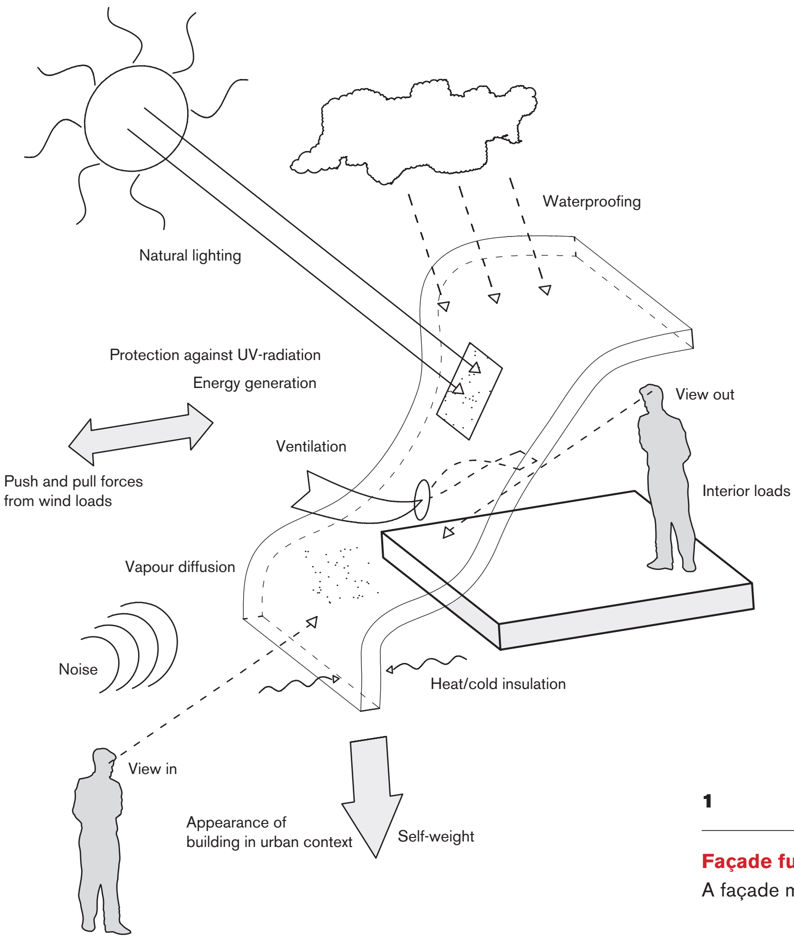
3 | Principles of Construction

The façade separates the interior from the exterior. Before addressing today's façade constructions we would like to call to mind the different functions that a façade serves: it defines the architectural appearance of the building, provides views to the inside and outside, absorbs push and pull forces from wind loads, bears its self-weight as well as that of other building components. The façade allows sunlight to penetrate into the building while usually providing protection from the sun at the same time. It resists the penetration of rainwater and has to handle humidity from within and without. The façade provides insulation against heat, cold and noise and can facilitate energy generation. In addition, it must be long-lasting, easy to maintain and to clean.

Sketch 1 shows the complexity of the requirements to be fulfilled. These requirements need to be considered during all phases of the façade construction: during the conceptual phase, while working on the principles of construction, during detailing and lastly during construction and usage.

Basically we desire a structure that is as simple as possible yet carries out all these functions and is adaptable to changing influencing factors. It should be an adaptive envelope similar to the human skin, fulfilling several functions of the body.

Today's façade is based on developments spanning several millennia. The solutions currently in use result from tried and tested construction methods, the materials available and traditional production and assembly processes.



1

Façade functions
A façade must fulfil various requirements.

Areas of construction

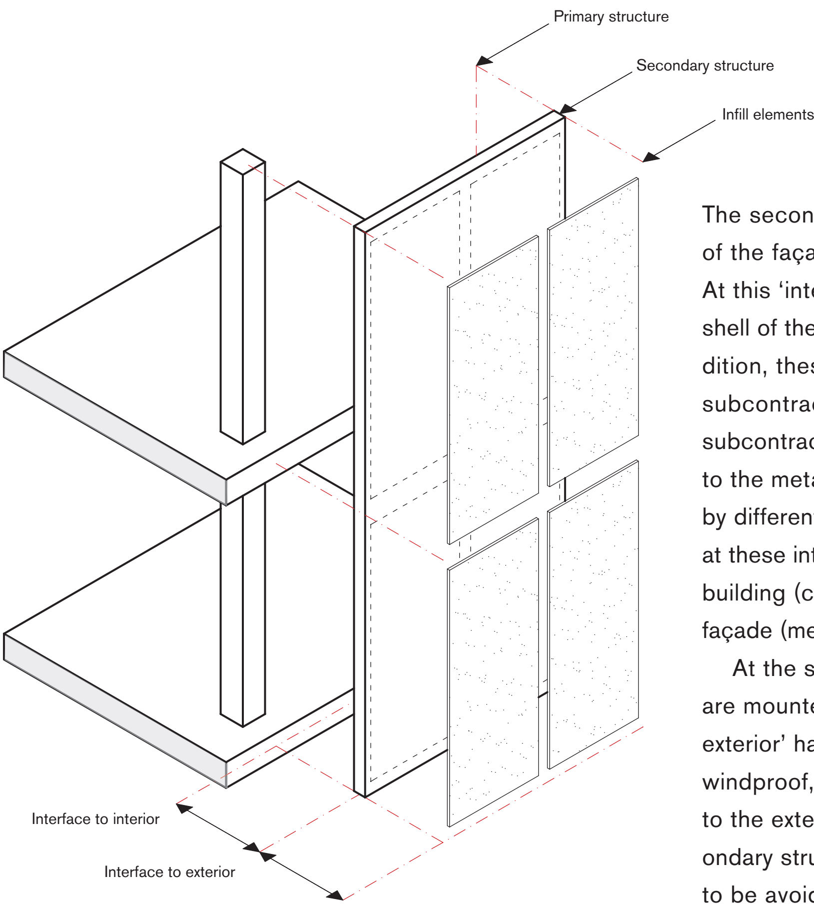
In the following we will describe the principles of construction using a metal and glass façade as an example.

Three main areas of construction (2) can be defined within the façade:

- Primary structure (shell of building) forming the main loadbearing structure of the building
- Secondary structure, which is the loadbearing structure for the façade and constitutes the connecting element between levels one and three
- Infill elements

The primary purpose of this assembly lies in the separation of the above mentioned functional requirements that the façade needs to fulfil. The functions are distributed among several different components. This arrangement simplifies the connection of individual façade components with each other and provides options to compensate for movement due to wind as well as thermal expansion.

The primary structure takes on the loadbearing function of the entire building and transfers the loads from the façade to the foundation.



2

Schematic representation of the elements of façade construction
In principle all façade constructions are based on this schematic design; however, different functional requirements can be combined into one component.

The secondary structure comprises the loadbearing structure of the façade. It transfers its loads onto the primary structure. At this 'interface to the interior' the differing movements of the shell of the building and the façade need to be balanced. In addition, these two structures are typically assigned to different subcontracts; the shell of the building usually falls under the subcontract for concrete work whereas the façade is assigned to the metal subcontract. As these elements are manufactured by different companies, there is a need for special coordination at these interfaces. Manufacturers' tolerances of the shell of the building (concrete) lie within the centimetre range whereas the façade (metal) tolerates only deviations of millimetres.

At the same time infill elements such as glazing, panels etc. are mounted on the secondary structure. This 'interface to the exterior' has to fulfil its own functions: the elements have to be windproof, resist water penetration, or it must be re-channeled to the exterior, movements between the elements and the secondary structure have to be tolerated and thermal bridges have to be avoided. Thus the secondary structure is a very complex component.

Of course there are also façade constructions where the primary and the secondary structures form one component, i.e. the secondary structure is part of the loadbearing structure of the building. In this case the interfaces to the internal and the external are reduced to one. When using this type of structure we need to closely examine it with regard to tolerances, deflection and building physics. And if the façade is part of the loadbearing structure of the building, individual façade components cannot be easily exchanged.

The actual space enclosure is created by the infill elements (3). These can comprise glass panes for lighting and view, panels for heat insulation and opening flaps for ventilation. The elements can also be layered. For example, it might be practical to arrange sun shading on the outside of the glazing, and glare protection on the inside. Double façades are another example of the principle of layered functions. Basically all façade designs can be categorised according to this system.

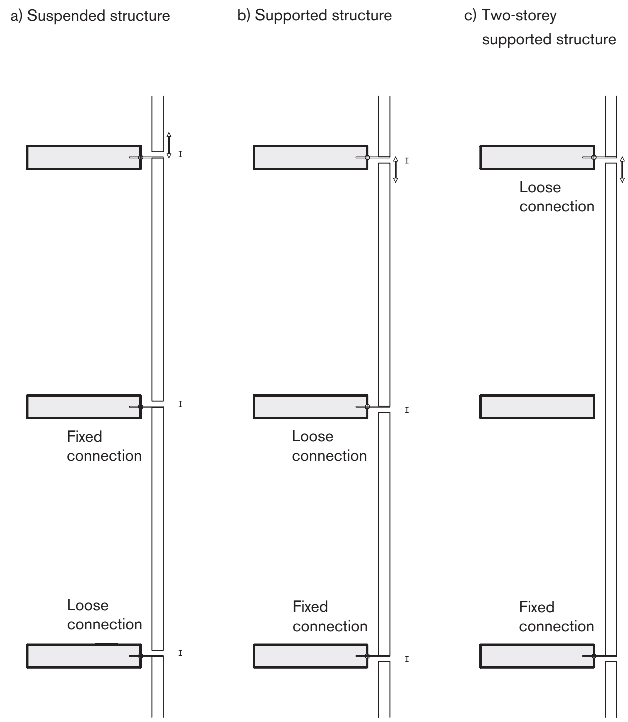
Façade bearing structures and load transfer

We can differentiate between different types of loads affecting the façade structure:

- Self-weight of the façade components
- Weight of snow
- Wind load (push and pull)
- Live loads e.g. a person colliding with the inside of the façade which in turn must be prevented from falling. (Fall protection)
- Stress loads. These are caused by deflections of components through changes in temperature or humidity.

3

Academy Mont Cenis, Herne, Jourda & Perraudin, 1999
The timber column of the primary structure can be seen on the inside; the secondary structure consists of wooden posts. Glass panes and ventilation flaps form the space enclosure.



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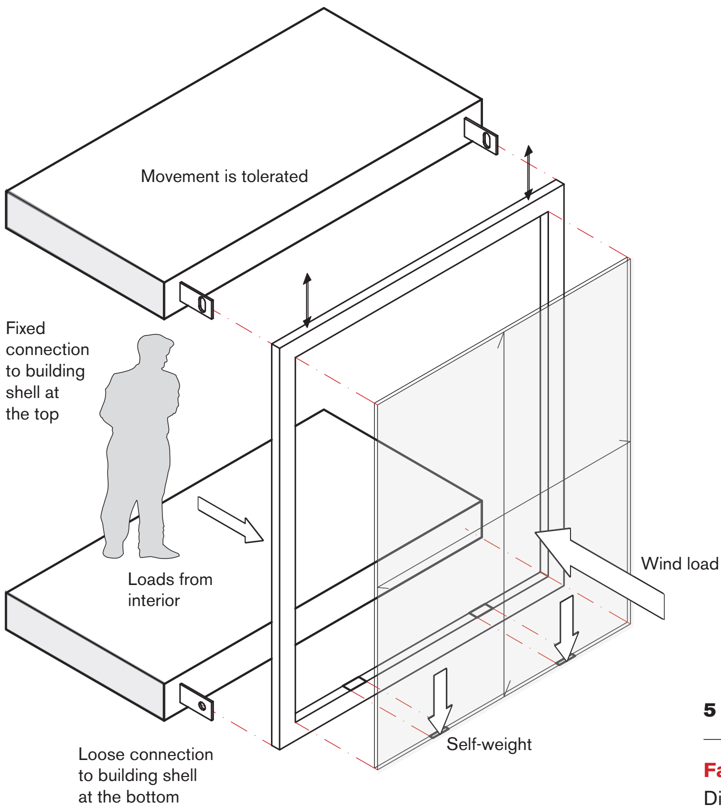
Load transfer
The drawing shows a suspended structure on the left, a single-storey supported structure in the centre and a two-storey supported structure on the right.

First we will examine a façade with extensive glazing and a perimeter frame structure (5) and its load transfer as per the above mentioned areas of construction.

The self-weight of the glass panes acts downward parallel to the façade. If glass panes are not fixed by planar fittings or suspended from above they sit on two plastic blocks. Only two blocks are necessary because vertical glass panes do not sag and therefore rest on two support points only, no matter how many support blocks are being used. For optimum structural integrity these blocks should be situated at a fifth of the distance from the edge. In this example the load bears on the lower edge of the frame (secondary structure). Depending on the type of glass used, a functional panel with several individual glass panes can weigh half a ton and more! The fixed connections hold the façade in place whereas the loose connections compensate for movements of the construction.

The push-pull-forces from the wind load and other dynamic loads acting vertically on the façade are transferred from the functional layer to the linear secondary structure (frame).
In turn the secondary structure transfers the loads to the primary loadbearing structure. It is to be expected that the façade as an exterior building component is subjected to different weather conditions than the shell of the building on the interior. Additionally, the façade is usually made from different materials, resulting in different linear expansions. Furthermore the primary structure is impacted by other loads and is liable to deflect accordingly. To avoid wedging, the secondary structure is supported on its lower edge or it is suspended from above (4).

In most cases it makes sense to transfer the façade loads storey by storey and to add expansion joints so that variations in dimensions do not add up across several storeys. This becomes possible when the secondary and the primary structures are separated.



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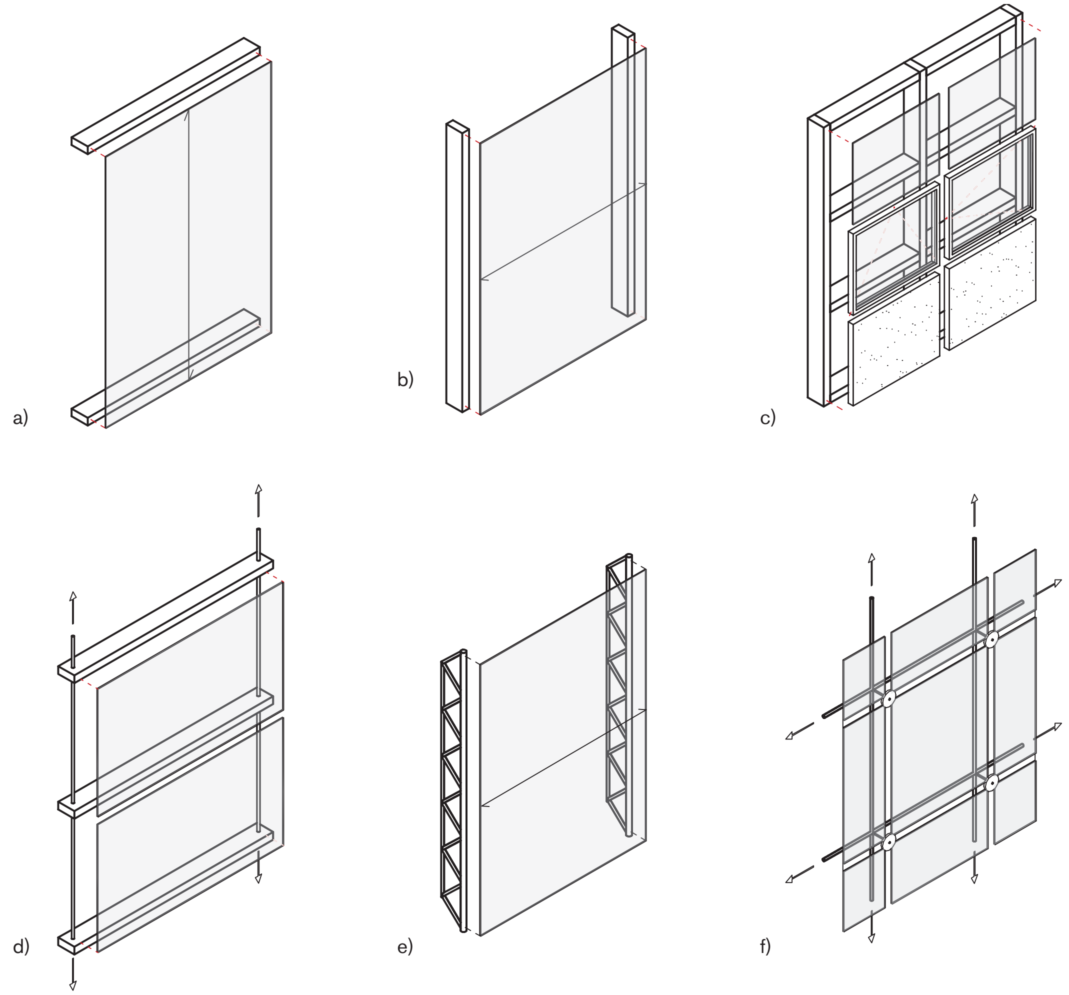
Façade load transfer
Different types of loads that need to be transferred.

If the façade is part of the primary structure (shell of building) and has a loadbearing function we need to consider the expansion differentials. In comparison to two separate structures, this can be a lot more complicated because the loads cannot be transferred via expansion joints as described above.

The drawing shows further examples of loadbearing systems for metal and glass façades (6).



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Loadbearing systems

a) Secondary structure without posts. The glass pane is subjected to one-sided vertical tension and must be dimensioned accordingly.

b) Secondary structure without beams.

c) Secondary structure with small partitions. Elements of varying functions are infilled.

d) Secondary structure consisting of lateral tie rods to transfer wind loads. Cables transfer loads up through the primary structure.

e) Replacement of the secondary structure by half-timbered structure.

f) Cable-mesh structure. The glass panes are connected with the cable-mesh structure by planar fittings mounted at the corners. The façade behaves like fabric under tension and relatively large linear deflections occur. This results in a rather large movement of the edge of the façade towards the façade plane, which has to be taken into account in the design of the structural connections.

In conclusion, there are numerous structural systems available for façade construction (7-9). The decision for a specific system depends on the following factors:

- Type of primary structure or shell of building
- Load transfer from the exterior towards the interior
- The size and properties of the infill elements (glass dimensions, deflections, weight, etc.)
- Architectural design

8

Wilhelm Lehmbruck Museum Duisburg, Manfred Lehmbruck and Klaus Hänsch, 1964
The façade consists of suspended glass panes with upper and lower framing. The suspended design allows for thinner glass material than a supported structure.

7

Detail of a cable-mesh façade
The glass panes are connected with the cable-mesh structure by point fixings mounted at the corners.

9

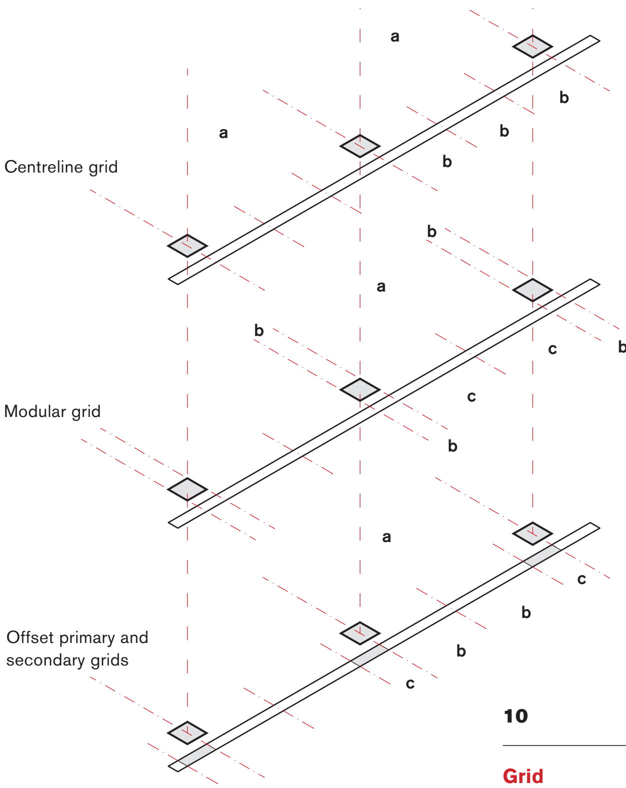
Point fixing façade
The loads from the glass panes are transferred via point fixings.

Grid and positioning of the façade within the building

Most buildings are designed with repetitive units, the so-called modular unit. The resulting grid helps to structure and organise the building volume into units based on the modular dimension. Thus, the position of each building component is specified and geometrically related to the adjacent components. Such grids are used to organise the entire floor plan as well as the individual components, e.g. masonry.

This kind of repetition is beneficial for the entire building process. In structural engineering, for example, a breakdown into standardised spans saves time and effort. Planning and communicating with project team members is simplified when everything relates to a basic grid. Even the furnishing of a building becomes easier. Of course different types of buildings may require different grids due to particular requirements, resulting in different structural systems.

Office buildings, for example, are usually based on a grid of 1.35 m (1.48 yd), allowing efficient furnishing. If the building comprises an underground parking garage the primary structure is usually based on a structural grid of 5.40 m or 8.10 m (5.91 yd or 8.86 yd), both multiples of the 1.35 m (1.48 yd) modular unit. This leaves sufficient space between the columns for two or three car-parking spaces.



10

Grid
a) Centreline grid. b) Modular grid.
c) Offset primary and secondary grids.

It is most efficient to use the same grid for the façade as for the building itself. Typically we distinguish between a primary and a secondary grid. The primary grid is based on the grid of the primary structure and the secondary structure of the façade is then aligned with the secondary grid. Hence the façade and bearing structure can be specified independently, and elements can be arranged at an offset. The recurrence of the geometrical relation between the shell of the building and the façade, i.e. the primary and the secondary structure, facilitates the alignment of joints and other details.

There are two basic grid types, whereby both can be combined in various ways (10).

Centreline grid: The base grid is aligned with the centreline of the building components. The length of the centreline is not defined. This can be particularly useful if the sizes of some or all components are not yet known.

Modular grid: A modular grid describes the extrapolation of the primary structure. The secondary grid of the façade is aligned with this primary grid. Zones with visibly varied widths are created in areas b and c.

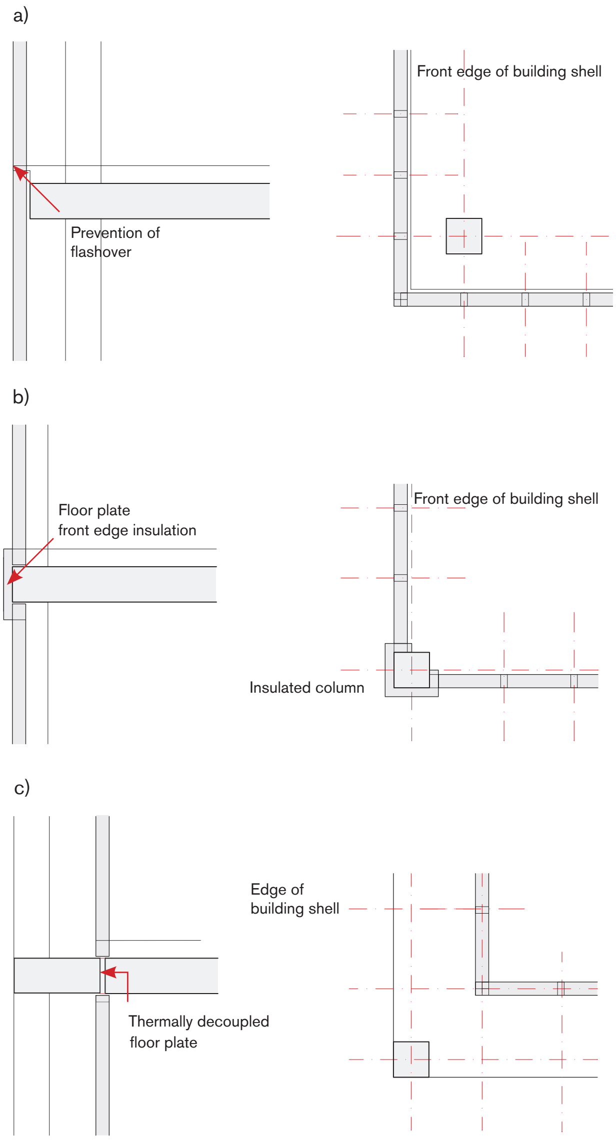
Primary and secondary grids at an offset: Offsetting the façade grid in relation to the secondary grid can have an intermediary effect. However, this needs careful consideration when designing the wall joints. Sometimes intermediate members (c) have to be inserted for adjustment, or they can be used as an optional design element.

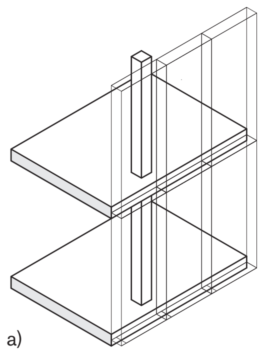
One of the most important attributes of a grid is that its definition entails a design decision. The organising principle of the grid is expressed in the façade. It defines the façade's proportion and rhythm. And choosing a particular grid helps to determine the horizontal and vertical arrangement of façade elements.

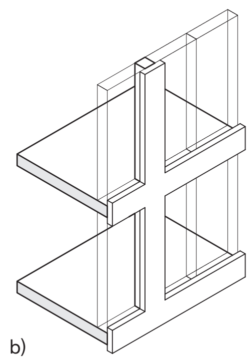
Deciding on the position of the façade in relationship to the load-bearing structure of the building is one of the primary considerations in terms of the design and structure of the building (11-12).

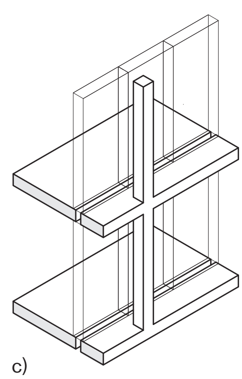
11

Atlasgebouw Wageningen,
van den Oever, Zaaijer & Partners Architecten, 2006
The façade lies behind the building's loadbearing structure.









12

The façade's position
a) The secondary structure of the façade is positioned in front of the primary structure of the building. The shape of the ceiling slab in front of the column can vary. If the grids were aligned the size of the corner elements would be predetermined. The corner is transparent. It is possible to avoid showing the ceiling slab in the exterior façade grid. When doing so special consideration needs to be given to the space between the façade and the shell of the building for fire protection.

b) The façade is flushed with the primary structure. The surface of the ceiling slab needs to be insulated due to thermal requirements. The column's position creates an enclosed façade corner.

c) The façade is situated behind the primary structure. In this example the ceiling-floor unit penetrates the building's insulation, and therefore needs to be thermally decoupled. The column stands unattached in the outer corner.