Lecture notes 11995 Design – theory and methods E16

What is engineering design?

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Publication date:
2016

Document Version
Publisher's PDF, also known as Version of record

Citation (APA):
Almegaard, H. (2016). Lecture notes 11995 Design – theory and methods E16: What is engineering design?

Lecture note 1 – 11995

What is engineering design?

Introduction

When Roald Amundsen started his expedition to the South Pole, the 20 October 1911, one of the goals was to map the last part of the globe. Doing this Roald Amundsen undertook the last big voyage of discovery. There were now hardly any more places to discover and map, on the earth. Any journey could now be planned and made by means of a map. From now on only expeditions were left for the adventurous.

Phileas Fogg was such an adventurer, who in the novel of Jules Verne from 1872, travelled round the world in 80 days. However, Phileas Fogg was not just an adventurer, he was also a sportsman. Like Amundsen, (actually it was the other way around) he wanted to travel fast. He was therefore also a vision of a new type of man. A man that mastered nature and had control.

Gustave Eiffel designed and build – or his company build - Le Viaduc de Garabit in France, which was opened on the 10 November 1888. Shortly after you could travel by railway across the “massif central” – and thus the whole of France became connected by a network of railways. Now, everybody could plan a journey minute by minute - by the railway and its timetables – and undertake it as planned.

Some design projects in the building sector are like a voyage of discovery. You are on the way into completely new land. You do not know what is waiting for you. You have only a vague idea of where you are going - or what it will look like. Therefore, you must plan and prepare well, and chose the right team for the journey. Underway you must be attentive, find your way through the landscape, navigate, adapt to the conditions and constantly adjust your plans from what you observe.

Many building design projects are like expeditions. There is a fairly clear vision of where you are heading. You may have an overview map, but it has no roads shown, and it is not clear from the start in which direction you shall go to get reach your goal fast.

Most building design projects and many subtasks are like train journey. They can be planned from the beginning to the end. In principle you just have to learn how to read the timetable and then follow the tracks that have already been laid out, to arrive safe and on time.

In this course, we will deal with engineering design theory and methods. This means that we will see how we can prepare for an expedition and how we can navigate and find our way while we are moving forward.

Roald Amundsen had chosen his equipment and his way of traveling for the journey to the South Pole from all his experience and tests results. He had in many years examined and tested both new and old arctic technologies, and he selected unprejudiced those technologies that were best to solve the actual task. He and his men were skiing and they used dog sledges to transport their food and equipment. Their clothing were furs developed by the Eskimos but they slept in modern tents made by windproof cotton. While overwintering they laid out supply depots and used these travels to adjust their gear and routines. As an example, they cut of almost one third of the weight of the wooden sledges to reduce the energy that the dogs should use to haul the sledges.

Figure 1. Amundsen and his man at the South Pole.

It came as a surprise that Amundsen went for the South Pole. Robert Scott, a British Royal navy officer, had announced already in 1909, that he would be the first man on the South Pole. Scott's expedition party was by far larger than Amundsen's was and he travelled with the whole British Empire in the back. He brought three new motor sledges for transport. In addition, he had a fair amount of ponies to pull sledges but only a few dogs. The motor sledges broke down under the cold conditions and Scott had chosen to leave behind the engineer who could have repaired them. The ponies had snowshoes but they sank anyway often into the belly. In addition to this, they could not handle the cold as well as dogs and was completely unable to climb glaciers. Scott did not like dogs, so he and his party ended up walking by foot, man hauling the sledges. They managed to reach the South Pole. But they never came back.

Figure 2. Robert Scott (i the middle) and his men at the South Pole.

You will not learn to drive a dog sled in this course, but it will be expected that you can and will use the tools and techniques that you have already learned. It is also expected that you will search out new knowledge and incorporate new techniques, when it show to be expedient.

What is engineering design?

Engineers make things that were not there before. The thing must be able to do something. It has a function - or more functions - and this function is physical. It will convert an electrical signal into sound waves, it will move something from here to there, it will convert a physical impact to a chemical process etc., etc.

Engineering designs can be split into four main groups:

- Structures
- Machines
- Processes
- Network

The primary focus of engineering design is not visible; it is the underlying mechanisms. Only when these mechanisms and their function are completely understood and clarified, you start to work with the physical form.

Engineers uses scientific results, methods and ways of thinking when they design. But engineering design is not applied science. Engineers are namely only interested in what works and that it works, and not why it works.

Engineers therefore normally use very simple models. These models may not have specific scientific evidence, in the sense that they do not describe what happens in the detail, they are just based on fundamental scientific principles such as the conservation of energy in a closed system or equilibrium in a system at rest.

What is good engineering design?

Good engineering design live up to four ideals:

- **Function**. It works – every time. In the whole lifetime. The brake will brake, the bridge will carry, the treatment plant will treat, and there will be connection. This is a completely fundamental requirement for engineering designs.
- **Efficient**. This off course apply to the design object, but it also apply to the process of making the object, including the design process. Efficiency means that the function is fulfilled with – if not a minimum of - then at least a small amount of materials and resources, over the whole life time.
- **Economical**. The good design is characterised by not only being efficient regarding materials and resources from a technical viewpoint as mentioned above, but also economical regarding money in the actual social context.
- **Aesthetical.** Good engineering design is also aesthetical. This apply both to the immediate appearance, this means the physical form, that has to be logical regarding the function, and to the solution by itself, that also should be elegant in its thinking and execution.

It is difficult to overestimate the engineering professions importance for modern society. The railroad and the steamship gave man a control over his own life that he never had before. And the sanitation engineers through their planning of water supply and sewers may have had just as much importance to public health as the medical profession. In this way, the engineering profession has affected our self-perception fundamentally

The four ideals of good engineering design reflects in a way a great responsibility towards the democratic society that wants the citizens' needs to be met safely, efficiently and economically, and human equality reflected in a high aesthetic standard.

How does engineers design?

Engineers constructs. They take objects and put them together to form new objects, that is, they take parts and put them together to form a whole – or a whole new part. In this way, every part of the whole may be a whole in itself, and the whole may be – or become - a part of a bigger whole.

To do this, you – the engineer - have to have both an overall idea of how it all works and an idea of what function, the individual parts have.

This means that you have to have knowledge, and knowledge on how to get new knowledge.

Engineering design knowledge has been divided into six categories:

1. Fundamental design concepts
2. Criteria and specifications
3. Theoretical tools
4. Quantitative data
5. Practical considerations
6. Design instrumentalities

The fundamental design concepts include such things as *the operational principle* and *normal configurations.* Only seldom, the fundamental design concepts are described or taught explicit, but analysis of existing – and especially older – engineering design can shed light on these.

Criteria and specifications are in general made during the design project, but some are given by codes and regulations, see lecture 2 and 3.

Theoretical tools include *mathematical methods and theories* and *intellectual concepts are* the type of knowledge that has most focus on the engineering schools.

Quantitative data has usually been obtained empirically and can be found in tables or graphs.

Practical considerations are learned during projects and on the job and may be tacit knowledge that you have to learn by experience or imitation.

Design instrumentalities are the focus area of this course and can be divided into *structured procedures, ways of thinking* and *judgement skills.*

Literature

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Lecture note 2 – 11995

Problem solving and other design process elements

Introduction

The word design originate from the Latin word *designare*, that means "to draw, make sketches, plan".

In this course, we see the engineering design process as consisting of a number of generic elements.

Problem solving

A basic generic element in the engineering design process is problem solving. The whole design process can be seen as one big problem solving process, but this one process contain many problem-solving processes, which are – as we will see – arranged in hierarchal structures.

The term problem solving may sound a bit reactive and technical as when someone present a problem to a mechanic and he have to solve it, but in the design process, problem solving is a very creative process, which contain both analysis and synthesis.

To 'have a problem' is in everyday language often considered as something negative, but from a designer's viewpoint a good problem make the possibility of finding a solution which is valuable for many people. This also means that it may have a business potential.

The problem solving method can be described in this way:
First, the problem must be identified as precisely as possible. Then the preconditions are examined and the design goals defined. This means that requirements to the solution, and the properties we would like the solution to have, are specified. Now solutions must be found. It is important to seek for many solutions in order cover most of the set of possible solutions and hence also the best solutions. To do this you seek for solutions on a conceptual level. Then the found principles are modelled to form solutions to the actual problem. This mean that they are described in a way and on an equal level of detail, so that they can be evaluated in relations to the design goals. Finally, the modelled solutions are compared and evaluated and the best solution is chosen.

To summarize, problem solving can be divided into the following four steps:

1. **Identify the problem and specify the goals**
2. **Find solutions**
3. **Model each solution**
4. **Evaluate and chose the best solution**

A fifth step: Implement the solution, could be added, but in a design process the next step would most often be to go to a more detailed level of design, solving new problems on this level.

Exercise 1: Find and describe differences and similarities between this process and the processes you use for solving problems in other courses.

Example 1

A standard building or construction project is an example of a design problem. In the Danish General Conditions for Consulting Services “ABR 89” the main phases in such a project is proposed to be:

1. Program phase,
2. Proposal phase
3. Planning phase
4. Execution phase
5. Operation phase

In the program phase, the problem and the design goals are defined. The rest of the architectural and engineering design is done in the proposal and planning phases, namely searching for solutions, modelling and adjustment of the solutions, evaluation and choice of solutions, and finally implementation of the solutions. In these two phases implementation of a design solution mean that the solution is used in the design and documented in the planning phase.

Example 2

Also the design of a detail in the project, as for example the connection between a beam and a column, is a design problem that follows the above steps:

1. Identify the forces that has to be transmitted and their size. Analyse which deformations are allowed. Check if other design goals.
2. Search for and sketch a number of different solutions. Textbooks, journals or catalogues from suppliers can be used as inspiration.
3. Find rough dimensions for the different solutions and judge production and assembly process, material usage and price.
4. Compare the solutions and choose a good solution.
5. Calculate and draw the solution.

Tree structure

It may be seen from the above examples, that a design project has a structure resampling a tree with branches and twigs, a so-called tree structure. For every problem there are several solutions, and each of these solutions implies a number of partial design problems on a lower level that have to be solved in order to make the solution work. To each of these partial problems there are again several solutions. And for each of these solutions new partial problems have to be solved and so on. (Figure 1).

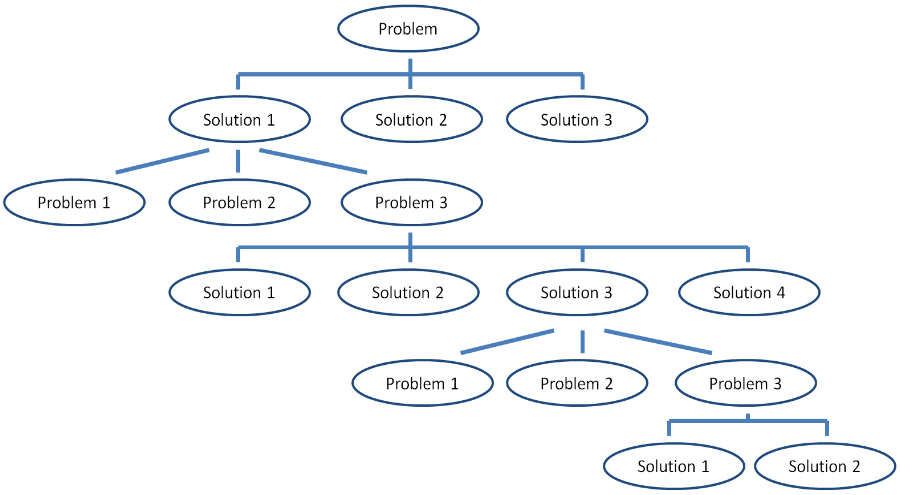


Figure 1. Design projects has a tree structure. Each problem has its specific solutions and each of these solutions imply a number of specific design problems on a lower level. Please remark that just one way through the tree is showed.

The tree structure of a design project can also be described as a fractal pattern because we have a main problem that contains partial problems, which again contain partial problems and so on. (Figure 2).

Figure 2: The problem solving structure of a design project can be compared with the fractal pattern in the Sierpinski- triangle.

Luckily, the tree structure of problem solving in design projects is not infinite like a fractal. When the evaluation show that an existing standard component is the best solution, this branch of the tree do not grow any further.

Systems

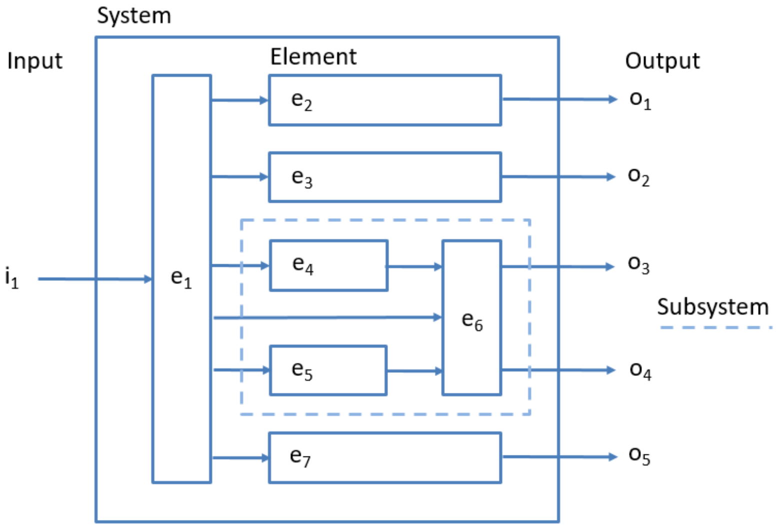
In engineering design projects and especially in the early phases, it can be an advantage to use system thinking. This make it possible to design with elements, which in the beginning are just rather superficial described, and find out how they can be put together in the most favourable way, before the individual elements are designed in detail.

Definitions:

System:	A set of elements that are directly or indirectly connected, form an integrated whole and functions following certain principles. A system has a boundary in space and time, and it is characterized by its structure and purpose.
Element:	The components that the system consist of on the considered level.
Subsystem:	A subsystem is a set of elements, which is a system itself, and a component of a larger system.
Surroundings:	Everything that is not part of the system.
Structure:	The system elements and their connections.
Input:	What goes into the system from the surroundings. It can be matter, energy, information etc.
Output:	What goes out from the system to the surroundings.
Function:	The way input is transformed to output in the system or in the considered element.

An object, whether human made or not, will usually contain multiple systems, depending on how you look at it. When modelling an object as a system it is necessary to choose a viewpoint and a level to look at.

Viewpoint:	Decide which system is observed in regards to a given object. A machine can for example be seen as a mechanical system or an electrical system, but also the relation between user and machine can be considered as a system.
Level:	As can be seen a system has a hierarchical structure and can be viewed on different levels. The chosen level decide if it is the whole system or a subsystem that is considered and if the elements in the subsystems are represented.



Figur 3. Graphical representation of a system.

Please remark that even though both design projects and systems has hierarchical structures; there will in general not be a one-to-one correspondence between the project's problem solving structure and the system structures of the design object.

System theory is used in many scientific and professional areas and can therefore be used for much more than modelling of technical systems.

Analysis and synthesis

The mental activities in a design project can be seen as a continuous interaction between analysis and synthesis. First analysis is taking place in order to establish the knowledge from which the synthesis, that is the creation of possible principal solutions, is based. Then the modelling of solutions comprises of both analysis of the actual context and synthesis in the modelling activity. The solutions are now evaluated and the best is chosen which again takes analysis.

Literature

Stahl, H. og Tjalve, E. (1977): Konstruktionsteknisk problemløsning, AMT, DTH. (in Danish)

Lecture note 3 – 11995

Problem analysis

The problem analysis consist in principle of the following subtasks:

- Collection of information
- Analysis of needs
- Problem statement
- Specifications

The purpose of the problem analysis is to clarify the problem and determine the design goals.

What is the problem?

The starting point for the whole problem analysis is the initial formulation of the problem, which is often not very accurate. This inaccuracy is usually an advantage, because an open problem allows for more - and thus better - solutions. If the first description of the problem is very precise, it may prove to be just a Jeopardy questions to an already envisaged solution.

It pays to spend some time questioning critically what the problem is. For example, if the problem is just an unfortunate side effect of a given design solution, then it might be better to solve the original problem in a new and better way than to try to repair the bad solution.

This means that one must be aware of the preconditions for the problem. This applies both to the assumptions one can immediately see or find through an analysis, and the assumptions that are made implicit - that is, without realizing them!

One way to clarify these assumptions is to establish a needs/means tree as described in (Stahl and Tjalve, 1977, page17-24) (see slides) and go up a few levels above the problem. Another method is to use critical thinking, see end of this note.

Collection of information

When solving a problem one must understand the problem and not least, the circumstances in which the problem occurs.

In a building design project, it is for example a good idea to visit the site place where the building are going to be build, in order to see possible options and limitations for placement, orientation and design. In addition, it may be appropriate to collect historical, geological and meteorological information about the place and the surroundings.

For a new product such as a new building component, it is necessary to study the situations in which it will be used, but also to examine similar existing products and their properties.

For more technical problems, where the design object is part of a larger system, the majority of needs and specifications will have been be established right from the start of the project. A subtask in a building project is an example of such a problem, but also many construction projects belong to this type of design problems.

Analysis of needs:
The analysis of needs intend is to clarify the actual needs that the design object must meet for the users and stakeholders. The purpose of this is to become able to specify the primary functions of the design object.

The needs can be divided into the following categories:
1. Task-specific needs
2. General or formal requirements

The general and formal requirements relates to needs that have become requirements in legislation, building regulations, codes, standards and the like. These needs should be obtained in the preceding step, namely when collecting information.

The analysis of task-specific needs - or just needs - consists of the following sub-tasks:
- Stakeholder analysis: who are the users and stakeholders?
- Examination of their needs
- Interpretation of results and description of needs.

The stakeholder analysis are carried out by answering the questions:
- Which users and stakeholders are affected by - or could have interest in - how this problem be solved?
- Who is the most significant of these, that is,
    - Who has the most influence?
    - Who has - directly or indirectly - the most interesting information regarding the problem?

The task specific needs can in principle be examined in three ways:

1. Ask user / stakeholder
It is said that Henry Ford once said: "If I had asked people what they wanted, they would have the said faster horses." This quote express very well the risk by asking the user directly about what their needs are. The user will usually refer to existing solutions and often just wish more of the same - or less - if associated with difficulty or discomfort in one way or another.

Example: If you interview car owners about their needs, they will probably mention more space for luggage, smaller turning radius, less fuel consumption and more mileage between services or the like. But a desire to get some exercise, while they are anyway just sitting and waiting to arrive, you will probably rarely meet.

If one takes hold of so-called "power users", one must be aware that they often have different requirements than the average user, because they have more extreme needs.

The conclusion is that to ask users directly is most relevant in the case of an individual design solution, or the improvement or repair of an existing design object.

2. Analysis of users / stakeholders' activities
To analyse users and stakeholder activities is to investigate who is doing what, where and when. Such analysis should in principle include both users and stakeholders, but at first, it will often be sufficient just to focus on the situation - or situations - of use because we are interested in the primary needs

and functions. The analysis can later be extended to all stages in the lifecycle of the design object and all stakeholders at each stage.

The advantage of examining the activities rather than just asking the person in question about their needs, is that by clarifying and analysing their situation, needs and opportunities that they themselves are not aware of, can be identified. Sony Walkman is an example of a product that has arisen in this way.

The activities can be clarified by:

a. asking users / stakeholders about what they do
b. observe users / stakeholders, see e.g. (Bernsen 2014)
c. imagine what activities will take place.

The images c) may be based on the

- Own experience
- Knowledge - typically from previous observations
- Fantasy and knowledge of human nature
- A vision - which ideally will be a vision of a better life.

The scope of the activity analysis and the number of stakeholders included depends on the size and nature of the design problem. Is it a new neighbourhood to be planned, or is it a window's U-value to be improved?

3. Analyse one or more existing solutions to a similar problem
An analysis of existing solutions to a similar problem will in many cases reveal at least the basic needs and often provide ideas for improvements in relation to those solutions.

How and to which extend the examination of the task specific needs are carried out of course depends on the type of design problem in question. It may be:

- An improvement / repair of an existing solution
- Invention of a new solution to an existing problem
- A new solution to a new problem.

Exercise: Discuss and arguments for the type of examination of needs that will be most suitable for each of the three types of design problems.

In technical-related design problems, the majority of needs and specifications are as mentioned already predetermined. Nevertheless, it might be sensible to conduct stakeholder analysis (which users / stakeholders are interesting) and activity analysis to clarify more secondary needs. These needs can be decisive in the situation of choice between several alternative solutions.

Example
If there had been a more detailed stakeholder analysis in the design phase for the extension to the Royal Library "The Black Diamond", they may have thought of the window cleaners. And then they may had found a more elegant solution than closing ring 2 once a month for traffic from 23 pm. to 5 am. in order to set up an aereal lift and get the windows cleaned.

Problem statement

The purpose of the problem statement is to have a clear description of the work that is taking place so that it can be communicated to the organization in which the project appear. The problem statement serves in this way as an agreement between the project team members and between the project and the surrounding organization.

Smaller and/or technically oriented design problems may do without a problem statement, although it also here can be a good help to pinpoint the problem.

The problem statement should include:

- A description of the problem
- An identification of the problem area
- A description of the main features and properties of the solution.

Example

In course 11981 and 11982 F12 the following assignment were given:

"The assignment is to design a new net-zero energy building containing the teaching facilities for the new bachelor in building design at the Department of Civil Engineering at DTU.

The building should be an extension of building 117 somewhere in the space between the North-Eastern corner of the parking area east of building 118 and the existing buildings 115-116-117-118.

It is envisaged that the new building should accommodate

- 60 new students every year, in total 180 students
- necessary teaching facilities, seminar rooms, group rooms, study rooms
- staff offices and facilities rooms
- possibly workshops, experimental areas, expositions areas, atrium etc.
- connection to building 117
- flexibility towards future usage and expansions

The challenge is to develop the building with respect to the following qualities:

- internal and external design in accordance with the design policy of DTU campus
- possibly negative energy consumption over the span of a year
- optimized to a minimum construction and running energy consumption per student
- supports sustainability with low-carbon footprint and minimizes the strain on natural resources over the entire lifecycle
- net-zero energy consumption including embedded energy in structural and functional materials and components from construction and renewal over the entire lifecycle."

Specifications

The specifications are intended to define the functions that the design object must have. Specifications are formulated on the basis of the needs identified and divided into requirements and criteria:

Requirements:	Fixed and unavoidable properties. Requirements must clearly separate solutions from non-solutions.

Criteria: Properties and qualities that are important. Should separate good solutions from less good solutions.

Requirements and criteria is supplemented with remarks, open questions, comments or desirable properties, which may turn into requirements or criteria later in the process.

The specifications should as far as possible be measurable, so that you can clearly see whether they are met or not. At the beginning of the project it is though much more important that you find the most important needs than to set precise goals on them. But as you moves down through the tree structure of the project, the specifications must become more and more quantified.

Construction projects are subject to numerous requirements from laws and authorities. Usually only deviations from these requirements are stated.

Requirements, criteria and remarks may be presented in a table, and based on the life cycle of the design object, see Figure 1.

The table can be further refined by indicating the most relevant stakeholders at each life cycle phase, and for each of them, the related requirements and criteria.

Life cycle phase	Requirements	Criteria	Remarks
Design			
Production			
Transport			
Construction			
Use			
Repair			
Demolition			
Disposal			

Figure 1. Example of how the specifications for a construction project can be divided in life cycle phases.

Note that the requirements belonging to a given phase concerns requirements to the design object - or the project - at this phase. This means that if it is required that the element for a prefabricated house have to be transported on trucks without the use of pilot cars, this requirement must be placed in the "transport" phase.

As the specifications often will be expanded, adjusted and quantified during the project, each version are marked with date and version number.

Quality

The transformation of activities to needs and further on to functional requirements and criteria involves interpretation, assessment and prioritizing. Since the specifications are the entire basis for the solution, these interpretations, assessments and prioritizing's are essential for the quality of the solution.

In the literature, you will find no instructions on how to overcome this problem. However, there are two classic ways to ensure some consistency in the interpretations:

Critical thinking

Critical thinking consists in essence of considering the following questions:

- Are the observations (premises) that are chosen as basis for the formulated needs (conclusions) representative and logically coherent?
- Are the conclusions logically from the premises or could other conclusions be drawn just as well?

Critical thinking is a structured method for quality control that can be used in every part of the design process.

Review

Here we will define a review as an evaluation of earlier decisions and actions, based on the experience and knowledge that has been collected after these decisions and actions were made.

At the end of phase 3 of the problem solving process when the solutions has been found and modelled, it is often good to review the problem analysis in phase 1 and see if the specifications need to be changed or clarified.

Such a review could consider the following questions:

- Does the designs that seem to be the most promising at this stage reflect the original understanding of the problem, or has the process drifted so that we now have created solutions to a non-existent problem – or to a problem of less importance?
- Does the solutions found and the process leading to these indicate that the original problem was not completely understood or somehow misunderstood, so that the specifications - or some of them - have to be reconsidered?
- Does the technical problems we have at this stage of the process, indicate that we have not fully understood the concepts and solutions that we have chosen at earlier stages?

Literature

Stahl, H. og Tjalve, E. (1977): Konstruktionsteknisk problemløsning, AMT, DTH. (In Danish)

Bernsen (2014): På feltstudie i privatlivet, Weekendavisen 7. marts 2014. (In Danish)

Lecture note 4 – 11995

Ideas and solutions – seek and find

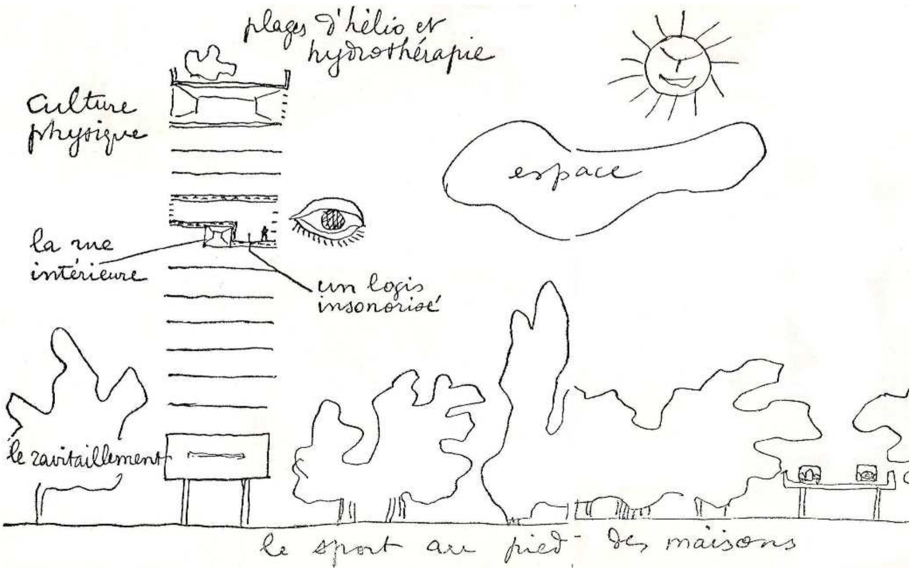


Figure 1. Sketch by Le Corbusier. Vision for ”La ville radieuse”

Introduction

How do you get a good idea? How do you find a good solution?

To find a good solution to a difficult problem requires tree steps:

1. Preparation
2. Let the subconscious mind work
3. Collection of results.

We properly all know the experience of getting a good idea, just having got out of the shower in the morning. The whole day before you have been pondered how the problem should be solved, the next day you wake up, take a shower and suddenly it is very clear what you can do. What happened?

First, you have prepared for it by thinking of all possible solutions - that is, all the solutions, that you could immediately think of - and of all sorts of obstacles. Then you have "slept on it", which means that you have given the opportunity to grapple with the problem and find a solution. The subconsciousness is really good at this. Where the consciousness has difficulties working with more than one thing at a time, the subconsciousness is used to work with a large variety of input, to find patterns in these input and conclude in an action. Finally, you gave the subconscious mind opportunity to make its voices heard, by standing in the shower and not really think about anything.

Preparation

The primary purpose of the preparation is to make sure that the subconscious mind has the information necessary in order to find a good solution.

The preparation may consist of the following items:
- To familiarize oneself with the preconditions
- To draw inspiration from different sources

To familiarize oneself with the preconditions is to go a few steps further than in problem analysis. It may be that you have to get hold of some material properties, geographic information or some new computational models. It could also be that you have to come up with a few proposals for solutions to find out if there is any information you are missing.

Inspiration means etymologically to “breath or put life or spirit onto the human body”. In practice it can mean anything from getting ideas to just copying. In this case, the aim is to find as many solutions as possible, and it has therefore a double purpose to look for inspiration: to get ideas and to open the mind.

Sources of inspiration

Nature

Nature has solved many technical problems. For example, the supporting structure of every mammal constitute an advanced prestressed structure consisting of parts in compression - the skeleton - and parts in tension - the muscles and tendons. The structure is even movable, thanks to the muscles. If looking more closely at a bone, you will see that it is designed as a tube. And when you look closely at the bone or the tube wall, you will see that it consists of a truss bracing the wall against buckling. Also you will see that the density increases, the closer you get the outer surface, which gives the cross section a high moment of inertia. The biological process of evolution has led to that many animal and plant kingdom's solutions are highly specialized and optimized. They therefore represent important sources of inspiration for engineers. Other parts of nature, for example the mineral kingdom can also be used. Crack patterns in clay soils, for example, provided the inspiration for the design of structures (Rietzel 1997).

Primitive architecture

It is characteristic of primitive architecture that it uses local materials and consider the local climate to a great extent. This means that the building is placed, oriented and designed observing the local weather conditions and that only few materials whose properties you based on many years of experience, know how to make optimum use of, is applied. This makes it interesting to study and analyze the so-called primitive architecture, and to study the conditions. Without knowing the conditions, one cannot judge the thinking and craft behind the solutions - and often this is more inspiring and useful than just copying the solutions.

Master builders

Example 1: Utzon’s platforms see lecture.

Example 2l: Torroja’s shells, see lecture.

Other areas of technology

Eksempel: ice screw – screw pile, see lecture

Scientific principles

Example: plate structures, see lecture

New materials/processes/technology

Example: Centre Pompidoux, see (Rice 1994) p24-47.

Let the subconscious mind work

Below are some methods that let the subconscious mind do the work:

Brainstorming

Brainstorming is carried out in a group. To intensify the process you may choose to stand around a table. The brainstorm rules are:

- **Focus on quantity**: This rule is a means of enhancing divergent thinking, aiming to facilitate problem solving through the maxim *quantity breeds quality*. The assumption is that the greater the number of ideas generated, the greater the chance of producing a radical and effective solution.
- **Withhold criticism**: In brainstorming, criticism of ideas generated should be put 'on hold'. Instead, participants should focus on extending or adding to ideas, reserving criticism for a later 'critical stage' of the process. By suspending judgment, participants will feel free to generate unusual ideas.
- **Welcome unusual ideas**: To get a good and long list of ideas, unusual ideas are welcomed. They can be generated by looking from new perspectives and suspending assumptions. These new ways of thinking may provide better solutions.
- **Combine and improve ideas**: Good ideas may be combined to form a single better good idea, as suggested by the slogan "1+1=3". It is believed to stimulate the building of ideas by a process of association.
- **10-15 minutes is enough:** Prepare for a brainstorm. Be careful to address a specific question. Then stop after 10-15 minutes - the ideas dry out.

Sketching

Sketching in pencil lets in many cases the subconscious escape of the consciousness shackles. With a stack of blank paper and a not too sharp pencil, one can in a short time produce a lot of sketches. The principle is like the brainstorm: many sketches, avoid (self) criticism, radical suggestions are welcome, keep the process short and intense. Categorizing and combinations may advantageously wait until later. Can be performed alone or in a group.

Building models

In some cases, especially when the spatial geometry plays a major role, it is an advantage to work with - often very simple - physical models. It is important to select materials that make it possible to work quickly and make experiments. During building and testing the model, opportunities that you had not seen before turns up, and can be tested right away (see lecture note on models).

Making physical experiments

Physical experiments can be used for more than just verifying hypotheses or study physical quantities. Practical experience shows that experiments of a more playful character often is a source of new knowledge and new solutions. Maybe it is because experiments of this type is based on instant physical experiences, rather than articulated theories (see also lecture note on models and experiments).

Systematic search for solutions

In those cases where you are convinced that there already exist solutions to the problem that you are dealing with, or that the solution can be found by a relatively simple combination of existing solutions, it may be appropriate to use a more systematic approach.

Collections of examples

Collections of examples are not necessarily built up systematically, but they can be examined and sorted systematically. In general, the examples in textbooks, instructions and catalogs are proven and documented.

Examples:

- Handbooks
- Textbooks (Old textbooks are particularly good because they more often describe concepts)
- Guidance's from national building research institutes like SBI
- Material from trade associations such as: "Træinformation"
- Catalogues
- Etc.

Morphological technique

This method is used to set up many solutions to well defined problems on a conceptual level.

1. Provide a list of properties that together describe a solution
2. Arrange for each property a list of means that have just this property
3. All the combinations of means for each property is now a solution.

See Figure 2 on the next page.

Overview Works

Overview Works such as (Engel 1997) and (Büttner und Hampe 1985) are examples of use of the morphological technique to a systematic arrangement of structural systems.

Reverse morphological techniques

This technique I have used successfully in a number of cases.

1. Seek solutions - many solutions. Use one or more of the above techniques.
2. Sort out the solutions. This process can take time. In fact, it should take time. There must be found an order in the solutions. There are basically many criteria by which the sorting can be performed. The intention is to find basic principles for solutions. Principles that are relevant to the problem. This introduces one or more systems. The process has the potential for gaining new ideas and knowledge, which in so far is also a goal.
3. New solutions are searched based on the found principles. For example, there will generally be gaps in the system and these gaps represent new solutions.

Postscript

There exist many other methods than those mentioned here to utilize the subconscious mind. "Creative problem solving" is a widely used generic term, and the techniques can be divided into four categories: mental state shift, problem reframing, multiple idea facilitation and change of perspective.

Note that they all intends to break down the usual patterns of thinking in order to make room for new ideas.

In this way one can say that from a management perspective the development of good ideas and solutions is all about choosing knowledgeable but curious people and setting up the right framework for the process.

Principper (principielle strukturer) for en plotter kan opstilles således:

Karakteristika: Relativ bevægelse mellem pen og papir for 2 koordinater
Bevægelsesgeometri pr. bevægelse
Skrivefladens form

Morfologisk skema (svarer til gruppe 3 ovenfor):

Relativ bevægelse	Bevægelsesgeometri pr. bevægelse	Bevægelsesgeometri pr. bevægelse	Skrivefladens form
1. pen + pen	A. retlinet	A. retlinet	I plan
2. pen + papir	B. cirkulær	B. cirkulær	II cylindrisk
3. papir + papir			

Principielle strukturer ud fra kombinationer:

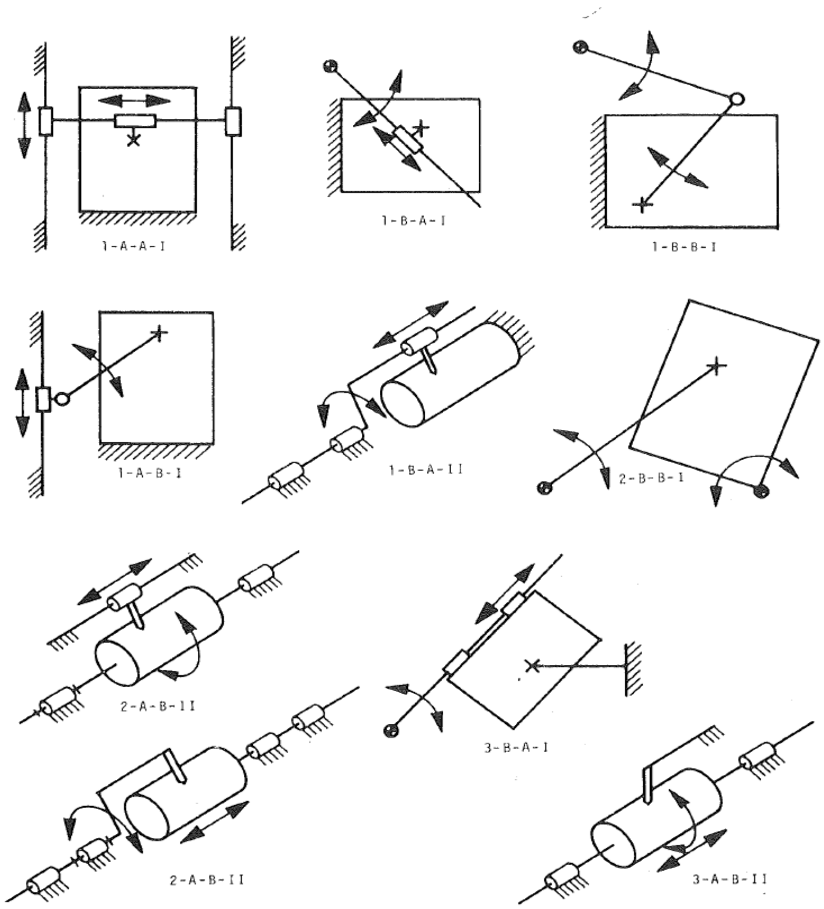


Figure 2. Morphological technique applied to solutions for a plotter (Stahl og Tjalve 1977) p101.

Literature

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Lecture note 5 – 11995

Models and experiments

Model definition

A model is a representation of a part of reality - or part of a possible future reality - that have certain properties in common with this reality.

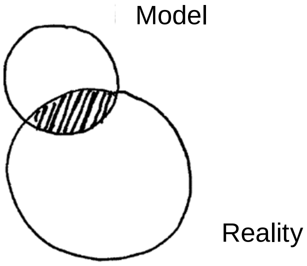


Figure 1. The relation between model and reality

I almindelig tale betegner en model det, som vi her kalder en fysisk model. Vi anvender således her *model* som et mere udvidet begreb og bruger det mere målrettet.

In ordinary speech, a model means a physical model. Here we expand the notion and we use it more deliberate.

Examples of models:

- drawings
  - Sketches
  - System diagrams
  - Dimensional drawings

- Mathematical models
  - Formulas
  - Calculations
  - Graphs

- Computer Models
  - Visual
  - System
  - Geometrical
  - FEM and CFD

- Physical models
  - Conceptual
  - Visual / Spatial
  - Structural

Exercise:
Describe for each of the above model types, the most important properties they have in common with reality. You may subdivide the model types. Are there any significant properties that you cannot represent with models?

Model technique

It takes time to produce models. It is therefore important to choose the right type of model. The model must have the properties that you want to investigate, but must also be as simple as possible. Generally, it is better to carry out two sets of models to study two sets of properties, than it is to carry out one set of more complicated models to study both sets of properties.

Models are used to grip and hold ideas, for sketching solutions, for experiments, to investigate and modify solutions and for evaluation of proposed solutions.

To grip and hold ideas and to sketch solutions simple hand sketches are the most suitable. If they have to be communicated to others, redrawing may be a good idea.

For experiments, the physical properties usually have to be modelled, and then either computer models - or even better - physical models can be used.

When the found solutions are to be evaluated and the best chosen, there may be a tendency to model the proposals that we already like best, to a higher level of detail than the other proposals. In order to evaluate the solutions on the same basis, it is important to model them all to a uniform level.

During the model work, you acquire knowledge. It may show that the problem analysis or specifications must be adjusted or supplemented, or new ideas may pop up. Also, it may show that one solution can be modelled in several ways.

Summary

- Make the models as simple as possible.
- Rather many simple models than a few very fine models.
- Physical models are particularly good because they talk to several senses simultaneously and therefore provide "broadband" information to the subconscious mind.

Figure 2. Simple physical static model of a frame structure.

The experiment
In principle, the basis for all new scientific discoveries is the following cycle (Figure 2):

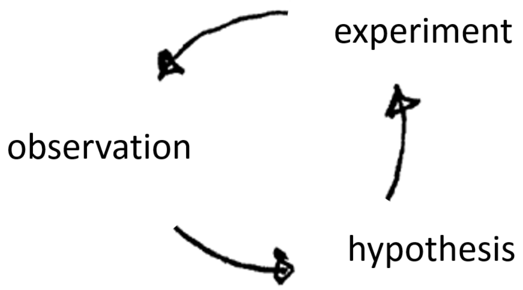


Figure 2.

Definitions:

Observation: to see - that is, to notice - a phenomenon

Hypothesis: a proposal for an explanation for this phenomenon

Experiment: an experiment that is designed so that it can test the hypothesis

The experiment has a central role in science. Also within the technical sciences have experiment a central role as a source of data and knowledge, see e.g. Vincenti (1990).

If we consider this cycle as a process that creates knowledge, can be seen that experiments also has - or should have - a key role in engineering design projects.

What is interesting in this context is that you can jump on this cycle on all three stages:

- The scientific approach: as it for example is explained with the story of Isac Newton, who saw the apple fall from the tree, it all starts with an observation. Based on this observation a hypothesis is formulated and then a test of the hypothesis is performed by means of one or more experiments. These experiments may then, moreover, lead to a new observation and a new cycle can begin.

- "The genius’s" approach: as described in the Romantic period, it will all start with the hypothesis. The hypothesis is obtained by a sudden insight or inspiration. The genius will then immediately embark in an experiment whose aim will be to examine whether the hypothesis holds.

- The playful child or the playful designer's approach will be a series of apparently random experiments. If it goes well, the experiments, however, lead to observations that will form the basis for hypotheses - which may be more or less clearly formulated. These will immediately be tested and lead to new observations, new hypotheses and new experiments.

The process may proceed quickly, as for the playful child, or slow, as for the scientist, if the hypotheses are extensive or much documentation is required.

This means that the experiment can be used in all phases of the design process. To clarify problems, to find new solutions and off course to prove that the solutions work as desired.

Lecture note 6 – 11995

Solving structural systems

The structural system in a building cannot be designed without taking the geometry of the building, materials and the construction process as well as economy and time into consideration. Often the design and construction of the building envelope also has to be taken into consideration.

From a problem solving viewpoint the architectural demands to the geometry of the building represent a requirement to the structural system, that restrict the number of possible solutions. In the same way a specific demand for the materials, will restrict the number of solutions.

Spiral process

Instead of solving one problem at a time, it can be beneficial to see the problems as connected and the problem solving process as a spiral, where you for every turn consider each problem, and for every turn bring the solutions to a higher level of detail (Figure 1).

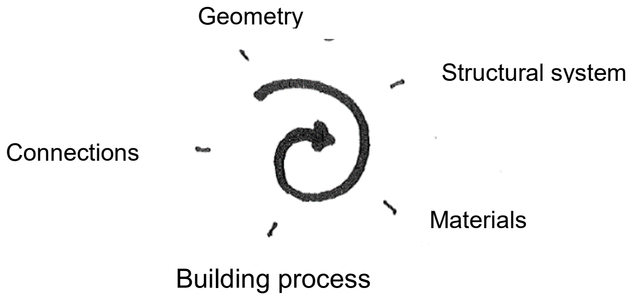


Figure 1. Spiral process

For the structural part of a project where neither the structural system nor the materials has been chosen beforehand, the problem solving process can follow this scheme:

Structural system, first turn:

1. Identify the problem and specify the goals
    - 1.1. Have a meeting with the architect/building contractor and discuss / clarify:
        - 1.1.1.Purpose of the building
        - 1.1.2.Architectural ideas
        - 1.1.3.Geometry of the building
        - 1.1.4.Materials, possible and preferable
        - 1.1.5.Possible structural systems
        - 1.1.6.Others ideas or wishes regarding the construction
    - 1.2. Obtain information about other "boundary conditions":
        - 1.2.1.The building's location and orientation
        - 1.2.2.Wind and snow loads
        - 1.2.3.Geotechnical conditions and foundation options
        - 1.2.4.The building's lifetime
        - 1.2.5.Other relevant issues
    - 1.3. Clarify the building's main geometry and the construction space, i.e. the spatial area which can be used for the structure

2. Find solutions
    2.1. Build up a structural system by inserting structural elements in the construction space, or
    2.2. Examine various known structural systems and how they function, and
        2.2.1. Use or customize a "standard" system, or
        2.2.2. Use or customize a unique system, or
        2.2.3. Compose a new system from known subsystems or
    2.3. Make a model of the construction space in an elastic material and use the principal stresses to design the structural system

3. Model each solution
    3.1. Clarify the load carrying system (Vertical loads)
    3.2. Clarify the stabilizing systems (Horizontal loads)
    3.3. Consider the connections, their placing, forces and type
    3.4. Consider elements prone to instability
    3.5. Clarify and describe the structural system

4. Evaluate and chose the best solutions
    4.1. Evaluative the solutions in relation to the requirements and criteria, as well as
        4.1.1. Structural clarity
        4.1.2. Possible materials
    4.2. Choose the best solutions

Materials, first turn:

1. Seek possible materials in relation to:
    1.1. Architectural idea
    1.2. The structural systems
        1.2.1. Physical properties
        1.2.2. Element Geometry
    1.3. Connection types
    1.4. Economy
    1.5. Impact on natural resources and environment

Building process, first turn:

1. Seek possible processes for:
    1.1. Foundation
    1.2. Production of elements
    1.3. Transport
    1.4. Construction and assembly on site
    1.5. Possible dismantling or demolition

Structural system, second turn:

1. More detailed analysis and design of the individual solutions
    1.1. Analyse and clarify the load transfer of each system completely
        1.1.1. Check and adjust if necessary the description of the structural principle
    1.2. Consider the most critical load combinations for each solution
    1.3. Sketch and calculate rough dimensions for the structural elements observing material and forces
        1.3.1. Consider the most critical load combinations for each element
        1.3.2. Calculate roughly the most critical forces
        1.3.3. Find rough dimensions for typical and for critical elements

- 1.4. Consider
    - 1.4.1. Placing and design of elements prone to buckling
    - 1.4.2. Elastic or plastic behavior
    - 1.4.3. Distribution of stiffness
- 1.5. Sketch solutions for the individual connections taking materials and forces into consideration
- 1.6. Consider the construction process (manufacture, transport and assembly) and may be price
- 1.7. Examine opportunities to simplify the system, use less material or make it easier to build.

5. Evaluate and chose the best solutions
    - 5.1. Add the following criteria in addition to above:
        - 5.1.1. Relation between the main structure, the sub structures and the elements
        - 5.1.2. Connection types
        - 5.1.3. Building process

Lecture note 7 - 11995

Materials for structures

Introduction

Materials for structures are in general chosen from considerations on architectural idea, overall building geometry, building regulations, economy and time. In the future environmental impact also may become a factor.

The physical properties of a material and the geometrical shape in which it is produced determine what types of structural elements can be made from this material. The physical properties also determine the type of connections that can be used in the structural systems constructed from this material.

In this way the choice of material, delimit the possibilities for structural systems and vice versa, the choice of structural system delimit the possible materials.

Physical and geometrical properties

For an initial sketching and modelling of proposals for structural systems, only the most basic physical properties have to be clarified:

- compression, tension and bending strengths,
- stiffness,
- brittle or ductile breakage.

For the geometry it is sufficient to determine whether the material is obtainable in bar-shaped (1D), the plate-shaped (2D) or as solid (3D) elements and how this depends on the actual size (Figure 1).

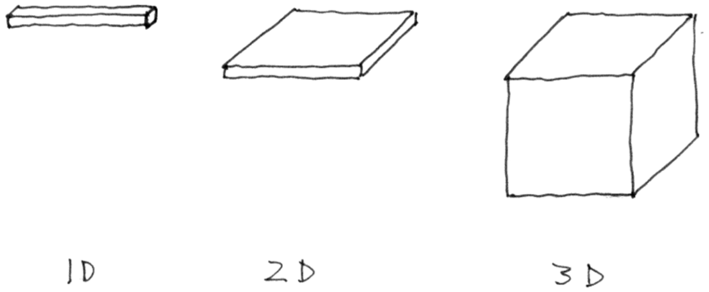


Figure 1. Element shapes.

For a more detailed design of the structural system and the dimensions of the elements, it is relevant to examine the following properties:

- Density	δ
- Design stress in compression	f_{cd}
- Design stress in tension	f_{td}
- Design stress in bending	f_{md}
- Design modulus of elasticity	E_d
- Thermal conductivity	λ
- Specific heat capasity	
- Thermal expansion coefficient	α
- Fire resistance	

The structural efficiency of the material that is, the load carrying capacity compared to the self weight of the structure, is indicated by the following ratios:

- Tension strength/density	f_{td}/δ
- Compression strength/density	f_{cd}/δ
- Modulus of elasticity/density	E_d/δ

Similar ratios can be calculated in relation to price and to environmental impact.

The practical aspects of the material, how they are produced, their availability, prefabrication, transport and how they are handled and assembled on site has a significant influence on price and time, and because of this also on the choice of materials.

A basic knowledge of materials, connections and building technique is therefore an important prerequisite for being able to asses and select materials for constructions.

Keywords for a number of current building materials
All stresses are design stresses.

Reinforced concrete, cast in situ
Principle: Concrete takes compression, steel reinforcement takes tension
Density = 2.400 kg/m3
Concrete compression strength: fcd = 14 – 35 MPa
Reinforcement yield strength: fyd= 370 - 500 MPa
Concrete stress-strain curve idealized => elastic-plastic
Reinforcement stress-strain curve idealized => elastic-plastic
Load carrying capacity are calculated using plastic theory
Bending capacity: planar sections, concrete strain ≤ 0,35%, steel strain ≤ f_{yd}/200.000MPa, typical height of compression zone = ω * h = 0,2-0,3 * h

Simple elastic rough calculation:
E = E_concrete =1.450*fcd_concrete, fd=fcd_concrete

Structural elements: columns, beams, shear walls (skiver) and plates (plus arches and shells)

Connections:
Contact (bearing)
Geometry: Bearing depth a ~ width b
Compression stress determine the dimensions

Glass Fiber Reinforced Polymer profiles
Strength, stiffness and Density, see eg www.fiberline.com

Structural elements: columns and beams
Load carrying capacity are calculated using elastic theory

Connections:
Bolted dowel connections with steel brackets. Bearing strength and reduced cross section and sometimes moment capacity of the bracket determine the load bearing capacity
Connections are calculated using plastic theory

Brickwork
Principle: The structures geometry is designed so that the trust line from external loads and self-weight always will remain inside the section
Compression strength f_{cd} = 4 MPa (stone type 25 and lime/cement mortar), tension strength = 0
Density =1.700 kg/m3

Structural elements: columns, arches, shear walls (skiver) and shells
Load carrying capacity are calculated using plastic theory

Connections:
Mortar joints = Contact connections with friction
Coefficient of friction μ_d = 0,5

Steel
Isotropic material
Strength: fyd = 200 – 400 MPa, Stiffness: Ed = 200.000 MPa
Density: 7.850 kg/m3

Structural elements: tension bars, columns and beams (and cables)
Load carrying capacity are calculated using elastic theory

Principle: Column and beam cross sections are designed so that the ratio between bending strength and cross-sectional area is large, but local buckling is avoided.

Connections:
Bolted connections: Dowel connections, friction connections and tension connections. Shear failure, bearing strength and reduced cross section typically determine the load bearing capacity
Geometry is determined by minimum values of spacing

Welded connections: For fillet welds, shear stresses typically determine the load bearing capacity, for butt welds normal stress typically determine the load bearing capacity
Principle: The weld is made with the same strength as the base material

Connections are calculated using plastic theory

Timber

Principle 1: Strength in the direction of the grains is much higher than perpendicular to the grains. Tension strength perpendicular to the grains are very low.
Strengths depends on the quality of wood, see eg “Teknisk Ståbi”.
Principle 2: Strength depend on the load-duration and service class (exposure from humidity)
Roundwood can be calculated as C30, see DS 413:2003
Density: 350 – 500 kg/m3

Structural elements: columns and beams. (Cross laminated timber: shear walls (skiver) and plates)
Load carrying capacity are calculated using elastic theory

Principle: Connections are placed where bending moments are zero.

Connections:
Contact Connections: compression strength perpendicular to the direction of grain are typically determine the dimensions

Dowel connections: Nails, screws, bolts and dowels. Diameter and number of dowels (nails, screws etc.) and size of cross section determine the load bearing capacity

Geometry of connections are determined by minimum spacings between dowels and between dowels and edges that depends on the direction of force and the direction of grains

Fish plates of steel can be slotted in without reducing the cross section of wood significantly.

Glulam: Glued in bolts make tension/compression connections possible and thus transfer of bending moments

Connections are calculated using plastic theory

Literature

Teknisk Ståbi, 21. udgave 2011, Nyt Teknisk Forlag, København.

Lecture note 8 – 11995

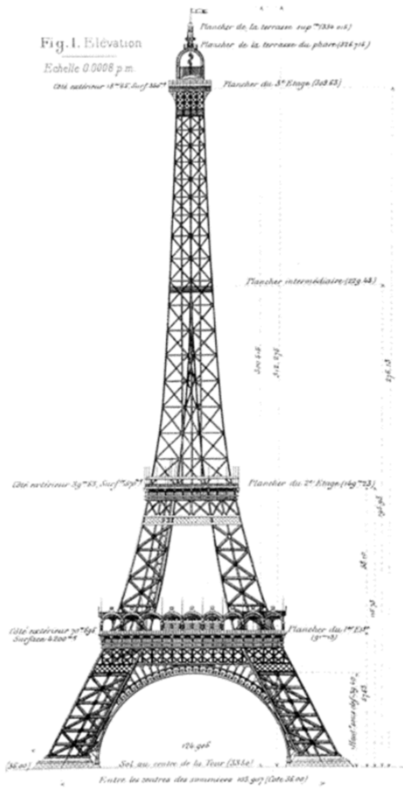
Concepts

The term ‘concept’ has been widely used in the design world the last 20 years or more. Here the term will be used in three meanings:

1. A proposal for a complete and coherent design solution based on a general idea or principle that form all sub solutions
2. An early design project phase that examine all major problems and the feasibility of new solutions
3. A method to generate many solution by systematically addressing relevant focus areas one by one (ideal concepts)

1. Complete and coherent solution

In many engineering and industrial design contexts, but also in product and business development, the term concept is used to describe a basic idea or a complex of solutions that - at least in principle - generates all other solutions. In this way, a concept become both a strategy for finding solutions, and a method of creating a coherence between all the solutions and thus in the finished product. Architects also uses the term “concept”. For them it represent both a way to attack the problem and a way to deal with it. From this perspective, one can say that the concept at one time reflects what you see as the problem and what you see as the solution. In this lies implicitly the notion that there is a necessary link between problem and solution, and that the problem, so to speak, provides the solution by itself, once it has been clarified.



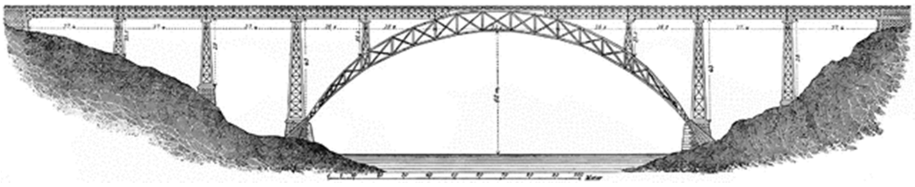


Figure 1. Ponte Pio, Porto, and Tour Eiffel, Paris, in approximately same scale.

Example

There is a clear relationship between the constructive concepts of Eiffel's three structures: Ponte Pia, Porto 1877 Viaduc Garabit, Cantal 1884, and the Eiffel Tower, Paris 1889. They are all truss structures. The individual bars are made from steel profiles that are riveted together. All the bars are standardized and prefabricated in a workshop. Thus, it is the same type of production facilities, which has been used for all three structures. All three structures are shaped by following the same procedure. First proposal for the design is based on a geometric shape that can be described mathematically simple, such as the parabola. The structure is then analysed and the internal forces are found. The shape is then adjusted so that the bending moments are reduced. For Ponte Pio, this means that the arcs form is composed of two parabolas that intersect and form a barely visible angle under the two pillars standing on the bow near the quarter points.

There is a slightly difference between the two bridges. In Ponte Pio the top of the arch become part of the bridge girder whereas the arch and bridge girder are separated at Viaduc Garabit. This separation means that the whole bridge girder can be prefabricated on shore and assembled on the arch without time-consuming fitting on site. Because the structural functions are separated the structural analysis also becomes simpler, and visually the structure become more clear and distinct.

Figure 2. Viaduc Garabit..

2. Project phase

In product development projects the concept phase lies between the idea phase and the development phase. In a building project, the concept phase typically is included in, or replace, the proposal phase.

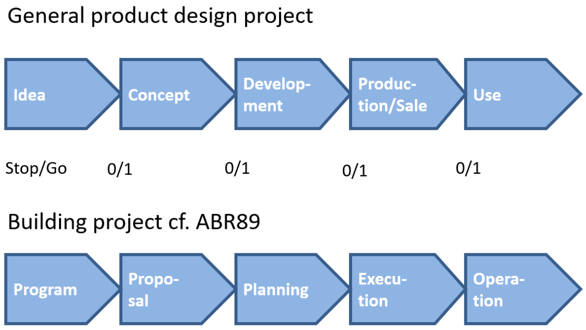


Figure 3. Diagram showing typical project phases in product design projects and building projects. ”Stop/go” indicate a decision point, where the project is evaluated, and it is decided whether the project is stopped or next phase can start.

The purpose of the concept phase is primarily to uncover all major problem areas and examine the feasibility of new solutions.

The early decisions has most influence on the outcome of a project. At the same time, these decisions are often taken on a thin basis.

A new design project is usually based on the new needs, problems or solutions that has emerged in the idea or program phase, and the special value of the project is based on the quality of these. However, as these needs, problems or solutions are new, they are also uncertain. A main purpose of the concept phase is therefore to examine and evaluate the new solutions, so that the risk of bumping into important and unforeseen problems during the design phase is small. By identifying and clarifying the major uncertainties in the concept phase, we can ensure that the project can be completed as intended.

Example 2

In connection with the development of DTU's project for Solar Decathlon 2012 "FOLD" we were uncertain on a number of issues regarding the "stressed skin" elements from which the whole structure was built. At the time, these elements appeared to be the best solution and they were a very important part of the whole project. Among other things, we had to find out:

- Would they be too complicated to build?
- Would we be able to lift and place the inclined elements with sufficient precision?
- Would we be able to mount them quickly enough?
- Would the connections work as intended?
- Could the solar panels be pre-mounted on the elements?

We decided to make a mock-up in 1: 1 of the two rows of the largest elements to clarify these issues. It turned out that all except the last questions could be answered with a "yes", and we chose to change the connections.

See https://www.flickr.com/photos/teamdtu/7016991625/

Example 3
The shells of the Sydney Opera House appeared after 4 years of analysis, not to be able to function statically as shells. A new concept had to be found. See Arup and Zunz (1969): Sydney Opera House, and lecture.

3. Ideal concepts

Ideal concepts is a method used to generate many solutions. First, a number of ideals set out in advance. It could be ideals as: installation-friendly, quickly to design, insensitivity to large tolerances, etc. Then solutions are proposed for one ideal at a time, just focusing on this ideal. When (many) solutions has been found for each ideal, the next step is to combine and adjust the solutions to make final proposals, with different weight on the different ideals.

Example 4
Ecodesign principles in “Environmental improvement through product development - a guide”, see
http://mst.dk/service/publikationer/publikationsarkiv/2009/apr/environmental-improvement-through-product-development-%E2%80%93-a-guide/

Lecture note 9 – 11995

On information, knowledge, choices and judgements

At the beginning in a design project, you only have an uncertain - if any - conception of where you will end. In the end, you have a fully documented design, that is, a sure knowledge that the design will work as desired.

In this way, the design project can be seen as a knowledge creating process, where many small sources of information are brought together and formed to a river of information. In practice this river consist of the project documentation, typically drawings, calculations and reports.

Three creative processes are involved in this:
1. To seek out and select knowledge and relevant information
2. To create knowledge from information collected
3. To select and assemble knowledge into solutions

Knowledge is knowledge of relationships between information. For example the relation between how the colour red is seen by our eyes and the word “red”. Knowledge is often contextual, which means that it is only relevant or only has value under some circumstances.

A design solution is composed of many small bits of knowledge from different areas that are combined and assembled, so that they together form the solution. A new solution can thus be created in principally two different ways: either by adding new knowledge to existing knowledge, or by putting existing knowledge together in a new way.

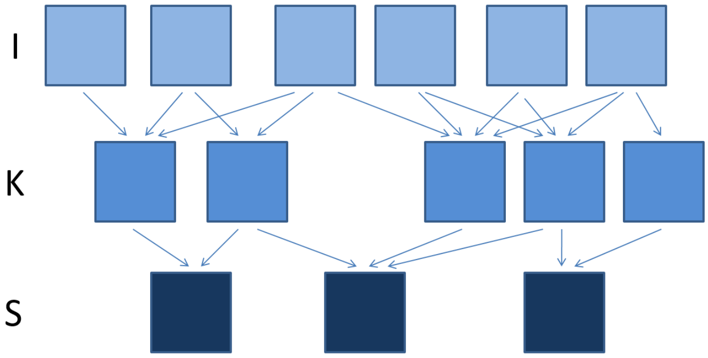


Figure 1. Diagram showing how information (I) can be assembled to knowledge (K) which in turn can be joined to solutions (S).

Note that there is in principle no great difference between a knowledge and a solution. Nevertheless, the solution is often more complex and more contextual, where knowledge is more general and may not be experienced quite as complex.

In this way, the design process can be seen from two perspectives:
1) The virtual construction process: The design object is assembled from components, which again is put together from smaller components or individual objects.
2) A knowledge process: Each solution is composed of many small bits of knowledge from different areas that are combined and put together to form the solution.

To collect knowledge and create solutions is commonly referred to as forming a synthesis or a synthesis process, and is in contrast to an analysis process.

As it can be seen above, the synthesis process is parallel to the construction process, only it is not objects but knowledge that are put together. Hence the knowledge process and the construction process in a design project are two uniform processes that occur in parallel but at two different levels.

Against this background, one can say that the art of engineering design is to look in the right places for information and to work constructively with the information you find.

Sources of information and knowledge
For problem analysis and evaluation of proposals:

- Stakeholders:
    - Client
    - Users *
    - Architect
    - Other engineers
    - Contractors
    - Suppliers
    - Local technical authorities

For search of ideas and solutions:

- Existing knowledge
    - Intern knowledge
        - Your own knowledge
        - Colleagues knowledge
        - Handbooks, archives and projects
    - External knowledge
        - Literature: journals and books
        - Suppliers
        - Experts
        - Authorities
        - Similar designs
- New knowledge
    - Experiments
        - Experiments with physical, numerical or geometrical models
    - Examinations
        - Collection and analysis of existing information from i.e. journals, books or the internet
        - Observation and registration on site
    - Experts
        - Discuss possible solutions – and also impossible
        - Ask for other possible sources of knowledge
- Inspiration
    - Nature
    - Primitive architecture
    - Master builders
    - Scientific principles
    - New material/processes/technology
    - Physical experiments

* including indirect users, for example: garbage collectors, caretakers, cleaning personnel, window cleaners, gardeners, repairers etc.

Choices

Let us assume that the various solutions that have emerged from the search for solutions, has been modelled. Let us also assume that the models have been examined and adjusted, so that they clearly shows the properties that we want them to show, and can be evaluated on these. Likewise, also the specifications may have been adjusted in this process, because modelling has clarified some requirements and criteria.

The next step is now to evaluate how well the solutions meet the requirements and criteria. Especially if it comes to many requirements / criteria, it is appropriate to use charts to show this, for example, bar charts or radar charts

We will now consider the situation where one or more of the solutions found must be chosen as the basis for further work, and let us assume that only one proposal can be chosen. Then you can have three situations:

1) The choice is clear, one solution is clearly better than the other ones. Select this solution.

2) Two or more solutions are equally good. Then you can just choose one of them.

3) Two solutions seem equally good when you compare them based on the criteria and requirements set up, but at the same time, it is clear that one solution is significantly better than the other is. Then will be necessary to revise the specifications, because there must be at least one requirement or criterion of importance that was not taken into account.

However, there will also be essential properties, which can not be modelled at this stage of the project. Then will you have to make a choice on an uncertain basis. Instead of examining the properties, one can only make a judgement of how the individual solutions will fulfil the requirements and criteria.

But what is a judgement?

Judgements

A judgement is an experience-based prediction of what a more extensive analysis would show.

A judgement is thus based on the premise, that the parameters being evaluated in principle could have been measured or quantified in another way. It just not done, because you either believe that you can predict the outcome with great certainty, or because it will require a great effort and/or time which is not available, to perform the measurement.

This means that any judgement in principle include a description of what is analysed and how this analysis could be made. This implies that if one is not able to provide this description, then, is not clear what it is to be analysed, and then, the judgement is meaningless.

Lecture note 11 - 11995

Project management

This note addresses only specific project management tools and concepts, and is on a very short form. More general management oriented disciplines such as employee management, organization, economy etc. you must look elsewhere for.

Project (definition)
A temporary organization tailored to solve a defined, difficult task.

The main phases of a project:

Phase 1: *Renewal* (Example: Program / Idea phase)
focus: overview and innovation
result: description and delimitation of the task

Phase 2: *Immersion* (Example: Proposal / Concept phase)
focus: quality
result: description of the solution

Phase 3: *Completion* (Ex: Planning / Development phase)
focus: delivery
result: delivery / documentation of the solution

Principles for management of projects:

- Clear distribution of roles
- Strategy determined by the project
- Management through clear agreements
- Control the results: Identify midway results and measure end results

Roles
Distribution of roles is the process where the individual participants' roles and tasks are defined. The distribution of roles must take place both within the project team and between the project and the surrounding organization - or organizations.

Strategy
The strategy is the overall approach of the project. The strategy is determined by each project's goals and conditions.

There are three basic strategic principles for uncertain and complex tasks:
1) make use of all forces
2) concentrate the forces
3) advance at high speed

Planning
The central agreements in a development project are the specifications, the project plan and an estimate of resource consumption. These agreements are concluded between the project and its surroundings.

The project plan is an agreement on the progress of the project. The project plan maintains the main agreements on the project: who does what, how and when. The project plan specifies phases and phase transitions.

Principles: Avoid unnecessary details. Define phases by their start and end state.

The start state is the preconditions for the phase. The end state is the results of the phase. Make sure that the results are measurable, so that there are no doubts whether they have been achieved or not.

At each phase transition the results are presented for the project's steering committee and it is decide whether the next phase should be initiated or not. In the planning of the project, every phase transition is given a name, and the criteria and procedures for assessment of the results are described and attached to the project plan.

Resources are in project context *labour*, i.e. expertise and working hours, and *economy*, which include cost of external services and goods.

A good estimate of resource consumption
- is based on sound professional judgment
- has a visible basis
- is easy to revise
- is contributing to collection of experience.

A visible basis makes it easier for the project to change the allocation of resources if the project conditions or developments require this. The basis of the estimate should therefore be annexed to the estimate. Whether the individual suppliers should estimate their own resource consumption, depends on the project.

Agreements
Agreements are the project manager's main instrument. In principle there are five activities relating to agreements:
- Find partners
- Make agreements
- Monitor agreements
- Revise the agreements
- Declare agreements for fulfilled

Responsibility
Agreements on activities and problem solving follows the principle of defining them by their preconditions and their results - that is, their start- and end state. Avoid unnecessary details. This also applies to agreements with the individual employee.

Responsibility for carrying out the specific task lies with the individual employee, which should be regarded as an expert - and know that experts seek help and information when they need it.

Recognition
Recognition must be visible and take place within the project team. However, it must also be visible outside the project team, especially for those people in the organization that the employee believes are best to assess and appreciate his or her expertise.

Project control
Project control is only needed if the project does not follow the plan, which it only rarely does. In order to control - or to know if there is a need to control - there is a need to measure. What can be measured is only the consumption of resources, the activities and the results. If the activities does not take place, the resources to execute them must be provided. If the activities do not lead to the desired results, new activities must initiated and plans changed. In both cases, agreements must be reviewed and new agreements made. Resource consumption can easily be measured, activities can hardly be measured, therefore, the focus should be on results and partial results, especially the identification and measurement of partial results.

Project Management main (and often only necessary) control tools are:
1) Project/task decomposition diagram
2) Time schedule
3) Task lists

A task decomposition diagram is used as the name implies, to break down the task into smaller parts - sub-tasks or activities - and is often shaped as a tree structure. It is not always clear how a task should be broken down. For a design project, it is important to be aware that the main purpose of the activities is to provide information, and therefore to consider what information is needed when.

For each phase there may be need for a more detailed time schedule. Here, a so-called Gantt chart can be used. It is based on an orthogonal coordinate system with time along the x-axis and the activities along the y-axis, with the first activities at the top (Figure 1).

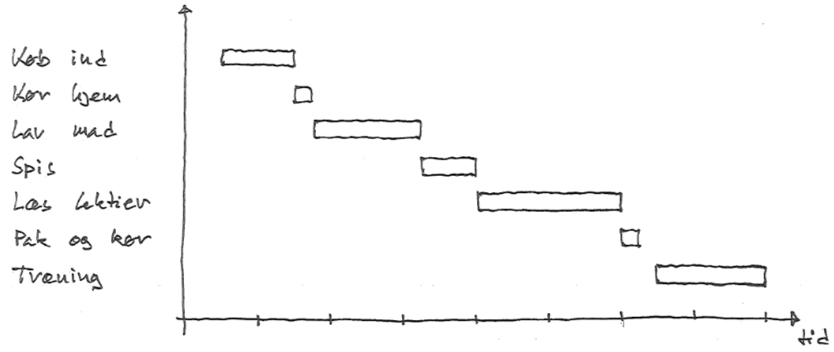


Figure 1. Gantt chart.

A Gantt chart shows both work time and calendar time. Interdependence between activities can be shown with arrows and the *critical path* used to find the shortest possible schedule for the complete task, can be found. Gantt charts are best suited for the late phases of design projects where time and resources for each task can be predicted with reasonable certainty.

Other relevant concepts

Integrated design:
Parallel in time and mutually informed and coordinated design processes of different disciplines.

Project team:
One for the occasion formed group of people. A project team normally goes through five phases: formation-, conflict-, norm-, efficiency- and dissolve phase. When the project team is formed, it is a good idea to agree on the ambition and ground rules for the team. The final ground rules will first be established in the norm phase.

Risk management
Normally included in the project planning. Consider all the events that could affect the quality, economy or time of the project negatively. Consider the probability and the effect of each individual events. Effect x probability = risk. Consider the options available to reduce the greatest risks. Evaluate, choose and implement.

Success Management:
Similarly procedure, but with the opposite sign. Should be part of project planning.

Some strategic principles for design projects:

- Solve the biggest problem first
- Solve problems by successive approximations
- Stop when the cost of finding a better solution exceeds the savings by having the better solution
- Freeze the design of the individual solutions at appropriate times in the project

Literature

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