4 | Detailing and Tolerances

Detailing is an integral part of the design process. The design process generates ideas for detailing solutions and ways of putting them into practice. Every detail is a key part of the design, and detailing problems reveal problems in design development. This may be illustrated with reference to the protection of traditional timber buildings. Projecting eaves play a key role in protecting timber structures in the façade from the elements, but also help to determine the character of these buildings (1). If they are omitted with the aim of achieving a clean modern profile, other effective means of protecting the timber elements of the building must be found. If this is not done, the building will weather rapidly.

1

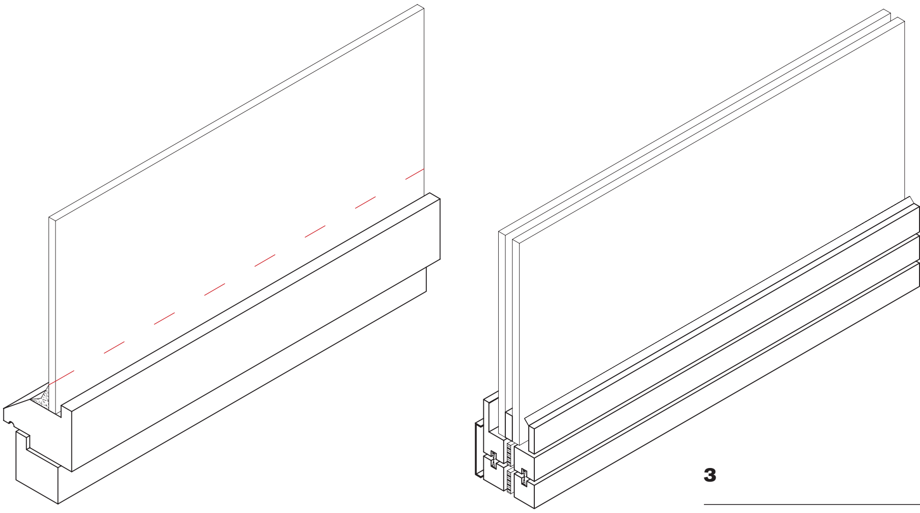
Traditional method of timber protection
Timber buildings will only last if consistent attention is paid to proper detailing of the structure. This example of a Swiss chalet clearly illustrates the role of projecting eaves in protecting the façade.

It goes without saying that attention must be paid to details in order to achieve good design aesthetics, but proper detailing is also essential in the interests of structural integrity. It is impossible to construct a building that is attractive and stands up to wear and tear in the long run if detailing is neglected.

Apart from aesthetic design requirements, the detailing of modern buildings is made more difficult by the increasing complexity of the construction. For example, if details on the façade were used traditionally to keep rain out and to keep heat in (2, 4, 6), the same details nowadays are responsible for the functions of windproofing, protection against wind-driven rain, keeping the building cool in the summer and warm in the winter and preventing vapour diffusion (3). This increase in complexity reflects the separation of different functions in different layers of the façade and the use of proprietary systems for individual functions – e.g. multiple glazing systems, sealant systems and mullion systems (5). Detailing is thus reduced to systematic combination of the appropriate discrete components to perform the required functions against a backdrop of growing overall building complexity. While discrete elements may be changed in this process, the components used generally remain constant.

2

Window with timber frame and shutters
This picture shows single glazing and shutters in a half-timbered house. The shutters not only keep rain off the window but also provide a climatic buffer, allowing the house to retain more heat during cold nights.



3

Traditional and modern window design

While traditional window design was limited to solving the problems of keeping rain out and heat in, modern window constructions have to meet more stringent requirements on protection against wind-driven rain and the effects of heating, thermal insulation, windproofing and prevention of vapour diffusion.

4

Traditional timber window

Ground-floor timber window. The timber sash of the casement shown in this picture closes against the metal window frame by means of an offset. A drip guard at the bottom of the frame protects against wind-driven rain. Plastic profiles for windproofing do not yet exist.

5

Modern timber window frame

Unlike traditional timber windows, modern timber windows are windproofed at the base by means of a number of folded seams and a silicone seal. In this example, a drip guard is again used to protect the sash against wind-driven rain. Water that does find its way into the frame can be led off via the drainage channel and an external aluminium weather strip.

6

Traditional sash window frame

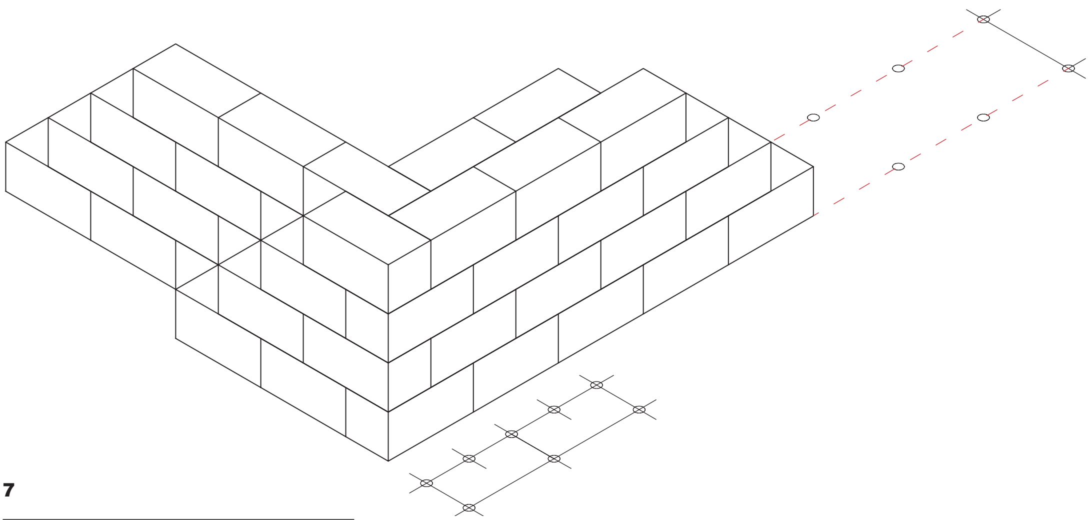
Example of a traditional sash window. It is relatively easy to keep water out at the bottom: since the sash slides at the front of the frame, bevelling the sash at the bottom will suffice to exclude water. Sealing off the sides is more difficult.

Building grid and positioning of components

The position of the façade with reference to the rest of the building can be determined with the aid of a building-related grid. Buildings consist of surfaces, which are formed by combining individual elements or components. If apertures are created in these surfaces, these define a transition between one component and another. In order to organise the combination of these components and the joints between them, grids are generally imagined to be superimposed on the building to allow recurrent situations to be solved in a uniform manner. Such grids may also be applied to the component parts of the building – e.g. the masonry, in view of the constant dimensions of the constituent bricks (7).

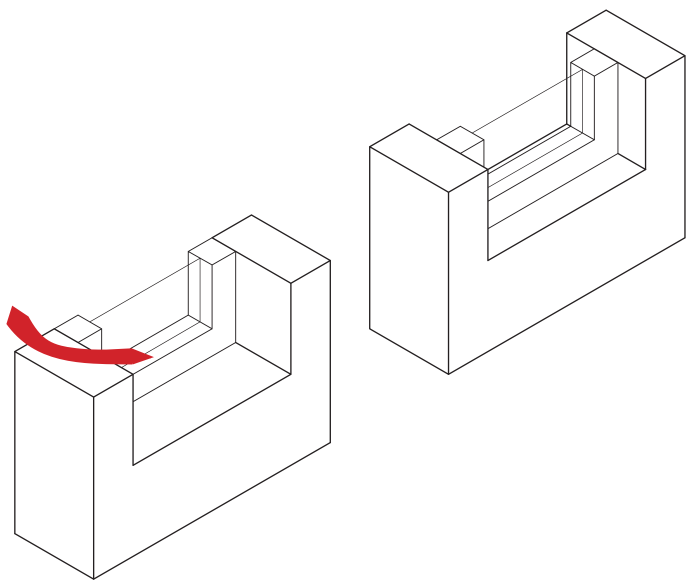
The precise position of a component in a building can have important consequences. For example, an aperture can be closed with the aid of a recessed window. In this arrangement, the window is protected by the building, while from a visual point of view the front edge of the aperture will cast a shadow that tends to cut up the façade. A disadvantage of this arrangement is that if the thermal insulation properties of the wall are inadequate, a thermal bridge may be formed round the window.

Alternatively, the window can be placed as far out as possible to emphasise the uniform appearance of the façade or may even be projected in front of the façade. Here again, there is the potential disadvantage of a thermal bridge round the window; in addition, the windows are no longer protected in these arrangements. It follows that the best solution is probably to locate the window in an intermediate plane taking into consideration the resultant visual impression created on the façade (8).



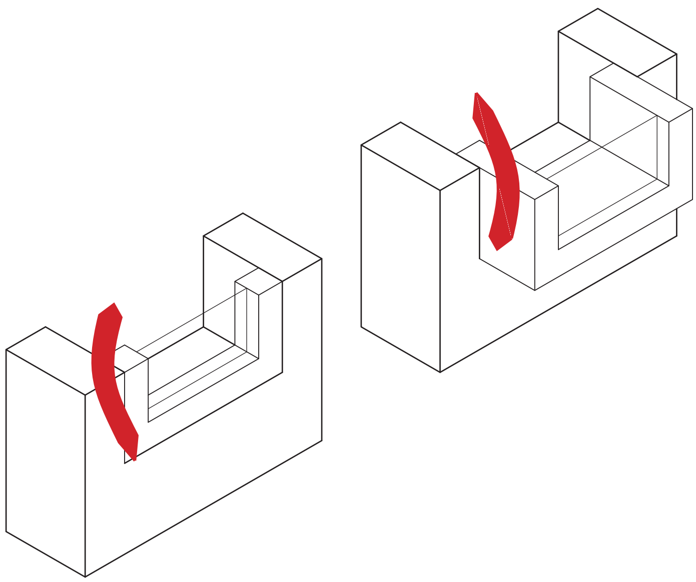
7

Masonry
The individual units of the masonry, the bricks, form a band pattern in combination.



Façades are influenced by different factors such as the façade's self-weight, acting vertically in the plane of the façade, and largely lateral wind forces acting perpendicular to this plane. If the façade is also used to carry the weight of the building as a whole, this load will also act as a vertical stress on the façade system (9). Other external factors acting on the façade include noise, wind, rain, heat, cold and solar radiation. The factors acting on the façade from the interior include air humidity, heat and cold.

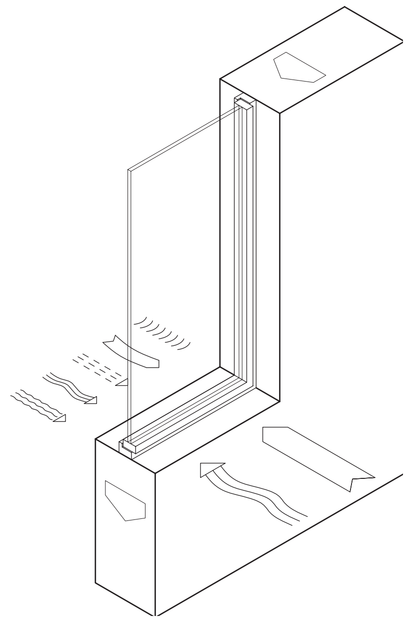
In general, these various factors are considered separately in view of the different requirements they pose on the construction, and they are dealt with in separate functional layers in the façade.



8

Position of window in building

The window may be placed in a number of different positions with respect to the structure of the building: recessed, in the median plane, flushed with the outer surface or projecting. The position in the median plane is the only one which can be detailed to avoid thermal bridges.



9

Factors influencing the façade

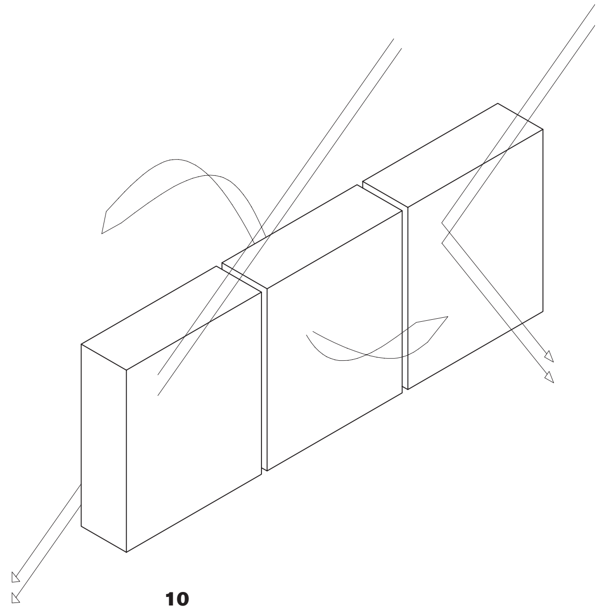
Façades are loaded in various ways by the overall structure of the building, the way in which it is used and the environmental conditions. External influences include noise, wind, rain, heat and cold, while factors acting from the interior include air humidity as well as heat and cold. The façade will also have to bear its self-weight and wind loads, and in certain cases loads derived from the structure of the building as a whole.

Combination of functions

When dealing with the appearance and the structural design of façades, we may divide them up in two different approaches, into functional elements (10) or into layered systems (11). In the former approach, each element will perform a particular task such as ventilation, lighting or the limitation of visual access. It is only when these elements are combined that the façade as a whole will perform all functions expected of it. Each element will perform its function at a particular part of the overall structure, and can in general be individually replaced if necessary (e.g. a dilapidated window unit can be replaced by a new one).

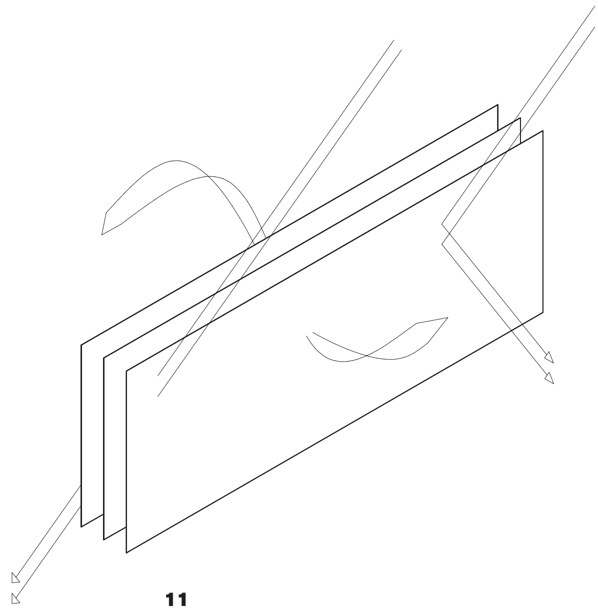
In a layered system, each function is performed by a different layer of the façade. The layers may be arranged so that the function can be performed at any point on the façade. Each function is performed via the layer in question to meet the relevant requirements. The complexity of the construction and the need to integrate the individual functions (such as ventilation, transparency and thermal insulation) are the challenges in this approach.

These two approaches are rarely used in isolation: many mixed forms and variants exist, and are designed to meet as many requirements as possible simultaneously thus giving optimum functionality with the most economic means. Continuing development is leading to the production of more and more specialised components, both in the field of façade elements and in that of layered façades.



10

Façade built up of elements
This figure shows a façade composed of separate elements, each one of which performs a separate function such as ventilation, lighting or transparency control.



11

Layered façade
A layered façade has a uniform appearance but allows all desired functions to be realised at any point on the façade.

Detailing principles

Independent of the choice of materials and the desired appearance of the façade, two fundamental guidelines of façade design corresponding to the basic laws of building physics may be formulated here.

Firstly, water impinging on the building should be led off externally. If despite protective measures water does get into the building, it should be allowed to drain off or evaporate without harming the structure. This second proviso is necessary because no building can be guaranteed to be entirely weatherproof throughout its entire life cycle. If water does manage to penetrate the building fabric, this can cause timber to rot, steel to rust and (in the case of frost) masonry to fragment. To avoid this, a water drainage system covering the whole façade should be built behind the outer weatherproofing layer. If this is not possible (e.g. when sandwich systems are used), then some form of monitoring should be present and the façade components should be made water-resistant.

Secondly, the impermeability of the façade to air humidity should fall off from the inside to the outside of the façade. This means that water vapour from internal sources should not be able to penetrate into the building structure. If water does penetrate into the façade it will cause condensation when the external temperature is low, causing damage to the façade fabric. On the other hand, if water vapour from the exterior penetrates into the building fabric it should be eliminated through evaporation. Furthermore, an impermeable inner envelope avoids draughts, thus reducing heat loss.

Layering of details

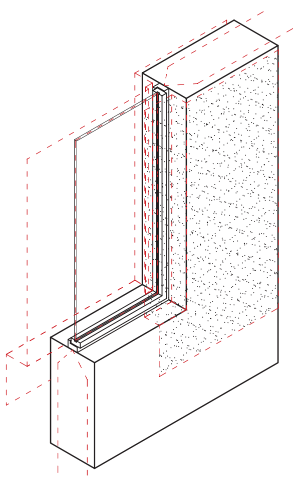
In general, separate layers of the façade (each with one or a limited number of functions) are used to provide protection against different environmental factors (12).

An external weatherproofing layer offers protection against rain, wind and solar irradiation. As described above, a second drainage layer should be provided behind this. If there are windows in the façade, some additional means of reducing the impact of solar radiation before it reaches the windows can be provided in this layer.

An intermediate layer provides insulation against heat and cold in both directions. To prevent or minimise the direct transmission of heat, this layer should be thermally isolated from the outer weatherproofing layer. To this end, direct contact between the two layers at various points, allowing passage of heat or cold, should be avoided – though this is not entirely possible from a constructional point of view, since the intermediate layer supports the outer weatherproofing layer. In any case, the contact points should be kept as minimal as possible or heat flow should be minimised by use of materials of poor thermal conductivity.

If the intermediate layer is sufficiently solid, it can also assume the task of soundproofing. If it is not sufficiently solid, this layer must also be decoupled from the others to minimise the penetration of sound waves. If the façade also has a loadbearing function, this is performed by this layer too.

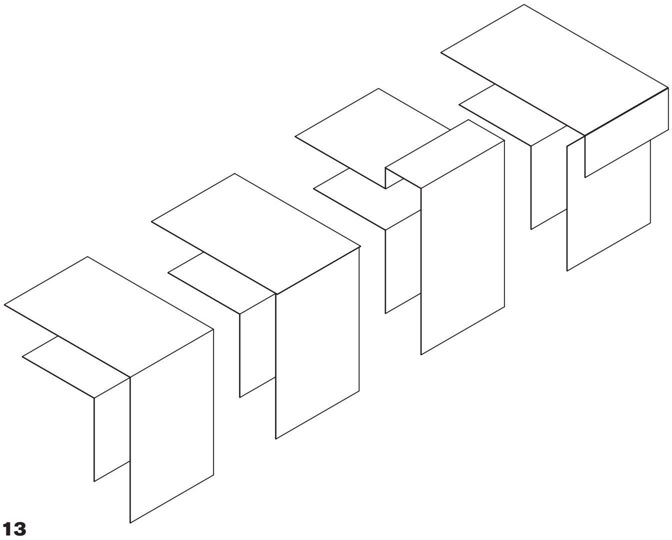
The innermost layer separates the interior space from the façade or from the external space. Windproofing and vapour barriers are localised here. In some cases, this layer may absorb water vapour from the interior space and return it to the interior space later. For the reasons indicated above, passage of water vapour through the impermeable layer should be avoided.



12

Layering in detail
Three layers in the façade detail provide protection against environmental factors. The outermost weatherproof layer keeps out wind-driven rain. The middle layer provides loadbearing capacity if required and also functions as thermal insulation. The innermost layer separates the interior from the exterior space and functions as vapour barrier.

The complexity of the connection of the three layers increases when structural solutions have to be sought for corners or façade-roof transitions (13). The desire to connect the layers without interruption round a corner gives rise to problems due to the different requirements imposed on the different structural components – vertical components (façades) have to be impervious to water, while horizontal components (roofs and eaves) have to be impervious to water and if necessary drain water off. Considerable construction detailing is required to take the layers round a mitred joint, since the decision about the overlapping occurs at the thinnest end where all layers meet. The problem is solved in a parapet construction by the use of specific profiles with sharp edges, but involves the difficulty of water exclusion from the roof on the inner side of the parapet wall. The use of eaves in this case deals with this problem by allowing the layers to project past the junction, but only at the expense of exposing the edges of some components which may compromise on aesthetics.



13

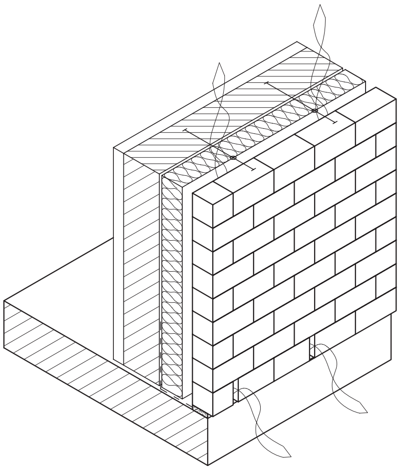
Principle of methods used at façade junctions
The treatment of façade layers at junctions reflects the problems associated with separation of function: vertical components are impervious to water, while horizontal ones also have to provide drainage facilities. This drawing shows on the left, absence of eaves, which is bound to lead to damage in the long run; then eaves in which only the outermost weatherproof layer projects; next a parapet, where separate drainage has to be provided; and on the right, a solution in which the intermediate functional layers are superimposed while the weatherproof layers overlap.

Examples of detail development

The principles underlying the development of details will now be illustrated with reference to five typical cases: masonry cladding, a post-and-beam façade, a unit system façade, a parapet and a plinth construction.

14

Example of masonry cladding taken from a housing development in Middelburg, the Netherlands
This double-skin construction consists of a concrete loadbearing layer with thermal insulation properties and a separate masonry weatherproof layer. The masonry is held in place by tie rods, which pass through the concrete layer. Following a procedure that is common in the Netherlands, the window frame is mounted before the masonry wall is built, which allows the latter to be adapted to suit the dimensions of the window. A waterproof membrane is mounted in the wall above the window, to allow water that has got into the wall to drain off again.



15

Sketch showing principle of masonry cladding
The loadbearing layer (here a concrete wall that also provides the thermal insulation) and the masonry weatherproofing layer are separated by an air cavity. Slits in the masonry act as air inlets. An impermeable membrane inserted into the wall is brought out near the bottom of the façade to allow water that got into the weatherproof layer to drain off.

Masonry cladding

One widely used double-skin construction is a masonry wall or a concrete wall made of prefabricated elements, which provides thermal insulation and loadbearing capacity, and an outer masonry skin for weatherproofing (14, 15). The thermal separation is provided by wire tie rods, which do penetrate the thermally insulating layer but hardly give rise to any heat flow because of their low cross-sectional area. These tie rods enable the outer masonry skin to resist lateral forces and the risk of bending due to its self-weight.

In this example, taken from a housing development in Middelburg, the Netherlands, a waterproof membrane passing through the double wall above the window allows water that managed to penetrate the façade above the window to be drained off before it reaches the window. The window frame was mounted before the masonry wall was built – quite a common practice in the Netherlands, which takes advantage of the prefabricated window elements and the possibility of adapting the faced masonry to fit the window-frame afterwards. The actual window with sash is mounted subsequently, to avoid damage during the building work.

The innermost layer (not visible in this example) is provided with a plaster finish, which gives not only complete impermeability but also thermal storage capacity.

Post-and-beam façade

Post-and-beam façades are made of storey-high posts, secured to the ceiling-floor units with the aid of mounting shoes, to which horizontal beams are connected (16, 17). This structure forms the loadbearing layer. The weatherproofing layer is formed by panels (sheets of glass or sandwich elements) fixed on to the post-and-beam structure with the aid of mounting frames. The loadbearing and weatherproofing layers are separated by spacers of low thermal conductivity and bolts fixed at appropriate points.

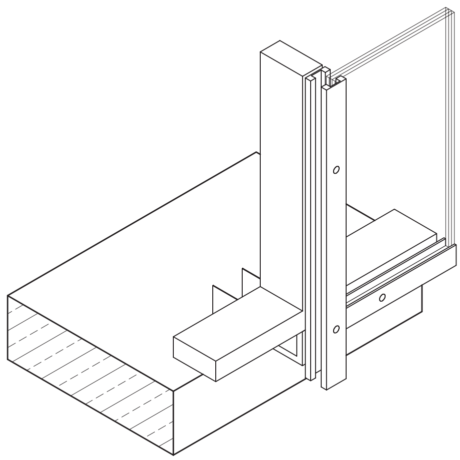
The separation is less clear at the layer of the glass sheets, since here the innermost layer, the loadbearing/thermal insulation layer and the weatherproofing layer are all combined in one.

Post-and-beam façades are made of prefabricated elements that are assembled by hand on site. This system works well, since the post-and-beam combinations are only mounted on the ceiling-floor units and are thus largely independent of the fabric of the building. As a result, tolerances can easily be corrected. A disadvantage is the necessity to close the gap between the ceiling-floor unit and the façade subsequently, to meet noise-control and fire safety regulations.

16

Post-and-beam façade: Fachhochschule Detmold, Werkstatt Emilie, 2007

This picture of a post-and-beam system shows how the façade structure rests on the ceiling-floor unit. The mounting shoes are clearly visible. Glazing and cladding panels are fixed in place in subsequent stages, with the aid of mounting strips.



17

Sketch showing principle of post-and-beam façade

The post-and-beam façade consists of storey-high posts to which horizontal beams are connected. The glazing and cladding panels are secured from outside with the aid of mounting strips, and are thus thermally isolated from the main structure.

Unit system façade

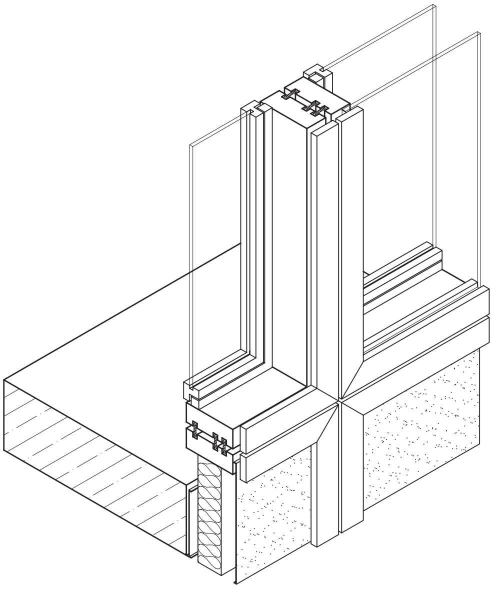
Unlike a post-and-beam façade, a unit system façade consists of fully prefabricated elements that simply have to be positioned and mounted in situ (18). This is also generally made storey-high, and usually consists of a loadbearing framework in which glazing and cladding panels can be infilled (19). Since each element is a complete unit, a given component of the system façade will usually perform several functions simultaneously: for example, as in the case of a post-and-beam façade a pane of glass inserted into the structure will not only separate inside from outside but also provide thermal insulation and weatherproofing.

Each façade element is connected to the building structure by means of an angled cleat mounted frontally near the ceiling. The element is suspended from the top, and stabilised against lateral forces at the base by a sliding bolt connection to the element below it. Successive elements can be combined in this way, either being stacked from bottom to top or connected in a row.

Since the individual modules are prefabricated and transported to the building site, they have to be fairly rigid. This can give rise to problems when sealing the gaps in and between the elements. Unlike the case of post-and-beam systems, where the mounting strips provide the seals in the weatherproofing layer, the sheets of glazing in unit system façades have to be individually sealed. In addition, an effective seal has to be provided between adjacent façade elements. This is usually done using three sealant profiles which have to be introduced in special grooves between the elements during assembly.

18

System façade: Double façade of Debitel Headquarters, Stuttgart, RKW Architektur + Städtebau, 2002
This system façade is built with a double façade solution. The individual elements are lifted into place with a crane, and require only a small labour force for assembly. They already contain all necessary components, so that further finishing (e.g. glazing) is not required.



19

Sketch showing principle of system façade
Unlike post-and-beam systems, unit system façades are built up out of fully prefabricated elements. Sealing strips have to be placed between adjacent elements to ensure complete tightness against wind-driven rain and wind from the exterior and water vapour from the interior.

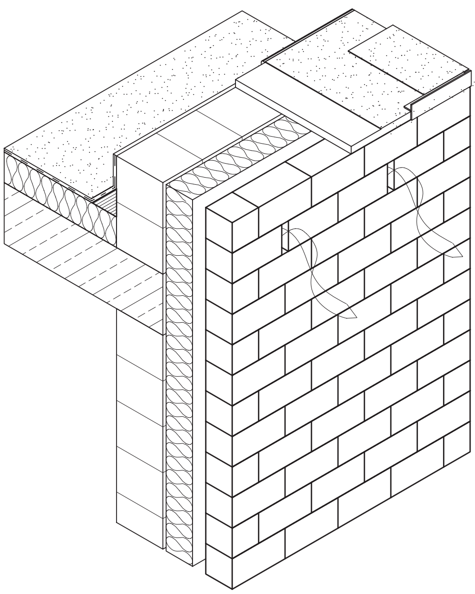
Parapet

The construction of a parapet on top of a building involves the problem of bringing about a suitable transition between the various layers of the façade and the various layers of the roof covering. The loadbearing and thermal insulation layers of the façade and the roof terminate at the base of the parapet (20), while the weatherproofing layers are continued up to the top of the parapet (the horizontal layers of membrane that form the roof covering have to be bent through 90 degrees for this purpose) – in any case far enough to prevent penetration of wind-driven rain or standing water on the roof.

To finish off this simple solution, a timber cap lined with membrane is placed on top of the parapet so as to cover the ends of both the façade layers and the roof-covering layers (21). An aluminium section with a drip guard is also provided at the front edge. An alternative – and possibly more durable – solution is to use a cap made of metal sheeting, which should also cover all layers involved.

20

Parapet on residential housing
In this case we see how the functional layers combining loadbearing capacity and thermal insulation come together while the weatherproofing layers are continued upwards. The membrane-lined timber cap used here could be replaced by a metal sheeting cap.



21

Sketch showing principle of parapet construction
The parapet is where the various functional layers of the façade and the roof come together. A suitable construction detail, providing adequate long-term protection against climatic influences, has to be devised here. The weatherproofing layers have to be continued vertically up to the top of the parapet on both sides, to prevent penetration of water. At this point, they are covered with a cap of membrane-lined wood or metal sheeting.

Plinth unit

The main problem in the design of a plinth unit is the transition from the façade to the foundations. Loads from the façade and the rest of the building have to be effectively transferred to the ground. In addition, a proper transition has to be realised between the weatherproofing of the façade and the foundation/soil vapour barrier.

For example, this detail could consist of a single-layer wall made of sheet-metal sections resting on a prefabricated concrete plinth (23). The layer providing separation from the interior space would in this case be made of recessed sheet-metal panels resting on the bearing structure of the building as a whole (22). The functional layer is the thermal insulation. The weatherproofing layer is made of sheet-metal panels on a support. Once again, the intermediate space is used to allow any water that may have penetrated this far to evaporate.

The prefabricated plinth consists of two concrete plates separated by a layer of high-density foam with sealed pores. This structure has the dual function of avoiding a thermal bridge and giving the plinth good impact strength.

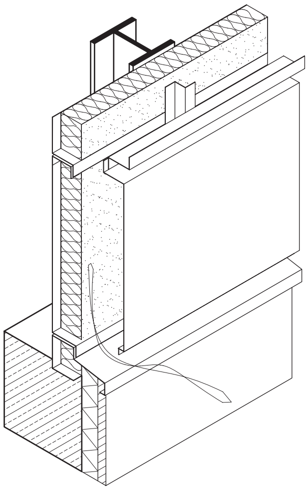
This example is a good illustration of compliance with the above-mentioned requirement that the impermeability of the façade to water vapour should be graduated from inside to outside. The outer layer repels rain falling on it, but air can pass through the seams between the different elements and the gaps in the plinth unit. All openings are provided with drip guards to hinder the penetration of water. The thermal insulation behind this can dry out if necessary. The interior space is provided with maximum windproofing by sheet-metal cladding – which has to have suitable sealant sections in the gaps between the individual sheets.

It should be noted that there are of course other façade construction methods based on different principles, which may not always follow the principle of separation of the different layers described above. These other methods may be perfectly appropriate in given situations. The examples given above have been presented solely to illustrate the general principles of layering in building structures and how the transition between these layers is handled at junctions and points of penetration.

23

Plinth design

This cross-sectional view of the plinth detail shows the sequence of the functional and weatherproofing layers. The innermost layer is here formed by the sheet-metal surface. Sealing strips are used in the gaps between the innermost sheet-metal elements to ensure water tightness.



22

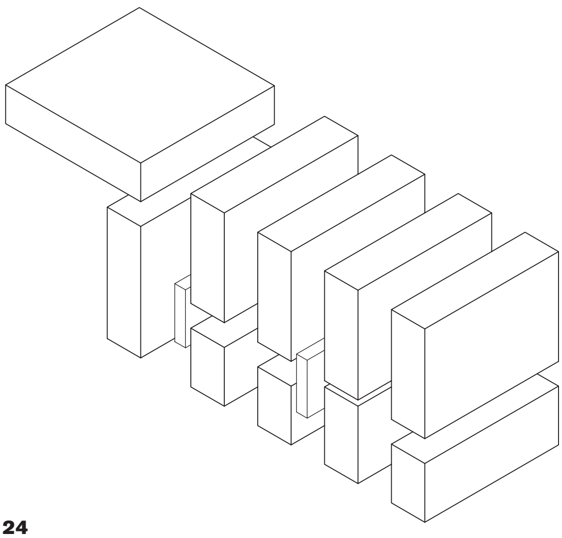
Sketch showing principle of plinth unit

The wall consists of a loadbearing layer of interlocking sheet-metal panels, within which the thermal insulation is introduced. A gap is left between the weatherproofing layer and the wall.

Joints

In order to realise the various functions required in the façade, it is necessary to combine a number of larger and smaller façade elements. These elements are generally connected by means of seams or joints between them (24). Care must be taken in this context to ensure that the joints do not interfere with the continuity of the individual layers or with the appearance of the façade as a whole.

A number of different types of joints may be distinguished visually, including hairline joints (gaps where the distance between the individual components is very small, though capillary effects can still lead to the risk of penetration of water), covered joints (25), joints with ridge reinforcement and false seams or shadow gaps (which look like seams on the surface, but do not correspond to any discontinuity in the underlying structure).



24

Types of joints
From left to right: covered joint, shadow gap, cover strip, hairline, open joint.

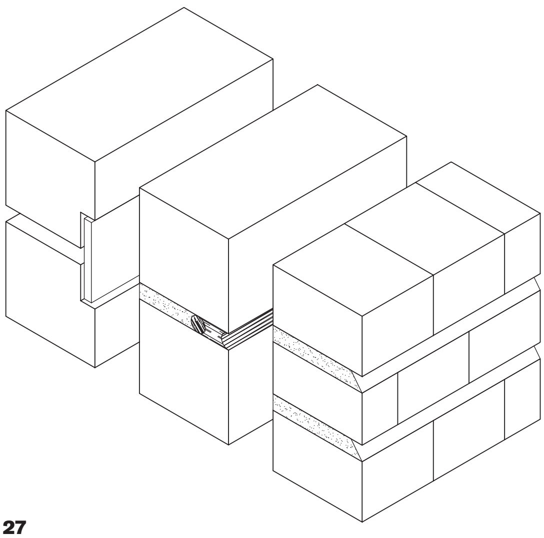
25

Joints in traditional timber window construction
Example of a traditional timber window construction showing different types of joints: the gap between the sashes is closed by a cover strip. The joints between the different components of the frame are realised as glued hairline seams. The bottom panels are connected by tongue and groove joints, while the panes of glass at the top are held in place with sealing putty applied on the exterior.

Apart from the effect of seams in the façade on the appearance of a building (26-33), it is also important to ensure that such seams do not impair the ability of the structure to exclude water, in particular wind-driven rain. To this end, open joints are covered or provided with a drip guard so that the water drips off harmlessly rather than penetrating into the building fabric. If joints are to be sealed, care must be taken in choosing the right type of sealant. If windproofing is also required, this is generally provided by another layer on the inside of the façade.

26

Larch shingle covering
Thin strips of larch can be used to give a covering similar in structure to that obtained using slates, which is both effective as weatherproofing and attractive. Since no two shingles are completely the same shape and size, a pleasing irregularity can be achieved with this form of covering.

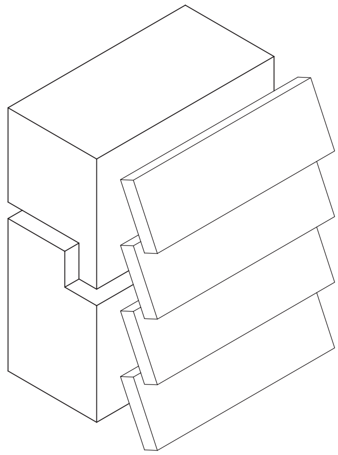


27

Sealed joint
Joints may be sealed in various ways to ensure good weatherproofing of the façade. Water can then only penetrate into the join if the sealant is damaged. This figure shows from left to right a cover strip with sealant section, a silicone seal and a mortar-filled join in brickwork.

28

Slate covering
A slate covering is effective at keeping wind-driven rain out of the building fabric, despite the gaps between neighbouring slates, because of the overlapping manner in which the slates are laid. The top slate is always laid over the one below it with a certain overlap and then fixed on to the wall.



29

Open joint
To ensure good weatherproofing in the presence of open joints, projections that keep the rain away from the join or drip guards (projecting members with a specially curved edge to ensure that water drips off rather than flowing into the crack) must be used.

30

Use of cover strips in pitched roof construction

When plank sheathing is used in the construction of a pitched roof, a cover strip is screwed over each join between successive planks so that even if the planks warp no open joints are produced.

31

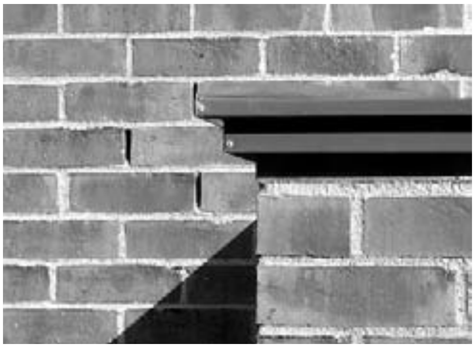
Cover strip in a post-and-beam structure

In this case, which is similar to that shown in fig. 30, the cover strip used in a post-and-beam system covers the gap between two panes of glass. Additional silicone sealant sections provide a good seal between the glass and the cover strip. A problem with this construction is that appreciable stresses can be generated at the point – clearly visible in this figure – where the horizontal and vertical cover strips meet.

32

Silicone seal

Unlike the cover strip, the silicone seal does not involve forces between horizontal and vertical members, since the seal is produced by the curing of the sealant compound introduced into the gap, and the resultant seal has a certain elasticity. Disadvantages are that care and skill are needed to produce a first-class seal, and that the seal has a limited lifespan.



33

Masonry detail with sheet-metal cover

In this detail, the gaps between some bricks are filled with mortar while a sheet-metal drip guard placed some distance in front of the masonry keeps rainwater away from the open gaps left for ventilation purposes.

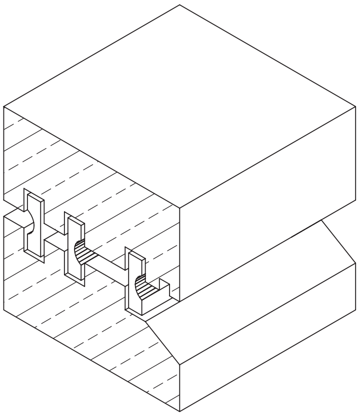
A closer look at the finished join will reveal the following picture, starting from the exterior: rainwater is kept out by an external sealing plane. Back-up protection against the entry of rainwater and drainage of water that managed to get in are provided by a second sealing plane. The innermost layer provides airtight separation of the interior space. Hence, even in the detailing of joints the individual functions are represented by separate recognisable layers (35).

Another function of joints is to take up movements of individual building components, many of which are predictable on the basis of design calculations. Where appreciable displacements are possible, joints must be capable of handling them. The sealant sections or sealant compounds used to fill the joints must be elastic enough to enable such movements (34, 36).

34

Concrete façade

In this view of a projecting concrete façade, the vertical joints between the different concrete elements are clearly visible. In this case, they are filled with a long-life silicone sealant. Also visible at the base of the façade are the drip guards used to allow rainwater to fall harmlessly off the surface of the building.



35

Construction of the seal in the gap between prefabricated elements

The seal in the gap between prefabricated elements shows a layered construction. The innermost seal provides windproofing, and the outermost seal provides weatherproofing. The intermediate seal provides a backup in case the weatherproofing fails.

36

Joint between façade and roof, Chek Lap Kok Airport, Hong Kong, Foster and Partners, 1998

Since the roof of the airport building shows appreciable movement with respect to the façade, the join between them must permit a great deal of tolerance. This was achieved with the aid of a concertina-like plastic profile, which provides the necessary weatherproofing and windproofing. The requirements for thermal insulation are generally not very stringent at such locations.

Tolerances

The question of tolerances is an integral part of detailing. In the building industry, the term 'tolerance' is understood to mean the difference between the actual position of a given component with reference to the building as a whole and the position predicted on the basis of design calculations. As a result of such differences, the gap between some building components could become too large, while other components could be forced against one another leading to substantial stresses in the building fabric. Measures must be taken to ensure that these two extreme situations do not occur, so that the various parts of a building do actually fit together as they should and the construction process can proceed smoothly. In other words, the detailing of a building has to take into consideration not only the functions to be performed by the building and the (external) factors acting on it, but also the planned and unplanned changes in building dimensions. It may be noted in this connection that reinforced concrete elements generally have tolerances of up to 3 cm (0.86 in), depending on the size of the element (37). The tolerance for timber construction details may be taken to be in the range from 0.5 to 2 cm (0.2-0.79 in), and that for steel constructional details in the range from 0.2 to 0.5 cm (0.08-0.2 in). These have two consequences: in the first place, care must be taken to ensure that building components made of a certain material do comply with the tolerances specified for that material; and when different materials are joined together, the differences in tolerance between the materials must be handled correctly.

To solve this problem, connection devices must be designed to permit dimensional adjustment in one, two or all three directions. This may be done e.g. with the aid of slots in the connection device that allow the position of the mounting bolts to be adjusted over a significant length in the given direction (38, 41). Alternatively, bearing bolts may be designed so that their length varies with the load to which they are subjected, thus permitting motion of the component supported (39, 40). The most expensive solution would doubtlessly be the ad hoc positioning of the component in situ followed by fixing in the desired position (e.g. by welding).

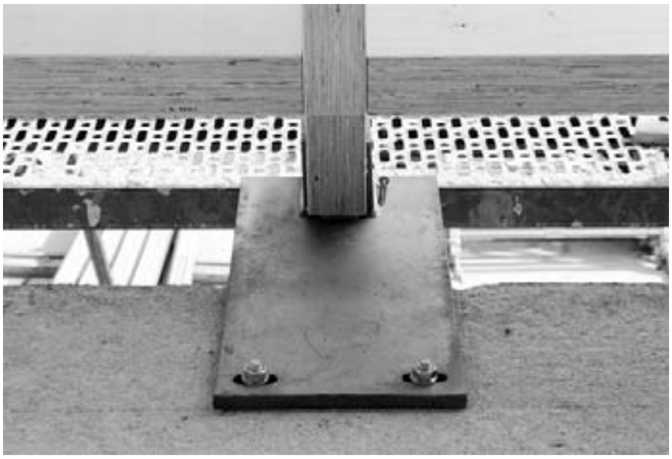
37

Tolerances in prefabricated concrete parts
Tolerances of up to 3 cm (0.86 in) may be expected in concrete structures, whether cast in situ or prefabricated. These must be accommodated with the aid of specially designed connection devices, to ensure compatibility between the wide tolerance of concrete and the much more limited tolerances of steel and aluminium.

38

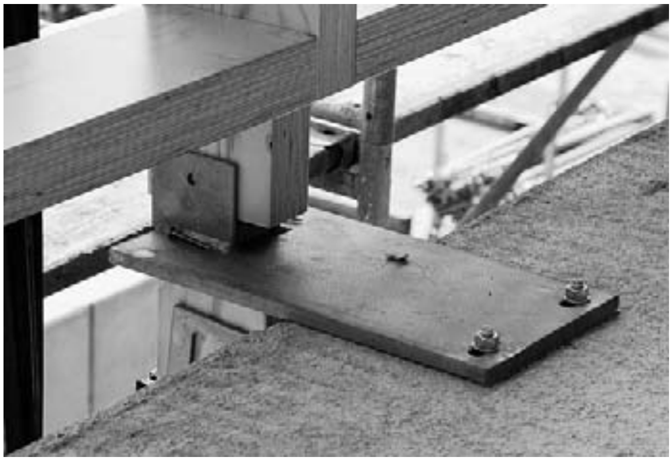
Angled cleat with slots
Example of a slotted connection device, used here for the mounting of a pane of glass. The illustration shows the slots in various directions, used to adjust the position of the individual panes of glass, and drilled holes in situ to increase flexibility.

It is important to note in this regard that uneven joints caused by a failure to take differences in tolerance into account during the planning stage generally have an adverse effect on the appearance of a building. The extent of this problem can be delimited by making the joints wide enough or by concealing them.



39

Point support for post-and-beam façade from inside
This point support for a post-and-beam façade is positioned in situ so that the axis parallel to the façade is kept flexible enough with the aid of a pin drilled into the concrete ceiling to permit fine tuning.



40

Point support for post-and-beam façade from outside
This view of the same support point shows that the axis perpendicular to the façade is positioned with the aid of a hole drilled in situ in the wood. If the façade were made of aluminium or steel, a horizontal slot would be provided to permit finer adjustment.

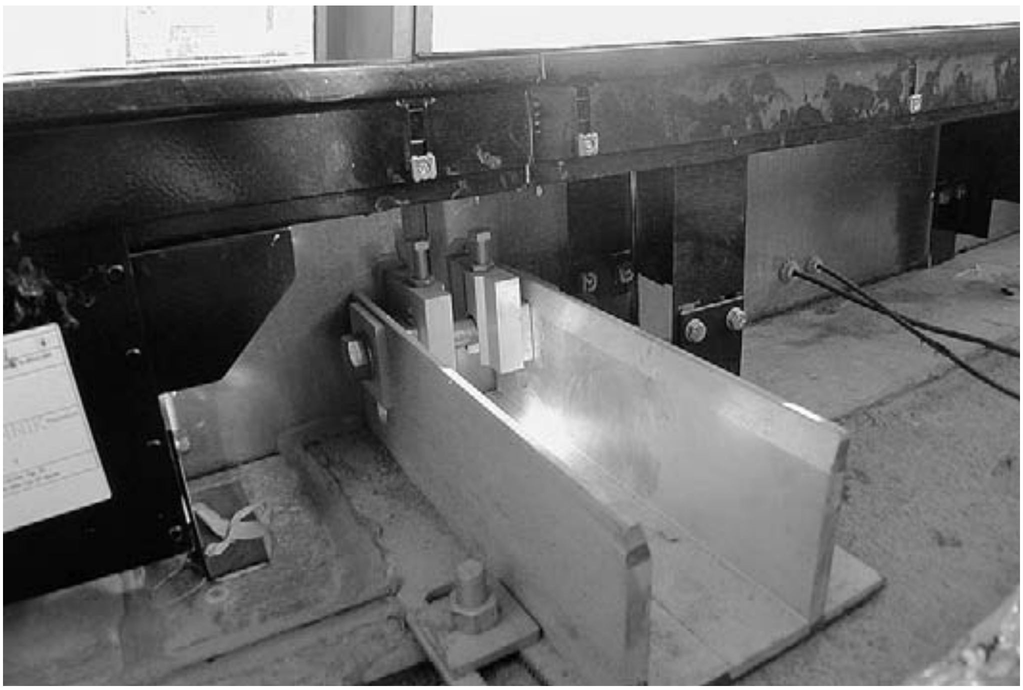
41

Point support for post-and-beam façade from above
In this final picture of the series, the top support point for the post-and-beam façade may be seen. A vertical slot is provided here, which may be used to accommodate both lateral tolerances and movements of the building structure itself.

Summing up, it may be stated that tolerances of the order of centimetres may be expected in reinforced concrete and timber building components, and of the order of millimetres in steel and aluminium. These tolerances must be taken into account in the detailing of buildings, in particular of façades where the commonly used combination of reinforced concrete and steel or aluminium may lead to problems related to differences not only in tolerance but also in thermal expansion between the various materials. Measures must therefore be taken to permit the adjustment of the connection elements to deal with the dimensional shifts that occur (42, 43).

42

Post Tower, Bonn, Helmut Jahn, 2003
Top view of façade base with connection points for fitting out like raised floors, mullions and partition wall.



43

Façade at base of Post Tower, Bonn
The unit system façade of the Post Tower in Bonn, designed by Helmut Jahn, is secured to the ceiling-floor unit with the aid of the mounting shoe that may be seen here. The picture also shows the means provided to allow adjustment of the mounting to accommodate differences in tolerances in all three directions: horizontally outwards with the aid of graduated slots and screws in the concrete surface, horizontally parallel to the façade with the aid of a locating bolt and vertically with the aid of locating grips provided with screw adjustment.