11 Building Design

The architectural and structural design of a building consists of four components which impact its form: the load-bearing structure, shell, media routings (pipelines, wiring etc.), and interior finishings. The “performance” of a building—that is its ability to serve both current and future purposes—is determined by the characteristics of the selected technical and structural solutions together with these four components. For those interested in examples of industrial buildings, a wide range of designs are presented in [Ada04].

In Fig. 11.1, we have illustrated our approach to a comprehensive discussion about the variations of structural characteristics from the perspective of the processes and the enveloping space. It is important to differentiate between unchangeable, difficult to change and easy to change characteristics in comparison to the anticipated changes in requirements because these decisions determine the future changeability of the building.

The load-bearing *structure* or structural framework is the most permanent component of a building and thus the most difficult to change. Generally, it is designed to last the full duration of the building’s use. The structure consists of the surface and column-like components, reinforcements and foundations required to ensure the stability of the building. The components used are either constructed on-site or modular and are made from steel, reinforced concrete, wood, light alloys or combinations of these materials. The selected structure strongly influences the long term functionality of the building as well as the interior and exterior architectural design.

The *shell* separates a protected interior space—as an independent climatic area—from an external space. It consists of stationary, closed or transparent elements for the façade and roof as well as moveable parts such as gates, doors, windows or vents. Aspects such as natural lighting, the afforded views and communication in particular, determine the long term quality and changeability of the building shell.

We use the term *building services* to refer to all of the equipment necessary to ensure the production processes, users’ comfort and building security including the technical equipment centers, pipelines, wire routings, connections, etc. It covers all measures which guarantee the spatial comfort of users and provide the necessary technical media for the production facilities.

The technical facilities associated with the building are treated in literature under the term TBE technical building equipment, and include facilities for sewage, water, gas and fire extinguishing systems, heat supply, ventilation, electrical systems and building control systems. In particular, aspects such as modularity, upgradeability and accessibility (i.e., for maintenance purposes) determine the degree of the building equipment changeability.

With *interior finishings* we are referring to all of the stairways, building cores and special built-in units like elevators or wet rooms as well as static optional components (walls, windows etc.).

H.-P. Wiendahl et al., *Handbook Factory Planning and Design*,
DOI 10.1007/978-3-662-46391-8_11,

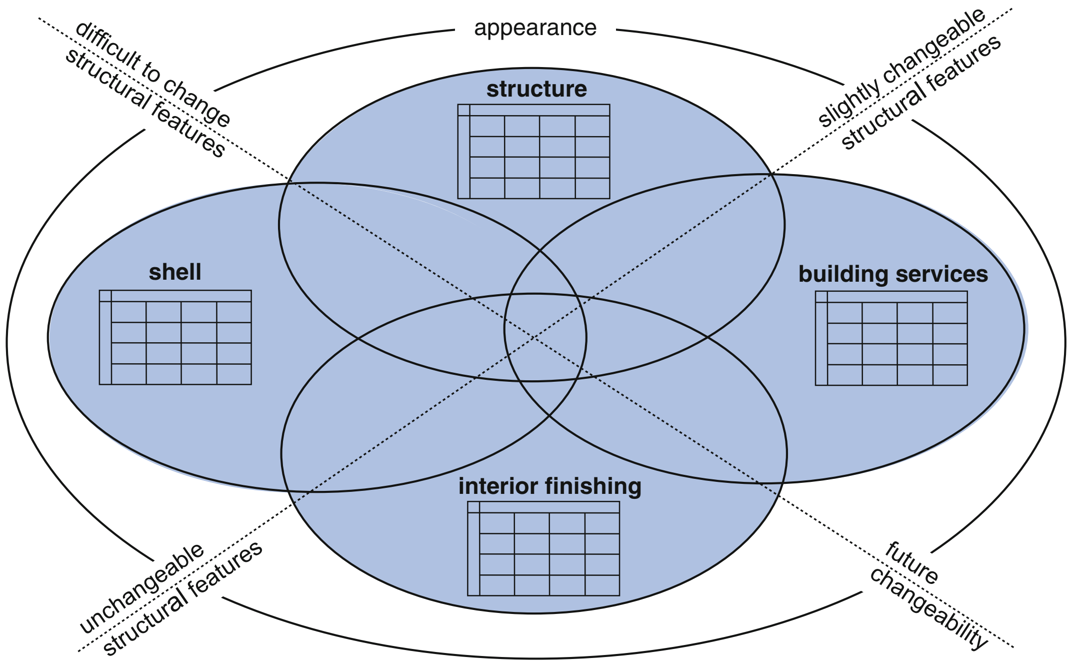


Fig. 11.1 Design fields of a building. © Reichardt 14.782_JR_B

Generally speaking, permanent interior finishings should be kept to a minimum so as not to limit or impede the changeability of processes.

Finally, the appearance of industrial and commercial architecture is created by the overall atmosphere, structural order and clarity as well as the balance between unity and diversity. The resulting feeling of harmony is attained through internal cohesiveness of the elements in relation to their entirety much like a living organism. The clearly articulated structures and architectural forms as well as the immediate understanding and legibility of each component's purpose play a decisive role in the overall construction.

A high aesthetic quality does not necessarily mean high costs nor does it require special fascia-work or unique treatments. The principle of simplicity should not be mistaken for banality, lack of imagination and primitivism found in common commercial construction. Rather, the demand for economic efficiency goes extremely well with the concept of minimalism as do a lack of fascia-work and the avoidance of embellishment.

As mentioned above, the "performance" of a building, (i.e. its ability to serve current and future purposes) is basically determined by the features of the chosen technical and structural solutions together with the building structure, shell, media and finishings. The most important objective when planning a building is an in-depth discussion through which everyone involved in the planning reaches a mutual agreement upon all of the performance related features.

An optimized layout designed with modular resources and spaces is helpful in effectively coordinating the processes and spatial planning. Choosing a common dimensional scheme simplifies the allocation of media systems to production units and facilitates modifications in the sense of changeability. Moreover later, it expedites cost-effective addition of building elements such as hall bays on the façade.

In order to exploit the building's changeability with regards to current tasks, tasks extended in the future as well as to tasks not yet known, it is important to strategically combine unchangeable, difficult to change and changeable structural

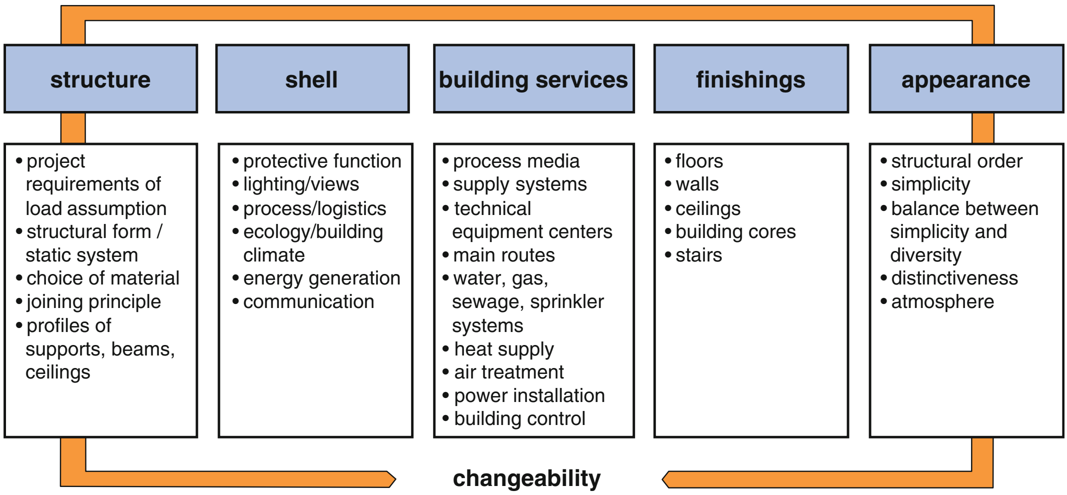


Fig. 11.2 Structural features of a building. © Reichardt 15.181_JR_B

features. The term 'unchangeable structural features' refers here to the load-bearing capacity of the foundation and base plate, whereas 'difficult to change' structural features include the load-bearing capacity of support columns and beams profiles as well as the diagonal braces of the static reinforcement which limit the expansion of a hall. Changeable structural features include moveable, closed or transparent façade elements, which, depending on the need, allow daylight inside the building either from the hall façade or roof openings.

Figure 11.2 provides an overview of the structural features of the building's design fields described above. In this chapter we will discuss each of these in detail with regards to their significance for changeability.

11.1 Load-Bearing Structure

11.1.1 Project Requirements and Load Assumption

In order to meet the manifold and in some cases contradicting requirements of a specific project, it is necessary to find a way to design the load-bearing structure oriented towards the long term production strategy of the company. Figure 11.3 depicts examples of various project requirements for the structure. The geometric and technological parameters derived from the production and logistic processes are the primary factors influencing the load-bearing structure and determine how the building services are installed. As explained extensively in Chap. 5, the changeability of size and utilization areas as well as built-in units plays a dominant role. During the utilization phase the protection and safety of people and property as well as comfort levels are equally important criteria. Ultimately though, the main priority is economics i.e., the costs and construction time.

Pursuing what we call a 'synergetic factory planning' (presented in detail in Chap. 15), fuses the project specific requirements together into a so-called 'requirement profile'. The concrete parameters are then aligned by all those participating in the planning process, especially in view of the long term changeability.

Once the basic project requirements are defined, the dimensions for the structural members should be estimated early-on; this can be accomplished using tables such as those found in [Kra07]. In order to do so, the load assumptions for the traffic loads, static loads and dynamic loads need to be determined. In most cases, countries have set standards, which help in determining the applicable load assumptions for

- **processes, logistics**
  - manufacturing facilities:
  - conveyor and store technology (1)
  - column grid
  - room heights, ceiling heights
  - vibration resistance
  - media routing (2)
- **changeability**
  - expandable areas (3)
  - reinforcibility
  - platform fittings (4)
- **personnel safety**
  - fire protection
  - escape routes
- **protection of property**
  - value of goods
  - insurance conditions
- **comfort conditions**
  - soundproofing
  - ability to store energy
- **building erection, costing**
  - construction costs & time
  - utilization costs & time
  - recycling building-materials
  - economy

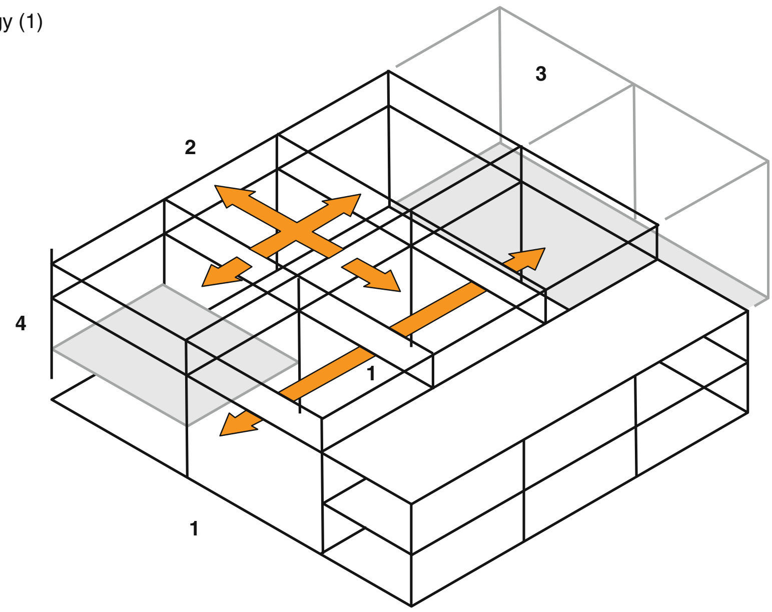


Fig. 11.3 Project requirements for the load-bearing structure. © Reichardt 15.182_JR_B

various building typologies. For example in European countries, loads generally need to be established in compliance with the EN Eurocode standards, Similarly one could refer to BS 6399 "Loading for Buildings". Part 1 of the practice code refers to *dead and imposed loads*, Part 2 to *wind loads* and Part 3 to *imposed roof loads* [BS6399] for projects which need to be in compliance with the same.

In the absence of the relevant data, the planning team has to make common assumptions. For example, the location of the main technical centers for the equipment or suspensions for media needs to be addressed at an early stage of the project with care. It is therefore advisable to document all findings and assumptions related to the project in segments and to continually refine these as the project progresses (see also Chap. 16 Project Management and Chap. 17 Facilities Management).

Figure 11.4 provides an overview of important load assumptions for the main elements of the structural framework. Some of these are conditional on processes, others are due to local conditions e.g., the snow load. The effort to create foundations and the base plate is largely determined by the quality of the specific subsoil, especially by groundwater level and location as well as the existence of load bearing soil layers, which is why a qualified soil report must be submitted when the project starts. The floor plate plays a special role with regards to changeability as it decisively determines the possibilities for changing the location of equipment and machinery or re-designating floor surfaces e.g. from logistics to manufacturing or vice versa.

It is well worth taking time for a detailed discussion on the possible additional future loads. Although the initial cost of the structure increases if the building is designed for additional future loads it also provides for a corresponding higher degree of changeability. When making decisions it is critical to practically weigh both strategic and economic factors. Expanding floor areas or overhead areas have to be considered with foresight, in the same way as anticipated changes in the production e.g., a new generation of machinery and equipment along with their structural requirements.

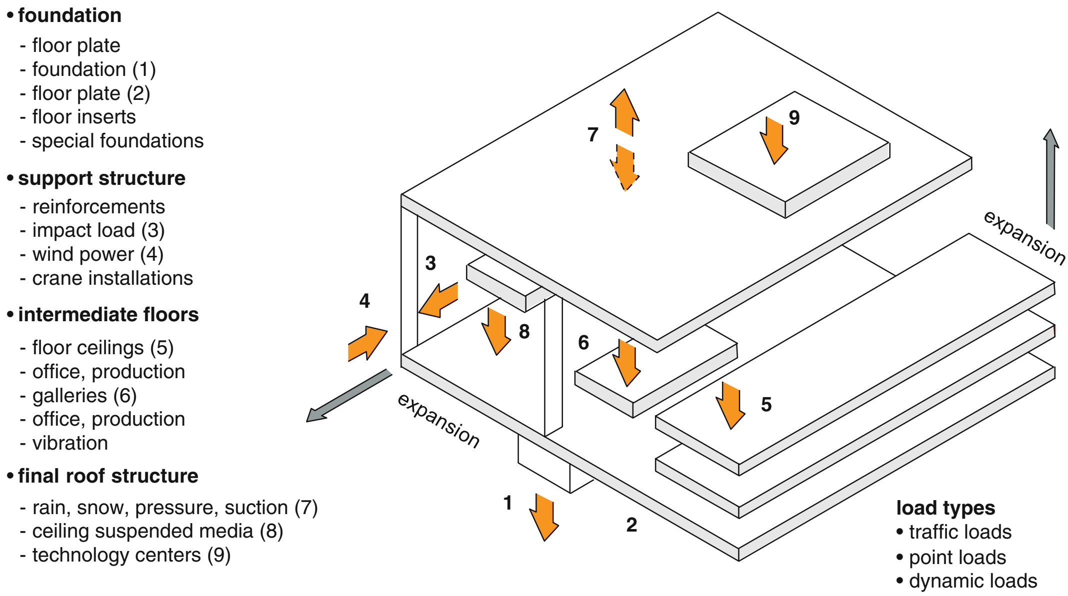


Fig. 11.4 Overview of load assumptions for a building structure. © Reichardt 15.183_JR_B

11.1.2 Building Structure Form as a Static System

The properties of the building structure are determined by the architectural usage of beams and supports systems, ceiling systems, floor plates, foundations, load-bearing walls and cores. In general, the resultant distributions of the static system's forces define the structural form of a building. In turn, the selection of the structural form and the principle behind the load transfer and bracing determine which directions the building can be extended as well as its suitability for accommodating special loading conditions. Based on [Eng07], eight families of structures can be roughly distinguished: beam structures, grids, frames, arches, cable suspensions, cable trusses and domes as well as cable nets and textile constructions.

According to [Gri97] structural forms for halls can be simplified into four groups: supports and beams, frames, arches and space frames. Figure 11.5 provides an overview of structural forms for halls which employ either combined support/truss structures or just truss structures; arch systems and space frames are seldom used in factory buildings and thus not addressed here.

Generally, every hall and multi-story building has to be braced longitudinally and transversely. Space frames or arch structures are inherently stable in transverse direction and thus only need to be braced longitudinally. Directed structures are clearly identifiable by the location of the main and secondary support beams. Here, the vertical load is directed along a single axis over the main beam into the support columns. In comparison, non-directed structures distribute the vertical load bi-axially over all the structural members into the support columns. Non-directed structures are thus usually only efficient on square support fields. Nevertheless, it is easier to extend in two directions with non-directed structures than with directed structures.

According to Fig. 11.6, it is also critical to discuss how the modularity, span width, reinforcements, load distribution and extensions can be combined for every project from both the process and spatial perspective. When doing so the horizontal and vertical extensions should be distinguished from one another. It is advisable to employ 3D modeling techniques so as to identify possible areas of conflicts between process facilities and building services early on. In general, a higher degree of changeability leads to a number

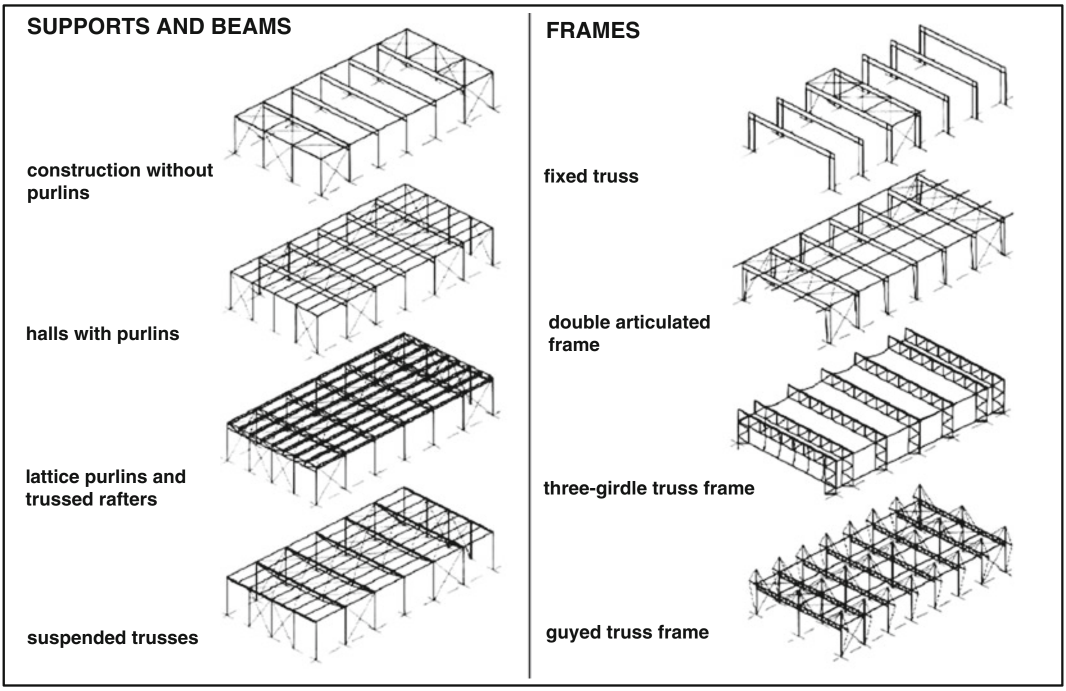


Fig. 11.5 Load-bearing structures and static systems for halls. © Reichardt 15.184_JR_B

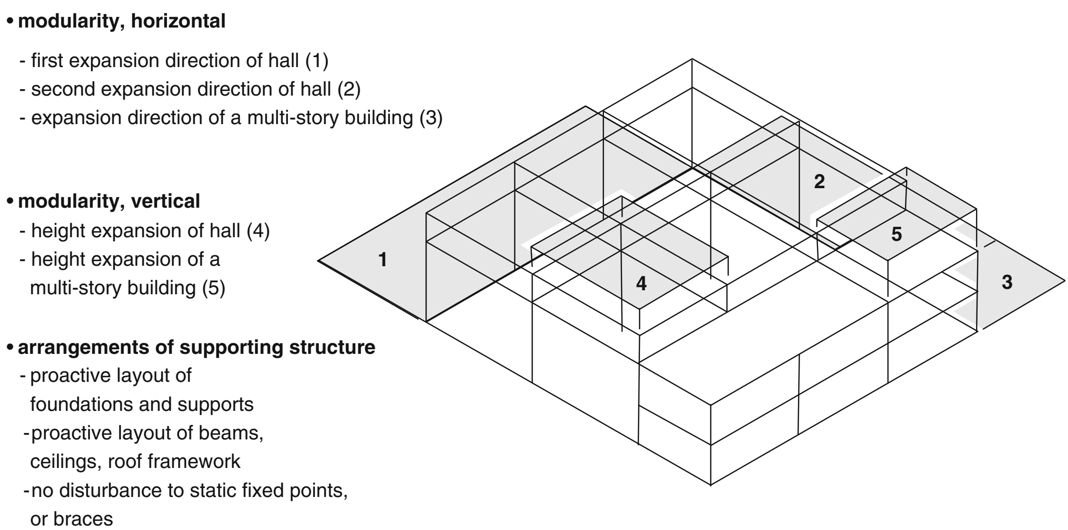


Fig. 11.6 Possible structural framework forms. © Reichardt 15.185_JR_B

of possibilities for extensions and expansions. The building structure for large halls, for example, should permit galleries to be built-in for administrative functions closely related to the production (work planning, production control, quality assurance etc.) and should thus allow interiors to be easily modified. If necessary, these auxiliary levels could be suspended from the hall structure in order to provide for an unobstructed column free space below.

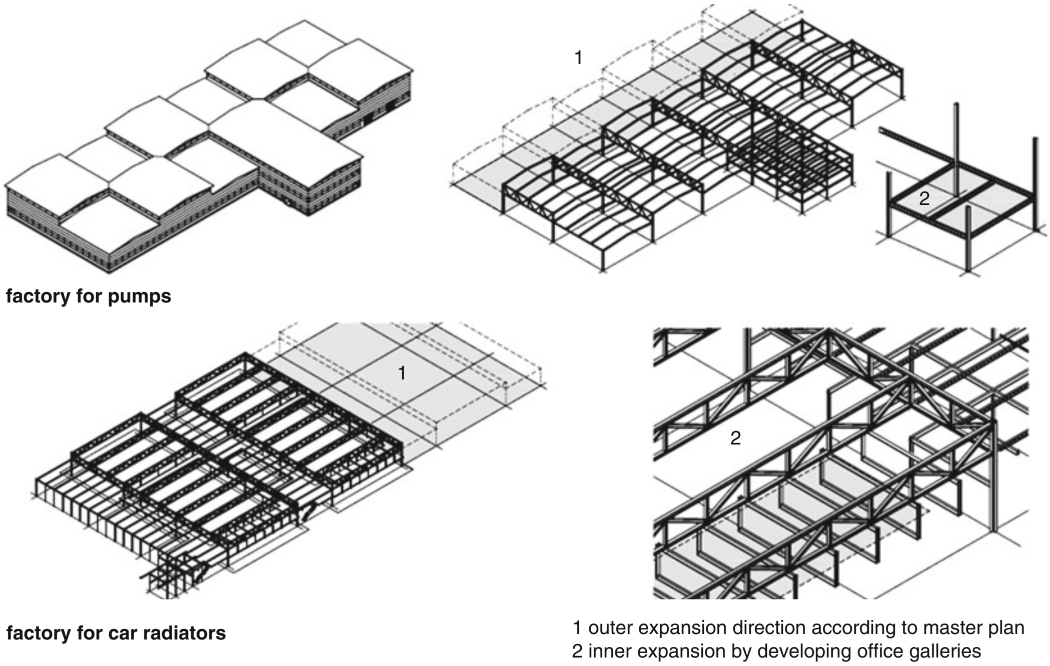


Fig. 11.7 Building structures examples. © Reichardt 15.186_JR_B

Figure 11.7 shows two projects that were realized and the options they offer for external or internal extensions. In the case of the pump factory, six additional modules of 21 × 21 m (68 × 68 ft) could be added on to the length without disrupting the production. The interior of the module set at the front is furnished with office spaces that continue into the factory and thus facilitate direct communication. Similarly, in the car radiator factory large and independent modules spanning 18 or 36 m (59 × 118 ft) can be added without disruption of operation. Instead of a separate administrative building, an integrated office gallery offers room for the management with a direct view on to the production processes (see also Fig. 11.43).

Skylights are recommended for providing naturally lit work areas in low-rise buildings and halls. These naturally lit areas either run parallel or perpendicular to the span of the load-bearing structure. If naturally lit areas are installed perpendicular to the structural span, the structural members would then lie within or outside the temperature regulated area underneath the building's shell. This type of construction can rarely be justified in the sense of energy consciousness due to the cold bridges that are thus created. It is therefore much more practical to install exposure areas in relief structures parallel to filigree beams so that the daylight can penetrate the girder area. Examples of various applications of lighting elements as well as the relationships between the light openings, room heights and room depths are discussed further in Sect. 11.2.3 on natural lighting.

In regards to the economy of hall structures with large spans, it is also important to pay attention to the impact loads resulting from the movement of the fork lift trucks on supports as well as the sum of the loads to be suspended by the roof structure. Furthermore, the use of a floor based distribution system for media should be investigated as a means of minimizing the load with broad-spanning hall roofs.

In order to find solutions for a specific project it is advisable to discuss optional plans from different perspectives. Figure 11.8 depicts a comparative analysis of a few possible modular

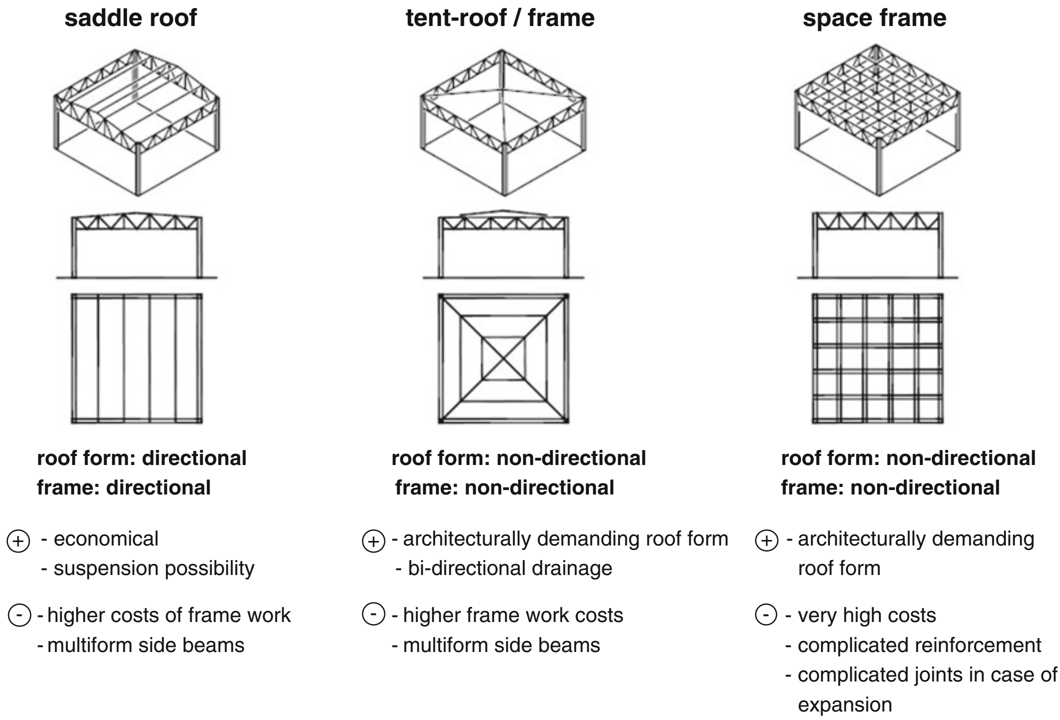


Fig. 11.8 Possible building structures for a car assembly hall. © Reichardt 15.187_JR_B

structural forms and static systems based on a typical car assembly hall. A comprehensive assessment includes studying the advantages and disadvantages of the processes, architecture, structure, building services and economic efficiency.

Steel, a material that can withstand a great deal of stress, is a preferable option for changeable load-bearing structures for a number of reasons. Wide spanning structures can be developed with relatively minimal weight. It also allows for comfortable routing of services pipes through the truss-work. In order to ensure that the building structure complies with fire protection regulations composite steel constructions (i.e., load-bearing elements encased in concrete) can be used.

In Europe, the Euro codes, which were introduced as construction standards, regulate corresponding requirements for building structures e.g., DD ENV 1993 Eurocode 3: *Design of Steel Structures* [ENV1993], DD ENV 1994, Eurocode 4: *Design of Composite Steel and Concrete Structures* [ENV1994], DD ENV 1998 and Eurocode 8: *Design of Structures for Earthquake Resistance* [ENV1998]. In the United States (I) E72–E1670 regulate the entire construction process with reference to 108 subsystems, processes and quality controls [E1670].

11.1.3 Span Width

Determining the span width for halls or multistoried buildings is one of the important, if not the most important decision from the perspective of processes and space. The aim to have as few supporting columns as possible obstructing the use of space has to be weighed against the efficiency of the building structure; the optimum targets a compromise that is tolerable from both perspectives. Polonyi examined the cost development as a function of the span, roof load and material for an approximately 300 m^2 (3,229 sqft) hall with a clearance of approximately 6.50 m (21 ft) [Pol03]. A double articulated frame, a

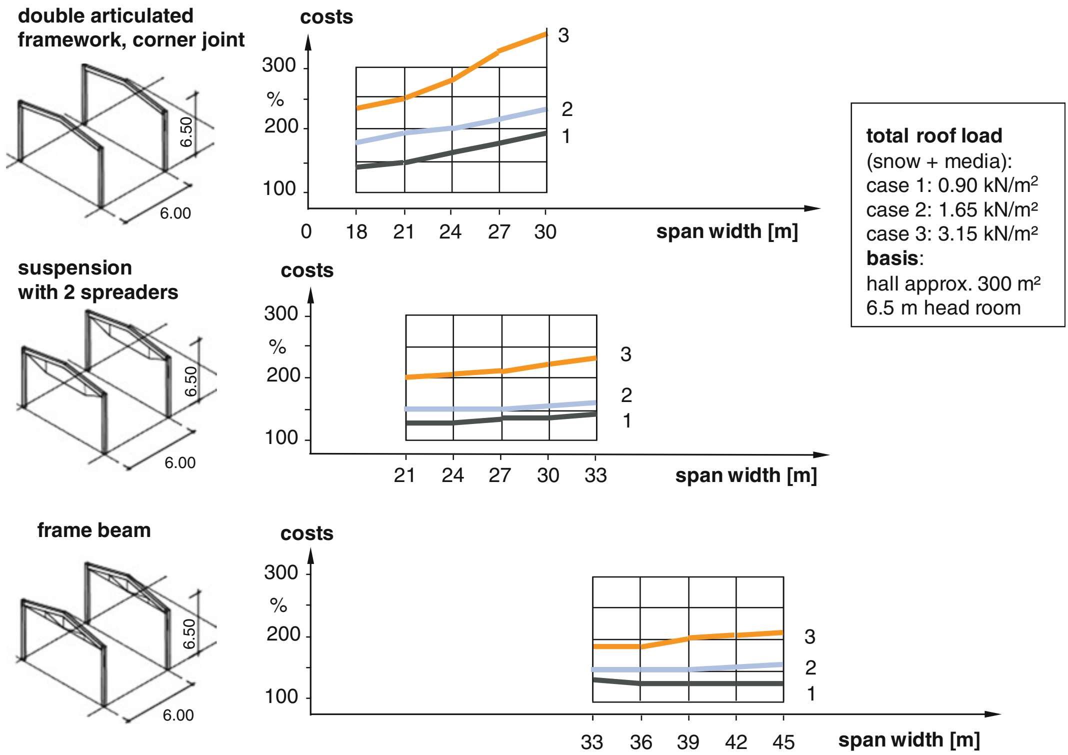


Fig. 11.9 Relative costs for timber load-bearing frames. © Reichardt 15.188_JR_B

cable-supported double-spreader structure and a frame-beam system were chosen as the basic optional static systems to be compared for both steel and timber cross-sections. According to Figs. 11.9 and 11.10, the relative costs can be derived as a function of the span width.

Accordingly, in industrial hall construction, in comparison to the standard solutions with a 20 m (65 ft) span, structures with a span of 30–50 m (98–164 ft) are also possible without additional construction cost burden provided that the roof loads (i.e. snow load, suspended loads, etc.) are minimal. In some cases, cable supported timber constructions divided in compression and tensile zones having spans ranging from 21 to 30 m (68–98 ft) may provide cost effective alternatives.

Additional studies were conducted on the afore-mentioned load-bearing frames for the car assembly hall with span widths of 15 × 15 m (49 × 49 ft), 20 × 20 m (65 × 65 ft) and 24 × 24 m (79 × 79 ft). Various alternatives of fixed supports in steel and concrete as well as roof structures made of steel, pre-stressed concrete and timber were also considered. An in-depth analysis showed that when compared to the original 15 × 15 m (49 × 49 ft) column grid, a 21 × 21 m (68 × 68 ft) column grid offered value addition over the long term with an approximately 10 % higher construction cost.

11.1.4 Selecting the Materials and Joining Principle

In industrial construction there are a multitude of materials available for the occasional large span construction with roof loads. Since steel is capable of carrying large loads without buckling, it is particularly well suited for modular construction as well as halls with large spans. Laminated timber and cable supported timber constructions are appropriate for halls having average spans while light-weight metal constructions facilitate building and dismantling

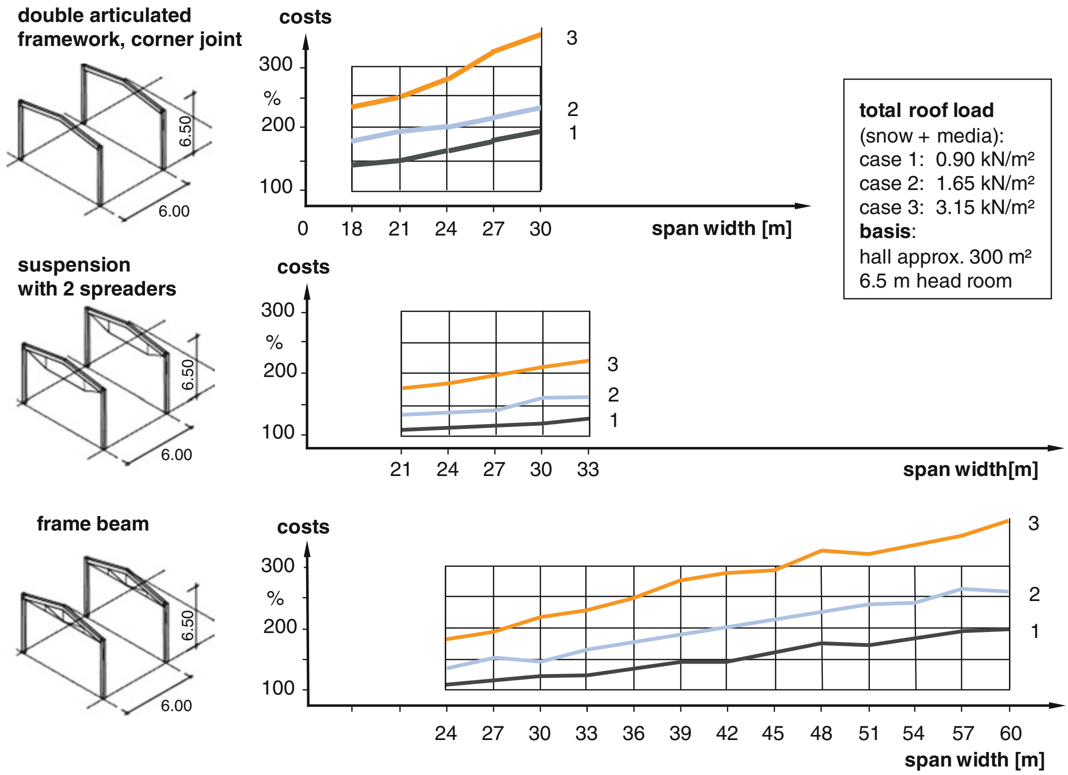


Fig. 11.10 Relative costs of steel load-bearing frames. © Reichardt 15.189_JR_B

temporary building structures quickly due to their lighter components.

When selecting materials it is also important to take into consideration fire safety issues. In addition to the fire rating of the materials, the fire load due to processes, operating facilities and logistics is also critical. By applying appropriate coatings, fire safety ratings up to F 90 (fire safety up to 90 min) can currently be attained for steel halls, while fire rating values up to F 60 are currently achievable for timber constructions with suitable profiles or intumescent coatings. Multi-storied buildings, which have to meet higher safety requirements with regards to the fire resistance of supports, beams and ceiling slabs, are built with concrete steel or composite steel. Figure 11.11 depicts the dimensions of beams and supports with various materials or combinations of materials. In comparison to reinforced concrete, steel composites allow a leaner profile for a lower static height.

Similarly, resistance to corrosion and weathering could be other criteria for selection of construction materials. Building structures made out of steel, timber or reinforced concrete needs to be protected with appropriate measures from driving rain. For example, steel is protected by hot galvanization or coatings against corrosion. In general, industrial buildings need to be constructed as quickly as possible; modular structures that are pre-fabricated are often advantageous than in situ concrete constructions. Modular components not only allow the structure to be assembled almost regardless of the weather and even in snow, they also have basic advantages over monolithic constructions. The choice of joining principle (welding, screwing or inserting) determines the geometry of the joints as well as the planning, manufacturing and assembly schedule. The ability to easily dissolve or undo construction joints makes it possible to later strengthen or retrofit support beams with greater loads, a feature

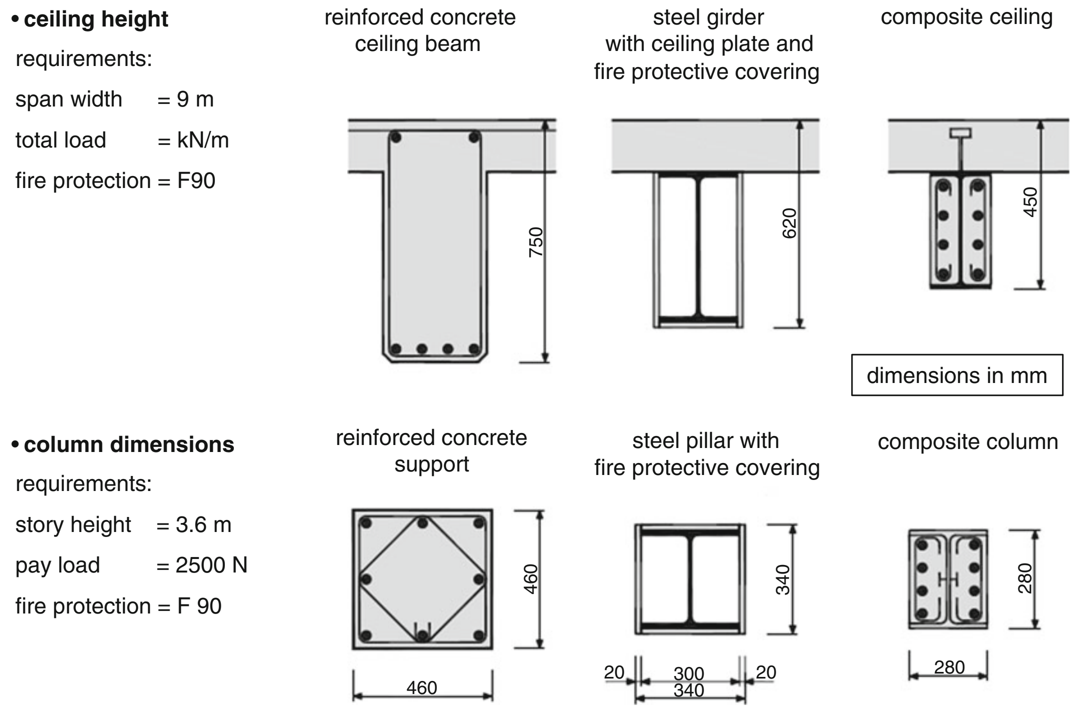


Fig. 11.11 Relevant measurements for structural members from various materials. © Reichardt 15.190_JR_B

that supports changeability. Furthermore, when the building is dismantled, materials need not be separated for recycling purposes.

Based on the degree of prefabrication and modularization, we can identify four types of systems for joining structural members: monolithic constructions (with so-called in situ concrete) are built with homogenous, non-dissolvable joints on-site. Homogenous but dissolvable joints are created by welding steel joints. With a corresponding amount of effort, such building structures can once again be separated into individual structural members. With partial prefabrication, structural members that are partially reinforced can serve as lost formwork; their final stability being provided by the concrete applied on-site. A steel skeleton bolted together represents the highest degree of modularization with complete prefabrication of all components, whereby the structural members can be fundamentally changed with additional joining.

Figure 11.12 depicts an overview of several materials and joining principles for halls and multi-storied buildings. According to [Ack88], there are a large number of materials available for halls, all of which have different properties especially with regards to fire protection classes. For multi-storied buildings these materials are limited to reinforced concrete, steel and steel concrete composites. Nowadays, as indicated in [Rei08], innovative fire-resistant timber constructions can also be considered for industrial and commercial construction.

For the changeable factory, modular constructions (see also examples in Fig. 11.42) seem to be the preferred approach to developing structural frameworks:

- Completely prefabricating a load-bearing structure with easy to dismantle joints facilitates changes wherein beams can be equally quickly and easily reinforced or replaced.
- Removable ceiling panels, allows for future vertical openings between stories e.g., for conveyor systems.
- Required internal extensions can be realized through gallery areas, which when prepared appropriately can be hung on existing structural members (see also the example in Fig. 10.6).

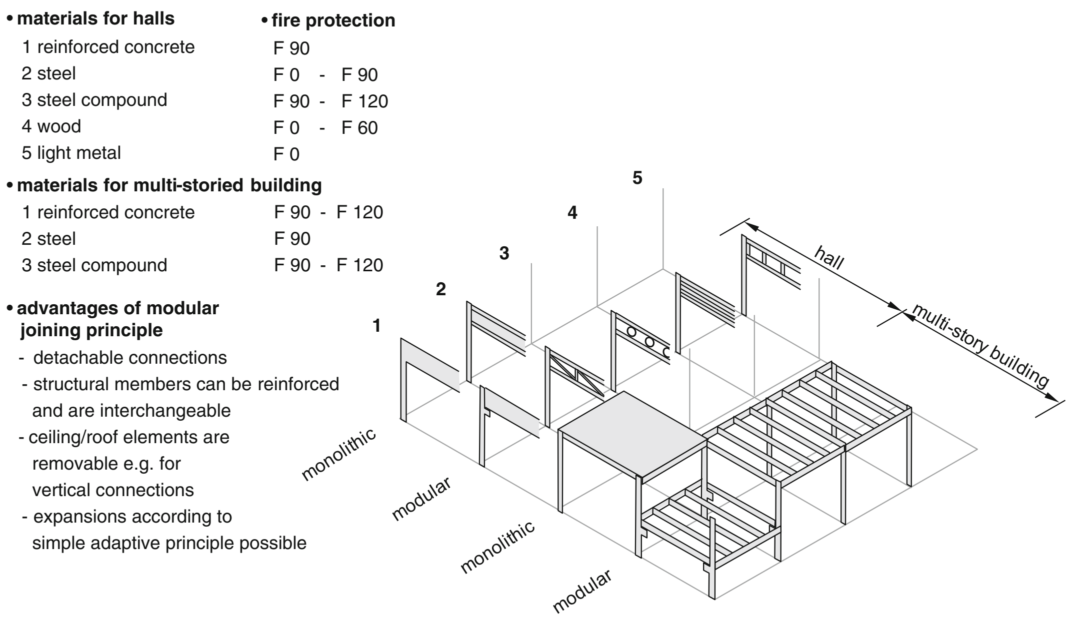


Fig. 11.12 Materials and joining principles for load-bearing structures. © Reichardt 15.191_JR_B

According to [Lac84], the design idea behind the construction can generally be implemented in steel, concrete steel, timber and light steel. Particular details such as plug-in connections allow structural members to be quickly assembled and disassembled thereby meeting the requirements for temporary or even mobile factories. However, it is advisable to weigh in the additional costs against the increase in changeability (i.e., quicker retrofits and fewer disruptions with reference to the on-going operations).

11.1.5 Profiling Support Columns, Beams and Ceiling Slabs

Depending on the structural form, span width, materials and joining principle a multitude of designs are possible for the support columns, beams, roof coverings, intermediate floors and ceiling slab components. Ideally fewer supporting columns are preferable; however, supporting columns are equally important for integrating conveyor facilities and building services. Guiderails for overhead or slewing cranes as well as other lifting equipment needs to be closely coordinated for safe anchoring into support columns. Columns can also be used to fix vertical trusses for building services such as uptakes, downspouts or air ducts. Moreover, the framework for the machinery supply and disposal systems (e.g., electricity, compressed air or water pipes) can be attached to supports. Cross-shaped supports allow media routings to be suspended within the arms of the cross.

With modular building structures the construction time can be reduced with foundations molded around the support columns. Impact sockets with a height of ca. 1.2 m (3.9 ft) anchored in the foundation plate dissipate the impact load of e.g. trucks without subjecting the support to a further static load. Lowering the upper edge of the foundation on the support shaft can make it easier to horizontally route media lines or retrofit them below the floor plate. In our car assembly example, the use of concrete and steel with various profiles for the hall’s support columns was investigated in accordance with the roof load and clearance to determine the costs of the supports, beams and foundation for a module area of 20 m × 20 m (65 × 65 ft) (see Fig. 11.8). In this case, concrete supports with a molded foundation proved to be an efficient solution.

The profiling of the beams as solid web girders, castellated beams, truss girders or cable-supported trusses influences both the distribution of media and daylight. For example, filigree beams allow media to be routed within the girder area whereas in case of solid web girders the clear usable height of the hall is reduced by the space necessary for installing media lines below the beams. At times, floor-high truss girders allow maintenance bridges or technical galleries to be integrated into the roof structure. Since permeable beams support the spreading of natural light in the roof area, profiled beams can be drawn upon to optimize the lighting of work areas by redirecting the light. A flat roofing system is advantageous for systematically installing media services as well as arranging lighting. In comparison, moderately sloped surfaces and trusses profiled to facilitate roof drainage, while requiring slightly more effort to design and construct offer the added benefit of beams at equal distances, in turn facilitating suspension systems for cables, pipes etc. for media and processing or conveyor equipment. A consistent and well-coordinated plan for the media supply and disposal system is extremely important for planning, coordinating and/or making future changes (see also Sect. 16.9 Building Information Modeling).

The structural system, choice of materials and modularized components of the roof should allow skylights or other necessary roof penetrations (e.g., vents, etc.) to be retrofitted. The roof detailing should also allow for sound absorption where necessary. Surfaces that reflect light more increase the brightness of the room, whereas porous surfaces made from perforated metal or hanging sails decrease the sound level. Corrugated or profiled sheeting materials allow for a number of possibilities for hanging elements or systems in future, if necessary.

The advantages of a modular system for a storey-high roof compared to a monolithic construction lie in the possibility to integrate building service equipment, the future changeability of the structure and the speed of the building process.

Equipping modules with details such as "tracks" allows installed media to be varied with minimal effort. Moreover, with modular elements vertical connections between multiple floors can be easily added. With greater spans, media systems can be cleverly organized and routed within the static height of ceiling or roofing elements when they are implemented as ribbed panels.

Another critical factor with regards to long term changeability is the load-bearing capacity of the floor plate. The entire surface—without any exception—should be consistently able to bear the same load. Moreover the consistency in level floor construction needs to be considered. In case of vacuum de-watered floors, mistakes in flooring levels cannot be altered at a later date and needs to be planned accordingly with an eye to the future, especially keeping in view of the requirements for processing technologies.

Detailed planning for the floor plate may include: media routings, conveyor technology, process related waste removal, special foundations and fire escape routes. If built-in cable trays, guide rails or chip removal systems cannot be avoided, their cover plates should be standardized and inter-changeable. In addition, special foundation systems for specific machines limit the changeability considerably; similarly location of escape tunnels as well as their entrances should be examined with an eye to the future.

If we adhere to the principles introduced here, we can, in accordance with [Pol03], see the futility of decorating a building with unnecessary or impractical constructions.

Figure 11.13 summarizes the characteristics of changeability that are applicable when profiling the supports, beams and ceiling/floor slabs.

11.2 Shells

Encasing the building structure involves vertical façade surfaces as well as horizontal or sloped roof surfaces. These generally consist of

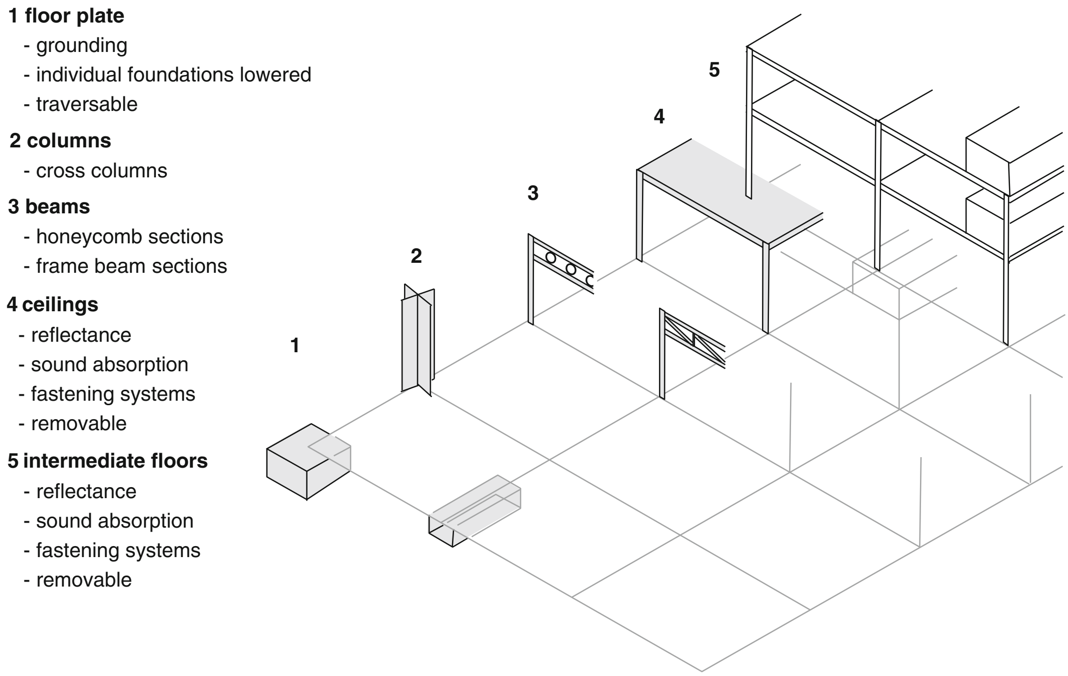


Fig. 11.13 Profiles of structural members. © Reichardt 15.192_JR_B

combinations of closed and transparent surfaces. Openable elements such as windows, doors or gates are integrated as required into the shell surfaces. A shell plays a protective role, fulfills production and logistic requirements, aids in providing light as well as outdoor views, facilitates communication; the shell could also be eco-friendly and can produce energy. A plethora of possible solutions along with types of construction and examples are presented in [Her04, Sch06].

11.2.1 Protective Functions

The shell should be designed to provide suitable climatic protection depending on the geographical location of the building. Meteorological data from the nearest weather station can provide the mean temperatures of the hottest and coldest periods along with data on wind, rain and snow. A comprehensive 3D analysis of the shell's energy losses and gains within the frame of a synergetic factory planning is advisable before defining the wall and roof structures. The analysis should also include the energy generated by the processes (e.g., machinery heating-up) and is best conducted for a number of alternative wall constructions as well as possible future scenarios regarding the cost of energy.

The orientation of the building in relation to prevalent wind directions influences the arrangement of the gates, canopies or air exhausts. If building laws and regulations require certain noise levels to be adhered to, closed surfaces and openings in the shell need to be planned accordingly. Similarly, if the building is located near a highway or an airport it may be necessary to provide sound insulation from external sounds (e.g., by implementing special noise reflecting measures on the façade).

Figure 11.14 provides an overview of the basic features which play an important role against cold, heat, rain, wind and noise. The value of the heat transfer coefficient (U-value) determines the thermal insulation, whereas the solar heat gain coefficient (SHGC or g-value) measures the amount of heat gained through

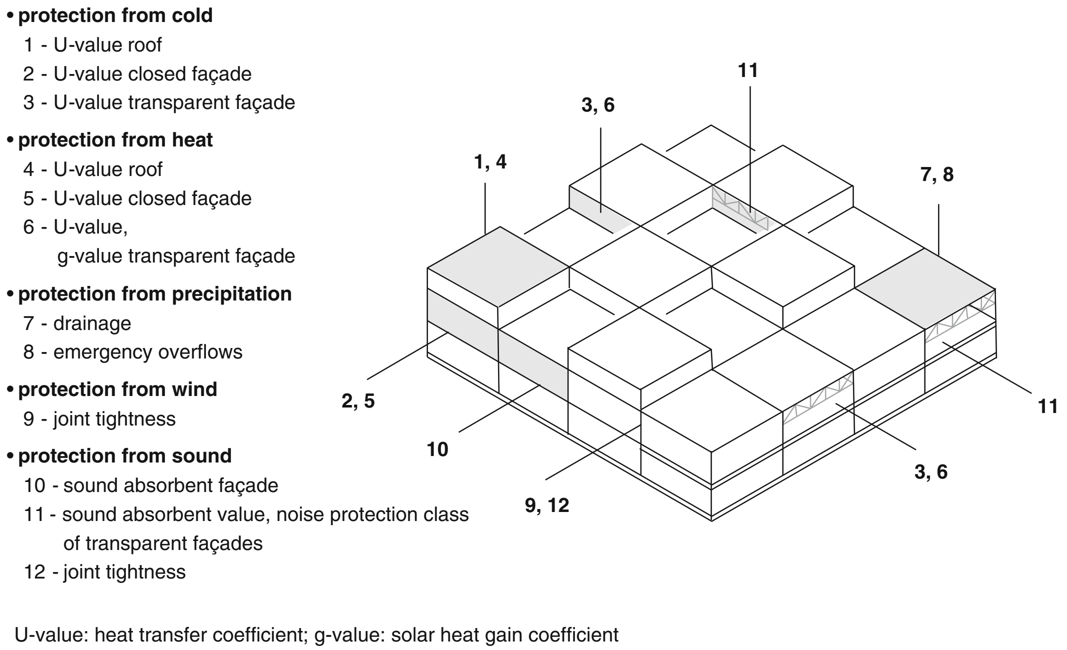


Fig. 11.14 Building shell features with protective functions. © Reichardt 15.193_JR_B

solar radiation. Depending on the geographic location, the maximum anticipated rainfall could be critical selecting the roofing system. The demand for the shell to have greater changeability generally means avoiding load-bearing outer walls since monolithic constructions are difficult to modify or extend. In comparison systems that are modular can be more quickly and economically adapted to new requirements.

11.2.2 Production and Logistics

In terms of the shell, structural requirements that result from production and logistic are related mostly to: receiving and dispatch points, escape routes, assembly openings and media systems for processes, fire protection, and building services that penetrate the shell. Examples of these requirements are presented in Fig. 11.15.

With the aim of increasing the degree of structural changeability monolithic constructions should be avoided for the roof and walls; instead it is advisable to plan them as a number of non-rigid or easily changeable zones. For the vertical façades, modularized transparent or translucent components of approximately 3.00/4.50 × 4.50 m (9.8/14.7 × 14.7 ft) are well suited. Supplementary exits as well as truck entrances into the halls may be designed based on this grid, to enable changes at a later date.

In order to provide protection from the weather when loading and unloading vehicles, it should be possible to erect canopies with their own foundations anywhere along the periphery of the hall. Interchangeable façade columns extending between the floor plate and girders permit larger openings in the façade for bringing larger machinery into the hall. Furthermore they make it easier to quickly extend the hall. Skylights, heat exhausts as well as other process related air ducts can be integrated in band-like roof structures. Modularized transparent and closed panel systems for sheds and floor to ceiling windows can always be adjusted to meet new requirements. Two façade systems that were developed based on this strategy for a plant that assembles automobile cooling systems are illustrated in Fig. 11.16.

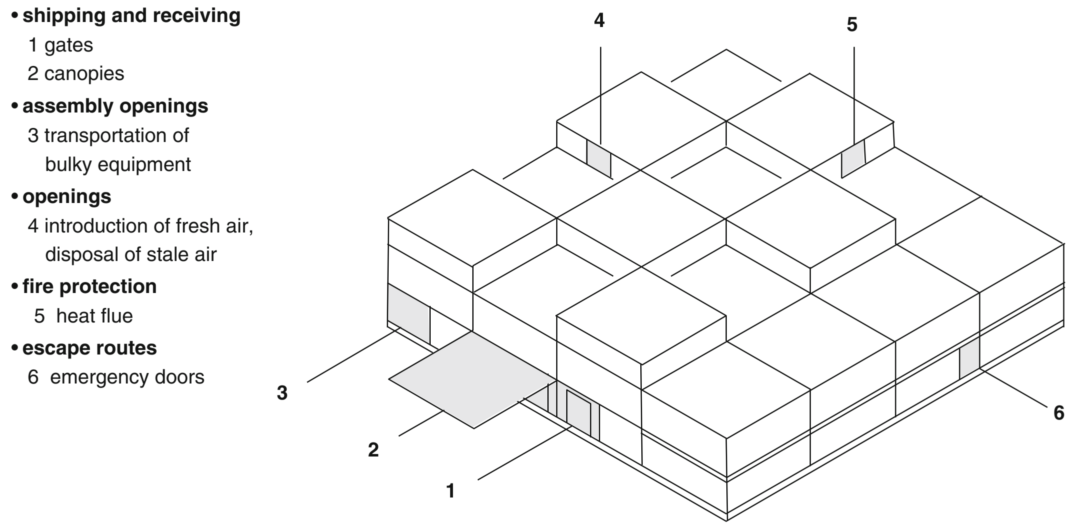
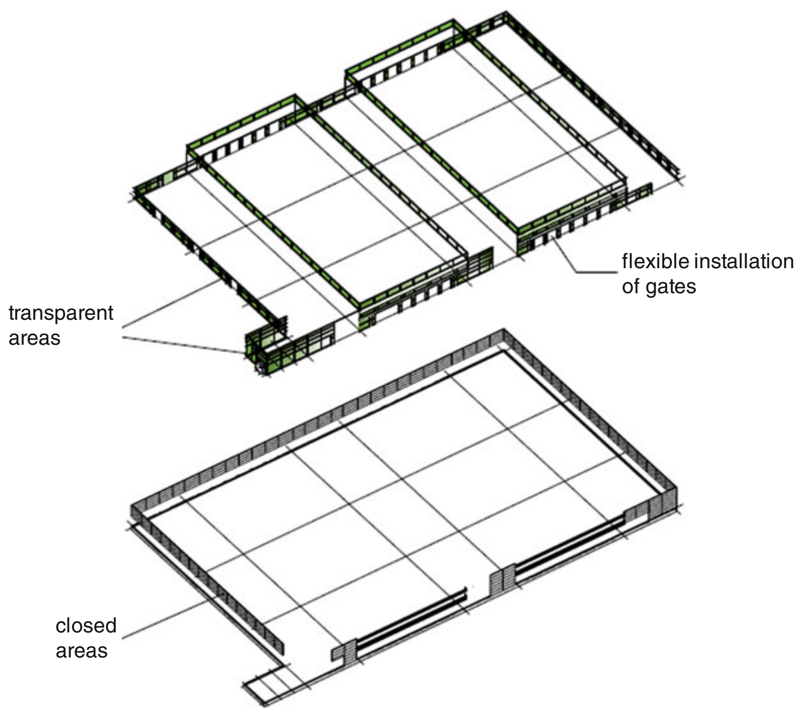


Fig. 11.15 Features of a building's shell from the perspective of production needs. © Reichardt 15.194_JR_B

Fig. 11.16 Façade systems for an assembly plant (example). © Reichardt 15.195_JR_B



11.2.3 Lighting, Views, Communication

According to the specifications of German workplace guidelines 10 % of the ground floor area of halls up to 2000 m^2 (21,500 ft^2) in size should be reserved for transparent façades at eyelevel. For larger halls there is no requirement for a direct outdoor view due to the depth of the hall, instead the focus shifts to skylights providing natural daylight to the work area. In order to provide a comfortable and livelier atmosphere for their employees, enterprises are increasingly trying to create brighter work places. Changeable work areas are not dark areas; rather openings in the shell allow workers to be aware of the time of the day and changes in the weather outside, if any. A roof that has been properly profiled would provide work areas with glare-free and naturally diffused light for comfortable working environment. Beyond providing outside views and natural light, façades can contribute meaningfully to the communication between a building and its surroundings as well as convey a sense of identity and significance. Figure 11.17 provides an overview of the elements of a building's shell which help to determine these features.

In addition, particular attention needs to be paid to the drainage of roof extensions. An appropriately profiled roof ensures that every point of the roof has a slope of at least 2 % to remove rain in a clear direction. Large span building structures necessitate girders with structural camber. Damages to roof structures and buildings due to sudden and heavy torrential downpours overloading the rain water drainage system led to a comprehensive revision of the DIN and EN standards. This in turn has impacted the design and detailing of even the emergency overflows.

11.2.4 Ecology and Energy Production

Façade surfaces are extremely well suited for implementing measures that improve both the ecology of a building and its energy balance. Green façades and roofs can be integrated as ecologically valuable measures when calculating equalization areas. Furthermore, roof plants help in reducing the amount of rain water flowing into the public storm water drainage network and are thus advantageous when applying for necessary approvals for discharge.

Nowadays a number of tested systems for actively producing energy on façades are available. Thermal collectors for generating warm water, photo-voltaic collectors for generating power and wind turbines are plausible either as independent units or as systems integrated into façade and roof elements. With a synergetic factory planning a 3D computer model is used to optimize their efficiency, depending on the orientation of the building as well as their economic considerations.

Figure 11.18 provides an overview of features from an ecological perspective as well as with regards to energy production and illustrates how they can be integrated into the building shell. In

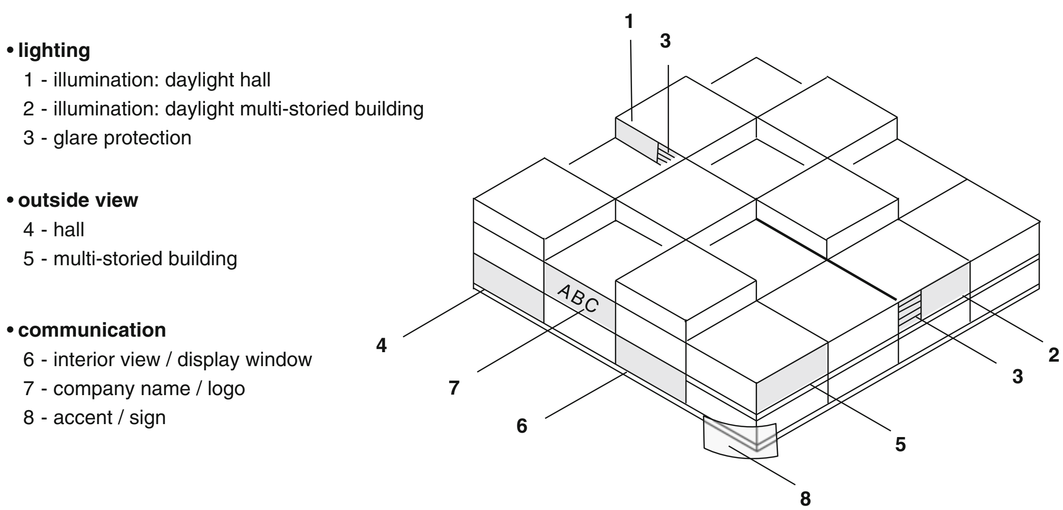


Fig. 11.17 Requirements of a building shell in terms of lighting, views and communication. © Reichardt 15.196_JR_B

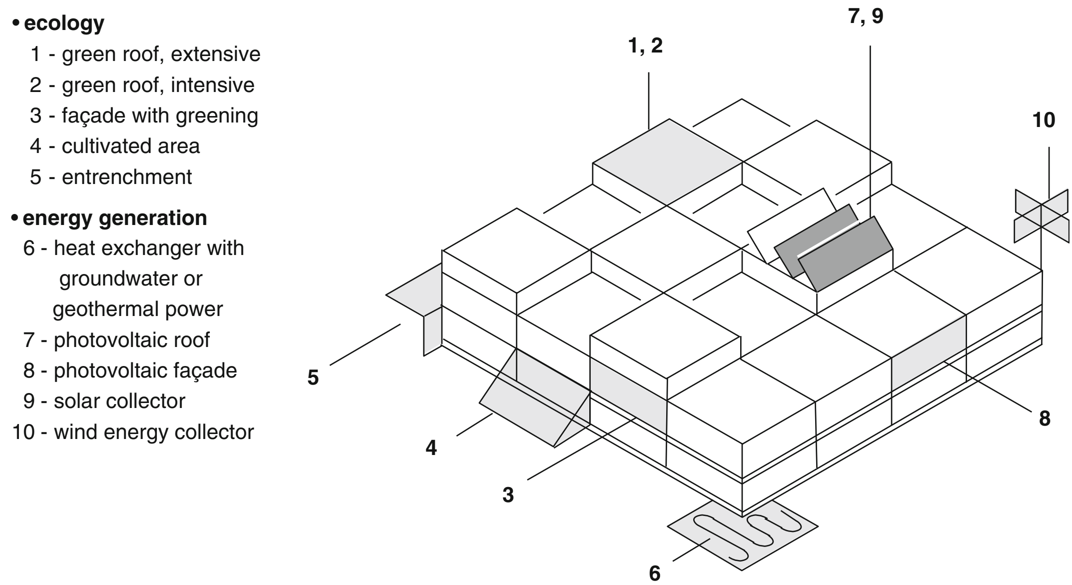


Fig. 11.18 Features of a building shell from the perspective of ecology and energy production. © Reichardt 15.197_JR_B

Germany we anticipate that, in accordance with [Hau07], the "passive building standard" (yearly required energy for heating less than 15 kWh/m^2), already in place for residential buildings, would be soon enforced for commercial and industrial buildings too. Currently a large number of façade and system manufacturers are developing integrated systems for generating environmentally friendly solar and geothermal "passive" energy in particular. Additionally, certification systems for attaining a "Green Building Standard" have also being developed for industrial and commercial buildings (see Sect. 15.7.2). Ecological and energy conscious façades thus also hold the promise of future sustainability.

11.3 Building Services

As mentioned earlier, we are using the collective term "building services" to refer to the building service equipment, the supporting structures needed to run the building services as well as the wires, cables, pipes etc. for the operation of the manufacturing facilities. In industry, "building technologies" (planned by architects) are commonly differentiated from "process technologies" (planned by technology planners). Traditionally, these were assumed to be independent of each other; however, they pose a significant risk, if their potential synergy is not harnessed. In view of the increasing complexity, all the media systems should be holistically optimized keeping in mind future savings in energy and natural resources (see Fig. 3.28). Examples of optimizing energy in industrial buildings can be found in [Hat06]. In order to facilitate integrated planning, a variety of advanced software programs are available making it possible to model all the systems in 3D, simulate energy generation and losses and provide thermodynamic flow simulations (see Fig. 11.35).

In [Dan96], Daniels describes general requirements and principles for planning building services:

- Find the optimum between investment and consumption costs.
- Minimize the use of energy and natural resources as well as pollutant emissions within the frame of a cost-benefit analysis.

- Discuss the type and provision of electricity and heating or cooling energy (e.g., the possibility of the company operating its own block-unit heating power plant).
- Carefully determine requirements and dimension them according to specifications with sufficient reserves for growing needs.
- Carefully plan supply systems for processes and buildings, where possible with short distances, flexibility and adaptability for new technologies with as little downtime as possible.
- Separate building service centers, main routes, line paths and outlets that need to be always accessible according to a superordinate system plan.
- Clearly identify common main and secondary lines and mark the direction of media flow.

Changeability plays a particularly important role in the design of the supply and disposal systems, service centers, main routings, line paths and outlets. The hierarchy of these systems in the building structure is clarified in Fig. 11.19. For the factory planner the location and development of centers and main routes are particularly significant and should facilitate both current as well as future production needs.

11.3.1 Supply and Removal Systems

The building's media structures have to be designed with regards to supply and disposal systems and within the overall framework of the building's master plan. Transfer points, quality, quantity and especially possibilities for extending them determine the distribution and collection structures. In general the supply systems include power supply, heating, ventilation and air-conditioning, pressurized air, water, coolant, lubricant, etc. while removal systems would include sewage and drainage networks, coolant and lubricants. In their overviews, Pistohl [Pis07] and Krimmling et al. [Kri08] point out basic designs for supply and removal systems.

To begin with, one needs to decide whether a centralized or decentralized layout is better. A centralized supply is definitely a practical solution when media is required in large quantities throughout the plant, considering the investment and operating costs. Also, implementing heat recovery technology for ventilation systems is often economically efficient. However, one of the disadvantages with centralized systems is that defects and malfunctions can cause complete operating disruptions. In addition, there tends to

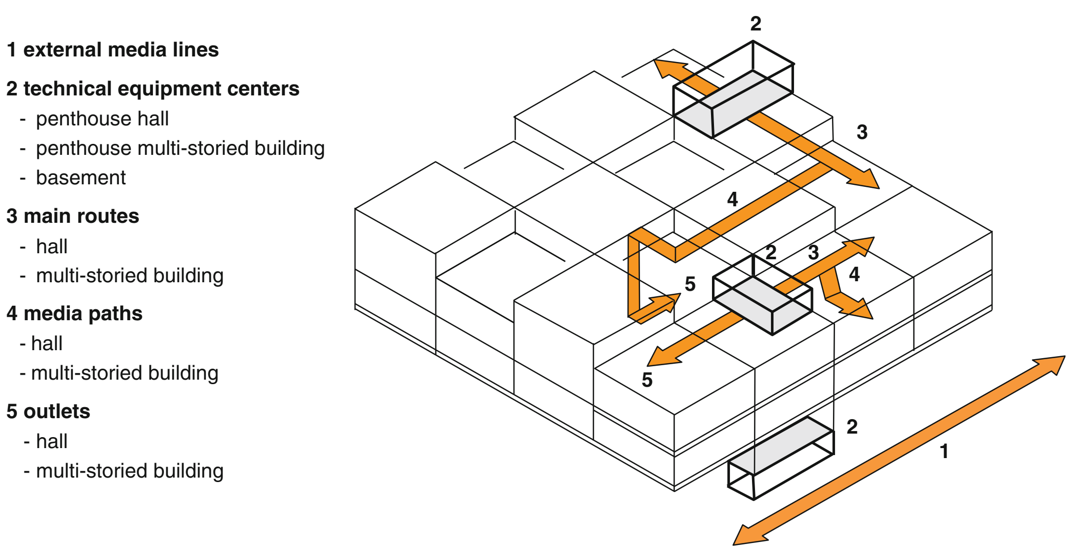


Fig. 11.19 Hierarchy of media systems. © Reichardt 15.198_JR_B

be a far more number and length of cables and pipes than with decentralized systems which in turn means a greater number of horizontal and vertical lines in the building. A further disadvantage is the loss of efficiency that goes hand in hand with the longer line paths.

Compact systems with a higher efficiency factor lead to decentralization. With regards to planning, operating and changes, the greater independency of decentralized systems means a considerable increase in flexibility and changeability especially where modular factory concepts are concerned.

Figure 11.20 depicts an example of a decentralized solution for the supply system of a motor assembly plant with four “sub-factories”. Each of the approximately 5000 m^2 halls is a three-story service building with technical centers for ventilation systems and others; space for the electrical systems was allocated on the roof top. A comb-like branch flow system was proposed for the distribution network for ventilation, pressurized air and electric system. This modular concept allows the supply system to be adapted to the sub-factories’ future requirements at any time without disruptions.

11.3.2 Technical Centers

In order to generate, operate and monitor media (pressurized air, steam, cool air etc.) the main machinery are located in so called technical centers. Planning them should result in a comprehensive and pragmatic concept including where the centers are located, their spatial requirements and room specifications as well possibilities for future expansions.

The location of the technical centers in a building is determined by the combination of whether they are centralized or decentralized as well as whether they are built in-house or erected separately. Ventilation and air conditioning systems are frequently located near to heating centers (boiler rooms and distribution centers) and refrigerating machines. Due to fire regulations

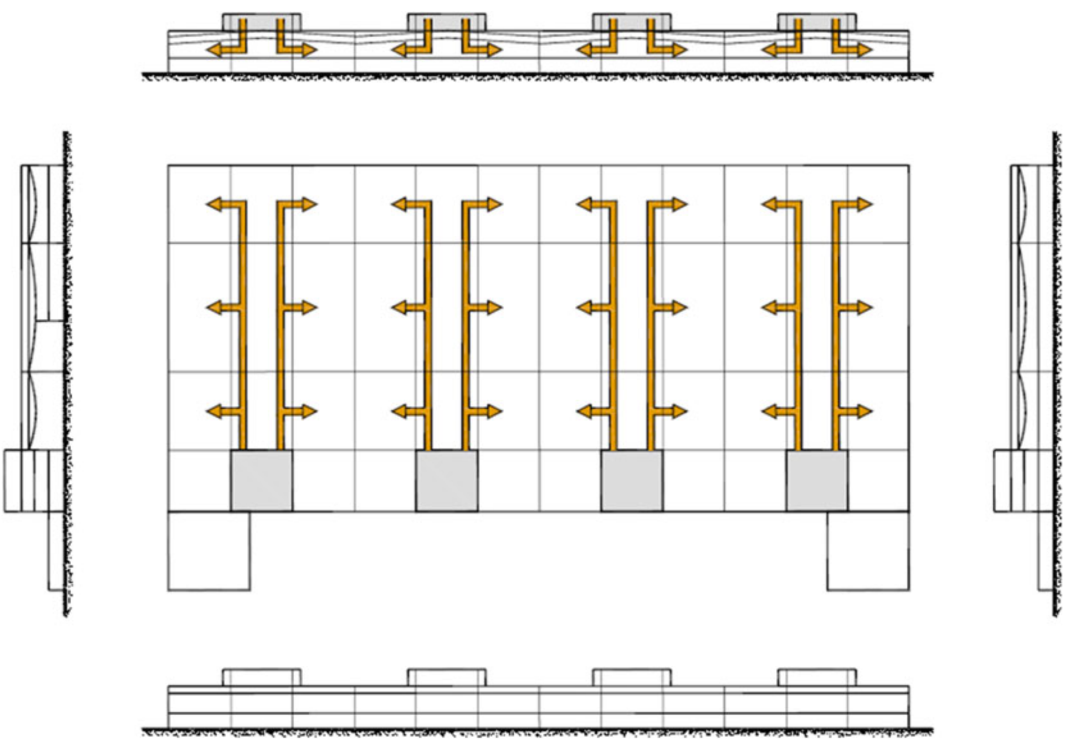


Fig. 11.20 Modular supply system for a motor assembly plant. © Reichardt 15.199_JR_B

locating the ventilation plant and heating system in the same area or close to each other may not permissible. It can however, be advantageous to link the centers close to the vertical installation shafts of the building's core. Other factors that are an integral part of the planning discussion include:

- Calculating the load assumption of the technical centers in the final stage as well as provisions for changing technical units early on.
- Required partitioning against noise, fire and vibrations.
- The location and layout of sprinkler systems and tanks needs to be discussed together with insurance agencies and public authorities. Moreover they need to be closely coordinated with the strategic extension of the plant outlined in the master building plan.

The advantage of a centralized design lie in its lower investment costs with minimal floor space requirements and simplified machinery installation in a synergetic way. In comparison, decentralized systems are far more beneficial in terms of their changeability; it is easier to convert individual production areas and their associated media systems locally with minimal disruption to the on-going production during the replacement of lines or enhancement of the networks.

Locating technical centers in the basement is advantageous since it helps to economically shield against noises and vibrations; also the heavy equipment load is directly transferred to the ground thereby enabling a more economical structural framework. Nevertheless, especially with high halls, long distances and a loss of floor space in the ground floor plan negatively impact the main routings; exchanging systems however can be facilitated via simple lifting equipment.

Locating centers on the ground floor should be avoided, if possible, since they represent fixed points in the floor plan when it comes to options for extending the building. Nowadays there are possibilities to even install electrical and transformer systems at upper floors.

The basic advantage of locating a center on a mezzanine floor lies in the generally smaller channel cross-sections, nonetheless greater measures have to be taken to avoid transmission of noise and vibration (e.g., implementing shielding, installation of shock absorbers, etc.) through the building.

Structurally independent and weather-proof technical components set on the roof floor or on the periphery of the building provides a greater possibility for changeability especially when buildings are not too tall. As a structural measure, an appropriately constructed load-bearing frame should be able to accommodate additional technical modules for potential factory alterations or extensions taking into consideration future anticipated loads. Recent developments are heading towards "ship and plug-in" modules i.e., mobile construction units consisting of completely pre-equipped technical containers that need only to be connected (plugged-in) to one another on-site forming supply and disposal systems that are ready-for-use.

With wide spanning halls, the structural framework zone is often a floor high and can be used to house technical centers as well. The lower joist of the frame can support transverse beams for equipment platforms or maintenance catwalks. Moreover, the entire roof layout is available for integrating the technical building systems in a holistic manner. It is advisable for this strategy to use a 3D computer model to closely coordinate the structural framework design with the media layout.

Compared to centers located in structures independent from the main building, housing centers within the building structure are advantageous because they can be re-arranged overtime; main routings and supply grids can be easily threaded, continuously monitored, maintained or repaired in a protective environment. However, in some cases special encasings for sound or fire protection needs to be integrated.

Figure 11.21 depicts three possible variations for housing technical centers including: a modular penthouse solution atop a multi-storied engine plant, a container type "ship and plug-in" technical center on the hall roof of a cooling system assembly plant and a gallery built into the frame work of a tire factory. The transformer systems were integrated in the penthouses for both the engine and assembly plants.

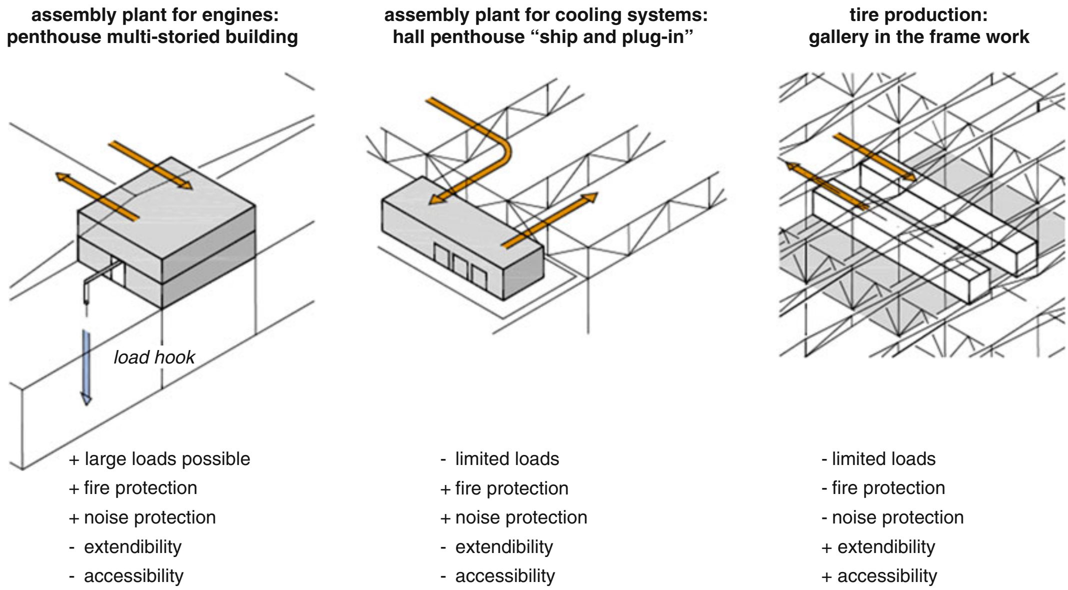


Fig. 11.21 Trouble-free locations for technical centers. © Reichardt 15.200_JR_B

Accordingly, individual loads of up to 40 kN were taken into consideration by constructing grated platforms for landing areas for equipment and providing access via lifting equipment or mobile cranes. The advantages and disadvantages of these basic solutions are stated below each option, based on the criteria of possible loads, fire protection, noise protection, extension possibilities and accessibility.

The spatial requirements for technical centers should be determined in the early planning stages, since the building design and structure are considerably influenced by them. Sound damping requirements need to be considered early on as they greatly influence spatial requirements. The necessary ceiling clearance is often underestimated especially with low floor to ceiling heights in the basement floor; restrictions result in chaotic media routings in the technical centers and limit changeability at a later date. In the course of planning a factory in the long run, it is important to think ahead about possible step-by-step solutions for easing the control and maintenance of the plant. Here too, it is critical to integrate these ideas when planning future spatial requirements.

Since the lifecycle of the technical systems vary from 5 to 15 years, the center's machinery components should ideally planned and constructed as modules which could be easily exchanged and extended. Once again, 3D modeling of the technical centers within the frame of a synergetic factory planning is advisable along with a facility management system which incorporates documentation and maintenance of the components (see also Chap. 17).

11.3.3 Main Routings

The main routing's vertical and horizontal manifolds lead from the technical centers to the distribution systems. Vertical lines are often routed in the shafts of the buildings core, while horizontal lines are routed through or below the structure of the hall roof or ceiling slabs. When selecting the anticipated positioning of the main routings, special attention has to be paid for future options of vertical or horizontal extensions. It is difficult to reroute ill-conceived media packages, often blocking meaningful growth of building facilities and literally stifling any further development.

Shafts and canals for the main routings should be planned so that they meet the requirements for structural stability, fire safety, dampness protection, thermal insulation and hygiene. Moreover, they should be designed so that they are easily accessed for maintenance and cleaning either externally or internally. Shafts having control valves and systems requiring periodic maintenance needs to be large enough for comfortable human movement.

When selecting systems and planning the details of the building structure the layout of the main routings plays a special role. The following points should be taken into account:

- With multi-storied buildings, the connection between the horizontal trays and the vertical shafts are critical points.
- The static reinforcement that should be provided by the core can be negatively impacted when the layout of building services and other media is not designed well.
- The connection openings have to be wide enough to accommodate retrofitting the main routings.
- Horizontal main routings frequently traverse the zone of building structure's static beams.

Moreover, the choice of materials and the overall form of the building structure are decisive for flexible routing of media, especially with regards to their capacities for future retrofitting. Often during the planning, all the possible points of conflicts between the building structure and routings may not be detected. During construction, this could lead to further decrease in clearances when the routings have to be laid unplanned below the load-bearing frame. With the aid of a 3D model, conflicts can be detected early on thereby ensuring the required ceiling clearance as well as preventing unpleasant joints and problems with extensions and retrofitting.

In case of factories, the layout of the electrical power supply for the production facilities as well as the IT-connection of the production and offices is often not considered adequately. International Electrotechnical Commission (IEC) documents 60374-5-51 to IEC 60364-5-54 (Electrical Installations of a Building [IEC11]) provide necessary guidelines in this regard and have been introduced as national standards in 170 countries.

11.3.4 Line Nets

Once the main routings are planned, a practical distribution network to the outlets needs to be developed. The branched media runs behave similarly to the main routings in terms of their vertical and horizontal pathways through the building. The modular system of the building structure should meet the needs of a coordinated system plan for all the proposed line paths. The density of the supply and disposal networks has to consider issues related to both the building services and processes. All of the pathways need to be easily accessed and modified without disrupting the production. Horizontal and vertical points at which the networks of cables, wires and pipes can be installed onto the building should be identified and finalized in accordance with the superordinate dimensions and based upon a standard assembly system. Moreover, implementing a factory wide color coding system and labeling the direction of the media's flow serves as a valuable aid to quickly identify the distribution networks.

Figure 11.22 depicts the 3D media routing plan developed for the fresh air, ventilation, lighting and sprinkler systems for a meeting room of an assembly plant. The distribution networks were coordinated using a system grid of 1.25 m (4 ft); the modularized ceilings with perforated boards for acoustic purposes were accordingly aligned in the plan.

11.3.5 Inlets and Outlets

Many work processes create dust, gases or vapors. Unwanted or disturbing particles are best filtered out at the point of their creation with the aid of ducts. These are the transfer points where media enter the rooms (air supply duct) or flows out of them (exhaust vents). Ducts have to be

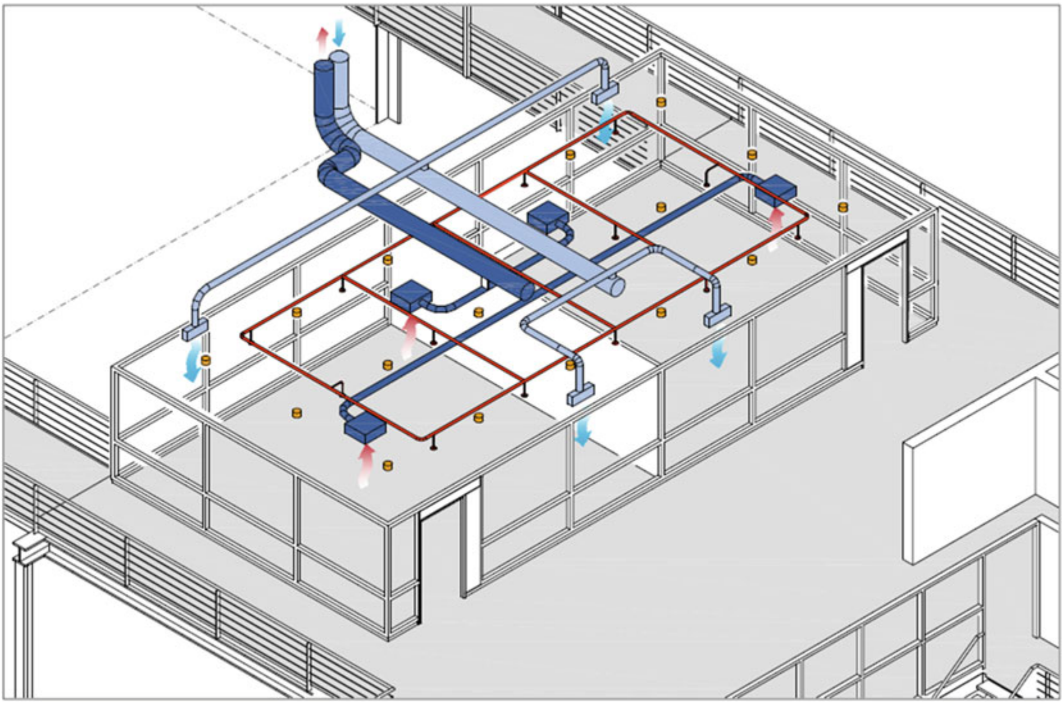


Fig. 11.22 3D modeling of media routings for a meeting room (example). © Reichardt 15.201_JR_B

extremely carefully dimensioned and executed in order to prevent disruptions or breakdowns due to drafts, contamination or soiling of workplaces.

Media intakes and outlets should be easy to locate so as to not interfere with re-arrangement of machinery or installation of new equipment with different requirements.

Once again we can see that creating a 3D model when planning the location and size of the inlets and outlets helps to prevent different media from colliding with each other. With respect to ensuring a high degree of changeability the locations of lights, data lines and air ducts should be closely examined. In addition to the required quantity of illumination covering the floor area of the hall, the distribution of light and its quality should planned such that the hall could be used for various purposes. Similarly, data lines should be distributed throughout halls and multi-story buildings so that equipment and offices could be re-arranged as freely as possible.

Figure 11.23 depicts an example of an adaptable air supply duct made out of fabric for a large bakery (see also Fig. 15.75). The hose-like system filters the air through the material's micro-fine pores distributing it without any noticeable air draft. In addition, the ducts can be easily cleaned (machine washable) and quickly adapted both with regards to its location and its length.

11.3.6 Building Services

By Gerhard Hoffmann[1]

11.3.6.1 Introduction

As discussed in the introduction to this book, the development cycles in industrial manufacturing are becoming shorter while the demands for economic efficiency increase. In addition to

[1]This section was made kindly available to the authors by Gerhard Hoffmann, Managing Shareholder of ifes GmbH Cologne. We would like to express our sincere gratitude to him.

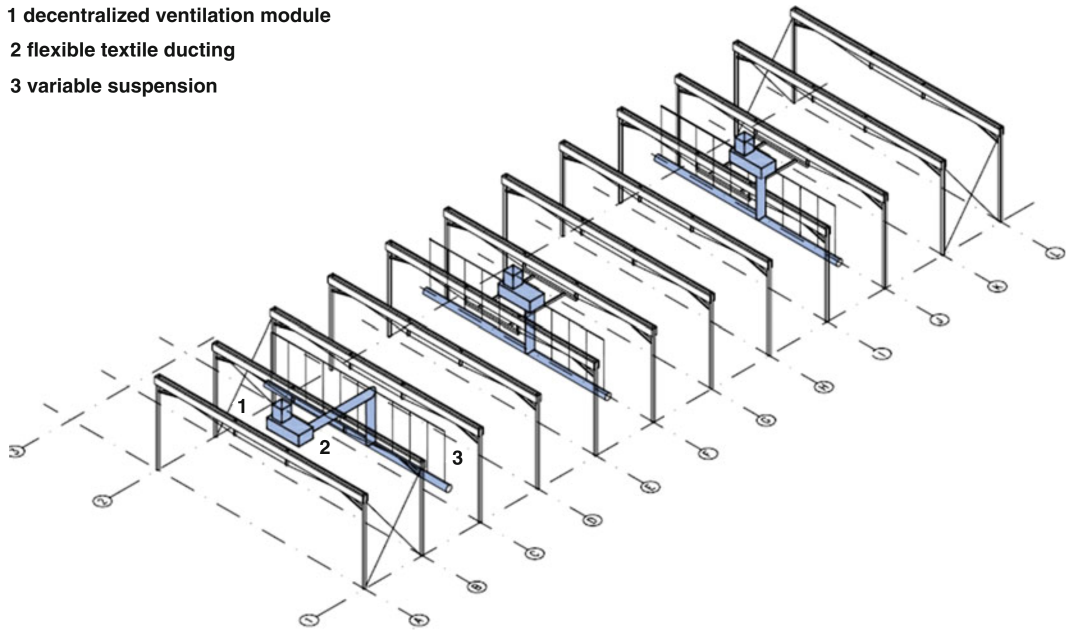


Fig. 11.23 Example of an adaptable air supply system. © Reichardt 15.202_JR_B

highly flexible production equipment, shorter product and innovations cycles require the technical systems in factory halls to be equally flexible. These are generally referred to as building services sometimes also as Facility Systems [Tom10]. When we consider the breakdown of the total costs for building a factory, the building construction, the shell and interior finishing usually represent 30–40 %, the facade approximately 12–30 % and building services the remaining 30–40 %.

DIN 276 subdivides the construction costs of a building into 7 main groups [DIN08]. Building services is further broken down under DIN 276 Cost Group 400 with the heading "Building—Technical Equipment". It encompasses the costs for all of the technical systems or system parts that are built into the building, connected to it or securely fastened to it. Whereas Sect. 16.7 will closely examine how to calculate and control costs of a building, Fig. 11.24 depicts the subgroups of Cost Group 400 relevant for our discussion. Each of these is briefly clarified below.

Media supply (cost group 410) to industrial buildings' includes water, various gases and fire extinguishing systems. The latter serves to protect both the structure and the technical equipment. Since manufacturing halls are specialized structures, the fire protection concept has to be developed by relevant fire protection experts. The expert planning team should also determine which technical fire protection systems need to be installed; for example, a sprinkler system is not always required for a building. However, systems that are able to remove heat and smoke in case of a fire are generally mandatory requirement for industrial buildings. The specifics of this are discussed in detail in Sect. 10.5.

Heating systems (cost group 420) comprise all systems and equipment for generating, distributing and utilizing heat, while air conditioning and ventilation systems are concerned with controlling temperature, humidity, and air circulation within given a space. Air conditioning systems are further sub-divided into different types (see Sect. 11.3.6.4).

Electric power plants (cost group 440) supply the factory with energy for electrical drives and processes. In view of increased flexibility, the cables for supplying electricity to systems in

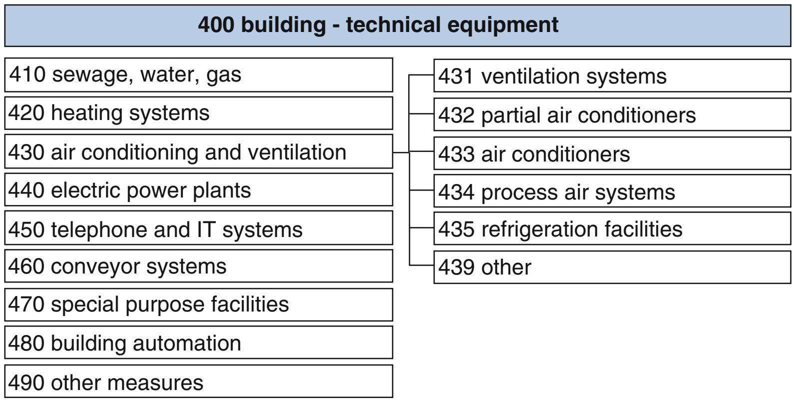


Fig. 11.24 Cost structure—technical equipment (per DIN 276). © IFA 17.600_B

industrial halls should be ideally routed above the ground whenever possible. This allows for process-related conversions to be quickly implemented. In addition to supplying processing equipments with electricity, the hall lighting is critical to the employees' performance. Standards and guidelines, like DIN EN 12464-1: Lighting of Workplaces [DIN11], describe the principles and conditions for work-appropriate lighting.

Telephone and IT systems (cost group 450) ensure internal and external communication. Due to specific security and environmental requirements, special rooms may be required for the server clusters.

Conveyor systems (cost group 460) refer here to facilities that move parts in progress or finished goods and need to be securely installed to the building structure at higher levels above the production area. Typically such systems are common in automobile plants. Special purpose facilities are rarely found.

Building automation (cost group 480) refers to all equipment which is required to monitor, control, regulate and optimize the building systems and is thus an important part of Facility Management (see Chap. 17). The aim here is to automatically perform operational sequences throughout the plant in accordance with given settings while minimizing the required energy and simplifying their operation and monitoring.

Due to the direct impact of a factory's layout and its facilities on the indoor climate, we will only take a closer look at the heating, ventilation and air conditioning systems (also referred to as HVAC).

11.3.6.2 Requirements

Building services have to meet the production requirements as well as ensure the health of personnel working in the hall. The key comfort factors relevant to the workers' health (incl. room temperature, humidity, air circulation and air purity) are clarified in Fig. 11.25. These are discussed in more detail in Sect. 10.4.

Although flexibility and changeability are desirable, the key parameters which continue to decide most of the technical systems are economic efficiency of investment and future operating costs. Most companies expect a ROI (Return of Investment) of 2 to a maximum of 5 years for capital investments. Due to growing concerns of environmental protection and sustainable—energy efficient production (i.e., in terms of a "Green Factory") it is possible to extend the ROI in individual cases to a maximum of 10 years.

The following criteria should be taken into account in order to comprehensively design the technical systems for heating, cooling, aeration, ventilation, electricity and compressed air:

- the products' demands on the hall climate and the production processes',
- demands on building services,
- demands on the flexibility and changeability of the building services health and safety requirements,

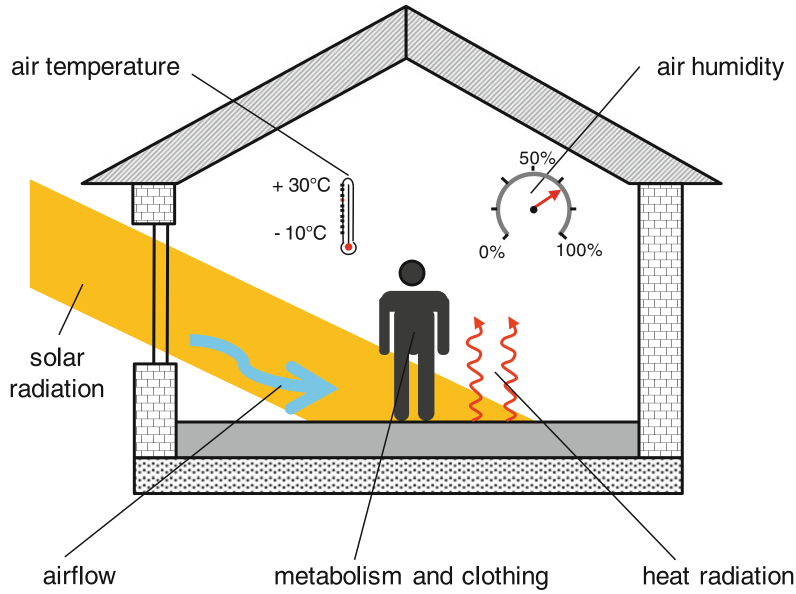


Fig. 11.25 Influences on thermal comfort. © IFA 17.601_B

- dissipation of thermal loads and contaminants for improving the quality of the workplace,
- the location and local climate.

The steps documented in Fig. 11.26 have proven to be a practical and necessary checklist for analyzing and determining the basis for planning building services. The steps refer to the building with its physical properties, the production along with the consumption of energy and media, the thermal and pollutant load created by the production process as well as the air movement with their characteristic airflow, temperature and humidity.

The concentration and thresholds of substances need to be taken into account depending on the type of production (foundry, painting, mechanical manufacturing, metal forming or assembly). Readers are requested to refer to the current regulations, standards and guidelines as explained in Sect. 8.4.

The planning and costing of building services are completed in accordance with DIN 276 Table 2 for Cost Group 400—Technical Equipment. Estimating and controlling costs are discussed in their entirety in Sect. 16.7. This division allows the individual planning and/or construction costs to be objectively compared with other plans. In accordance with HOAI [HO13], these costs are also used as a basis for calculating the planning fees and determining the lifecycle costs for a comprehensive feasibility study.

11.3.6.3 Heating Systems

Heating systems include systems required for generating the heat (e.g. a boiler), the distribution network, individual devices for heating rooms and others. Industrial heating systems could be broadly differentiated between centralized and decentralized; heat could be introduced into a building via convection or as radiant heat via ceiling mounted radiators.

Heat radiators are generally the most economical option for maintaining a steady and comfortable temperature at body height in a typical production hall as explained in Fig. 11.27 [AS13]. The left side of the diagram shows how heat is introduced radiantly. This type of heating does not warm the air, but rather heats the fixed bodies underneath it and the floors by thermal radiation. As these bodies warm up, they in turn release convectional heat (center diagram). Finally the warm bodies, in turn heat up the air in the absence of airflow (Fig. 11.27 right).

With convective systems, centralized indoor air systems are distinguished from decentralized

Fig. 11.26 Partial steps and data required for the design of building services [VDI10]. © IFA 17.602_B

data group	required data
1. building data	dimensions, building structure, building shell physics etc.
2. production data	production flow, production volume, production equipment data (dimension, simultaneity factor etc.), energy and material flow, floor plan, construction and layout of the conveyor equipment etc.
3. heat and substances release data	*thermal load*: location of release, type (convection, radiation), duration, time function (delay and damping by buffering) recording the energy consumption (meter reading etc.), recording of fluid flows and temperatures, recording of surface temperatures *substance load*: location and type of release, type of dissemination, type and characteristics of substances, substance flow, time function, characteristics of release (temperature difference, characteristics of individual movement, contaminated air flow, dissemination direction etc.) evaluation from existing work area analyses or by analyzing consumed substance amount or by measuring (e.g. acc. to DIN 33981 or EU guide lines)
4. air treatment data	construction, quality features and airflow of the existing extraction equipment, airflow and construction of supply and exhaust air systems, space for climate controls (site of central systems, air purification systems, opportunities for the installation of air ducts) etc.

air recirculation systems which are either equipped with gas burners or hot water conduits.

11.3.6.4 Air Conditioning Systems

Overview

Indoor ventilation and air conditioning systems are responsible for maintaining the target values for the air quality while maintaining thermal comfort and optimizing energy costs. One of the key ways of doing this is by planning and installing energy-saving and well-coordinated ventilators.

The basic functions of a ventilation system in a production hall are depicted in Fig. 11.28. In the left side of the hall, the conditioned air is introduced close to the work environment, while to the right of the workplace the air pollutants are extracted by the exhaust system. The halls are heated with ceiling radiators; the exhaust air is extracted from the entire hall while the leftover heat is used to pre-heat the fresh outdoor air.

Figure 11.29 provides an illustration of how, in accordance with [DIN04], the air equipment used in production facilities is classified and allocated. Compressed air systems are designed as closed units thus avoiding losses associated to large networks. Free flow ventilation systems use the natural air currents created by the different temperatures to provide a trouble-free extraction. Ventilation and air conditioning systems either force a flow into the circulating air without a fresh air feed or introduce fresh air into it. In the latter case, the fresh air is partially mixed with the recirculated air for economic reasons. Air equipment is further sub-divided according to the

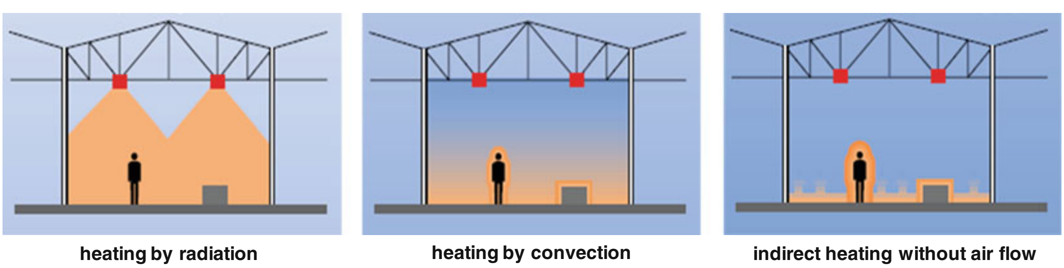


Fig. 11.27 Types of hall heating [AS13]. © IFA 17.603_B

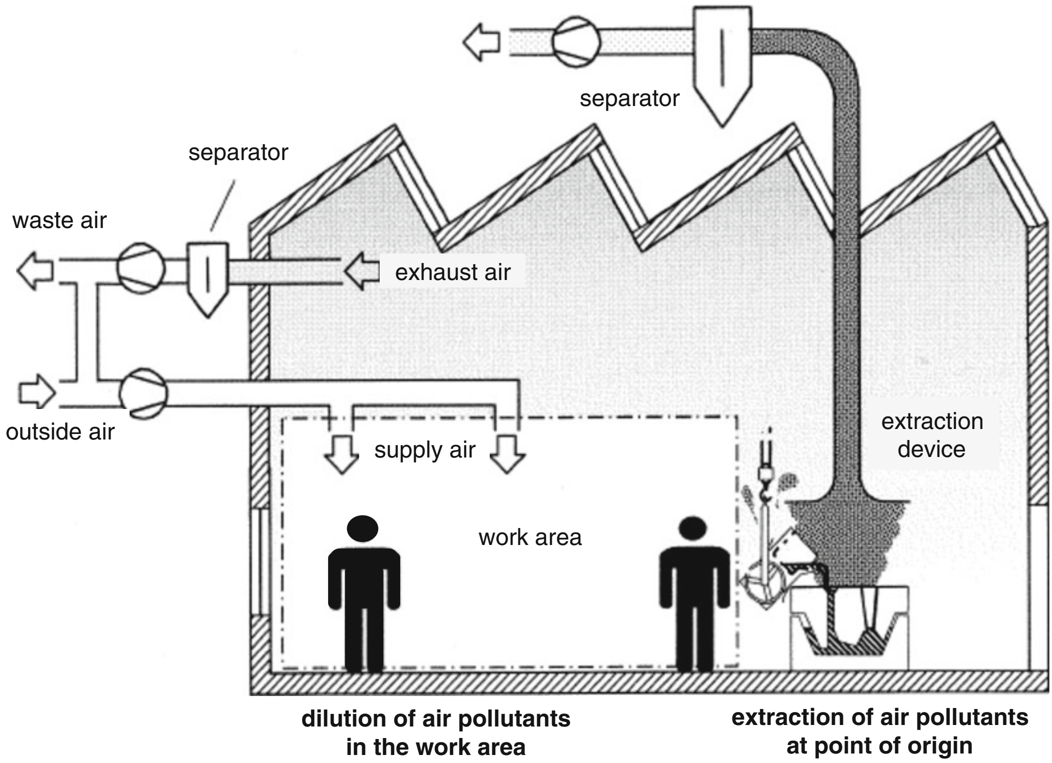


Fig. 11.28 Functions of a ventilation system in a production hall (Kolarik [Kol02])

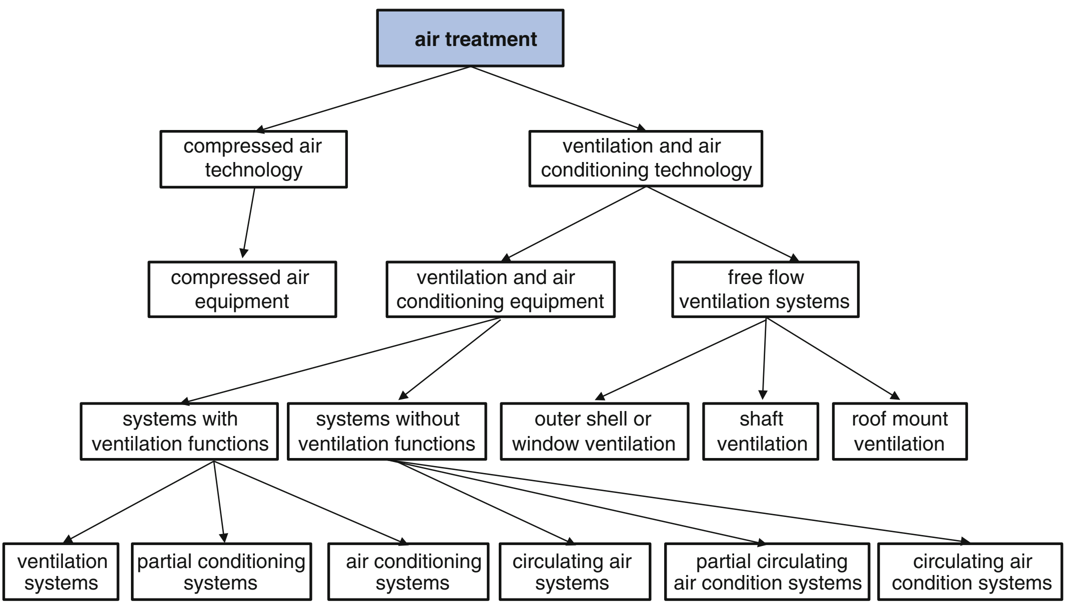


Fig. 11.29 Classification of air equipment (per DIN04). © IFA 17.605_B

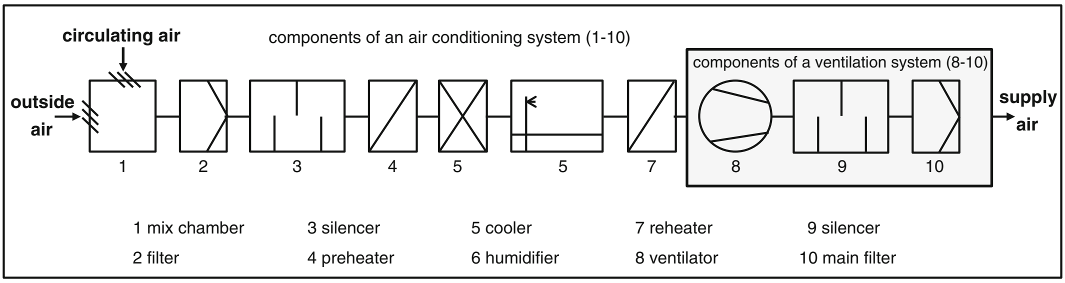


Fig. 11.30 Structure of an air conditioning system (per Recknagel [Rec13]). © IFA 17.606_B

four thermal dynamic methods of treating air: heating, cooling, active humidifying and active de-humidifying.

When a ventilation and air conditioning system conducts all four functions it is referred to as a 'full air conditioning system', whereas those which conduct only some of these functions (heating and cooling, humidifying or de-humidifying) are referred to as a 'partial air conditioning system'. The principle structure of an air conditioner is presented in Fig. 11.30. The outdoor air is first mixed with the recirculated air that is fed back into the system and filtered. It is then routed over a silencer and through a preheater, cooler, humidifier and re-heater. These functions are individually activated depending on the state of the input air and the state of the mixed air. With the use of blowers, the conditioned air is then routed over silencers and filtered once more before it is introduced into the room. Depending on what functions are required and desired, placeholders can be installed for individual components, thus facilitating future retrofits.

Ventilation systems can be executed as either single-channel or dual-channel systems (see Fig. 11.31). In the first case, a centralized air conditioning plant in installed from where the conditioned air is directly supplied to the various rooms. This makes it possible to implement and use different sources of energy. In terms of sustainability, a heating system based on wood chips, for example, is possible; the hall heating would then be almost CO_2 neutral.

With dual-channel systems the air is pre-conditioned using a central system and is then routed through decentralized pipes in each zone for final conditioning before releasing the same into the space under consideration. Dual-channel systems are advantageous in that they are easy to install, can be adjusted locally and are easy to shut down to avoid smoke and fire spread. However, there are also a number of disadvantages including the higher space requirement and the need for a large number of decentralized electrical terminals. Keeping in mind a modularized and changeable structure, dual-channel systems appears to be better option since it is easier to adapt to localized requirements when for example a part of a factory is not working or a zone is undergoing conversion and must be switched off.

For decentralized heating systems, which usually work with recirculating air, suppliers offer compact ventilation systems with heating and cooling functions along with integrated heat recovery. Figure 11.32 depicts an example of a decentralized ventilation system as a roof installation. It fulfills the following functions: The outside air passes through a filter and enters a heat exchanger where it is warmed by the re-circulated air that has been extracted from the hall. The supply air fan pushes the pre-heated air through a heating/cooling register and an air diffuser into the hall. The cooled recirculated air leaves the building through a filter as exhaust. The circulating air and bypass flaps control the ratio of fresh air to exhaust air. The condensers serve to generate cold when the air has to be cooled. This example of a ventilation system does not include devices for humidifying or de-humidifying the air.

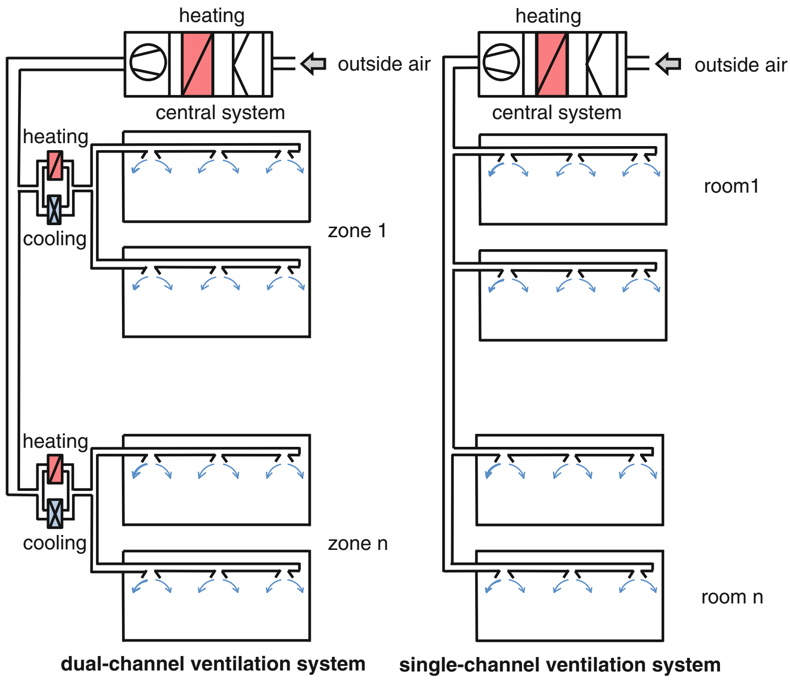


Fig. 11.31 Single and dual channel ventilation systems (per Kolarik [Kol02]). © IFA 17.607_B

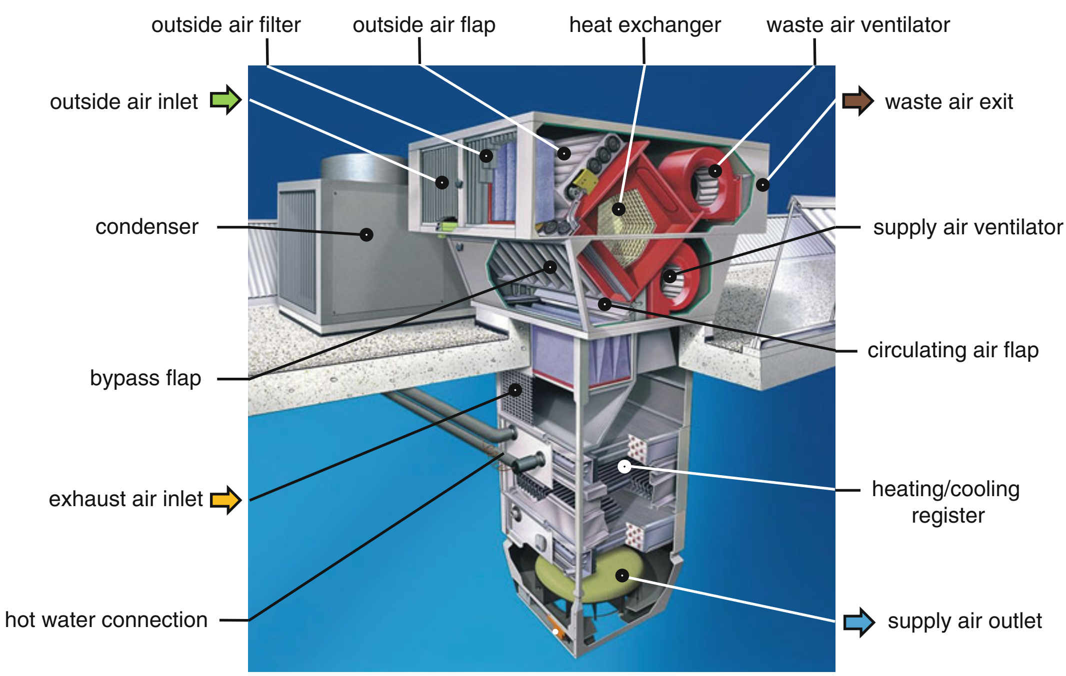


Fig. 11.32 Ventilation system—roof installation (by permission of Hoval AG). © IFA 17.608_B

The cost of HVAC systems increase with the number of functions. The following table can be used to roughly estimate the costs (as of 2013):

• Full air conditioning	22 €/m^3 intake air
• Heating and cooling	14 €/m^3 intake air
• Ventilation and aeration	8 €/m^3 intake air

Detailed investment costs can be obtained from the local manufacturers'. Obviously both initial investment costs as well as operating costs are higher for full air conditioning and air cooling systems. According to VDI 6022, both humidifiers as well as dehumidifiers require periodic and thorough maintenance. The cold water quality needs to be tested for bacterial or fungus growth every 6 months while the entire ventilation and air conditioning system needs to undergo a hygiene inspection from time to time depending on the quantum of air humidified. Based on VDI 2067, the operating costs for maintaining humidifiers and dehumidifiers is approximately 2 % of the investment costs per year while for heat recovery units it is approximately 10 %.

As already mentioned, comfort conditions depend not only on the perceived temperature and humidity, but also on the air movement in a given space. Drafts are often the cause of common colds and influenzas. Disruptive air movements are usually the result of ill-designed ventilation systems, thermal imbalances at sources of heat, cold downdrafts from poorly insulated external surfaces or doors and windows temporarily left open.

Ventilation systems thus have to be planned to ensure a comfortable air movement, which, depending on the climatic zone and the proposed system lies between 0.2 and 0.7 m/s (0.7 and 2.3 ft/s). Ventilators and air supply ducts should be selected and arranged in the hall space in accordance with these target values. The principles and details of thermal comfort in the workplace along with calculation and evaluation methods are provided in the relevant national and international guidelines and standards e.g., in [ISO08].

HVAC systems are also responsible for ensuring the air quality of a workplace. The air contaminants have to be extracted from the airflow and removed from the hall.

The flow of the contaminated air depends on the source of the substance and the manner in which the substance is dispersed. This is determined by:

- air density differences due to temperature differential (e.g., tire presses, welding plants, foundries, etc.)
- external forces such as inertial force, gravity or aerodynamic forces (exhaust blowers, cold air blowers, back flows etc.) and,
- how the air is distributed.

Types of Air Flow

In terms of a comprehensive plan, when designing an HVAC system, one of the first decisions to be taken includes the method for controlling the air distribution. There are three basic types from which to choose, depending on the needs of the production: laminar (or unidirectional), mixed and stratified.

Mixed and stratified airflows created by displacement from the bottom-up are well suited for manufacturing halls. They are described in detail in [Bac93].

- Laminar

The supply air is introduced into the hall via large diffusers. The low turbulent, unidirectional airflow displaces the contaminated air. Due to the costs involved, this type of air distribution was generally reserved for processes requiring high quality air (e.g., painting/spray booths, clean rooms for micro-electronics or pharmacies). In recent times, such systems are increasingly used for mechanical engineering environments where mechatronic or medical components are involved.

- Mixed

The fresh air supply is completely mixed with the room air in the manufacturing hall. As a result the temperature and concentration of substances is almost the same throughout the hall. This intensive mixing is attained through high impulse air jets. In order to maintain the physiological requirements, the impulses and temperature differentials need to be minimized outside of the work area. Also, the sources of contamination need to be controlled carefully.

- Stratification

The air supply is introduced at a low velocity (≤0.5 m/s (0.64 ft/s)) as well as impulse so that the thermal levels surrounding the production facilities in the manufacturing hall remain undisturbed. The hot air from the work area rises into the unused space above it in the hall. If the extracted air in the work areas is completely replaced with the fresh air supply, this results in a less contaminated zone at the workplace but a greater level of contamination at the higher level. In order for this to occur, there have to be heat sources in the work area and the majority of the contaminated flow has to be released near the heat sources into the thermal flow. The air temperature in the work area is then set higher than the temperature of the air supply. Moreover, the rate of the air supply has to be set so that it is sufficient for the thermal and collected air flows to rise up to a defined room height. When ideally designed this type of air distribution can keep the air contamination in the work area at a very low level.

Designs

- Mixed Airflow Designs

Air distribution systems which create mixed airflows throughout the entire hall are state of the art and commonly found in a variety of designs (see Fig. 11.33). When the supply air vents are placed horizontally below the hall roof, the air diffusers create zones with circular flows and return contaminated air into the work area. The supply and thermal airflows are thus mixed together. Thermal flows can be diverted into the

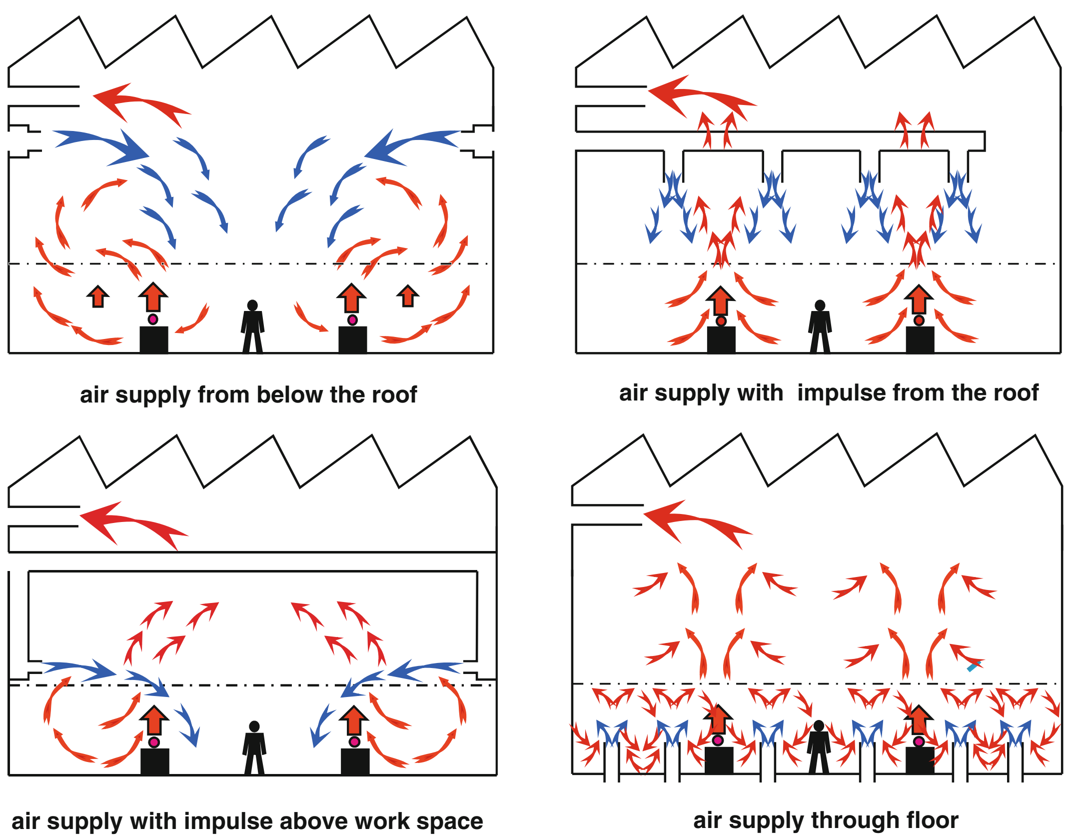


Fig. 11.33 Types of air distribution with mixed airflows (per [VDI10]). © IFA 17.609_B

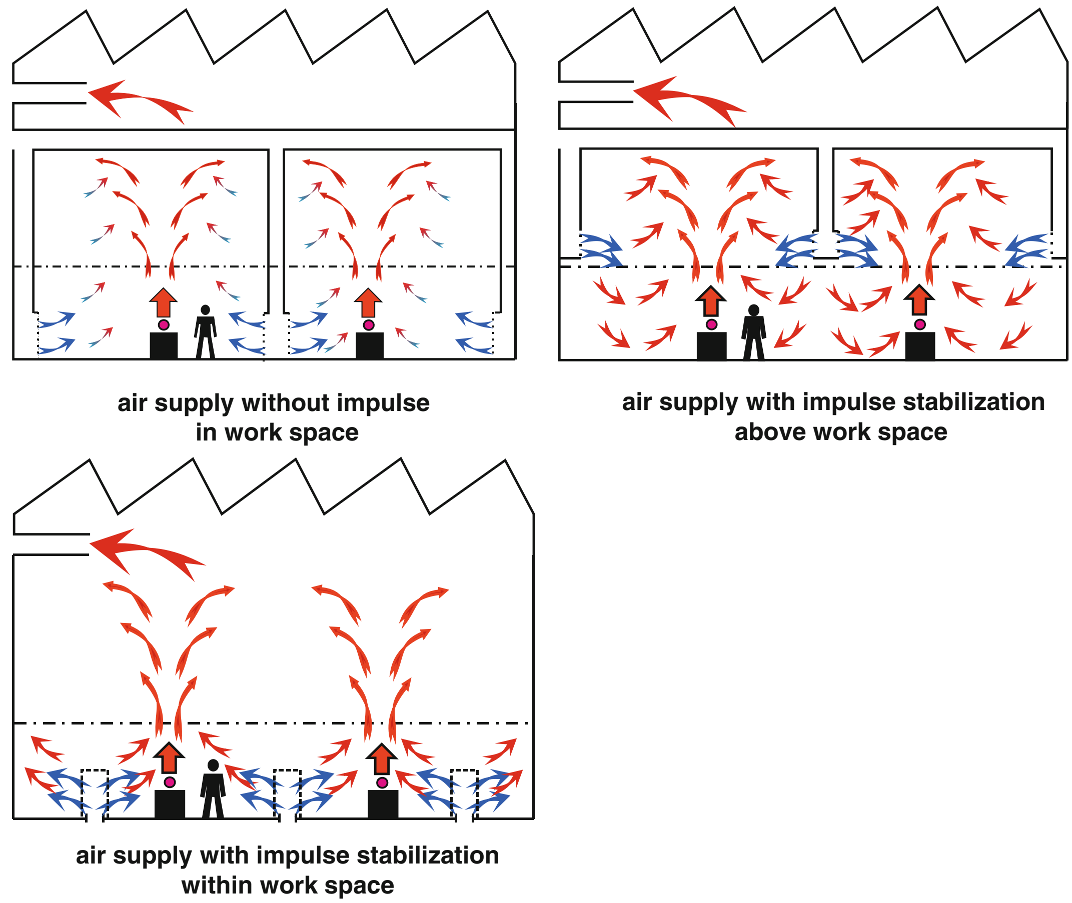


Fig. 11.34 Types of air distribution with stratified airflows (per [VDI10]). © IFA 17.610_B

work area and the air flow can be disrupted. With a large number of air supply openings in the hall roof, a mixed flow can be attained in the entire hall due to induction at the air diffusers.

- Stratified Airflow Designs

Stratified airflow designs use thermodynamics for transporting both heat as well as contaminants. The supply air has to be introduced with impulses that are low enough not to disrupt the layers or thermal currents, moreover the supply outlets needs to be installed close to the sources for the heat and/or contaminants. Figure 11.34 depicts a number of designs, which basically differ from one another in the location of the air outlets. Air impulses are stabilized through outlets with a fine mesh opening or using textile hoses that also allow the dirt to be easily washed away.

Temperature and flow profiles can be simulated and visualized nowadays with sophisticated software. As an example, Fig. 11.35 depicts the temperature and flow profile for a manufacturing hall. The requirements here included a temperature profile of ±1 K with a range of 0–6 m high and a flow rate of 0.2 m/s (0.65 ft/s). HVAC systems with requirements such as these can only be reliably and economically designed using simulations.

11.4 Interior Finishing

Once the structural frame, shell and media have been determined, the focus is directed at finishing the buildings' interior. There are a number of

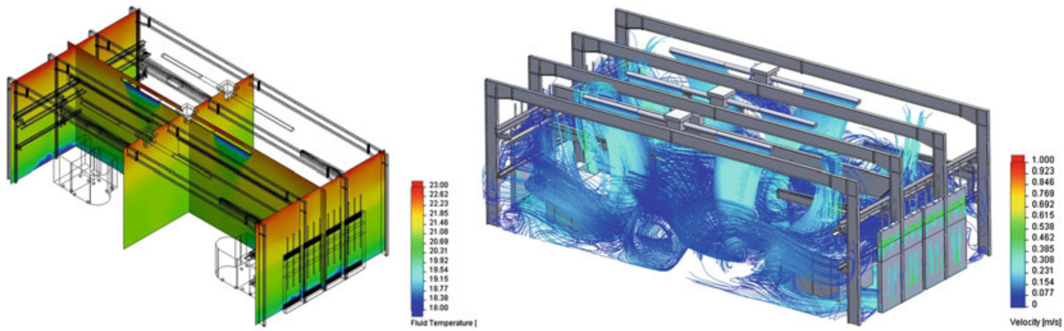


Fig. 11.35 Temperature and flow profiles for a manufacturing hall (ifes). © IFA 17.723E

systems and materials available for this. The building system for the floors, walls and ceilings should be aligned with the user's interests but should also avoid constraints that might negatively impact the buildings' changeability. The demand for a high degree of changeability for a building is similar to being able to easily change stage sets between acts in a theater or constructing exhibition spaces for a trade show. This means monolithic constructions should be avoided as much as possible in a buildings' interior finishings. Instead, modular, variable and easily convertible building systems should be favored even for the stairs and core areas.

Ideally a building's floors, walls, ceilings, core and stairs should be developed as modularized construction kits from the perspective of both engineering and aesthetics. The fundamentals of developing the interior of a construction project are summarized in [Pot07]. Lightweight constructions can also provide a high level of fire protection without monolithic structures. A 'building within a building', takes these factors into account. With due consideration to details, projects built on this approach are spatially variable and allow for changes without disrupting on-going processes.

Figure 11.36 depicts an overview of 5 design fields involved in the interior finishing along with 4 design elements for each field. In the following sections, we will discuss the structural characteristics of each of these elements in view of their changeability.

11.4.1 Floors

Figure 11.37 provides an overview of the structural features that are relevant for the changeability of floors along with their parameters. The user perceives the surfaces while the structural specifications are based upon the process and environment requirements. In terms of changeability, it is also critical that the floors are sustainably robust, easily installed and simple to modify.

The *surface* is primarily determined by the load. Construction materials for industrial floors should thus be both resistant and durable. In addition to being even and easy to maintain, they should be constructed easily, efficiently and economically. These requirements can be fulfilled by monolithic or multi-layered constructions. For centuries now, surfaces made from concrete have proven to be durable. They are found to be robust for the most part against soiling, mechanical impacts, water and frost. Concrete floors are easy to clean and keep clean while entailing extremely low maintenance costs. In addition, old concrete floors can be recycled to make new concrete. Monolithic floor plates made out of steel-fiber reinforced concrete can replace the on-site reinforcement with steel normally applied.

Multi-layered constructions are usually finished with a hard surface course or wearing coat after they are laid. The required durability and flatness of the overall structure is specified based

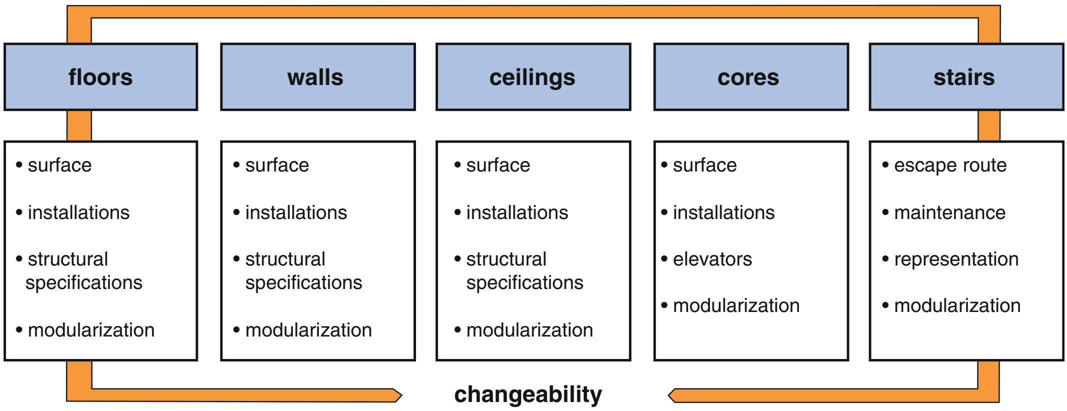


Fig. 11.36 Overview of structural elements in a building's interior finishing. © Reichardt 15.203_JR_B

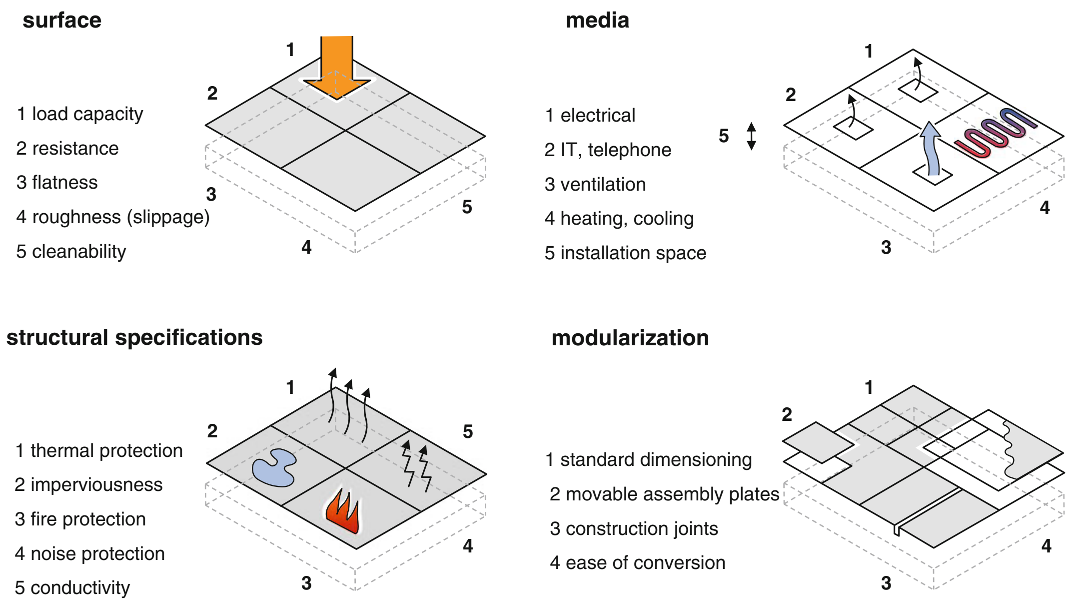


Fig. 11.37 Structural features of floors relevant for changeability. © Reichardt 15.204_JR_B

upon the needs of the processes and logistics. Since it is quite impossible to change the level and durability criteria at a later date the present requirements should be coordinated with possible future needs.

DIN 51130 provides further details regarding non-slip and easy to clean surfaces. In order to ensure a high degree of changeability in terms of process and logistics, hall floors should be kept free from media routings and ducts as much as possible. In comparison, with ceilings in multi-storied buildings it is often advisable to integrate systems like—electric, IT, ventilation, cooling and heating, together. With these types of installations it is recommended not to build them directly onto the static ceiling construction, but rather as separate layer. Systems such as double floors or floor plenums create a number of possibilities for adding media routings and ducts later.

The *structural specifications* of the floors are derived from the project's guidelines and requirements particularly with regards to protection against heat, noise and fire as well as water. In cold countries, a 3D energy simulation may be used to review and determine the floor's capacity to provide sufficient warmth in the work areas and avoid excessive heating. Better insulation values resulting in higher surface temperatures for the hall floor increase the possibilities of changing the arrangement of workplaces in the hall and support changeability. Impervious hall floors are required to protect against possible water ingress into the building from the sub-soil and surroundings. Additional coatings made of epoxy resin could be helpful under extreme circumstances. Such coatings are best applied during the construction period for perfect adhesion between the layers.

Requirements for protection against fire, noise and conductivity are usually related to floor and ceilings between the various floors of the building. Ideally, inflammable materials should be used as much as possible. Surface treatments made of out of PVC seem to be economical at first glance. However they release toxic fumes in case of a fire and require special care for disposal making them expensive in the long run and are best avoided. With proper detailing, unwanted noise generated out of footsteps on a floor can be avoided. Furthermore, with the aim of increased changeability, it is important to keep in mind that the use of computers would continue to grow in the future, floor properties should thus be planned so that they can dissipate correspondingly higher levels of electrostatic energy. Accordingly, floor systems should be installed so that they can always be easily retrofitted and simple to replace.

The degree of *modularization* significantly determines the effort required to alter floors. In order to be able to extend, dismantle or exchange systems, components should be uniformly dimensioned. If an industrial floor—characterized by its ability to withstand considerable weight, lasts long and easy to recycle—is required, the floor surfaces can be created using components like Stelcon large plates or Stelcon hexagon elements. These large plates are produced with a concrete quality of DIN C 35/45 and a standard size of 200 × 400 cm (6.6 × 13.2 ft). They are 14–16 cm (5.5–6.3 in) thick and have edges protected from damage by special mild steel angle sections. The large surface plates are used for example as finished floors in plants and storage halls, but also as anchors for port facilities and rail systems, transshipment sites in the chemical industry, access roads and gas stations. When planning the details of necessary structural joints, it is also important to consider any discontinuities that might be created (e.g., induction loops and transponder points) from the perspective of processes and logistics.

11.4.2 Walls

Figure 11.38 provides an overview of the basic structural features related to the changeability of walls. Whereas surfaces have to fulfill various purposes, the structural specifications determine the technical features. Walls that can be easily installed and changed are becoming increasingly important. And finally, here too, the aim is to find a consistent and modular system that can be harmonized with the building's grid.

Modern working methods and styles are constantly changing when compared to working in labs, workshops or operating out of offices. Spatial boundaries that can be easily adjusted depending upon the size of the workgroups and the content of their work are becoming increasingly preferable. In contrast to monolithic construction, prefabrication provides the required freedom to not only select the wall position but also select the position of the closed surfaces (for privacy), glass panels (for visual contact) and doors (for circulation). Transparent walls that connect the individual areas visually are particularly important for communication between personnel and encourage employees to identify themselves as a team.

Generally, there are two systems available for lightweight wall constructions: so-called 'drywalls' made from gypsum boards and wall panels made from sheets of wood, plastic or metal. Drywalls made from gypsum boards are fixed onto aluminum or wood stud frames, patched and painted or covered with wallpaper. In comparison,

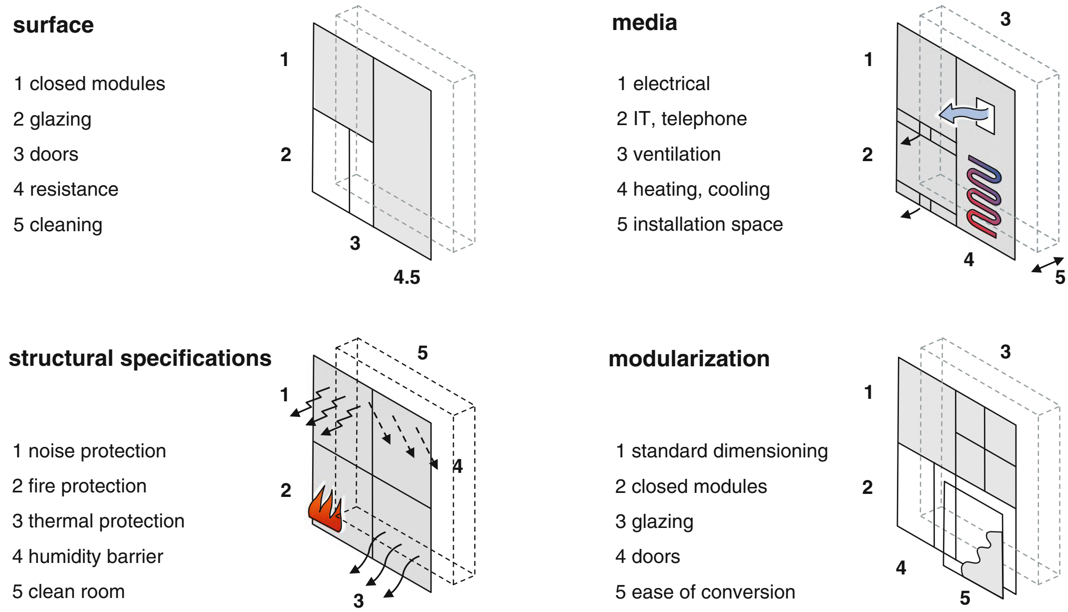


Fig. 11.38 Structural features of walls relevant to changeability. © Reichardt 15.205_JR_B

wall panels are supplied as elements with a finished surface and joint systems for connecting each other. Glass panels and doors do not disrupt wall surfaces, but are instead equally weighted elements.

Construction kits such as these can be uninstalled in a few days and re-built in another combination at another location in the factory. With the right attention to detail, systems for supplying electricity, IT as well as heating and cooling can be integrated at the skirting level or just below the window sill. In some cases, office furniture such as closets or bookshelves can be locked into the system's joints.

By providing insulation materials between the gypsum boards or wall panels, special physical requirements for noise, heat or fire protection can be met conveniently. Drywalls with suitable paneling and insulation materials can resist fire up to 3 h and satisfy F 180 fire ratings, if need be. Modularized wall panels can resist fire up to 2 h (F120). In case of precision industrial manufacturing, wall panels can be also used for enclosing clean rooms. In order to attain the required impermeability, sealants can be applied after installation. Wall panels are advantageous in that they can be easily reinstalled without the dirt and dust associated with tearing down dry walls. Thus, they support changeability especially in sensitive processing and logistic facilities.

Here too the basis for modularization is a consistent dimensional system for all closed surfaces, glass paneling and doors. Floor plans ideally should be designed in grids of 1.00, 1.20, 1.25 or 1.5 m (3.3, 3.9, 4.1 or 4.9 ft).

11.4.3 Ceilings

With regards to changeability, ceilings are subjected to almost similar characteristics as floors and walls. Figure 11.39 provides an overview of the structural features relevant for the changeability of ceilings.

Similar to wall systems, the varying spatial requirements of modern work-forms require flexible ceiling systems. So-called 'house in house construction' offers the benefit of coordinated wall and ceiling elements. Here, the precision of industrial pre-fabrication is best suited for meeting the structural specifications and allowing a carefully planned installation.

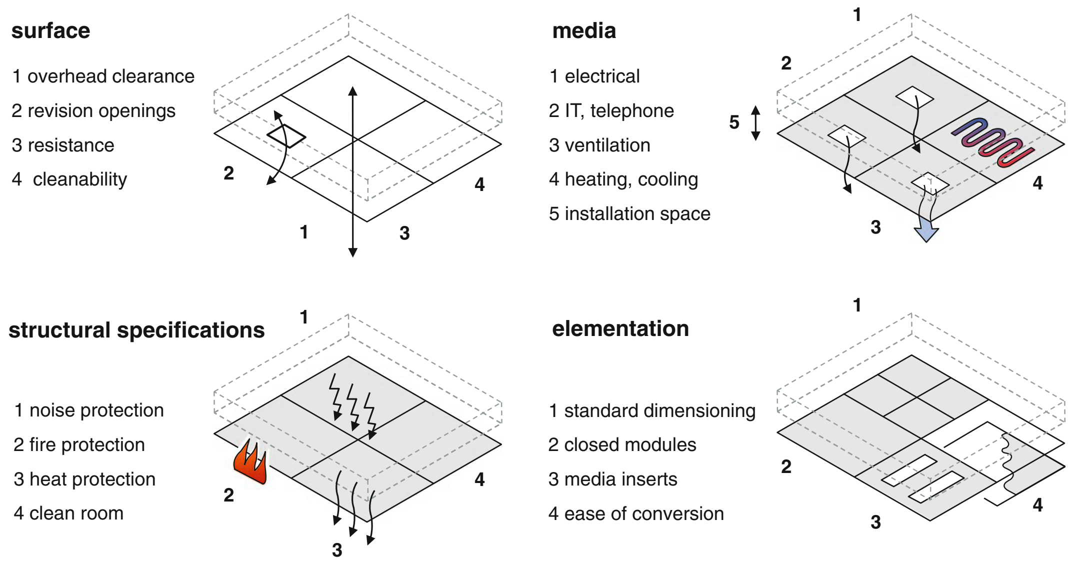


Fig. 11.39 Structural features relevant for the changeability of ceilings. © Reichardt 15.206_JR_B

One of the basic features of changeability is the overhead clearance. Rooms larger than 50 m^2 (538 ft^2) should have at least 2.75 m (9 ft) headway, whereas rooms larger than 100 m^2 (1,076 ft^2) should have at least 3.00 m (9.8 ft). When designing the floor plan the minimum clearance of the smaller rooms also needs to be verified in view of future developments. One of the design principles for modular ceilings involves mounting panels fixed below a supporting metal framework. The cavity that is thus created can be used for media routings and the ceiling panels can be made from a variety of materials.

Ideally the *surfaces* should be durable and easy to clean. System grids are commonly found in 0.50, 0.60, 0.625 or 1.00 m (1.6, 2.0, 2.05, 3.3 ft). Access areas for maintaining, or retrofitting the media routing installations that are located above ceiling panels can be created through certain removable panels. Another basic characteristic that is relevant to changeability is the actual clearance above the ceiling construction: For example, if air ducts need to be replaced with ones that have a larger cross-section in order to meet increased ventilation demands, they can only be installed provided the necessary space is available for the same.

The *routings* and media outlets for the electrical supply, EDP/telephone, ventilation, cooling and heating should also be modular and therefore adaptable without impeding each other. The physical requirements for sound proofing, fire protection, thermal insulation and clean-room specifications can be met only through careful planning of the mounting plates and the interim space below the structural slab. Perforated plates improve the spatial acoustics by increasing the sound diffusion. Insulating layers made out of non-flammable materials such as mineral (rock) wool or special fire-proof plates increase the fire resistance of ceiling structures or individual media lines. In clean-rooms, the joints (e.g., between walls) can be made impervious by applying suitable sealants.

When developing the elements for *modularization*, careful attention should be paid to maintaining standard dimensions and minimizing customization. If the layout grid is free from disruptions, peripheral areas remain available for media and elements can be interchanged in the entire floor plan. Ceiling plates and routing systems with pre-finished surfaces and clip-on/plug-in connections minimize both the time required to reconfigure them as well as the risk of contamination when doing so.

11.4.4 Cores

Cores are building areas that serve to dissipate a concentrated static load and are serve additional functions. For economic reasons it is often advisable to transfer the vertical and horizontal loads of a hall's structure over concrete or steel walls and to use the space thus created for elevators, emergency staircases or installation shafts. The general positioning and spatial layout of such core areas should be discussed together in detail along with factory planning, since once cores are planned and constructed they are more or less unchangeable. The location of the cores in the building as well as the required widths and depths of them is generally derived from the plan of the load-bearing frame.

Cores should be positioned with an eye to the future, so that possible options for changes in processes and logistics are in no way impeded. The clearance space allowances for the *installation shafts* needs to be checked to ensure that there are enough allowances for future purposes. Changes in processes or logistics often require additional media and thus the requirement of additional space inside the shafts.

A critical point for most of the shafts is the space where the verticals pipes and wires are separated and are to be routed horizontally. Finally, the openings to the shafts that are important for fire protection and should make it easy to maintain, repair, retrofit or replace routings.

One of the key characteristics in regards to changeability is the detailed design of the passenger and freight *elevators*. Since elevator technology has to be replaced every 15–25 years, it is of paramount importance that elevator clearances as well as the height and width of the elevator doors are planned with an eye to transport larger volumes in the future.

The possible *modularization* in the sense of changeability and therefore the potential to modify cores is greatly restricted due to the above-mentioned reasons, especially when constructed using monolithic (in situ) concrete. Cores can be also constructed using precast concrete elements as well as steel frameworks with infill wall panels. Implementing elements that are assembled together generally even makes it possible to change the core's width and depth. In summary, Fig. 11.40 depicts an overview of the structural characteristics relevant to the changeability of cores.

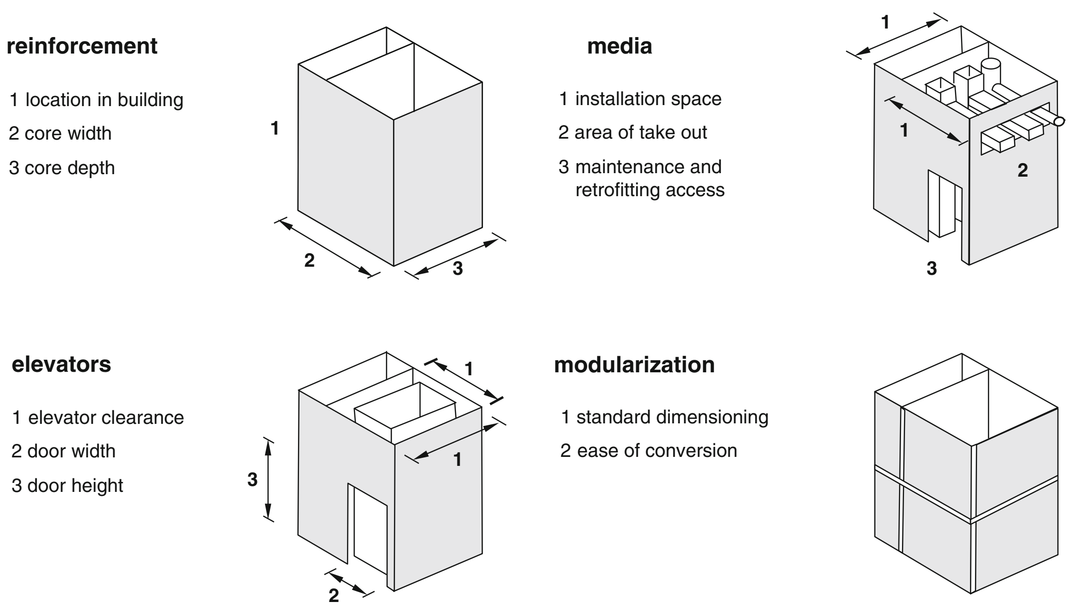


Fig. 11.40 Structural characteristics relevant for the changeability of building cores. © Reichardt 15.207_JR_B

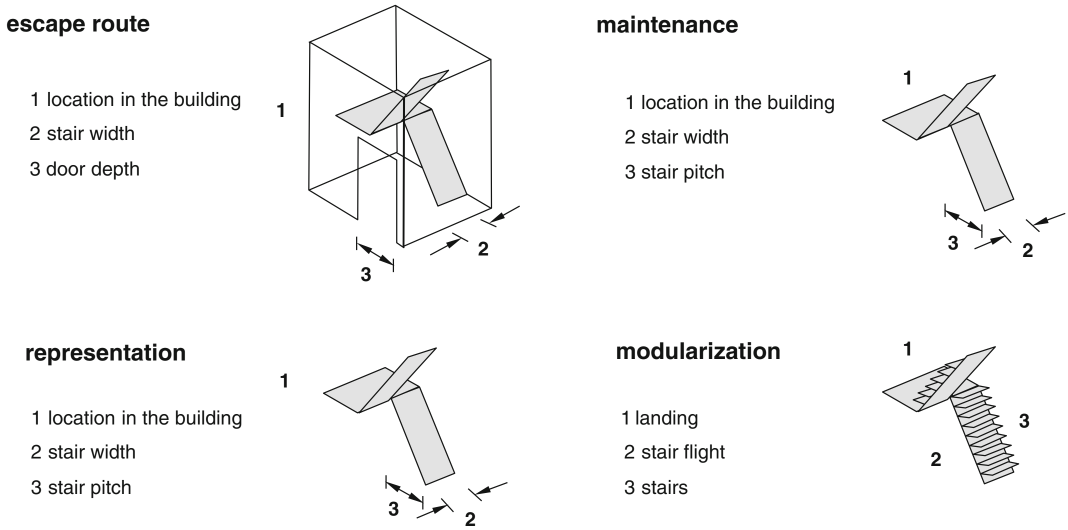


Fig. 11.41 Structural characteristics relevant for the changeability of stairs. © Reichardt 15.208_JR_B

11.4.5 Stairs

By making use of fire resistant constructions, stairs located within cores are generally planned and implemented as escape stairways. However, escape stairways can be located in other parts of the building also. According to most building regulations, the seal required for stairways that are planned as escape routes require a fire resistance of 1.5 h (F 90) and can also be realized with assembly kits made out of materials ranging from dry or completely vitrified construction. Similar to cores, the location of evacuation stairwells in buildings needs to be planned keeping the future in mind. Later modifications require not only reconstructing the stairways, but also reviewing the escape routes and obtaining re-approvals from the concerned fire department.

The required width of the stairs and doors is oriented on the number of people who would need to be evacuated in the worst case scenario, thus when planning stairwells, the area for possible office extensions should also be taken into consideration. Stairs for maintenance are not subject to the same requirements as those meant for evacuation, rather their location in buildings are more oriented towards functional needs. The necessary stair width, pitch and design details have to be built in accordance with the relevant workplace and accident prevention guidelines.

Additional stairs in foyer or galleries can be constructed as open stairways and need not be enclosed or complaint with the necessary fire regulations. The width and pitch of the stairs should also be oriented towards possible number of future users. Generally, with regards to changeability, stairways with a modularized construction should be given preference over those built in concrete and thus fixed at a certain location. As with the other finishings, the modularity allows the staircase, landings and individual stairs to be altered in a variety of materials. An overview of the structural characteristics of stairways presented here as relevant for changeability is provided in Fig. 11.41.

11.5 Examples of Changeable Buildings

Figure 11.42 depicts two factories that were actually built with focus on changeability when designing the structural frame, shell, interior finishings and media.

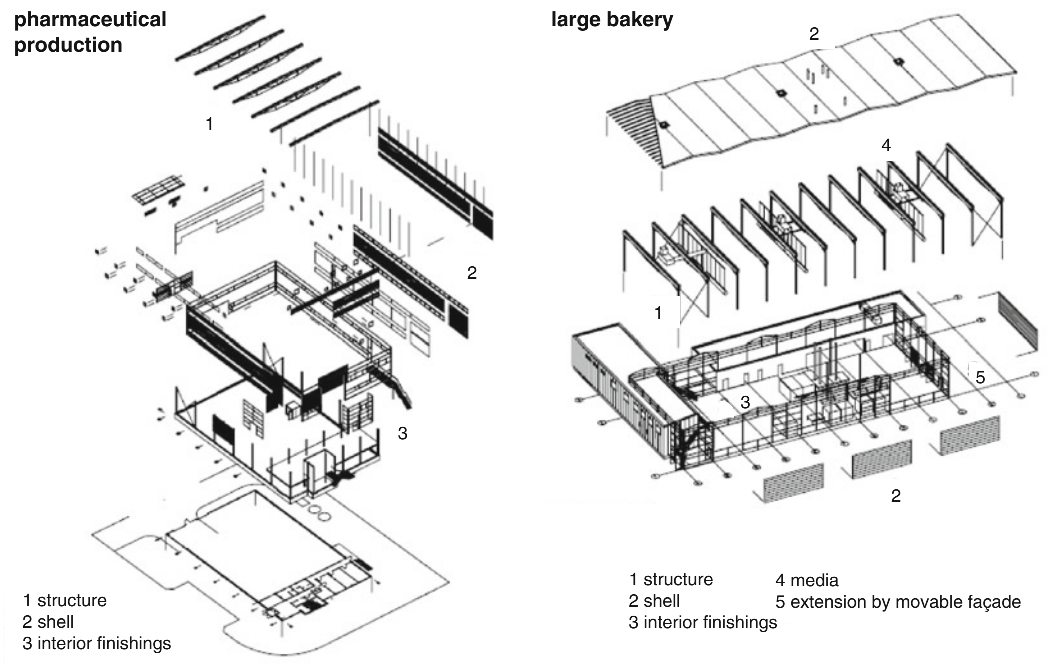


Fig. 11.42 Modular design principle as applied to a building (examples). © Reichardt 15.209_JR_B

In both cases, the building concept was implemented according to modular design principles with separate building components for the structure, shell, media and interior finishings. In the case of the large bakery, the project requirements necessitated a timber skeleton construction for the load-bearing frame, a metal and glass façade for the building shell (independent of the structure), as well as modular air circulation devices within the structural frame zone for the ventilation technology. By strictly separating the systems, the baking hall was able to be extended by one grid field (approx. 6 m × 22 m (19.7 × 72.2 ft)) 'over the weekend' without causing any disruptions.

The same applies to the pharmaceutical production in which special attention was given to ensure the building could be expanded with minimal disruption and that the interior could be easily changed.

An example of a modular and versatile assembly factory for car coolers shows Fig. 11.43, which is also available as a video animation in Appendix D3. The target was to design for trouble-free scalability of processes, systems and buildings as well as re-usability. Hall spans of 18 and 36 m (59 and 118 ft) and 8 m (26 ft) building height enable easily movable work places.

11.6 Grace and Aesthetics

Architecture reflects the forces that were at work during the building's creation. Unfortunately, this applies to most of unsightly industrial and commercial buildings across the world. It appears that most companies view their buildings as tedious necessities, which they would prefer to do without entirely. Architecture is the most fundamental and permanent expression of social culture and it is time that industries and businesses reconsider their attitude and approach to architecture. "Graceful" aesthetics arise when the design elements—that is the location, type of construction, structural framework, shell, media and interior finishings—are cleverly and creatively combined based on

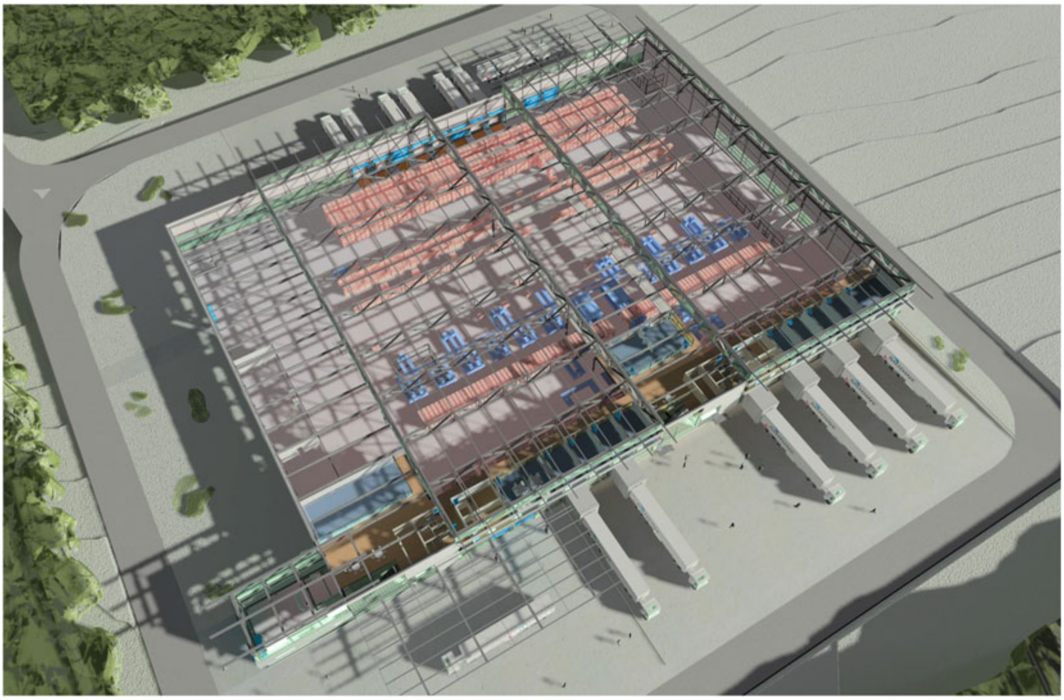


Fig. 11.43 Example of a modular and changeable assembly factory (Reichardt)

synergetic planning approach. Examples of such graceful factory buildings can be found in [Uff09].

Thus according to [Mes05, Kni06], for each of the specific tasks, it is necessary to develop an innovative overall design strategy for the forms, materials and colors. Ideally this strategy should permeate the building in every detail including how they are combined both "externally" and "internally". Details such as the design of the façade's proportions or the color to be used are secondary design features. The tectonics of how the buildings' volume is developed and how the buildings are distributed are essential to the overall impact of the construction. Often when there are creative differences, 'grace' becomes a victim under pressure to keep costs down or to increase 'economic' efficiency.

Outstanding industrial architectural examples across the world however provide a strong counter-point. Henry Ford, the king of the automobile industry was supposedly a penny pincher in his days; yet his extremely functional factories, which were considered to be a model of production processes, impressed everybody with their extreme efficiency as well as their exemplary grace [Hil74]. Ford's remark that "good design pays" demonstrated his conviction and his awareness of the value of aesthetic design. By 1920s and 1930s, the Ford factories had reduced the number of people 'taking sick days' and/or quitting thereby increasing the overall profitability of operations and forging long term bonds between the company and employees.

The objective of graceful industrial architecture can be summed up with the following fundamental parameters: structural order, simplicity, balance between unity and diversity and distinctiveness. Böhme [Böh06] suggests that the emotional or 'atmospheric' quality of a building should also be taken into consideration as an additional design value.

11.6.1 Structural Order

The principle of structural order creates a feeling of harmony. Structural order is attained with a consistent relationship between the parts and the whole, one reminiscent of a living organism where there is internal coherence between the elements and their totality. The immediate sense of clearly articulated structural shapes and architectural forms along with the careful understanding and legibility of the elements' functions (e.g., the structural frame, shell and interior finishings) all play a decisive role in the overall structure. The structural order naturally unfolds with the help of its own grammar: the floor plan, sectional and vertical projections. Clarifications are not necessary to understand the building, since the relationship between the parts is easily understandable. An example of a structurally ordered type of construction is a modular plant based on hall segments.

11.6.2 Simplicity

With industrial buildings there is no need for filling, cladding or laminating. Solving a building project in this way, i.e., without "stage magic" pleasantly corresponds to the rational design principle used in medieval cities. Aesthetics need not be costly. At the same time, simplicity should not be mistaken for the banality, lack of imagination and primitivism of common commercial construction. Rather, the demand for economic efficiency goes hand in hand with minimalism and the lack of extensive and complicated fascia work.

The 'appearance' of many enterprises across the world seemed to be saying something quite different; they confuse the simple-minded with their over the top and unnecessary fascia treatment. Intelligent reduction of forms, materials and color allows for powerful aesthetic effects. Liberated from unnecessary coverings, the quality impacts the viewer directly and is more sustainable than attempts to present a deceptive package with flashy gimmickry.

11.6.3 Balance Between Unity and Diversity

The balance of visual information within the field of tension between monotony and chaos requires aesthetic comfort. Unity and diversity are mutually exclusive but require one another. They are necessary poles between which the balance has to be re-adjusted for every project. On one hand, viewers are quickly bored when they detect a total uniformity and monotony dominating in the architecture. On the other hand, an agitated mind results in a 'ball of confusion'. The excited oddity of short-lived fashions is soon forgotten and seems embarrassing when looking back after a few years. The ideal solution is a viable urban and architecturally sustainable design. Fixed building heights set over the long term or a canon of materials that can be implemented with options for design possibilities within this framework create potential for individual solutions for the future.

11.6.4 Distinctiveness

Distinctiveness stands out when compared to forgettable visual experiences. It often seems that the anonymity of insignificance is the goal for many industrial projects. How else could one explain the degree to which these projects have refrained from a notable design? In reaction to this, some enterprises attempt to gain attention with unnecessary detailing—a formal arbitrariness oriented on a surprise effect which rarely sustains in the long run or defines the character of a building or its users. A distinctive design results out a creative combination of specific agreements, special local situations and conscious selection of the components of the construction and building. This type of "value-added" architecture has a much stronger visual impact using much less capital than elaborate print and film advertising campaigns; it is the embodiment of a project's mission, accomplished through the total innovative performance of the planning team.

11.6.5 Emotional Quality, Atmosphere

Graceful buildings touch an inner chord and a positive relationship develops between the observer and the building. According to [Böh06], this emotional quality influences the deeper perception of spaces, materials, color and light far beyond the organizational and functional references. When we consciously design the type and form of the spatial environment, starting with the buildings' orientation and the internal/external views etc. we create an immediate understanding of the architectural structure and facilitate its usefulness. The way in which materials are used and joined together can convey everything from the greatest industrial precision to handcrafted artistic spontaneity. Structural parallels to the quality of the manufactured industrial products are thus directly produced or can be at least interpreted. Just as with the product design, the emotional quality of the building should be given special consideration while determining the objectives of a project. Examples and suggestions for this can be communicated and updated in goal planning workshops.

In short, the exterior of a building should reflect the company's claims and its interior the product's claims; or as [Rei05] suggests aesthetics and efficiency have to be aligned.

11.7 Summary

The architectural design of a building consists of four main components: structure, shell, building services, and grace. The performance of a building is essentially determined by the chosen technical, constructive and last but not least aesthetic solution in the interaction of these components. One has to differentiate between constant, difficult to change and easy to change structural components. In many cases, the phase of the basic evaluation, with the detailed discussion of all major building requirements, is underestimated. It is recommended that a project-related transparency and quality assurance of all structural detail solutions and a documentation into project parts, assumptions and findings takes place. A high adaptability and high sustainability ensures a construction project with a large reuse potential in second and third use. This task requires considerable coordination and planning.

Bibliography

[Ada04] Adam, J., Hausmann, K., Jüttner, F.: Entwurfsatlas Industriebau (Design Manual Industrial Construction), 1st edn. Birkhäuser, Basel (2004)

[Ack88] Ackermann, K.: Tragwerke in der konstruktiven Architektur (Structures in constructive architecture). DVA, Stuttgart (1988)

[AS13] ASUE Arbeitsgemeinschaft für sparsamen und umweltfreundlichen Energieverbrauch. Die Erdgas-Strahlenheizung (Work group for saving and environmental friendly energy consumption. The natural gas radiator). http://asue.de Kaiserslautern (2013)

[Bac92] Bach, H. et al.: Gezielte Belüftung von Arbeitsbereichen in Fabrikhallen (Targeted ventilation of work areas in factories). Forschungsbericht HLK 1-92. Stuttgart (1992)

[BS6399] British Standard Institution: BS 6399 Loadings for Buildings. Part 1: Code of practice for dead and imposed loads, 1996. Part 2: Code of practice for wind loads, 1997. Part 3: Code of practice for imposed roof loads, 1988

[Böh06] Böhme, G.: Architektur und Atmosphäre (Architecture and Atmosphere). 1. Aufl. Verl. Fink (Wilhelm), Paderborn (2006)

[Dan96] Daniels, K.: Haustechnik, ein Leitfaden für Architekten und Ingenieure (Building Services, a Guide for Architects and Engineers). Oldenbourg, München (1996)

[DIN08] DIN 276: Kosten im Hochbau (Building Costst). Beuth, Berlin (2008)

[DIN11] DIN EN 12664: Licht und Beleuchtung von Arbeitsstätten (Light and lighting - Lighting of workplaces). Beuth, Berlin (2011)

[DIN04] DIN EN 12792:2004-01: Lüftung von Gebäuden - Symbole, Terminologie und graphische Symbole. (Ventilation for buildings - Symbols, terminology and graphical symbols). Beuth, Berlin (2004)

[Eng07] Engel, H.: Tragsysteme (Structure Systems), 3rd edn. Hatje Cantz, Ostfildern (2007)

[ENV1993] British Standards Institution: DD ENV 1993-1-1: 1992 Eurocode 3. *Design of Steel Structures. General Rules and Rules for Buildings* (1992)

[ENV1994] British Standards Institution: DD ENV 1994-1-1: 1994 Eurocode 4. *Design of Composite Steel and Concrete Structures. General Rules and Rules for Buildings* (1994)

[ENV1998] British Standards Institution: DD ENV 1998-1-4: 1996 Eurocode 8. *Design*

Provisions for Earthquake Resistance of Structures. General Rules. Strengthening and Repair of Buildings (1996)

[E1670] ASTM International: Building Constructions E72 to E1670-I—Annual Book of ASTM Standards, Section 4: Construction, vol. 04 (2008)

[Gri97] Grimm, F.: Hallen aus Stahl (Halls from Steel). Stahlinformationszentrum, Düsseldorf (1997)

[Hat06] Hatz, R.: Auf Sparflamme. Energetische Optimierung von Industriebauten (On Low Flame. Energy Optimization of Industrial Buildings). In: db 8/2006, pp. 71–75

[Hau07] Hausladen, G., de Saldanha, M., Liedl, P.: ClimaSkin- Konzepte für Gebäudehüllen, die mit weniger Energie mehr leisten (ClimaSkin - Concepts for building Shells that do more with less Energy), 1st edn. Callwey, München (2007)

[Hil74] Hildebrand, G.: Designing for Industry. The Architecture of Albert Kahn. The Massachusetts Institute of Technology (1974)

[Her04] Herzog, T., Krippner, R., Lang, W.: Fassaden Atlas (Facades Atlas). Birkhäuser, Basel (2004)

[HO13] HOAI Honorarordnung für Architekten und Ingenieure (Fees for Architects and Engineers) Federal Law June (2013)

[IEC11] International Electrotechnical Commission: IEC 60364-5, 51, 52, 53, 54, Electrical Installations of Buildings Edition 3.0 (2011)

[ISO08] DIN EN ISO 13790: Energieeffizienz von Gebäuden - Berechnung des Energiebedarfs für Heizung und Kühlung (Energy performance of buildings - Calculation of energy use for space heating and cooling)

[Kni06] Knittel-Ammerschuber, S.: Erfolgsfaktor Architektur – Strategisches Bauen für Unternehmen (Success Factor Architecture - Strategic Building for Companies). Birkhäuser, Basel (2006)

[Kol02] Kolarik, F. et al.: Energieeffiziente Lüftungsanlagen in Betrieben (Energy efficient ventilation systems in enterprises). Landesgewerbeamt Baden-Württemberg, Informationszentrum Energie. Stuttgart (2002)

[Kra07] Krauss, F., Führer, W., Jürges, T.: Tabellen zur Tragwerklehre (Tables for Structural Design). Rudolf Müller, Köln (2007)

[Kri08] Krimmling, J., Preuß, A., Deutschmann, U.: Atlas Gebäudetechnik – Grundlagen, Konstruktionen, Details (Atlas Building Services - Fundamentals, Designs, Details). Rudolf Müller, Köln (2008)

[Lac84] Lachenmann, G.: Industrialisiertes Bauen (Industrialized Building). In: Ackermann, K. (ed.) Industriebau, Ausstellungskatalog, S. 118–141

[Mes05] Messedat, J.: Corporate Architecture – Entwicklung, Konzepte, Strategien (Corporate Architecture - Development, Concepts, Strategies). Av edition, Ludwigsburg (2005)

[Pis07] Pistohl, W.: Handbuch der Gebäudetechnik (Handbook Building Services), 6th edn. Neuwied, Dessau-Roßlau (2007)

[Pol03] Polónyi, S., Walochnik, W.: Architektur und Tragwerk (Architecture and Support Structure). Ernst & Sohn, Berlin (2003)

[Pot07] Pottgiesser, U., König, K.: Baukonstruktion Ausbau (Interior Building Construction). UTB, Stuttgart (2007)

[Rec13] Recknagel, et al.: Taschenbuch für Heizung + Klimatechnik (Handbook for Heating + Air-Conditioning, 76th edn) Oldenbourgh, München (2013)

[Rei05] Reichardt, J.: Ästhetik Effizienz (Aesthetics Efficiency). In: Nelte, H.M. (ed.) Ästhetik Effizienz - Industrie Gewerbe Verwaltungsbauten (Aesthetics Efficiency – Industrial, Commercial Administrative Buildings), 1st edn. Nelte, Wiesbaden (2005)

[Rei08] Reichardt, J.: Industrie- und Gewerbebau in Holz (Industrial and Commercial Buildings in Wood). Holzbau Handbuch, row 1, part 3, vol. 11 Bonn (2008)

[Sch06] Schnittich, C.: Im Detail Gebäudehüllen (Building Shells), 2nd edn. Birkhäuser, Basel (2006)

[Tom10] Tompkins, J.A.: Facilities Planning, 4th edn. Wiley, Hoboken (2010)

[Uff09] van Uffelen, C.: Factory Design. Braun, Berlin (2009)

[VDI10] VDI-Richtline 3802:Raumlufttechnische Anlagen für Fertigungsstätten. Absaugung luftfremder Stoffe an materialabtragenden Werkzeugmaschinen (VDI Guide line 3802: Air conditioning systems for factories – Capture of air pollutants at machine tools removing material) Beuth, Berlin (2010)