# Conceptual design

STEP lecture E2
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## Objective

To introduce the basis of conceptual design, taking into account the more important quality criteria for timber in design.

## Summary

A summary of quality criteria for the design of timber structures is presented. The summary focuses on a discussion of general design considerations which have developed through many years of research and practice.

## Introduction

Many years of practice and research have resulted in the consideration of a number of problems, some of which are certainly applicable to other building materials but all of which are applicable to timber. Long term fundamental research and research work of shorter duration oriented toward practical applications have led to a variety of structural wood based products and more efficient connection details for instance. Despite the increasing role given to timber as an ecological building material, the fact that timber is avoided by many engineers is perhaps not so surprising since timber requires more judgement than other building materials because of its anisotropic behaviour and variability of properties. This is unfortunate because timber has so many good qualities.

Given its properties, timber as a building material, requires particular conceptual work in the same way concrete and steel do in their own domains. The following paragraphs are intended to highlight some of these timber specific design concepts.

## Roles of the architect and the engineer

The architect is concerned with the totality of the building whereas the engineer generally focuses on structural optimisation. The key to a successful design is the determination of the critical criteria from which the final decisions are made. Structural optimisation should not be over-emphasised at the expense of other important criteria. Architectural aspects such as building function, space, circulation and lighting are certainly as important during the conceptual stages of a project as the design, fabrication and erection of the structure. For the architect and engineer, the basic design considerations include the determination of the areas of responsibility for the design of a timber construction. During the preliminary discussions, a design inventory which includes the development of space requirements and schemes for the building function is established. Their suitability within the environment surrounding the building must be considered. The deciding criteria should be put on paper and cleared with the owner and the building authorities. Some of the criteria are listed below:

| | | | |
|---|---|---|---|
| - Restrictions | - fire protection | - Site | - land |
| | - acoustic protection | | - access |
| | - surrounding right of way | | - aspect |
| | - storey number | | - topography |
| | - volume to be built | | - weather exposure |

| | | | |
|---|---|---|---|
| - Restrictions | - surface to be built<br>- building line<br>- materials<br>- ecology | - Site | - environment<br>- geology |
| - Building Usage | - size<br>- lighting<br>- fire protection<br>- in-plan organisation<br>- functions distribution<br>- space division | - Loading | - dead load<br>- wind load<br>- snow load<br>- utility load<br>- crane load<br>- impact load |
| - Technical Installations | - ventilation<br>- heating<br>- lighting<br>- acoustics<br>- water supply<br>- liquid waste evacuation | | |

This check-list forms the basis that influences the decisions of the engineer. The overall aim is to achieve an optimisation for safety, cost, functionality, durability and aesthetic appeal. Elements of the architectural check-list which result from discussions between the architect and the engineer are outlined below.

*Restrictions*
Designers have to work within constraints. Legal restrictions set down by the authorities have become multi-faceted and although they result in increasingly heavy bureaucratic limitations, they provide an improved safeguard for the requirements of the individual and the community and they have a stabilising effect on the appearance of the built environment and surrounding landscape. Restrictions set down by the planning authorities have the same effects. Renewed emphasis on environmental considerations has become a necessary and welcome challenge in recent years.

*Site*
The size and the shape of the site have an important influence on architectural features of a building, such as the height of the frontage and the angle of the roof. At the same time the requirements of the authorities concerned with the protection of landscape and monuments, the topography and adaptation to the existing built environment need to be considered very carefully. Site conditions can affect the orientation of the building which in turn affects the use of natural light. The engineer must work out the conditions of the site regarding climatic influences such as snow, wind and earthquake loads. In addition the ground conditions and accessibility of the site are criteria for the foundations and the determination of the size of the building.

*Building usage*
The requirements for a building's usage determine its height, the number of storeys and the possible points of support. Special functional requirements should be taken into account from the very beginning of the design process. Certain building functions require natural lighting which will determine the roof shapes to a great extent. The current fire-safety requirements are also dependent on the intended use of the building.

*Loading*

During the early stages of design, loads which are likely to affect the structure are evaluated. The engineer should be conscious of less common loads such as those due to various installations, cranes and storage of goods as well as the more common loads such as wind, snow, earthquake and traffic. The loading may well affect the structural requirements and allowable spans.

## Preliminary design and planning

The development of the shape of a building can be affected to a great extent by the surrounding townscape or landscape in order that it is consistent within an overall design framework. The profile image of a sports hall, that of the diving tower for a swimming pool or that of a garbage disposal plant, together with its lighting and ventilation, can become determining factors in the profiles of the surrounding built spaces and the shape of the structures.

*Development of the building shape*

During the preliminary design phase, the architect develops the basic character of the building. During this phase, which usually ends with the submission of plans, the engineer must suggest, in the first place, an achievable structure. If he recognises the architectural image behind the preliminary design, then he will be capable, in co-operation with the architect, of developing structures that not only correspond to static criteria but also to functional and site-related requirements. The engineer should, at the same time, develop structural alternatives that ensure both the accomplishment of the design-concept and the consideration of the various technical and economic requirements. On the other hand, the architect must recognise the behaviour of the structural systems. The architect should be capable of transforming the static systems given to him into a building shape. Examples of building shapes are shown in Figure 1. Only when the shape of the static systems has been adapted to the shape of the building, can further consideration be given to the choice of materials and connections. In the initial stages of a project it is particularly important to consider the viability of a great number of structural alternatives for various design criteria, by both architect and engineer, in order to ensure the quality of the end-product.

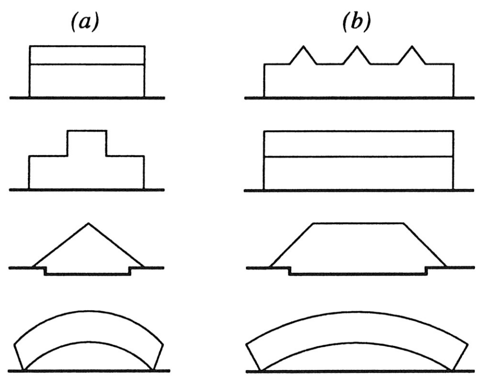


*Figure 1 Building shapes. (a) end elevation, (b) side elevation.*

*Development of the structural form*

The decision to allow the structure of a building to be visible on the inside and/or on the outside is important from both a creative and an economic point of view. In this regard timber is superior to other building materials due to aesthetic and insulation considerations. It is possible to achieve attractive architecture and fulfil structural demands with an exposed structural system. This can be achieved by a suitable arrangement of main and secondary structural elements that can be linear, plane, curved or doubly curved. The development of the inner space must be in tune with the structural demands from which appropriate sections follow. The structural shapes for the building cross-section can be developed along the length or width of the building plan or equally well along the diagonal of the building plan. The main support systems define the visual appearance of the structural system as shown in Figure 2. Their design in combination with the wind and stability bracing give the building its characteristic shape. The overall behaviour of the structure as well as the effect of the bracing can thus be expressed from the outside of the building.

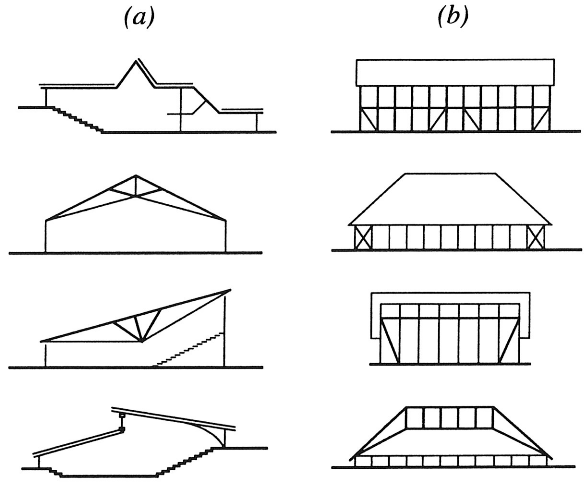


*Figure 2 Some complex structural forms. (a) section, (b) elevation.*

*Load path systems*

The number of main supporting structures as well as their spacing and distribution are determined by the development of the ground plan. The design of the frame depends on the building usage as well as partitions and lighting. Locally unstable soil requires special foundations which in turn result in longitudinal structural support whereas circular or polygonal foundations lead to radial or spatial arrangements of the main supports. Roofs which are both functional and economical can be achieved by means of branching systems. Secondary support systems shape both the roof and inner space of the building. The secondary supports are determined by the position and the type of the main supports, as well as by the number, shape and type of connections of independent support units. Well selected secondary systems support small spans and, at the same time, fulfil stability requirements. A great number of economical and interestingly shaped arrangements of bracing can be obtained. Examples of typical primary and secondary load path systems are shown in plan in Figure 3.

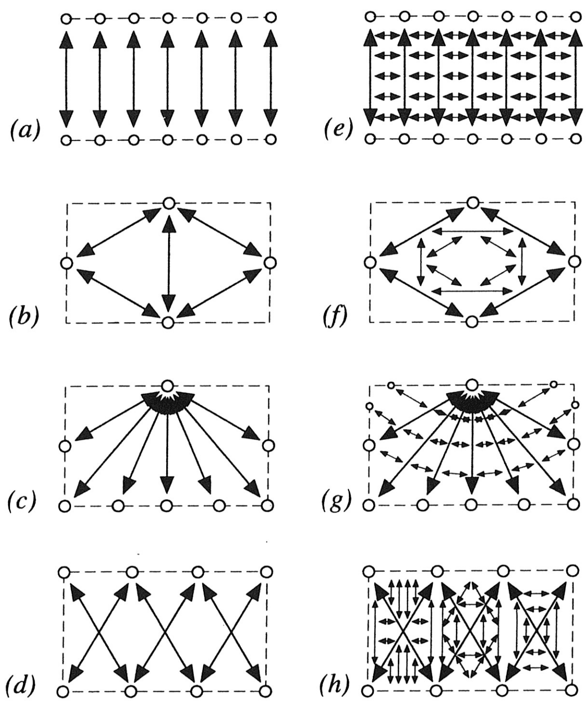


*Figure 3* *Load path systems. Primary systems: (a) linear-parallel, (b) linear-diagonal, (c) radial, (d) diagonal; secondary systems: (e) linear-parallel, (f), diagonal, (g) tangential, (h) linear-diagonal.*

## *Modelling of support systems for stability*

The shape and size of the main and secondary supports are developed largely according to their effective height, since the effective height is a cubic function in the moment of inertia of the section rigidity of the supports. The building function fixes the height between ceiling and floor below. The construction height affects the distance between ceiling and floor above. Low construction heights permit the use of joists and/or beams for small spans and require closer supports. Larger construction heights can take advantage of planar truss systems which are more economical for longer spans. Spatial combinations of planar truss systems eliminate the need for stabilisation of the individual systems. Structural support systems can be optimised by adjustment of the construction height as well as by the alteration of supports and by the integration of the bracing system with the main support system as shown in Figure 4.

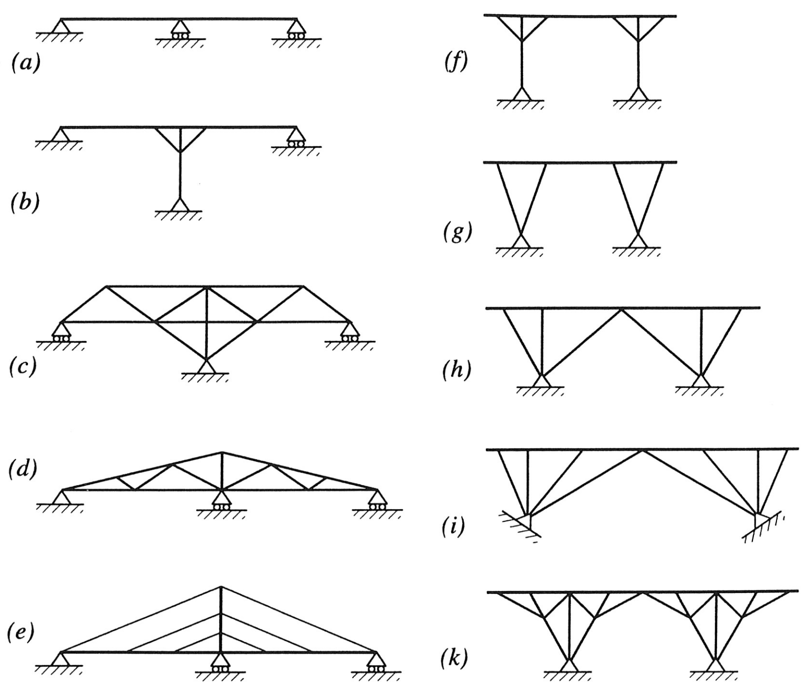


*Figure 4* *Structural forms. Continuous systems: (a) standard, (b) with knee-bracing, (c) framework, (d) truss, (e) cable-stayed; braced systems: (f) knee-bracing, (g) split-column, (h) propped beam, (i) strut frame, (k) knee-braced strut frame.*

Shell structures are economical for roof systems of large spans since they require neither system nor member bracing. In addition, they respond well to the demand for minimum structure weight and maximum inner space.

### *Material selection*

The choice of material and sections for main, secondary and peripheral structural systems should be decided upon as early as possible in order to determine the support system requirements. In timber construction, a variety of sections is available: logs, square timber in single or assembled sections, as well as beams, planks and glued-laminated sections. A well thought out section geometry can not only provide stability but can also provide fire resistance (except in the case of small cross-sections) and insulation for sound and heat. The qualities of the surfaces offered by timber allow the architect a range of choices: natural, rough-sawn, planed or polished. In the area of manufactured timber products, materials such as veneered sheets, particle boards and numerous types of sandwich boards are available to the user.

Timber-concrete composite systems are used in timber construction in order to reinforce existing structures and to reduce material and production costs of new structures. Such composite elements are very often used for beams, floor-systems, panels, diaphragms and shear walls. They provide good acoustical properties, they are fire-resistant and flame-retardant. Bridges are often constructed with timber joists and a concrete deck which is used to distribute concentrated wheel loads and to protect the joists from chemically aggressive rain waters.

There is, in addition to a variety of timber sections, a choice in the types of timber to be used for instance spruce, pine, fir, larch, birch and tropical timbers.

The choice of a species depends on the expected strength of the required material, its availability and cost, and occasionally its visual effect. A combination of light and dark timber species may be used to better underline a detail or a structural system.

*Fasteners*
In the process of detail optimisation, the expense on both material and labour regarding the fasteners should be in proportion to the aesthetic and technical demands. The type of fasteners and the technology for their production should be discussed as early as possible with the architect. The finished aspect of a timber construction is dictated to a great extent by the fasteners used and their cost. For instance, these can be timber-timber connections, dowelled joints or spliced steel fasteners with or without visible steel components. The choice depends on the materials used for the members such as roundwood, sawn timber or glued-laminated timber. Steel components which are exposed require constructional timber protection against weather and/or fire.

## Representation of the structure

*Isometrics and perspectives*
An important criterion for the quality of a timber construction is the effectiveness of the enclosed space. The representation of the internal space by means of an isometric or perspective drawing as shown in Figure 5 is recommended as early as the preliminary design stage since it illustrates the distinctive character of a construction even to untrained readers of a drawing. In addition, this type of drawing aids in the establishment and the optimisation of the production technology for timber fabricators.

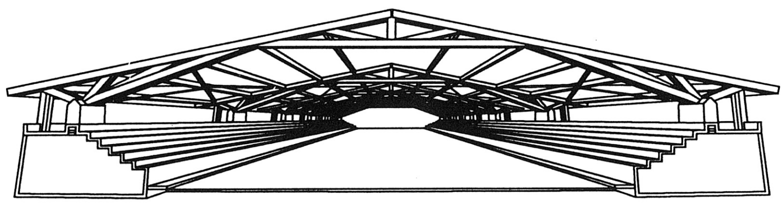

*Figure 5 Perspective of an ice arena.*

*Construction model*
A construction model is an important means for the representation of the inner space. It allows the quality of the design to be represented in an understandable fashion to decision makers such as building committees, municipalities and especially, to the prospective owners. On a construction model, details become visible. Discussions between architect and engineer are facilitated. Detail variations of the support structure and of the elements of construction become obvious and are sufficient for the aesthetic appraisal at scales of 1 to 20 or 1 to 50.

*Computer modelling*
As timber engineering deals with a relatively easy to use material, there is an increased freedom for structural design and detailing. The contribution of CAD is therefore that much more valuable. An additional reason for the use of CAD is the large investment in labour costs required to determine the geometry as well as the detailing and working drawings. By using CAD in timber design, even

very complex space connection details can be shown easily to fabricators. It can be an advantage for both the architect and the engineer to work from the very beginning with spatial representations. This requires three-dimensional CAD programs that are not only drafting programs but also a means of aiding the building engineer. Design alternatives which include structural analysis as well as the simulation of inner space with the representation of surfaces and colours are all possible. Interactive data processing in constructional timber engineering results in a simplification of the recording and modelling of geometric structures for structural analysis as well as for the development of drawings. This accelerates the optimisation process considerably. The aim in the development of CAD is to define the building and the structure in spatial terms. Based on the support of the data obtained, the computer is able to carry out the planning of the construction and to transfer the total package in order for workshop drawings to be produced and to provide instructions for automated fabrication machinery.

## Conclusion

This chapter is intended to provide a general outline of requirements for the design optimisation of timber structures. The co-operation between the architect and the engineer is stressed from the beginning of a project study until the final presentation to the authorities and the potential buyers. It is only by increasing the engineering component in timber structures that constructional savings can be made making timber competitive with other building materials.

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