For example, with this system, the load-bearing structure of a single-family house can be erected within three to four days (fig. C 3.7).

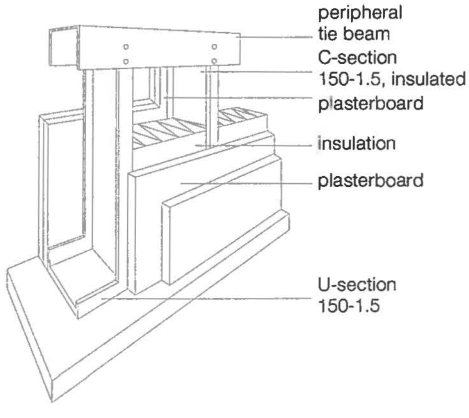
- application:
  external and internal walls, intermediate floor slabs, fire-proof walls
- usage:
  office and administration buildings, housing, social facilities, small industrial facilities

Construction materials and elements

Sectional sheet panels

Wall panels of sectional sheeting are prefabricated, non-load-bearing elements and are solely suitable for partitioning and enclosure (fig. C 3.9). They can be manufactured as single or double-layered elements, with or without insulation (fig. C 3.6). Coated sectional sheets are mounted to substructures in production plants to produce wall elements; the cavities between can be filled with thermal insulation on site, as desired. They are very economical building materials due to the minimal assembly required and can be easily reused when building alterations are carried out. Due to their low thermal storage capacity, these panels do not satisfy the requirements of structural physics for housing construction and are, therefore, mostly used for industrial applications.
In the housing industry, double-layered, thermally insulated, trapezoidal or corrugated metal wall panels are well established. The highly processed external layer and the internal layer are connected by spacers, although still thermally separated. The humidity that penetrates the

C 3.7

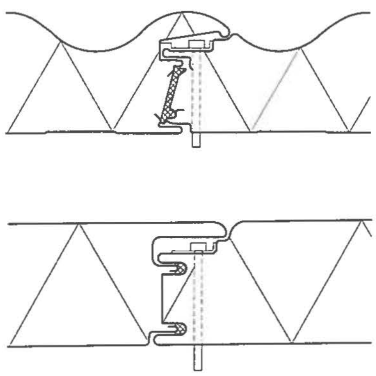


C 3.8

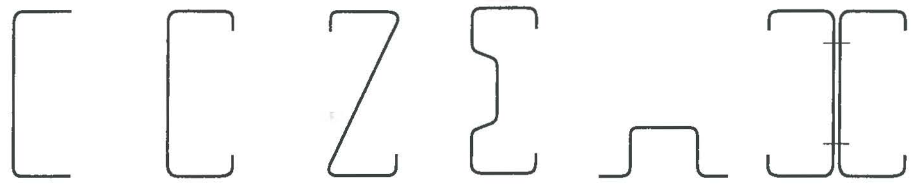
C 3.9

a

b



C 3.10



C 3.11

panels from the inside of the building is transferred to the outside via the air layer behind the outer surface. The cavities between the spacers are filled with mineral fibre thermal insulation. Fixing the sheeting to the substructure, and the wall panels to each other, are both executed with screws and keyed joints.

Sandwich elements

Sandwich elements are self-supporting composite building units that can be used for both facade and roof cladding. They consist of two thin metal layers fixed together in a shear-resistant manner with an internal insulating core; they are resistant to bending moments and can easily absorb out-of-phase forces, such as wind, in spite of their minimal thickness and weight. The stability of the metal layers of the sandwich elements is enhanced by additional preliminary rolling and folding processes; suitable materials are aluminium, steel and stainless steel. The insulating core is usually manufactured of rigid polystyrene foam panels. The production of sandwich panels takes place in specially equipped fabrication plants that produce continuous lengths. Sandwich roof panels are usually 1000 mm wide and measure between 70 and 110 mm in depth. Facade elements are produced in standard construction dimensions of 600 to 1200 mm with depths of 40 to 200 mm. Both panels can be delivered in lengths of up to 20 m.

System-specific connections and intersections have been developed for sandwich element based building systems (fig. C 3.10). In addition to the standard screw fixings, non-visible connections such as concealed screw fixings and pin connections are available for more highly developed facades. Surface structure, colour selection, joint arrangement and manner of fixing are critical for the final appearance of sandwich panel facades [1].

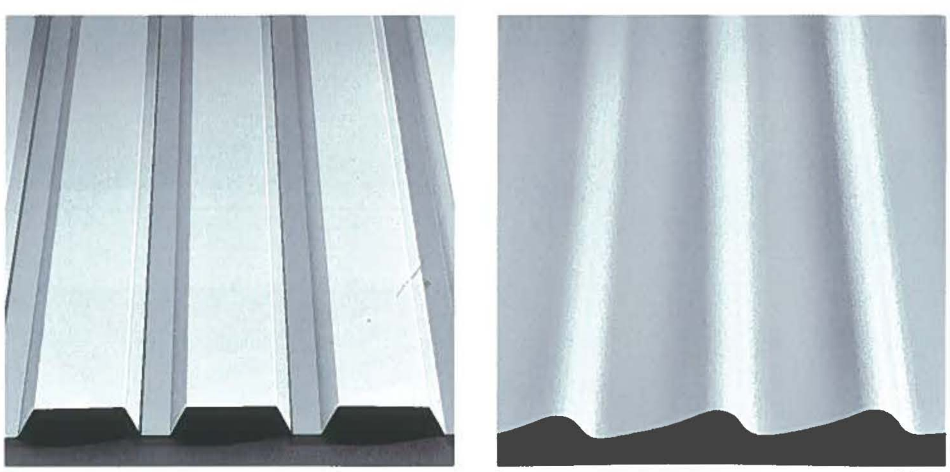
Lightweight steel sections

Lightweight steel sections are formed of hot-dipped galvanised steel sheeting with thicknesses of 1 to 2.5 mm. The most common sections are C, U and Z-sections that are available in lengths of up to 12 m (fig. C 3.11).

Steel sheeting

Steel sheeting is rolled in fabrication plants in widths of 2000 mm. Cold-rolled sheeting can be up to 100 mm thick, and hot-rolled sheeting up to 3 mm thick, prior to being further processed as trapezoidal or corrugated sectional sheeting. The stability of non-sectional sheeting can be enhanced by further processing, such as the forming of ridges or ribbing (fig. C 3.12).

C 3.6 Trapezoidal sheet steel wall
C 3.7 House, steel frame construction (Cocoon Transformer), Zagreb (HR) 2006
C 3.8 Construction of a cocoon wall
C 3.9 Manufacture of trapezoidal steel sheeting
C 3.10 Concealed jointing for sandwich elements
a Sandwich element with corrugated cover plate
b Sandwich element with flat cover plate
C 3.11 Lightweight cold-rolled steel sections
C 3.12 Steel sheet sections
a Trapezoidal sheeting
b Asymmetric corrugated sheeting
C 3.13 Sandwich element facade, administration building telecommunication concern, Oporto (P) 1997, Joao Alvaro Rocha and José Manuel Gigante



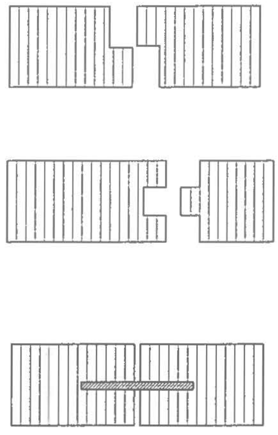
a b C 3.12

C 3.13

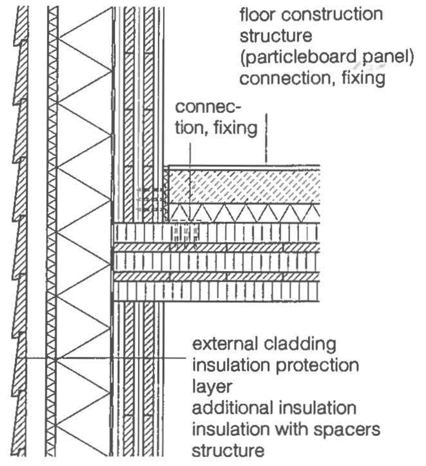
a

b

c



C 3.14



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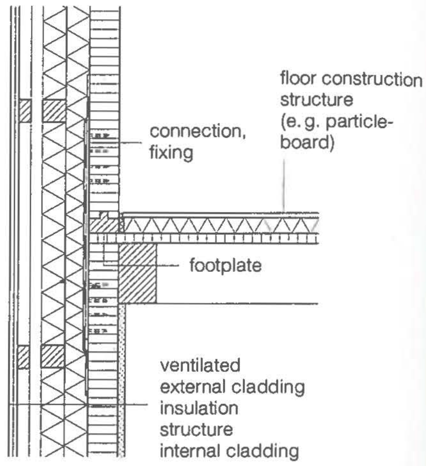


b

Building with timber panels

Timber panel construction systems are subdivided into panel construction, framework construction, block construction and building with timber modules. The elements used in timber panel construction are usually made of solid timber or processed timber construction materials with stiffening cross ribs, whereas clad timber frames are used in framework construction. .

Timber panel building methods

The different building methods are described below:

Timber panel construction

The load-bearing elements in timber panel construction can be both small or large panels of timber building materials. They fulfil both structural and partitioning functions (fig. C 3.15). The loads are transferred to the foundations via the panels; in timber building methods, the foundations are concrete floor slabs.
The junctions between the timber panels are fabricated as butt connections generally fixed with either tongue-and-groove joints, with rebated joints, pinned with either hardwood or steel dowels, or nailed with perforated steel plates (fig. C 3.14). Corner junctions are secured by either screws or bolts. Sealing profiles or sealing strips are necessary to protect the joints against moisture penetration.
The selection of transport vehicles and hoisting equipment is dependent upon the dimensions of the elements and their resultant weight.
Large panels are often used in housing construction where they are employed in room-high or building-high sizes. Timber panels for external walls can measure up to 14.5 m in length. Slab elements can be up to 2.5 m wide and span up to 10 m. Small panels are also room-high but with widths of 60 to 125 cm. The dimensions of the slab elements correlate with the large panels. Due to the minimal weight of these elements, simple lifting equipment can be used. Both small and large panels are between 60 and 120 mm thick. Timber panel building is divided into construction with timber block panels and solid timber building units.

Timber block panels

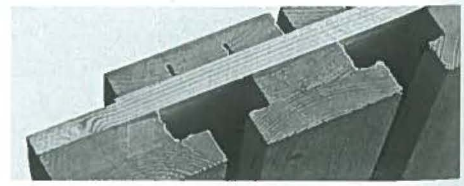
Timber block panels are manufactured of processed timber construction materials and stabilised against bending with cross ribs making them exceptionally stiff and dimensionally stable building elements. The fields between the ribs are either filled with thermal insulation or used for installation lines (fig. C 3.17).

Solid timber panels

Solid timber panels are produced by laminating solid timber, processed timber construction materials or timber shavings under pressure (fig. C 3.18). Compared with timber block panels, they can carry loads in two directions. The panels are fully prefabricated in the factory, openings for door and windows as well as cavities for installation lines, are accurately pre-cut (fig. C 3.16). All necessary insulation materials are mounted to the exterior of the structural system; the thickness of the insulation varies according to the individual requirements (fig. C 3.19) [2].

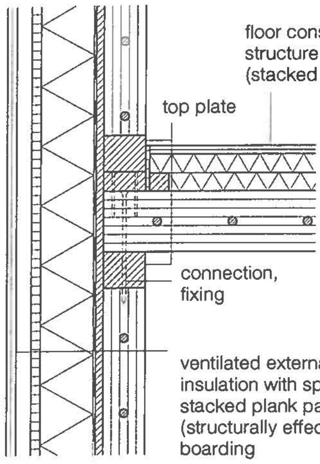
C 3.15

C 3.16



C 3.17

C 3.18



c C 3.19

C 3.14 Connection of solid timber panel elements
a rebated connection
b tongue-and-groove connection
c pin/dowel connection
C 3.15 Assembly of timber panels
C 3.16 Shell construction of a solid timber panel building, Atelier, Hellerau (D) 2004, Deutsche Werkstätten Hellerau, Albrecht Quinke
C 3.17 Timber block panels
C 3.18 Solid timber panels
C 3.19 Slab to wall connection with load-bearing laminated timber panels
a Plywood panel construction
b Particleboard panel construction
c Stacked plank construction
C 3.20 Haas System
a Double tongue-and-groove connection between stacked plank elements
b Vertical section; wall-slab connection
C 3.21 LIGNOTREND planar element
a Timber block panel elements
b Vertical section; wall-slab connection
C 3.22 Lignatur planar element
a Box, shell and planar elements
b Vertical section; wall-slab connection in timber frame construction

▸ System Haas
(Haas Fertigbau GmbH)
In this case, the solid timber units are stacked-plank-panels that measure up to 600 mm in width with thicknesses of 80 to 240 mm. Single span beams can span widths of 6 m, and continuous beams up to 7.5 m. The elements are jointed with tongue-and-groove connections, splices or timber construction strips. The great advantage of this system is that the panels can be finished with CNC controlled machines (fig. C 3.20).
- application:
  walls, slabs, roofs
- usage:
  single and multi-family housing, industrial and administration buildings, schools and kindergartens, sports halls and agricultural constructions

▸ LIGNOTREND planar elements
(LIGNOTREND AG)
The timber block panels of this system can measure up to 18 m in length and are 600 mm wide with a thickness of 282 mm. These panels are exceptionally stable due to their multi-layered construction and also offer high quality sound protection. The cavities between the cross-bracing can be filled with insulation (fig. C 3.21).
- application:
  walls, slabs, roofs
- usage:
  single and multi-family housing, industrial and administration buildings, schools and kindergartens

▸ Lignatur
(Lignatur AG)
The timber block panels are available as load-bearing box, planar or shell elements. They are connected by tongue-and-groove or steel pin fixings. The elements are available in thicknesses of 120 to 320 mm, the box elements are 195 mm wide and the planar and shell elements 514 mm and 1000 mm wide. All units comply with thermal and sound protection requirements, the box elements are additionally filled with insulation. The panels can be processed by CNC controlled machines (fig. C 3.22).
- application:
  walls, slabs, roofs
- usage:
  single and multi-family housing, industrial and administration buildings, schools and kindergartens

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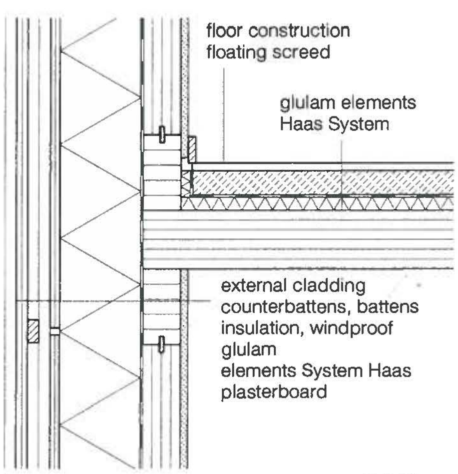
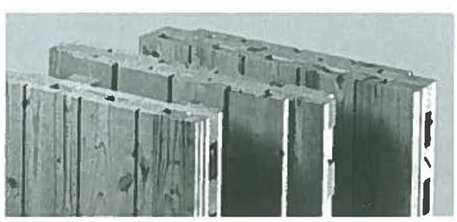


b C 3.20



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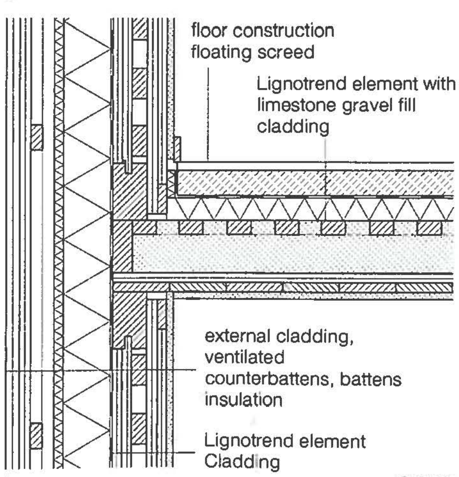

b C 3.21

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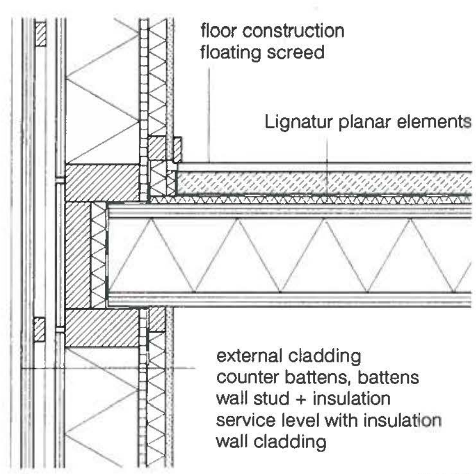
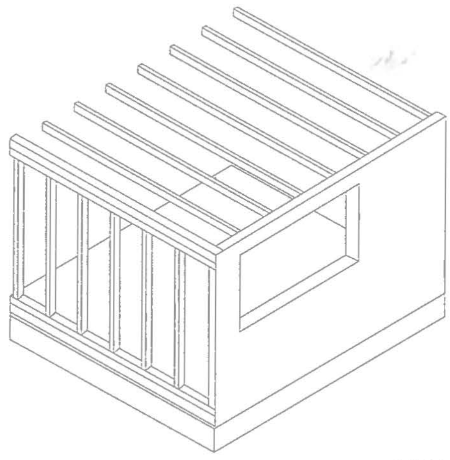


b C 3.22

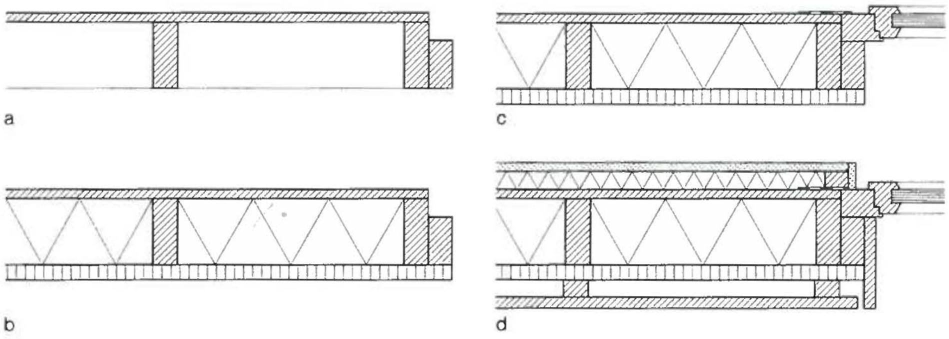
C 3.23



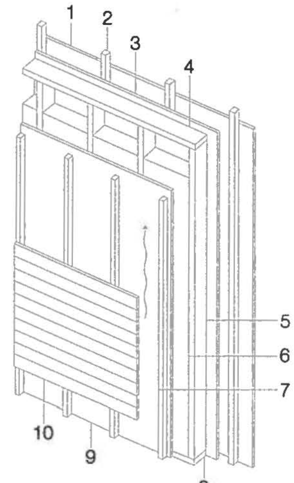
C 3.24

Timber framework construction
This technique is a further development of the traditional timber frame and lightweight stud construction techniques. The most important difference between these methods is the bracing principle. Traditional timber framed buildings are braced by struts or stays, while timber studwork structures are stabilised by being clad with processed timber construction panels. This modern system, however, combines these two techniques (fig. 3.24). Although timber frame elements act as non-load-bearing infill members in frame construction, they function as load-bearing walls in panel constructions.

In order to ensure the condition of the timber, the framework elements are manufactured in climatically controlled production plants. The first step is the cladding of the load-bearing substructure on at least one side with the panels of processed timber construction material and pre-assembly. Subsequently, openings are cut. The building unit is then insulated and clad on the second side (fig. C 3.25). The elements are available with varying levels of prefabrication depending on the required functions and standards of building physics. A high level of prefabrication is achieved when the panels are produced with complete facade treatment, internal wall cladding surfaces and installation ducts for technical services.
The load-bearing structure consists of frames of strut-like scantlings, which are clad with planar processed timber construction materials, thereby ensuring plate-like static performance. The vertical scantlings transfer the vertical loads from the roof and ceiling slabs, while the timber panels absorb the horizontal loads. The use of laminated spruce and fir timbers assists in the dimensional stability of the panels.
The cross-sectional dimensions of the scantlings are determined after calculations on the static situation have been made. Generally, the cross-sections are between 60 x 120 and 80 x 160 mm.
The fields between the timbers provide space for thermal insulation panels (fig. C 3.26). In order to prevent thermal bridging, the external walls can be additionally clad with conventional materials. This makes it possible for the building to achieve low-energy or even passive-building standards.
On site, the framework elements are placed with the help of hoisting equipment, anchored on the foundation or slab and, in this way, assembled storey-wise to produce a building.
The force-locked connections between the individual members are provided by steel elements which can be screwed to the wall panels (fig. C 3.23).
Although the maximum unit sizes are subject to transportation limitations, the dimensions of the rooms are determined by the allowable spans of the floor and ceiling slabs.
Processed timber construction panels, shingles and solid timber panels are often used as extra external facade cladding. The internal cladding also provides air and moisture sealing barriers.
When planning timber frame constructions, setting and shrinkage of the structure, which can be as much as 240 to 500 mm per storey, must be taken into account. [3].

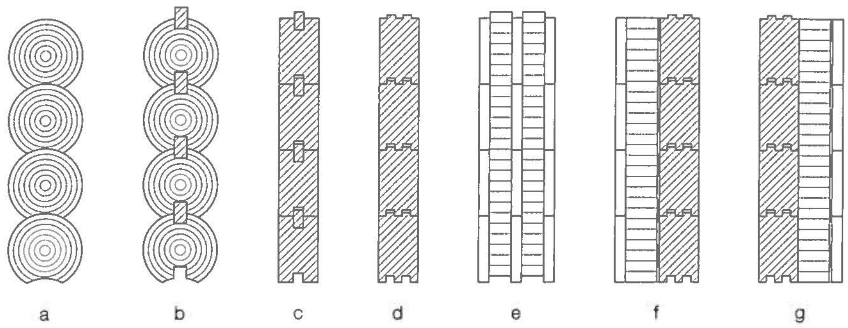


C 3.25



1 internal cladding
2 vertical battens
3 processed timber panel (impermeable)
4 frame top
5 side frame
6 insulation
7 battens
8 frame bottom
9 fibreboard, bituminised
10 horizontal boarding

C 3.26



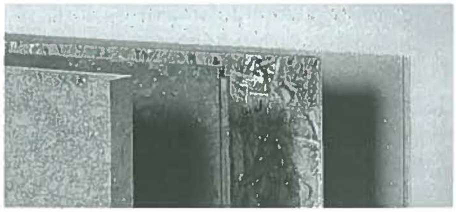
C 3.28

C 3.29

▸ AGEPAN building system
(Glunz AG)

The panel elements of the Agepan building system are frame constructions constructed of OSB panels and web beams. The system is not confined to a particular grid and the elements are specialised for each building project. The moisture-permeable roof elements are completed with cellulose insulation and the walls comply with the low-energy requirements for external walls (NEW-F30-B) (fig. C 3.27).

- application:
  walls, slabs, roofs
- usage:
  single and multi-family housing, industrial and administration buildings, schools and kindergartens, specialised facilities



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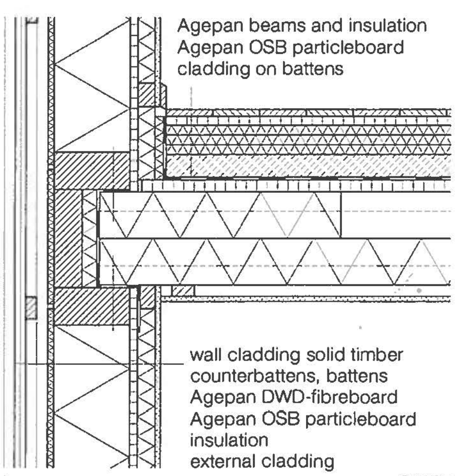
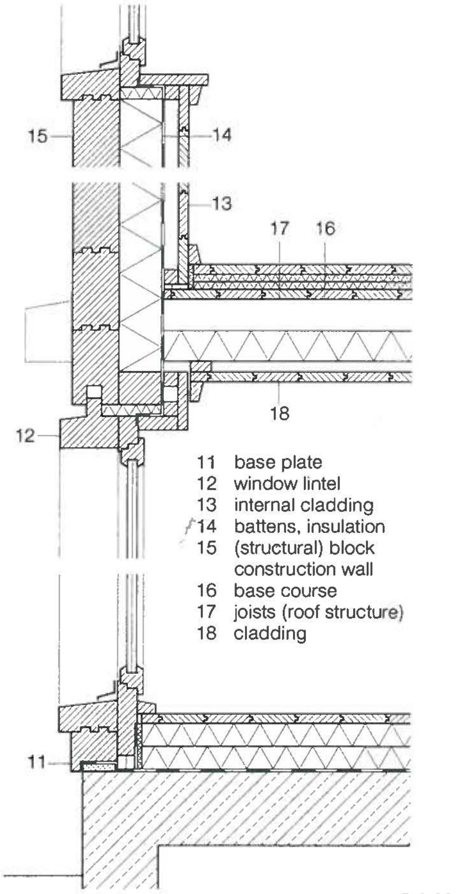


b

C 3.27

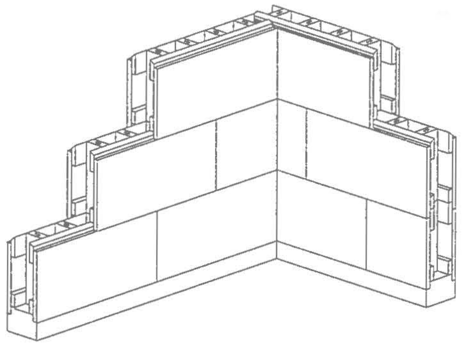
Timber block construction

Timber block construction has a long tradition and can be considered as being the forerunner of modern-day timber panel construction techniques using solid timber panels (figs. C 3.28 and C 3.29). The walls are constructed of horizontal beams that are fixed at the corners. Thus, the beams fulfil the functions of partitioning and load-bearing. Bracing occurs through the plate effect of the solid timber walls and the corner detailing which is based on cog junctions at the intersection of the wall panels and resistant to bending. It is important to take into account that the contraction of the solid timber elements can reach 25 mm per storey after assembly. However, the insulation level of traditional block construction no longer complies with modern requirements. In order to retain the traditional character of solid timber walling in spite of the additional insulation level, double-leaf walls are constructed, with insulation in the cavity. A variety of different systems have been developed with thermal insulation, installation cavities and cladding already provided (fig. C 3.30).



C 3.30

C 3.23 Shell, timber frame construction
C 3.24 Isometric diagram of timber frame structural system
C 3.25 Process of wall construction in timber frame construction
a single-sided cladding of a timber frame element
b double-sided cladding of a timber frame element with thermal insulation infill
c element, including built-in units; (windows and doors)
d element, including external and internal cladding
C 3.26 Isometric diagram of the layers of a timber frame wall
C 3.27 Agepan building system
a Agepan beam
b vertical section, wall-slab connection
C 3.28 Development of the external wall from traditional to modern block construction
a round timbers
b notched round timbers
c notched scantlings
d tongue-and grooved scantlings
e prefabricated sandwich elements
f block-construction wall with external insulation
g block-construction wall with internal insulation
C 3.29 Application of modern block construction in Switzerland, house, Blatten, Wallis (CH) 2001, Gion A. Caminada, Vrin Cons
C 3.30 Section through a house facade built in modern block technique



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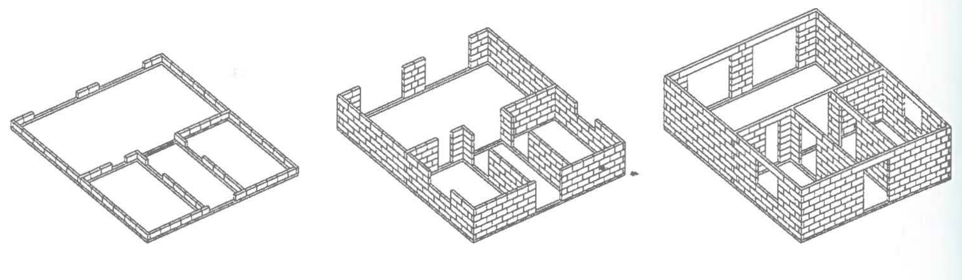


b

C 3.31

Building with timber modules
Industrially fabricated timber modules based on the cross-wise lamination of solid timber slats is a new development in solid timber construction (fig. C 3.32a). Similar to masonry blocks, these practical modules can be assembled to form load-bearing walls in a specialised, interlinked course (fig. C 3.31a). The structural system appears planar and can absorb both vertical and horizontal loads. Continuous hollow cavities through the elements provide access for the installation of technical services or insulation. The small size of these construction elements makes a great variety of different building forms possible.

The coordination of the modules and special building units, such as window sills and lintels, enables the creation of a closed building system combining the constructional advantages of masonry work with the positive characteristics of the natural building material, wood [4].

▸ Steko timber module connector system (Steko Holz-Bausysteme AG)

These modules are small box elements; the interlinked courses allow the assembly of walls (fig. C 3.31b). The modules are available in the standard width of 160 mm with lengths of 160, 320, 480 and 640 mm, and heights of 240 and 320 mm. The system is modular, creating great scope for design freedom in conjunction with simple assembly techniques. The timber module is constructed of cross-wise laminated solid timber panels and thus offers great stability and durability (fig. C 3.32b).

- application:
  walls
- usage:
  single and multi-family housing, industrial and administration buildings, schools and kindergartens, infill elements for frame constructions

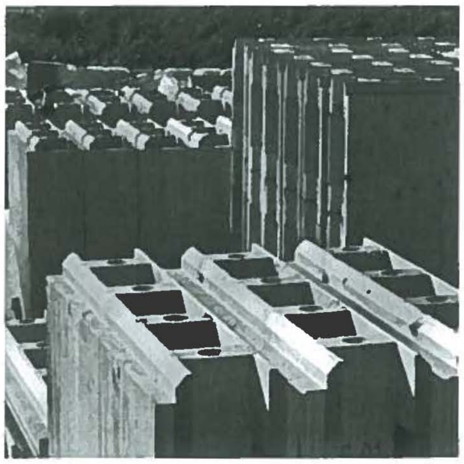
Construction materials and elements
In timber panel construction, simple panels can be regarded as elements and, if they are sufficiently thick, can then be considered to behave as solid panels.

Wood fibreboard
Wood fibreboard panels are produced by compacting and pressing fibrous timber particles. Their homogeneous panel structure allows spanning in both axes. In unitised construction, wood fibreboard panels are used for cladding and bracing timber framed elements.

Particleboard
Particleboard panels are produced of sawdust mixed with an adhesive agent and pressed flat. In unitised construction, they are most widely used as load-bearing and bracing elements for cladding walls, ceilings and roofs.

OSB panels
OSB panels (Oriented Strand Board) are produced of large chips of wood, glued under heat and pressure with their strands at 90° to each other. Due to the alternation of the strand directions, these boards can be loaded in both the longitudinal and transverse direction. Typical areas of application are the cladding of load-bearing and bracing walls in timber frame construction.

Cement-bonded particleboard
The standard dimensions of cement-bonded particleboard (produced with timber fibres, Portland cement and water) are 3100 × 1250 mm. The panel thicknesses vary between 12 and 18 mm. They are particularly suitable as facade elements due to the specific material characteristics of frost resistance, mois-



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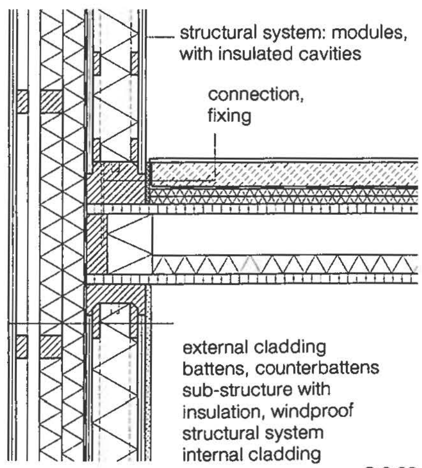
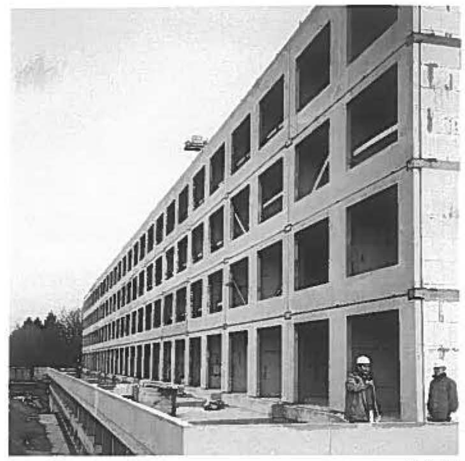


b

C 3.32

C 3.31 Steko timber module connector system
a Corner connection
b Construction process
C 3.32 Steko timber module
a Front view of module
b Vertical section; wall-slab connection
C 3.34 Heavy-gauge laminated timber panel
C 3.35 Stacked-plank timber element
C 3.36 Shell of a multi-storey housing block in large-panel construction



C 3.35

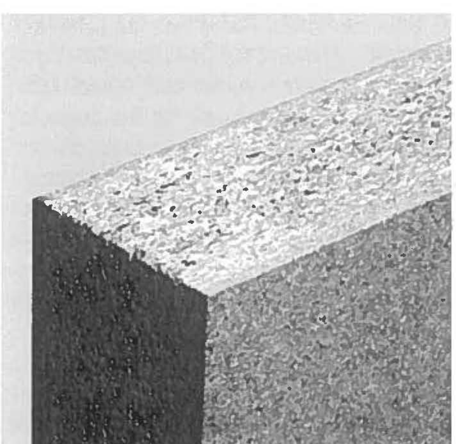
ture resistance and minimal moisture expansion.

Glue-laminated timber panels (glulam)
Glue-laminated timber panels are manufactured of three or five glued timber layers orientated according to alternating direction of fibre to produce a building material suitable for the planar transfer of loads. They absorb loads in both vertical and horizontal directions and are dimensionally very stable. Glue-laminated timber panels are used for load-bearing timber construction and bracing cladding for walls, slabs and roofs in unitised constructions.

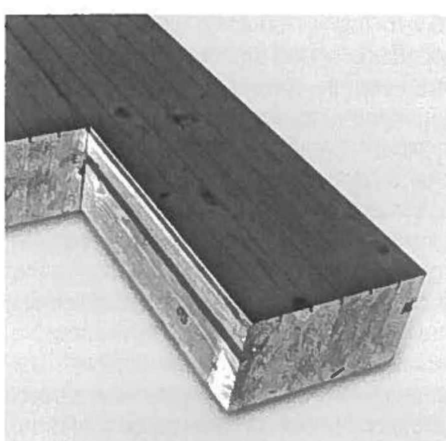
Laminated veneer timber panels
Laminated veneer timber panels are constructed of multiple layers of timber veneer which, in contrast to glue-laminated timber panels, are laminated parallel to the direction of the fibres. The veneers are pressed with a water-proof binding agent with the edges off-set. Laminated veneer timber panels can be considered as acting like glulam panels.

Heavy gauge laminated timber elements
Laminated timber elements of pressed timber shavings or multiple layers of laminated timber construction panels can also be produced with thicknesses of 60 to 100 mm. Wall elements constructed of these industrially manufactured heavy gauge panels can act as load-bearing elements. The panels can be produced in any desired dimension and standard elements such as door and windows can easily be inserted in the factory (fig. C 3.33).

Stacked-plank panels
Stacked-plank panels are solid timber elements with a high load-bearing capacity. They are constructed of planks or boards that are stacked parallel to each other and connected with special nails or hardwood dowels. Stacked-plank panels usually have a thickness of 80 to 240 mm and their maximum length is 12 m. Openings for doors, windows and other slab penetrations can be allowed for during production [5] (fig. C 3.34).



C 3.33



C 3.34

Building with concrete panels

Concrete panel building methods
The most frequently used form of panel construction system is prefabricated reinforced concrete panels (fig. C 3.35). Although multi-storey housing construction makes use of crosswall, small and large panel construction techniques, crosswall construction is the most commonly employed method (fig. C 3.36a, p. 120). The load-bearing walls, which are set transverse to the building length (crosswalls), can act simultaneously as partitioning elements between two dwelling units. A flexible planning layout is possible between the crosswalls. These load-bearing elements are dense enough to also fulfil sound insulation and fire protection requirements. An economical load-bearing system is accomplished when the floor and ceiling slabs are set directly onto the crosswalls as continuous elements.

Small panel construction methods are commonly used techniques for low-rise housing. The small sizes of the building units allow a great variety of design and combination alternatives. Due to their minimal weight, aerated concrete panels are particularly suitable here as they only require small-scale hoisting equipment on site.

In large panel construction, the elements for walls and floors are reinforced concrete slabs, which are prefabricated as either normal or lightweight concrete according to the specific requirements. Wall panels can be prefabricated in the factory room-high and up to 6 m long, with windows, doors and service ducts already installed. The assembly on site is carried out storey by storey. Dimensional

C 3.36 Structural system of large-panel construction
a Crosswall construction with load-bearing transverse walls and continuous slab
b Large-panel construction with load-bearing longitudinal walls and non-load-bearing transverse walls
c Large-panel construction with load-bearing longitudinal and transverse walls

C 3.37 Reinforced concrete sandwich element

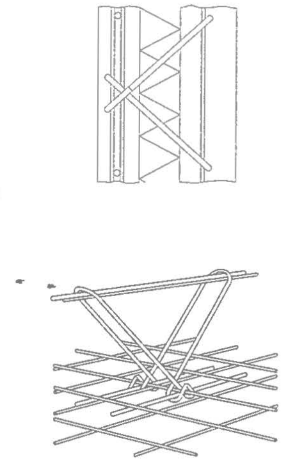
C 3.38 Fixing anchor for the connection of layers of a sandwich element
a Fixing anchor
b Connection of anchor with reinforcement

C 3.39 Joint treatment with tongue-and-groove

C 3.40 Joint treatment of sandwich panels
a Sealing strip with chamfered bond
b Sealing with sealing compound
c Tie-shaped sealing strip with edge bonding
d Horizontal and vertical joints

C 3.41 Filling of cavity with in situ concrete

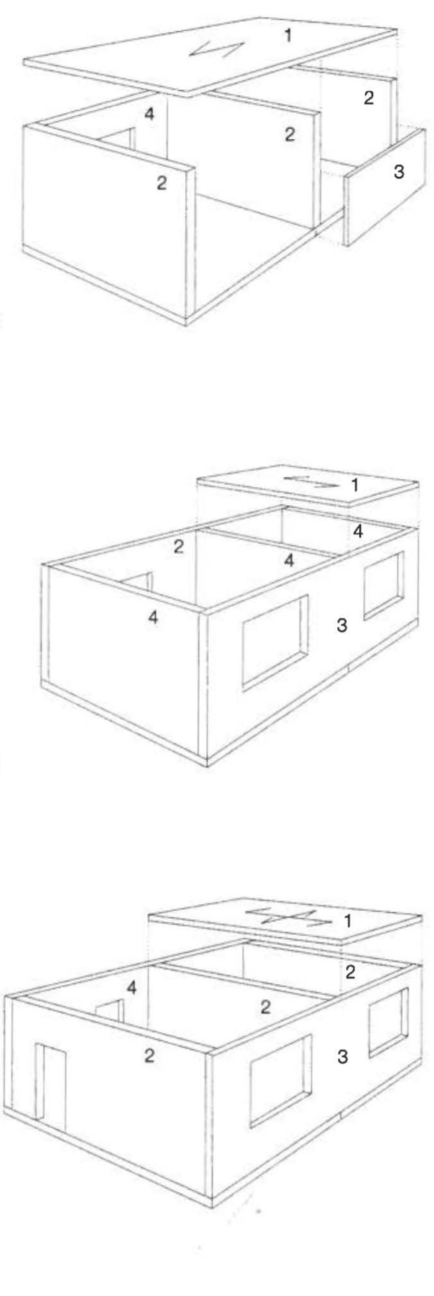
C 3.37



a

b

C 3.38



a
b
c

1 slab
2 transverse wall
3 facade element
4 longitudinal wall

C 3.36

tolerances are fixed in the German DIN 18 203-1 building standard.
This type of construction technique was decisive for building the mass housing that was necessary after the Second World War. The characteristic appearance of these buildings results from the fact that the internal layout is recognizable from the visible arrangement of the joints on the facades. The subsequent departure from multi-storey housing developments, and the desire for more individualised architectural design solutions, caused large concrete panel construction to be confined to projects where speedy assembly is required and where heavy-duty hoisting equipment can be economically employed (figs. C 3.36b–c).

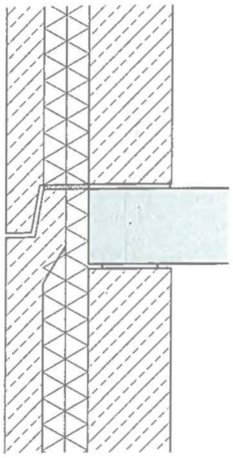
Construction elements

Reinforced concrete wall elements

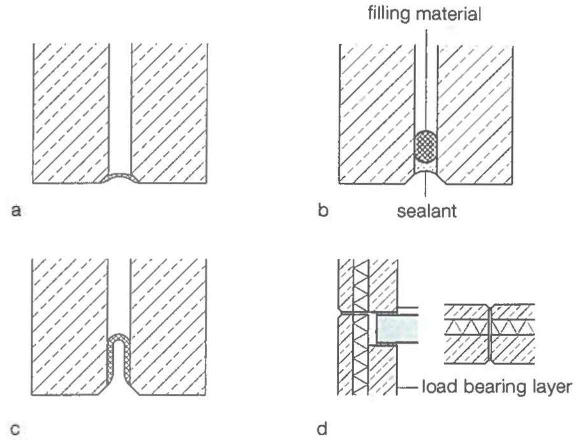
Reinforced concrete wall elements are the characteristic features of both large panel and crosswall construction methods; they can be used as either load-bearing or non-load-bearing building elements. The thickness of the load-bearing walls is determined by static calculations and the minimum allowable depth of the floor slab which is between 14 and 20 cm. This is also sufficient to fulfil the necessary sound and fire protection requirements. Non-load-bearing walls are employed as bracing and partition elements.
After setting and adjusting the reinforced concrete wall elements on site, the butt joints are filled with special mortar to ensure a rigid connection.
In contemporary building applications, shell constructions are usually erected with reinforced concrete panel techniques, while individual systems are used for interior fit-out construction and external building envelopes.

Sandwich elements

Sandwich panels are manufactured in plants for use as external walling. They consist of three layers – load-bearing, insulating and facing (fig. C 3.27). High-strength concrete is poured into steel formwork and can harden under optimal conditions, independent of weather. A better surface finish and narrower elements are possible with factory-controlled prefabrication than with in situ production methods. The individual elements are horizontally produced in a number of stages and finally assembled to create the final panel. During production the surface treatment and structure of the external facade is determined; usually by the base of the formwork. The upper surface of the slabs are planed, either manually or mechanically, or later rendered or clad on site. The same applies when exposed concrete is desired for the internal surface. The fixing anchors, which are poured with the slabs, can absorb loads from all directions and are responsible for the connection of the individual layers of the sandwich panels (fig. C 3.38).
The load-bearing layer of the sandwich panels, which supports the floor slab, transfers all vertical and horizontal loads to the foundation. Therefore, it must be statically correct and reinforced; the thickness of this layer is usually between 80 and 150 mm. The thermal insulation between the concrete layers consists of flame retardant, closed-pore rigid foam. The thickness of the insulation is dependent upon thermal protection requirements. The facing concrete layer provides protection from the weather and determines the design of the facade. Due to the required steel reinforcement, this layer is at least 70 mm thick.
Should increased levels of moisture make a ventilation layer necessary, this must



C 3.39



C 3.40

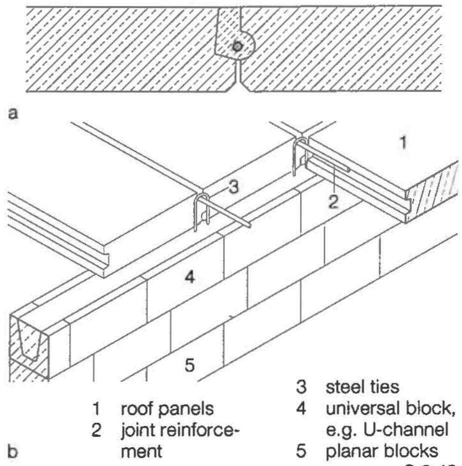
C 3.41

measure at least 40 mm and be coordinated into the sandwich panel between the insulation and facing layers. Additionally, during assembly, protective plastic stippled membranes or removable polystyrene blocks are set between the layers.
The dimensions of the sandwich panels are determined by production, transport and assembly possibilities. The standard lengths are between 4 and 10 m. Larger panels are usually considered more economical due to the reduced assembly time on site. The maximum size of the facing concrete layers is usually restricted to 15 m² which is smaller than the dimensional restrictions of the load-bearing layer. This is so because the external facing layer is exposed to the elements and temperature-dependent expansion can occur. The small-scale joint arrangement of the facade must be taken into account by the designers during planning.
The corners are usually formed using special moulds [6].

Joint treatment
It is of great importance that a suitable detailing of joints be developed during the design of sandwich panels in order to prevent the penetration of water, among other things, into the joints. Structural solutions are, for example, tongue-and groove joints, where the horizontal connections are rebated (fig. C 3.39).
Another possibility is to ensure that the vertical joints are off-set from one another at the joint intersections.
Waterproofing by way of sealant materials is usually carried out using pre-compacted sealing strips or sealing masses. These materials must be capable of fulfilling the requirements of permanent elasticity and weatherproofing over long periods of time. They must not become brittle, in order to avoid the development of cracks. During planning, building joint tolerances must be calculated exactly to prevent overstraining of sealant materials [7] (fig. C 3.40).

Double wall elements
An economical and precise system for the production of load-bearing concrete walls is the semi-prefabrication of double wall elements with in situ concrete completion. Thin concrete walls are fitted together with intermediate steel gratings; all necessary reinforcement is already installed between the walls. These double walls are delivered to the site where they are poured with filling concrete to produce a stable, single-layered wall construction element. (fig. C 3.41).
The external surfaces of the reinforced concrete shells have exposed concrete quality and do not require any further processing after assembly. Openings for windows and doors, as well as installation ducts, can all be incorporated during prefabrication in the factory. Walls are prefabricated with heights and widths of up to 12 m which enables the minimisation of constructional butt joints. Cranes are used to set the double walls onto the prepared reinforcement bars of the floor slabs on site.
The building elements, which are constructed with a double wall system, can transfer loads both vertically and horizontally. Their positive properties, such as sound protection and moisture resistance, enable the application of these elements in housing construction for external, internal and even basement walling. Depending on the requirements, double walls can be constructed to resist fire and thus be used as protection walls [8].

Porous concrete elements
Porous, or aerated, concrete elements belong to the class of lightweight concrete that provide great stability with minimal weight. Porous concrete units are used as wall, slab and roof elements. As load-bearing members, they are produced in heights of up to 350 cm, widths of up to 150 cm and thicknesses of up to 37.5 cm. Slabs and roof panels of porous concrete have maximum dimensions of 800 cm in length and 75 cm in width. If they are to be subjected to bending loads, load-bearing, porous concrete elements are stabilised with additional corrosion-protected reinforcing steel.
Due to their material properties, porous concrete elements have the advantage that, even as single-layer panels, they fulfil the requirements for thermal and sound insulation and fire protection. It is possible to design entire construction systems based on porous concrete wall, slab and roof elements for buildings up to three storeys high. These wall elements are also capable of absorbing soil pressure and, as such, are suitable for use as basement walls. Porous concrete panels can also be prefabricated with ducting for technical installations and openings for windows as desired.
Porous concrete wall panels are set onto foundations or strip footings in a mortar bed (fig. C 3.43, p. 122). The panels can be butted against each other, connected by tongue-and-groove joints or by open hollow joints. When open joints are selected, the hollow cavities require filling with concrete after the panels have been erected. Butt joints and tongue-and-groove joints must also be fixed – however with thin mortar.
The strip-like slab elements are laid on top of the wall panels during assembly. The connections between the slabs and



1 roof panels
2 joint reinforcement
3 steel ties
4 universal block, e.g. U-channel
5 planar blocks

C 3.42

C 3.43

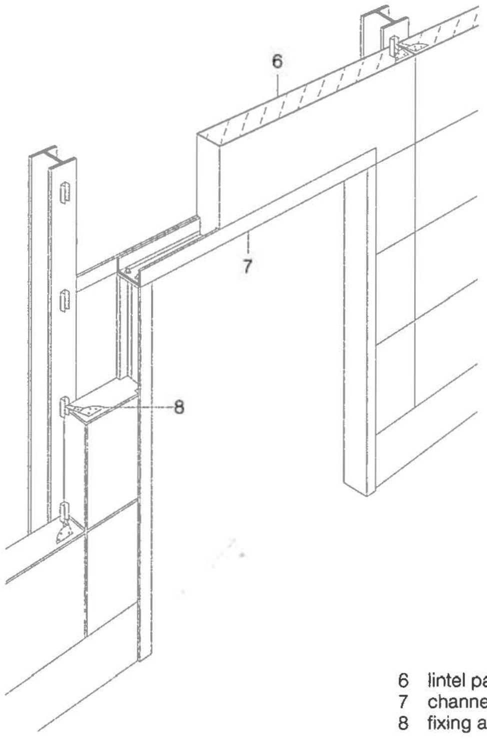
C 3.44

roof elements comply with the principles of wall panel connections. By connecting the slab panels with joint mortar, the slab as a whole behaves as a panel (fig. C 3.42). Due to the minimal weight of porous concrete panel elements, lightweight hoisting equipment is sufficient for assembly on site.

Porous concrete facade elements
Porous concrete elements can be employed both horizontally and vertically as facade elements or as infill panels for frame structures (fig. C 3.44). In addition to the bracing functions which these panels provide, they also perform functions relevant to building physics. Horizontally arranged elements are fixed to the load-bearing substructure by way of splices inserted into the horizontal joint of the concrete wall and fixed with angles or sleeves (fig. C 3.45). Vertical wall panels are fixed by way of reinforcement rods set into the hollow sections of the vertical joints. The reinforcement rods are connected to the substructure with anchoring sleeves. The joints are subsequently filled to ensure force-locked, rigid connections [9] (fig. C 3.46).

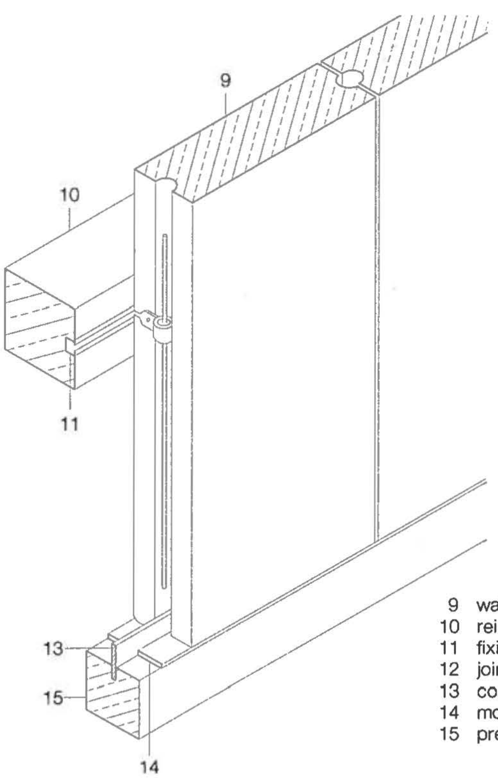
Ceiling and floor slabs
Prefabricated concrete slab elements are produced as solid, hollow or web panels. They offer planar structures of reinforced concrete or pre-stressed concrete which act as the partitioning elements for frame or panel constructions. These elements are predominantly responsible for the absorption of bending moments, and transfer both vertical and horizontal loads – such as wind loads – to the load-bearing structure. The slabs are required to fulfil the requirements of structural stability, thermal and sound insulation and fire protection.

Solid slabs
Solid slabs can rest on wall edges in a linear manner or be point-loaded on columns. They are seldom applied for spans exceeding 6 m as the necessary thick-



6 lintel panel
7 channel section
8 fixing angle

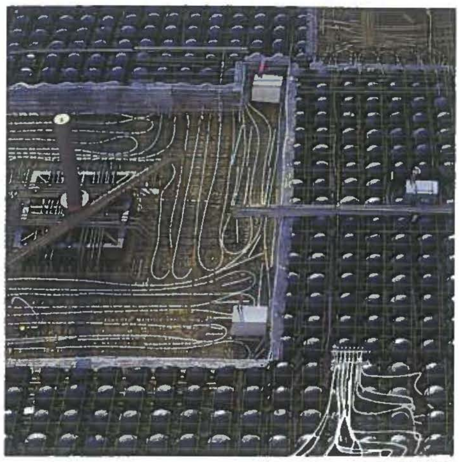
C 3.45



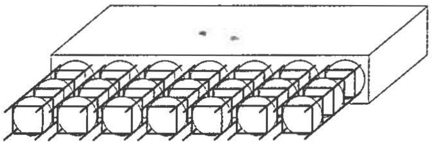
9 wall panel
10 rein. conc. const.
11 fixing rail
12 joint reinforcement
13 continuous rail
14 moisture barrier
15 precast base

C 3.46

C 3.47



C 3.48



C 3.49

ness of the slab for larger spans would become prohibitively heavy. In practice, solid slabs are used in conjunction with large-panel and crosswall building methods. Individual slab elements are connected on site with mortar fixed butt junctions, whereby rigid connections are achieved.

Unitised slabs
Another widely used slab system is the unitised slab of partially prefabricated slab panels with in situ concrete completion. The elements are manufactured in widths of up to 3 m and consist of a prefabricated slab measuring approximately 5 cm with exposed steel reinforcing anchors. These reinforcements act as the connecting elements between the prefabricated elements and the in situ concrete. Longitudinal and cross-reinforcement is laid on the anchors, whereby biaxial directions of span are achieved (fig. C 3.47).
Joint-free in situ concrete completion enables the unitised slab to behave as a continuous slab [10].

Hollow slabs
Elements constructed of hollow reinforced concrete panels are highly economical for large spans because they make it possible to economize on concrete. Weight reductions of up to 50 % are possible using hollow slabs compared with solid slabs of the same dimensions. Depending upon the production techniques, the cavities are oval, round or rectangular. Displacement forms are inserted in the direction of span of the hollow slabs during production, although here only a single direction of span is possible. The panels have standard dimensions of 60 cm which enable flexible coordination with a large variety of different layouts.

With panels measuring 15 to 40 cm in depth, it is possible to span distances of 6 to16 m. In order to achieve the static action of a diaphragm, it is necessary that the joints be filled with mortar. The mechanical production of these elements in steel formwork ensures high-quality, exposed concrete surfaces.

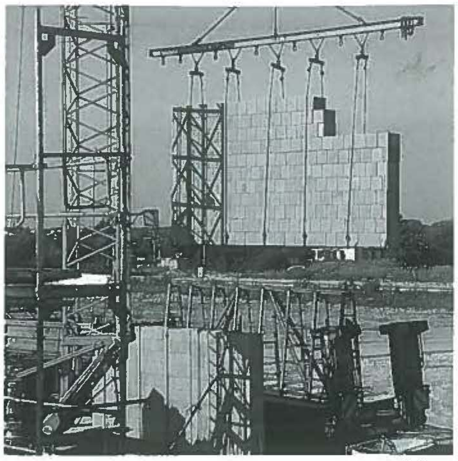
In order to manufacture hollow slabs with biaxial span directions, plastic spheres are used as displacement forms (fig. C 3.48). They ensure that the concrete is repelled from the areas where it would have the least static influence. Slabs with thicknesses of 23 to 60 cm may include spheres with diameters of 18 to 36 cm. These spherical cavities reduce the self-weight of the slabs by up to 35 % (fig. C 3.49). These systems are available as semi, or fully, fabricated elements. In the semi-fabricated modules, the plastic spheres are fixed to the, statically necessary, reinforcement grids. After assembly on site, the hollow-core slabs are finished with in situ concrete thereby forming a single shell hollow slab.

Web panel slabs
For much greater spans and larger loads TT-panels can be employed; for example, in industrial situations. They are particularly suitable for the installation of services between the webs which are usually spaced at 120 cm. The maximum dimensions measure 250 cm in width, 80 cm height and 160 cm in length. Spans of up to 20 m can be achieved with prestressed elements, but the maximum height of the slab is then extended to 95 cm. TT-panels can also be produced as semi-prefabricated elements and finished with in situ concrete [11].

Special elements
With regard to concrete panel construction methods stairs, lift wells and balcony balustrades are considered to be special elements. Stairs act as linear elements within a structural system, while lift wells are prefabricated room elements and can be used to provide bracing. Balcony balustrades, as non-load-bearing building units, are also prefabricated in factories and can have a huge variety of forms. These components are also used as special prefabricated elements in in situ buildings where they receive supplementary treatment.

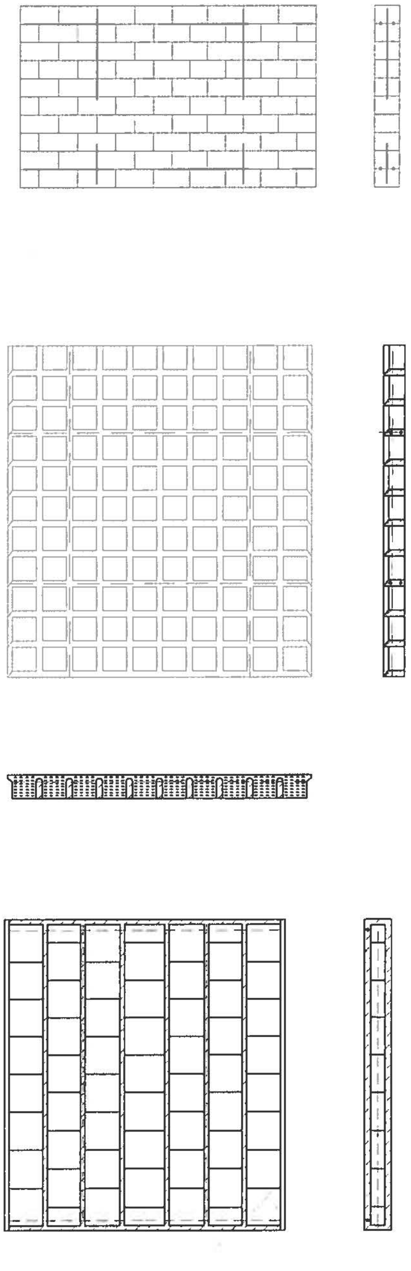
C 3.42 Porous concrete slabs
a Connection of butt-joint between two porous concrete slab elements
b Location and connection of porous concrete slab onto load-bearing walls
C 3.43 Assembly of a large porous concrete panel
C 3.44 Plastic facade treatment with porous concrete elements, warehouse and sales building in Eichstätt (D) 1995, Hild & Kaltwasser
C 3.45 Assembly of horizontally fixed porous concrete elements
C 3.46 Assembly of vertically fixed porous concrete elements
C 3.47 Assembly of unitised slabs
C 3.48 Hollow slabs with plastic, spherical displacement forms prior to in situ concrete finishing
C 3.49 Schematic diagram of hollow slabs

C 3.50



C 3.51

C 3.52



a

b

c

C 3.53

Building with masonry panels and brickwork elements

Prefabricated masonry building elements

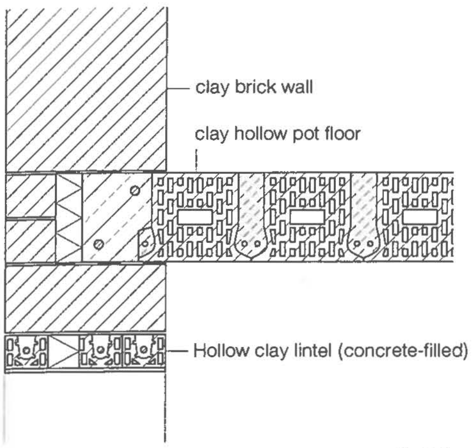
The industrialised manufacture of prefabricated building units is the natural further development of traditional elements, manually produced on site. The brick manufacturing companies, in particular, have been responsible for the advancement of industrially prefabricated masonry panels in the last few years. This construction technique combines the advantages of traditional building materials with the possibilities of industrial fabrication and permits cost-and time-intensive on-site building procedures to be rationalised.
Prefabricated masonry building elements are high-quality wall, floor and roof elements of various thicknesses that have been produced out of clay bricks, pumice or calcium silicate bricks in factories. It is possible for the panels to be manufactured ready for the installation of services.
Prefabricated masonry elements are essentially suitable for all areas of residential, commercial and industrial building and offer great architectural design freedoms.
During the fabrication of masonry panels, looped reinforcing bars are inserted into the bed joints for later assembly; these overlap at the joints between adjacent building units. Storey-high vertical reinforcing bars are inserted into these loops and the panels are subsequently fixed with mortar to provide compression and tension-resistant connections (fig. C 3.50).
The assembly of heavy, storey-high masonry panels can only be carried out with the help of heavy-duty lifting equipment (fig. C 3.51). External walls must fulfil all the requirements of thermal and insulation, also moisture control.
Masonry panels are manufactured as hand-laid, cast, or composite panels.

Hand-laid masonry panels

Today, it is possible to produce masonry panels in almost any desired form using the latest production technology. The dimensions and tolerances of prefabricated masonry panels are comparable with those of precast concrete panels. The dimensional accuracy of prefabricated masonry panels is so high that only a thin coat of plaster must be applied with a trowel to finish the interior.
The production of hand-laid panels is completed under factory conditions; the bricks or blocks are laid in the traditional manner with mortar joints to form storey-high panels. Standard clay, calcium silicate or concrete blocks are all suitable for this process. Masonry robots or automatic machinery assist in the production of the vertical panels in manufacturing plants. The standard dimensions of these panels are 6.5 to 7 m in length and 2.65 m in height, although alternative dimensions are possible under factory-controlled conditions. According to the DIN 1053-4, the masonry panels should include vertical ducts for inserting and fixing transport anchors. Prefabricated masonry elements weighing up to 5 t can be positioned with mobile cranes without any problems. The structural and building physics properties of masonry elements are specified in the DIN 105.

Cast masonry panels

In contrast to hand-laid masonry panels, cast panels are produced horizontally in moulds. Perforated or hollow bricks are laid in prepared beds and bonded by special grouting concrete. Due to the higher proportion of concrete used in this technique, an additional layer of insulation should be applied to external wall panels in order to achieve the necessary



C 3.54

C 3.50 Positioning a prefabricated masonry panel on a bed of mortar
C 3.51 Erection of prefabricated masonry panels
C 3.52 Erecting a clay hollow pot floor
C 3.53 Drawings of a hand-laid panel, a cast masonry panel and a composite masonry panel, (elevation, horizontal and vertical sections)
a hand-laid masonry panel
b cast masonry panel
c composite masonry panel
C 3.54 Junction between clay hollow pot floor and loadbearing wall
C 3.55 Isometric view of a clay hollow pot floor on concrete-filled hollow clay beams
C 3.56 Junction between floor shown in C 3.55 and internal wall (floor finishes also shown)

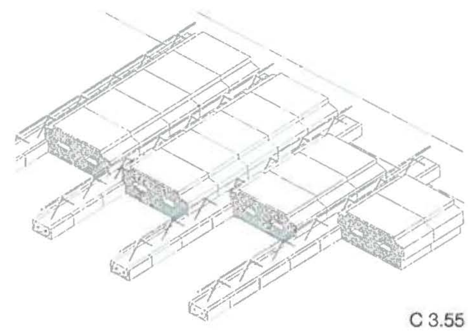
U-value. Individual elements are room-high and up to 10 m long. A high level of prefabrication can be achieved when windows, door frames and service ducts are installed in the production plant.

Composite masonry panels
Composite panels are a special form of cast masonry panels. They are essentially precast reinforced concrete elements that include specially formed perforated bricks 25 to 50 cm long. During production, the bricks are laid in a freshly poured concrete backing 35 mm thick. The spacing between the bricks must be at least 30 mm. Subsequent to the laying of the bricks, another layer of concrete is poured in order to fill the joints between the bricks and cover them with at least 35 mm of concrete. All the work is carried out under factory conditions [12] (fig. C 3.53).

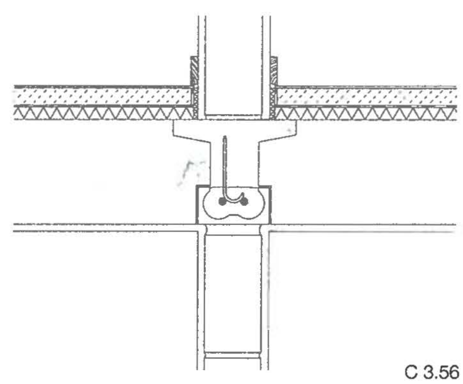
Hollow clay brick elements
Room-high elements
The standard height of hollow clay brick wall panels is 250 to 280 cm with widths ranging from 30 to 60 cm. Such panels can also be used for roofs. Room-high elements are individual units that can be combined as required with special corner, lintel and spandrel units within a system. The basic unit is a perforated brick, which functions as a loadbearing element – fabricated either with or without core insulation – and forms the external surface of the panel without further treatment. Reinforcing bars are integrated into the panels in the factory, or can be inserted into the cavities on site and subsequently fixed with in situ concrete. These reinforcing bars are anchored to the foundations or other building elements with further reinforcing bars.

Clay hollow pot floor elements I
Clay hollow pot floor elements (the pots are also known as hollow blocks or tiles) are industrially prefabricated panel elements (fig. C 3.52). They are manufactured from specially formed hollow clay elements laid next to each other. The joints between the elements are reinforced with steel bars and subsequently filled with grout. When the individual panels are connected together, the suspended floor act is structurally like a plate; the discrete hollow clay elements contribute to this action. With individual element sizes of 1.0 to 2.5 m, distances of up to 6 m can be spanned without support from intermediate walls or columns. The clay hollow pot floor offers a formwork-free and efficient construction technique which requires no additional concrete topping. The finished slabs can be subjected to loads immediately after construction (fig. C 3.54).

Clay hollow pot floor elements II
In this variant of the clay hollow pot floor, the hollow clay elements are supported on concrete-filled hollow clay beams (fig. C 3.55). On site, the beams are laid on load-bearing walls at a spacing equal to the width of the hollow clay elements. Special lifting equipment is used to lay the hollow clay elements between the beams, and the joints between the elements, above the beams, are subsequently filled with mortar. Depending upon the loads to be carried, the structure can be strengthened with in situ concrete and reinforcement. This form of suspended floor requires no formwork and can be quickly assembled [13] (fig. C 3.56).



C 3.55



C 3.56

Notes:
[1] Stahl-Informations-Zentrum: Dokumentation 558. Bausysteme aus Stahl für Dach und Fassade. Düsseldorf 2000, p. 25ff.
[2] Kolb, Josef: Holzbau mit System. Basle 2007, pp. 112–115.
[3] ibid. [2], pp. 62–67.
[4] ibid. [2], pp. 1134–1135.
[5] Hugues, Theodor et al.: Detail Practice. Timber Construction. Munich 2002, p. 37ff.
[6] Döring, Wolfgang et al.: Fassaden. Architektur und Konstruktion mit Betonfertigteilen. Cologne/Bonn 2000, p. 56ff.
[7] ibid. [5], pp. 62–63
[8] Syspro-Gruppe Betonbauteile e.V. (ed.): Die Technik zu Decke und Wand. Wie wird's gemacht?, p. 21ff.
[9] Weber, Helmut et al.: Porenbeton Handbuch. Planen und Bauen mit System, (5th ed.), Gütersloh 2002, p. 25ff.
[10] Fachvereinigung Deutscher Betonfertigteilbau e.V. (FDB). Wissensdatenbank. Elementdecken www.fdb-wissensdatenbank.de
[11] ibid. [9], Vertikale Lastabtragung. TT-Platten
[12] Pfeifer, Günter et al.: Masonry Construction Manual. Munich/Basle 2001, p. 119ff.
[13] Arbeitsgemeinschaft Ziegeldecke: Extract from the brochure "Planen und Bauen mit Ziegeldecken", chapters 1.3–4.4.2.