37 METHODICAL DESIGN OF LOAD-BEARING CONSTRUCTIONS

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37.1 PROBLEM DEFINITION

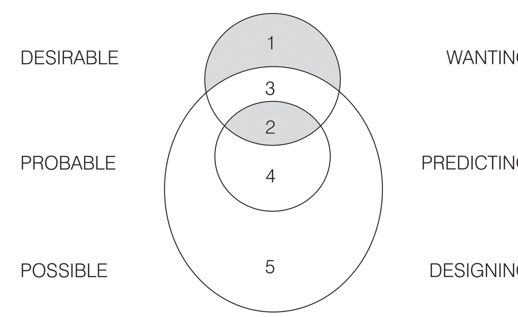
Throughout the last decades the building industry has changed considerably with regard to, for example, the use of construction equipment, logistics, products and management. These changes also affect the design process and the design methods for the design of buildings and for the design of parts of buildings like the load-bearing construction. Thus, because of increased complexity, buildings are more often designed by multi-disciplinary teams. Multi-disciplinary design is far from simple: part-products not independent of each other are designed separately and at a later stage part-designs often have to be tuned to each other (see page 345).

In order to ensure that the multi-disciplinary design process proceeds smoothly, design methods are required that permit concurrent and integral design of the whole building and the various parts. In order to attain optimal inter-action between the disciplines, methods which permit the design of the whole as well as part-products are preferred. The development of a method for the design of the support construction is based on a top-down approach. First, a general method for multi-disciplinary design is described and, next, this method is worked out for the design of support structures.

Figure 342 shows the influence of the participants of the design team, the authorities, and the client on a design. The number of designers and the influence of the designers on the whole varies per project. An inter-disciplinary design only comes about when the designers go beyond the boundaries of respective disciplines and design the whole together.

Authorities	
Client	Cost consultant
	Construction consultant
Architect	Installations consultant

342 The influence of the participants

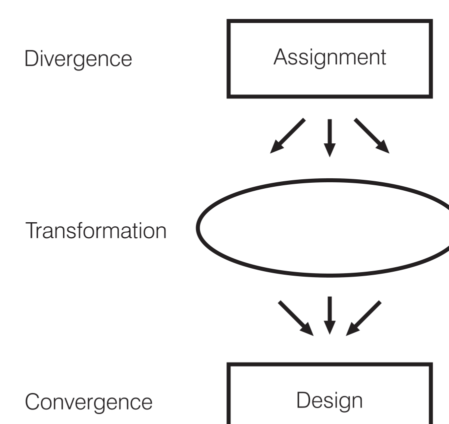


343 Views of the future

37.2 METHODICAL DESIGN

What is designing? Foqué presents the proposition: *"Designing is a concept with a very polyvalent content"*.[a] Eekhout, in the lecture notes for Design Methodology, gives an overview of the definitions used by lecturers at the different faculties of the Delft University of Technology, the Netherlands.[b] They show that the following facets are essential in designing: fulfilment of wishes and needs, taking decisions, shaping a product and originality. Based on these facets we can define the designing of the structure of a building as: to devise a system of building elements that can transfer the loads on a building to the foundations, while taking into account the limiting conditions dictated by the concept of the building.

Figure 343 shows the view of the future in politics, science and technology.[c] Like the politician, the designer tries to make the improbable possible. De Jong writes: *"The designer has the task of exploring improbable possibilities, especially when the most probable development is not the one preferred. Because of their improbability, these possibilities are not predictable, one has to design them"*.[d]



344 Schematic representation of the design process

There are different schools of thought on design methods and designing. Often, a distinction is made between the intuitive and the explicit method. In essence, these two categories overlap. An explicit method always has moments in the process when intuition governs, and an intuitive method also has phases in which analyses and selections take place.

In the divergence phase there is a marked increase in the number of possible variations and data. In the transformation phase concepts and solutions for part-designs are conceived. In the convergence phase the part-solutions are combined in alternatives and the preferred solution is chosen.[e]

a Foqué, R. (1975) *Ontwerpsystemen, een inleiding tot de ontwerptheorie*, p. 13.
b Ridder, H. de and A.C.J.M. Eekhout (1996) *Lecture notes design methodology*.
c Jong, T.M. de (1995) *Systematische transformaties in het getekende ontwerp en hun effect*. p.14, fig. 9.
d Idem, p.15.
e Foqué, R. (1975) p. 59

A design method for multi-disciplinary design must be able to be applied independently of disciplines and must foster inter-action between disciplines; further, the method should not interfere with creativity. What needs to be determined is whether the analysis phase - creative phase – and execution phase model[a] would be suitable, perhaps after some adaptation, for multi-disciplinary and interdisciplinary design.

The analysis phase - creative phase – execution phase model is as follows:

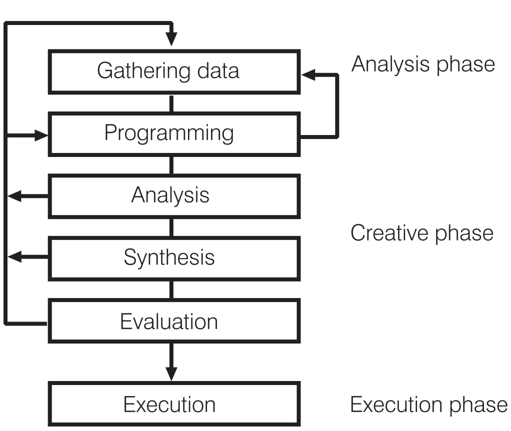
- The analysis phase: the problem is identified;
- The creative phase, with three sub-phases:
  - analysis phase: information collection, definition of the design criteria, classification of the design criteria;
  - synthesis phase: devising part-solutions, combining part-solutions in alternatives;
  - evaluation phase: testing the alternatives, selecting the preferred solution;
- The execution phase:the solution is presented in one form or another.

In the model, the creative part of the design process takes place mainly in the synthesis phase, when the solutions for the part-problems have been thought through and sub-solutions are combined in alternatives. Several methods have been invented to facilitate creative solutions, like:

- associative methods, for instance brainstorming;
- creative confrontational methods, using analogies;
- analytic systematic methods, like the morphological method, in which the problem is split into part-problems and solutions for part-problems are combined to yield alternatives.[b]

The first two methods are used, by preference, to come to a new concept of solving the problem. The morphological method fits in well with the model described, because, also in this model, the design problem is split up into part-problems, the solutions of which are then combined in alternatives.

The presentation of part-solutions and alternatives during the course of the design process is essential for multi-disciplinary designing. In the original model the presentation takes place mainly in the last phase. Because the members of the design team must tune their part-designs to the overall design, a continuous visualisation of part-solutions is essential for multi-disciplinary designing. For the sake of communication, the model must be extended in each phase with a visualisation of solutions and designs. During the last phase the chosen solution is further refined.



345 The Condensed model

37.3 CONSTRUCTION DESIGN OF A BUILDING

The design of the support structure is based on the architect's spatial outline plan. In this plan, the volumes and sizes of the areas are indicated globally. This spatial plan, together with the programme of requirements, defines the part-assignment for the design of the load-bearing structure. The design of a part-product is based on the detailed requirements which follow from the overall requirements. As the problem definition for the design of the part-product has already been defined in the analytical phase, a separate phase for the problem definition of the part-product is not necessary.

The design of the support structure is worked out simultaneously with the other part-designs. Thus, the implementation phase of the part-design can co-incide with the implementation phase of the overall design, so that no separate implementation phase need be included in the part-design process.

In view of the above, one may postulate that for the design of a part-product like the construction of a building, the method can be condensed to the three sub-phases of the creative phase, i.e., analysis phase - synthesis phase - evaluation phase. Figure 345 shows the condensed model for the design of a part-product like the construction of a building.

a Foqué, R. (1975) *Ontwerpsystemen, een inleiding tot de ontwerptheorie*, p.58.
b Tiemessen, N.T.M., Methodisch ontwerpen, p.15.

37.4 DESCRIPTION OF THE METHOD

Part-assignment

The architect's outline design is the basis for the design of the support structure. In this plan, a part-assignment, the volumes and the sizes of the various spaces are globally indicated.

Analysis

The problem definition and the data are analysed, differentiating between the problems and the data related to the location and those related to the function of the building.

Analysis of the location:

Investigation of the location and building site, adjoining buildings, cables and ducts, accessibility, site contours and elevation, soil profile, bearing capacity of the subsoil, drainage characteristics, climate and availability of personnel, materials and equipment. Determination of the variable loads on roofs and façades for the given site with regard to wind, snow, rain, earthquakes and similar.

Analysis of the object:

The making of an inventory of the requirements with regard to safety, for instance, in case of a calamity like fire, and preferences with regard to construction time, costs, deflections, position of the support points and of the stability provisions. Determining the variable loads resulting from the actual use, like floor loads.

Synthesis

In this phase, solutions for part-problems are devised and sub-solutions combined in alternatives.

Creation of sub-solutions

Generating part-solutions for the construction of foundation, roofs and floors, which are essentially different with regard to shape and construction material. Investigate which stability provisions are feasible. For easy communication with other members of the design team, visualise the part-solutions with the aid of sketches which clearly show position and shape of the construction aspects.

Combining the sub-solutions

Next, using a relationship matrix, the investigation focuses on which part-solutions for roofs, floors, and foundation can be combined in construction designs. Eliminating non-feasible alternatives at an early stage saves much time in combining the sub-solution. Making a display of the alternatives using sketches clearly showing form, position and dimensions. At this stage, the dimensions are determined globally only; for instance by rule of thumb and simple calculations. In the relationship matrix, at the intersection points of the horizontal and vertical axis, 1 indicates that the sub-solutions can be combined, 0 that they cannot.[a] There are in principle 3*2*2=12 combinations possible for the sub-solutions. After evaluation just four combinations remain: D1V1F1, D1V2F2, D2V1F1 and D3V1F1.

Evaluation

For evaluation of the alternatives, the criteria and their weightings are determined. Selection criteria may be, for instance, costs, aesthetics, feasibility, usefulness and load on the environment. Next, alternatives are compared with each other using the evaluation matrix.

Finalisation

In the finalisation phase, the dimensions of the building elements are checked, cost estimates made, and design and construction drawings prepared for the selected alternative design.

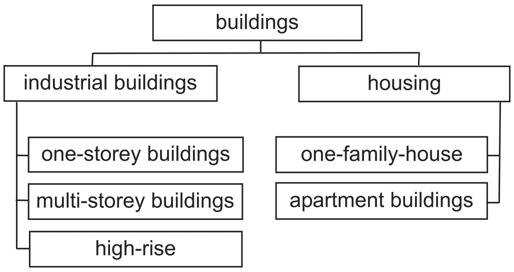
Function	subsolution	D1	D2	D3	V1	V2	F1	F2
Roof	D1				1	1	1	1
	D2				1	0	1	1
	D3				1	0	1	1
Floors	V1						1	0
	V2						0	1
Foundation	F1							
	F2							

346 Relationship matrix

	Weight	A1	A2	A3	A4	A5	A6
Criterion 1							
Criterion 2							
Criterion 3							
Criterion 4							
Total							

347 The selection matrix with the alternatives in the rows and the selection criteria in the columns.

a Tiemessen, N.T.M., Methodisch ontwerpen, p.18.

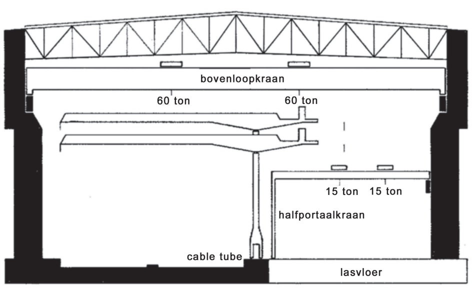


348 The classification of buildings

37.5 FINALISATION OF THE METHOD

The method described can be applied to any type of building regardless of its intended use. Because many buildings are very similar from the point of view of their construction, buildings can be classified, and for each class a design method can be specified. In line with established practice, we distinguish, as an initial division, between building dwellings and industrial plants. In building houses we distinguish between one-family housing and apartment buildings. In industrial buildings we differentiate between one-storey, multi-storey and high-rise. These different categories differ both in the loads they are exposed to and in the design solutions.[a] For instance, the roof construction and the ground floor construction are essential for the design of a one-storey building, while for a multi-storey building the floor construction at the different levels is important and for a high-rise building not only the floors at the different elevations, but also the bracing structures are of great importance.

For further clarification, the method is worked out for the design of a unit of the classification, i.e., the design of the construction for one-storey buildings.



349 Low-rise building

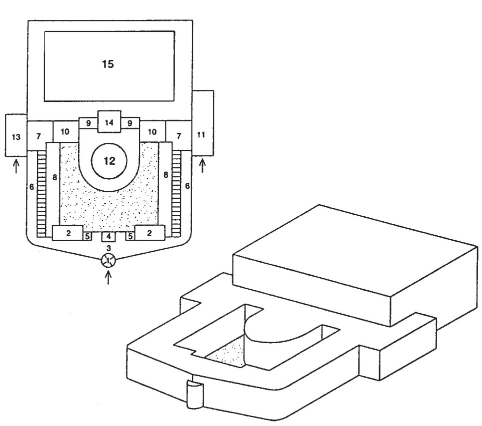
Figure 349. A one-storey building is a building with one main building layer, with possibly locally a mezzanine or landing.[b] The height of the building is not essential to the classification. The shipbuilding yard for Van der Giesen – de Noord, for instance, is 52 m high, 97 m wide and 264 m long. The design of the support construction of a one-storey building is based on the outline design of the building with the volumes and sizes of the spaces indicated. We discern the following steps:

Analysis

The problem definition and the data are analysed. Apart from the aspects mentioned in the general description, we specify the following aspects for one-storey buildings:

Analysis of the location

Investigating whether the one-storey building can be placed on footings, if necessary after soil improvement, or whether a pile foundation is necessary. Determining the variable loads on roofs and façades at the given location with respect to wind, snow, rain, earthquakes etc.



350 Outline design

Analysis of the object

Making an inventory of the preferences with regard to construction time, costs, deflections, position of support points, shape of the roof and position of the provisions for stability. Determining the variable loads on the ground floor and the horizontal loads from building cranes. Listing the preferences with regard to settlements. Investigate the possibilities with regard to locations for support points and provisions for stability, and the possibilities with regard to the shape of the roof: flat, sloping, curved or double curved.

Figure 350 is an outline design of a swimming pool. This layout makes the position and size of the building elements visible, and the spaces located within.[c]

Synthesis

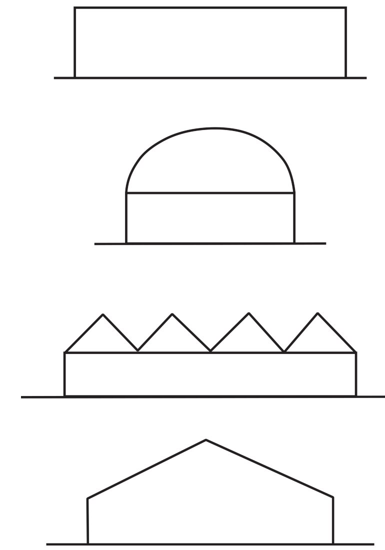
The generation of sub-solutions and the analysis of the sub-solutions.

- Analysing which construction solutions are feasible for the roof construction, starting with the position of the support points, possible roof shapes and the position of the possibly necessary stability provisions.
- Devising types of construction that fit the roof shapes, which differ from each other in shape and construction material, and draw the roof plans.

a Kamerling, J.W., M. Bonebakker et al. (1997) *Hogere bouwkunde Jellema. Dl. 9. Utiliteitsbouw; bouwmethoden*, p.7.
b Idem, p.144.
c Tol, A. van and R. Jellema (1983) *Bouwkunde voor het hoger technisch onderwijs. Dl. 11*, p.1

Possible roofshapes:

- Flat roofs with a linear support structure like beams, trusses, pre-stressed beams, cable-stayed beams and portals;
- Flat roofs with a neutral structure like space frames and beam rasters
- Sloping roofs: three-hinged frames and folded roofs
- Curved roofs: arches and barrel vaults
- Double curved roofs: domes, conoide shells and hyppar shells.



351 Possible roof shapes

- Analysing the possible types of floor construction; investigate for instance whether a reinforced concrete floor, a steel-fibre concrete floor or a prefab floor on a raster of beams is feasible. Analysing the possibilities with regard to the foundation, investigate whether a foundation on footings is possible, (if necessary after soil improvement) or whether the building will have to be supported on piles; and investigating whether the top layers of the soil are strong enough to carry the loads during construction from, for instance, building cranes, storage of construction materials and the pouring of concrete.
- Devising part-solutions for the floor construction and the foundation, and visualising them.

Combining the sub-solutions

Next, the relation matrix is used to investigate which part-solutions for the roof, the ground floor and the foundation can be combined in construction designs. The different part-solutions for the construction of roof, floor and foundation are placed in the relationship matrix. Then, the investigation focuses on which part-solutions for the roof construction, the floor construction and the foundation fit together with regard to load transfer, and can be combined in designs for the whole building. Making the alternatives visual in sketches of the plan layout and cross-sections in which shape, position and dimensions of the various construction elements are brought out. At this stage, the dimensions can be generally determined by rule of thumb and simple calculations.

Evaluation

For evaluation of the alternatives, the criteria and their weights are determined and ordered. Next, alternatives are compared to each other using the evaluation matrix. The alternative that meets the requirements best is selected and further worked out.

The design method for the construction of a one-storey building can be developed for other types of buildings.

The preceding displayed a scheme with combinatorial possibilities between variants of foundations, floors and roofs (see figure 347). The variants of the foundation may be combined with some floor-systems, not with others. The combinatorial possibilities with foundation variants x1…xm and floor-systems y1…yn may be rendered by a m x n matrix (figure 352)

The readings are limited to 1 and 0, possible and impossible. However, the elements in the matrix may also indicate the price at which a contractor is prepared to connect the foundation to the floor-system. An extremely high price is economically equivalent to ‘impossible’, but we should keep the possibility in mind, for everything here is possible technically speaking.

A matrix like this can now also be made for the combination of n floor-systems Y and o roof-systems Z and for the combination of m foundation-systems X and o roof-systems Z. The total number of technical possibilities is then n times m times o. The connection between foundation, floors and roof is formed in this case by a system of columns and/ or walls between them and the design of that system is depending on the combination selected from the possibilities mentioned.

	y1	…	yn
x1			
…			
xm			

352 Combinatorial possibilities

This example should make clear that three aspects are of importance on this level: the *components* (here: foundation, floors and roof), the *connections* between these components and their *size-co-ordination*. The last one is, for instance, of great importance for the economical feasibility of a foundation-system with a floor-system. When the size-system of the foundation is differing from the one of the pre-supposed points of support of the floors, the connection may become expensive and perhaps even 'impossible' economically.

Obviously, the number of combinatorial possibilities is determined in the first place by what is considered a 'component' (*classification*). In order to be able to combine these components, several connections are required: between foundation and ground floor, between columns and floors, and between columns and roofs.

Therefore, a study of designing methodically carrying constructions leads by the same token from combination via classification to the 'building node'.