Key Design Factors

Figure 2.11 (Above) Various forms of lattice truss used in industrial buildings

(a) Lattice girder - W form
(b) Lattice girder - N form
(c) Duo-pitch lattice girder
(d) Articulated lattice girder
(e) Curved lattice girder
(f) Curved lattice truss and canopy
(g) Articulated bow-string
(h) Mono-pitch lattice girder with canopy

Figure 2.12 (Left) Lattice truss using tubular members
Particularly in space structures, the joints may be very complex and more time consuming to construct and install. Therefore, possible applications of this type of structure are industrial buildings that also serve architectural purposes, rather than merely functional buildings.

Suspended structures can be designed by extending columns outside the building envelope, as illustrated in Figure 2.14. Suspended structures accomplish longer spans, although the suspension cables or rods also penetrate the building envelope, and can be obstructive to the use of the external space.

Lattice and suspended structures are complex and are not covered in detail in this Best Practice Guide.

**Fire Safety**

Even though the general context of fire safety regulations is the same throughout Europe, national differences do exist. For example a single-storey industrial building in the Netherlands with a compartment size of 50 x 100 m has no requirements concerning fire resistance, whereas in France, a fire resistance of 30 minutes is required in many cases, and in Italy the requirement is possibly as high as 90 minutes. At the design stage, the following fire safety issues should be addressed:

- Means of escape (number of emergency exits, characteristics of exit and number of staircases, exits, doors).
- Fire spread (including fire resistance and reaction to fire).
- Air supply and heat exhaust ventilation system.
- Active fire fighting measures (hand extinguishers, smoke detectors, sprinklers, plant fire brigade).
- Access for the fire brigade.

Fire resistance requirements should be based on the parameters influencing fire growth and development, which include:

- Risk of fire (probability of fire occurrence, fire spread, fire duration, fire load, severity of fire, etc.).
- Ventilation conditions (air input, smoke exhaust).
- Fire compartment (type, size, geometry).
- Type of structural system.
- Evacuation conditions.
- Safety of rescue team.
- Risk for neighbouring buildings.
- Active fire fighting measures.

The new generation of European regulations allow, in addition to performing fire tests, three levels of fire design calculations:

**Level 1:** Classification of structural components by using tables.

**Level 2:** Simplified calculation methods.

**Level 3:** Advanced calculation methods.

**Building physics**

**Thermal insulation**

The main purpose of thermal insulation in industrial buildings is to ensure an adequate indoor climate depending on the use of the building. During the heating season, one of the main functions of the building envelope is to reduce the heat loss by means of effective insulation. This is particularly true for buildings with normal indoor temperatures, such as retail stores, exhibition halls and leisure centres, it is true to a lesser extent for buildings with low indoor temperatures, such as workshops and warehouses.

For large panels, thermal bridges and airtightness of joints have a major influence on the energy-balance of the building. The thermal insulation has to be placed without gaps and the building envelope must be sealed and made airtight at longitudinal and transverse joints.
values of various types of imposed loads on roofs:

- A minimum load of 0.6 kN/m² (on plan) for roof slopes less than 30° is applied, where no access other than for cleaning and maintenance is intended.
- A concentrated load of 0.9 kN - this will only affect the sheeting design.
- A uniformly distributed load due to snow over the complete roof area. The value of the load depends on the building’s location and height above sea level. If multi-bay portal frames with roof slopes are used, the effect of concentrated snow loads in the valleys has to be considered.
- A non-uniform load caused by snow drifting across the roof due to wind blowing across the ridge of the building and depositing more snow on the leeward side. This is only considered for slopes greater than 15° and will not therefore apply to most industrial buildings.

**Horizontal loads**

**Wind loadings**

Wind actions are given by EN 1991-1-4. Wind loading rarely determines the size of members in low-rise single span portal frames where the height : span ratio is less than 1:4. Therefore, wind loading can usually be ignored for preliminary design of portal frames, unless the height-span ratio is large, or if the dynamic pressure is high. Combined wind and snow loading is often critical in this case.

However, in two span and other multi-span portal frames, combined wind and vertical load may often determine the sizes of the members, when alternate internal columns are omitted. The magnitude of the wind loading can determine which type of verification has to be provided. If large horizontal deflections at the eaves occur in combination with high axial forces, then second order effects have to be considered in the verification procedure.

Wind uplift forces on cladding can be relatively high at the corner of the building and at the eaves and ridge. In these areas, it may be necessary to reduce the spacing of the purlins and side rails.

**Imperfections**

Equivalent horizontal forces have to be considered due to geometrical and structural imperfections. According to EN 1993-1-1 for frames sensitive to buckling in a sway mode, the effect of imperfections should be allowed for in frame analysis by means of an equivalent imperfection in the form of:

- initial sway deflections; and / or
- individual bow imperfections of members.

**Other horizontal loads**

Depending on the project and other horizontal loading, members are to be considered such as earth pressure, pressure to operation of cranes, accidental actions and dynamic action.

**Concept design considerations**

**General issues**

Prior to the detailed design of an industrial building, it is essential to consider many aspects such as:

- Space optimization.
- Speed of construction.
- Access and security.
- Flexibility of use.
- Environmental performance.
- Standardization of components.
- Infrastructure of supply.
- Service integration.
- Landscaping.
- Aesthetics and visual impact.
- Thermal performance and air-tightness.
- Acoustic insulation.
- Weather-tightness.
- Fire safety.
- Design life.
- Sustainability considerations.
- End of life and re-use.

In the first instance, it is necessary to identify the size of the enclosure and to develop a structural scheme, which will provide this functional space taking into account all the above considerations.

The importance of each of these considerations depends on the type of building. For example, the requirements concerning a distribution centre will be different from those of a manufacturing unit.

To develop an effective concept design, it is necessary to review these considerations based on their importance, depending on the type of building. Table 2.3 presents a matrix which relates the importance of each consideration to particular types of industrial buildings. Note that this matrix is only indicative, as each project will be different. However, the matrix can serve as a general aid.

**Compartmentation & mixed use**

Increasingly, larger industrial buildings are designed for mixed use, i.e. in most cases integrated office space and / or staff rooms for the employees are provided. There are different possible locations for these additional spaces and uses, as shown in Figure 2.16:

- For single-storey industrial buildings, creation of separate space inside the building and possibly two storeys high, separated by internal walls.
- In an external building, directly connected to the hall itself.
- For two-storey industrial buildings, partly occupying the upper floor.

This leads to special concept design requirements concerning the support structure and the building physics performance. If the office area is situated on the upper storey of the industrial building, it may be designed as a separate structure enclosed by the structure of the building. In this case, floor systems from commercial buildings can be used, often based on composite
Hangers may be required on long spans.

Figure 3.7  Tied portal frame

Figure 3.8  Mansard portal frame

Figure 3.9  Curved rafter portal frame

Figure 3.10  Cellular beam used in portal frame

Figure 3.11  End gables in a frame structure
In this section, some national practices are given for several countries. The construction systems have been identified as good practice in the countries concerned, although they may not be widely used in Europe.

**Current Practice in Germany**

**Structure**

In Germany, industrial buildings are typically constructed as portal frames with pinned column bases. The span of the frames varies from 12 m to 30 m when hot-rolled or welded I-sections are used, and spans are most commonly between 15 m and 20 m. Lattice trusses are a typical solution for spans greater than 30 m. If there are no restrictions in the building usage, multi-bay portal frames using I-sections are often used with spans of up to 20 m.

Other load-bearing structures, such as simply-supported beams on columns, arches, grids, shells, etc. are less often used, except for some architecturally expressive buildings.

The column spacing usually ranges between 5 m and 8 m, while up to 10 m is possible. The eaves height of the frame is about 4.5 m in standard cases, increasing to 8 m and more, if overhead cranes are provided.

The columns of portal frames made of IPE- or HE-sections are often designed with rafters which are haunched in the highly stressed regions. Bolted connections are mostly used with continuous columns combined with beams having end-plates, as shown in Figure 3.15. In some cases, the haunched part of the beam is attached to the column in the fabrication shop and the part of the beam with constant height is then connected on site using a bolted connection.

It is equally common for the sheeting to span between rafters and between purlins. About 40% of purlins are hot rolled and 60% are cold formed, with the cold formed proportion rising.

The design is almost exclusively carried out by using elastic calculation of the internal forces and moments, and comparing these with either elastic or plastic resistances of the cross section. The current design standard is DIN 18800. Part 1, which is similar to Eurocode standard EN 1993-1-1.

**Roofing**

Roofs of industrial buildings in Germany are usually trapezoidal steel sheeting spanning directly between the portal frames or supported by the purlins.

Currently the single-layer, insulated steel sheeting roof, as shown in Figure 5.1 (left) is the most widely used type of roof cladding in industrial buildings in Germany. For this type of cladding, the slope should be not less than 2° in order to ensure sufficient drainage. This type of roof is comparatively low in cost, but is susceptible to mechanical damage of the weather-proofing layer.

Sandwich panel construction, as shown in Figure 5.1(right), has gained more importance, because it is easy to maintain and achieves longer useful life. Further advantages are a higher resistance to damage and good acoustic insulation and fire resistance. Often the waterproofing layer is fixed to the load-bearing layer by a clamped joint with
A typical open plan building is shown in Figure 5.14. Often a gabled roof with an angle of 3.6° or 5.7° is used. The spacing between rafters is typically 6 to 10 m. The walls are made from composite panels or profiled sheeting placed on light steel side rails. The insulation is placed on top of the profiled sheeting and covered with a suitable roof material. A plastic membrane is used for air and moisture-tightness.

Lattice trusses are generally used for the rafters. Spans up to 45 m can be achieved with standard sections. The columns are typically HEA-sections, fastened with four anchor bolts on a base plate. Although the columns are considered as pin-ended at the base, four bolts are recommended in order to provide column stability during erection.

For non-insulated industrial buildings, the profiled sheeting is supported by purlins, and Z-profiles are often used as purlins up to 12 m span.

Using pinned columns, it is essential to stabilise the building during erection. It is often necessary to brace columns and sometimes the rafters too. As bracing of the columns is necessary during erection, it is common to design the bracing as permanent, thus not considering diaphragm action of the walls.

**Roof cladding**

There are a number of products for roofs, mainly profiled sheeting and tiles. The profiled sheeting is typically of the form shown in Figure 5.15. Roof tiles may be used for roof slopes of 14° and more. Roofing tiles use traditional colours and are significantly lighter than ceramic or concrete tiles.

Deep profiled sheeting may be used for insulated roofs with spans up to around 11 m and the longer spans are achieved with sheeting stiffened in both directions. Shorter spans, up to 8 m, are achieved with more traditional profiles.
organisation. To facilitate this option, criteria such as minimum height and higher imposed loads are often specified to maintain the asset value and provide flexibility for future uses.

**Maintenance**
Many buildings are constructed for owner occupation. Where a building is let, ‘full repairing 25 year leases’ (where the tenant is responsible for maintenance), are being replaced by shorter leases, where the owner carries maintenance responsibility. Where the original owner has responsibility for maintenance, the choice of better quality materials with a longer life expectancy and reduced maintenance costs are encouraged.

**Sustainability**
Energy costs and the reduction of CO$_2$ emissions are becoming increasingly important and sustainability is now a key issue within the planning process. In the future, it is likely that planning permission will be easier to obtain with sustainable, environmentally friendly solutions. Many clients, potential clients and occupiers have sustainability policies against which their performance is monitored.

**Value for money**
Steel has achieved a large market share in this sector because of responsiveness to client demand. With the increasing complexity in design, there is also an increased inter-dependency between the various elements and a high degree of cooperation and coordination.

**Design Issues**
Steel construction is one of the most efficient sectors in the construction industry. Leading suppliers manufacture the components offsite, using computer controlled equipment driven directly by information contained in 3D computer...
Airbus Industrial Hall in Toulouse, France

Steel construction provides efficient long span and low weight structural frame for large industrial halls that will produce the next generation A380 Airbus aeroplane for intercontinental flights.

Application Benefits:

- Fast track construction
- Efficient use of steel components
- Flexibility of space organisation
- Sustainable design approach
- High crane facilities

This industrial building covers 200,000 m² of floor space, is 45 m high and provides spans of more than 115 m. Criteria to be met were efficient space occupancy and flexibility in arrangement of the internal space.

Due to the expected change in the industrial process after several years of production, a reconfiguration/refurbishing approach design was considered, taking count of rapid financial return. Architectural and structural appearance were intended to be an attractive reflection of the company performance.

The largest hall, which is 115 m long by 250 m wide, is equipped with the following heavy cranes:
- Two parallel industrial rolling cranes, 50 m span, 22 tonnes capacity for lifting of the wings.
- Two parallel industrial rolling cranes, 35 m span, 30 tonnes capacity for fuselage transportation.
- Two dual loads 2 x 4 suspended cranes for normal service.

The wing-lifting cranes roll on rails suspended on the truss of the frame of the roof. Sliding doors provide a 117 x 32 m² opening. They are supported by their own structural frame. This huge structure was designed and installed economically using fabricated sections and a trussed upper beam.
Distribution Centre in Waghäusel, Germany

The third distribution centre of dm-drogerie markt was completed in 2004 with a storage area of 20,000 m². By using the rack-supported building system, time and money was saved compared to traditional solutions.

Application Benefits:
- Maximum storage density
- Building use is unaffected by the structure
- Cheapest construction method for high-bay warehouse
- Short construction period
- Fast return of capital investment

Dm-drogerie markt – one of the leading drugstore chains in Europe – operates over 1,500 retail outlets and employs some 20,000 people. With a turnover of almost 3 billion Euros, dm-drogerie markt offers a range of some 12,000 product lines. In 2003, dm-drogerie markt decided to build a further logistics facility in Waghäusel, located in southern Germany between Karlsruhe and Mannheim.

The distribution centre is divided into four main parts. While the building for incoming and outgoing goods, servicing rooms, as well as offices, social rooms and canteen were built in reinforced concrete, the heart of the complex, the commission store, is built in steel. The commission store is 90 m long, 125 m wide and 20 m high and it provides space for 24,024 commissioning and storage bins.

The commissioning store was a rack-supported storage system, named because the construction of the steel racks also acts as the main support structure for roof and wall. Roof and wall cladding were rapidly attached to the racking construction parallel to the assembly. Compared to traditional solutions comprising a main support structure and racks that only support themselves, the construction period was significantly shorter, thus achieving an earlier return of the investment.

Apart from the short construction period and the comparatively low cost, the significantly shorter amortization period is an additional advantage. However, the racking system had to be designed taking into account the additional load cases due to the self-weight of the building envelope and imposed wind and snow loads.
Construction details
The steel construction of the rack-supported structure of the commissioning store was erected on a floor slab of reinforced concrete.

The wall cladding was designed using isolated cassette elements. The interior cassettes were attached to the gable columns and the columns of the longitudinal walls. The roof beams were arranged in accordance with the division of the racks in the longitudinal direction at a spacing of 3.14 m. An extensive ‘green’ roof was created using steel sheeting, 100 mm of thermal insulation, a sealant layer and soil covering.

There are a total of 5 stair towers in reinforced concrete with a fire resistance of 90 minutes. At the rear wall, external escape catwalks made of steel serve as connecting bridges to the stairway towers.

Fire protection
The commissioning store, hall for incoming/outgoing goods and servicing rooms are part of 90 minute fire walls. The fire walls reach up to 0.5 m above the roof of the incoming/outgoing goods store. Furthermore, an impact resistant roof strip made of reinforced concrete was erected to prevent the fire spread between commissioning store and hall for incoming/outgoing goods.

Both the commissioning store and the incoming/outgoing goods store are equipped with full sprinkler systems, with additional in-rack sprinklers in the commissioning store. In addition, an automatic fire alarm system was installed.