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Problems in Problem Analysis

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Abstract: The majority of literature on engineering design methods is focused on the processes of fulfilling the design goals as efficiently as possible. This paper will focus on - and discuss - the processes of determining the design goals: the specifications. The purpose is to draw attention to the inherent problems, dilemmas and possibilities in these processes bearing in mind that the most important decisions in a design project are taken in the beginning of the project.

Keywords: Engineering Design, Problem Solving, Problem Analysis, Efficiency.

Background

The author is teaching engineering design at the department of civil engineering at the Technical University of Denmark (DTU). The course was developed for the B.Sc. program in architectural engineering that started in 2012. The methods taught are based on the methods that were developed at DTU Mechanics in the 1970s, on experience from practice and on literature, first and foremost (Billington 1983 and 1996) and (Vincenty 1990).

Engineering Design

Engineers design things (structures, machines, network and processes) (Billington 1996) that have a function. And they aim for making the function reliable, efficient and economical. The way engineers do this is not very different from skilled craftsmen; they take different parts and put them together to form these "things" or more correct constructions. The origin of the word construction is the latin *construct-* 'heaped together, built', from the verb *construere*, from *con-* 'together' + *struere* 'pile, build'

One difference from craftsmen is that engineers do this on a scientific basis. This does not mean that engineering is just applied science, but that engineering is based on - and formed by - a vast body of engineering knowledge, that has been established using scientific principles (Jevons 1976).

Another difference is that in general engineers do not take the actual physical parts and bring them together. They plan what parts to bring together and how to bring them together. And they do this by taking different parts of the engineering knowledge and bring that together, to form either new knowledge or new versions of existing knowledge. (To make things a little more complicated, engineers may very well make physical constructions: models, prototypes etc. during the design process in order to obtain this knowledge.)

In this way the engineer constructs on two different levels. They make constructions on the practical level and although they don't do it physically they have their focus on the practical level, but doing so they also make constructions on a knowledge level.

In general engineering design involves problem solving processes which span between the two extremes: tame problems and wicked problems.

Tame problems are in short defined as problems where input determines output. This means that a tame problem can be solved by following a logical - often mathematical - procedure. The procedure is based on assumptions that have to be fulfilled; otherwise the result will be unreliable. We may say that solving tame problems just create new versions of existing knowledge, because in principle such a procedure just process information. But this process may produce new knowledge from which decisions can be taken.

Wicked problems were identified by Rittel and Webber (1973). In short they are indeterminate, ill structured and open ended. This means that it is part of the problem to give it structure and organise the processes. Also it means that the result can't be predicted. And often most of the premises for the actual solution have to be established during the process.

Wicked problems are much more complicated to handle than procedures, and as engineers are aiming for efficiency there is a constant desire for pushing design processes towards procedures. Also this paper is an example of this.

Design Projects as Design Objects

Design problems are wicked problems. This is self-evident; if no indeterminacy, everything is determined in advance, and then no design is needed. And since design problems are ill structured, also the design project in itself is a design object. The process

has to be designed - or redesigned - for every new project.

The whole reason for dealing with engineering design processes is that we want the whole process to be intelligent and not just governed by iterations based on trial and error. As found in many optimization problems iteration may just lead to a local optimum. So just as any other engineering design we want also the design process to be reliable, efficient and economical.

To design the processes in engineering design projects we use design methods. This is a variety of structured processes, intellectual concepts and ways of thinking that are based on design experience, design theories, project management methods and knowledge picked up from other scientific fields like philosophy and psychology. These methods are used to organise the intellectual processes in the project.

Unless you happen to be in a specific organisation with specific design objects, it makes no sense to focus on specific design processes. From a scientific point of view it makes sense instead to study general concepts and elements in the design process. From these the designer will be able to develop her own detailed processes.

Example: How to perform interviews in the early phase of the design project when needs are to be identified? A good answer would be: Ask open-ended questions. Use sentences starting with: who, what, where, when, why, how. But this answer is nothing but the general guideline for any conversation, where you want to know the person that you are talking to.

Two important design methods / intellectual concepts are the general problem solving method and the hierarchical tree structure of problems and solutions. Both concepts were described in Stahl and Tjalve (1977).

The General Problem Solving Method

The general problem solving method consists of four steps: 1) Analyse problem, 2) Seek solutions, 3) Examine and modify, 4) Evaluate and choose (figure 1). A fifth step: Implement, can 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.

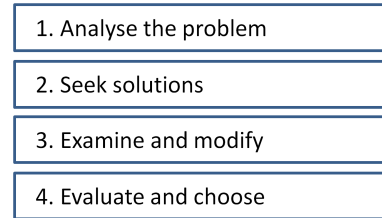


Figure 1. General Problem Solving

In this paper focus will be on the problem analysis, but it is important to notice that the most important reason for going through this process is the desire to uncover the whole space of solutions in order to find the best solutions.

The Tree Structure of Problems and Solutions

The tree structure of problems and solutions show a system structure with different levels and design elements or solutions (figure 2).

Considering a problem on one level we will normally have several solutions to solve that problem. Each of these solutions implies a number of design problems at a lower level. Each of these problems has several solutions and so on. If for some reason no acceptable solution can be found on a certain problem, this map shows that we can go one level up – or two levels up – and choose another branch of solutions.

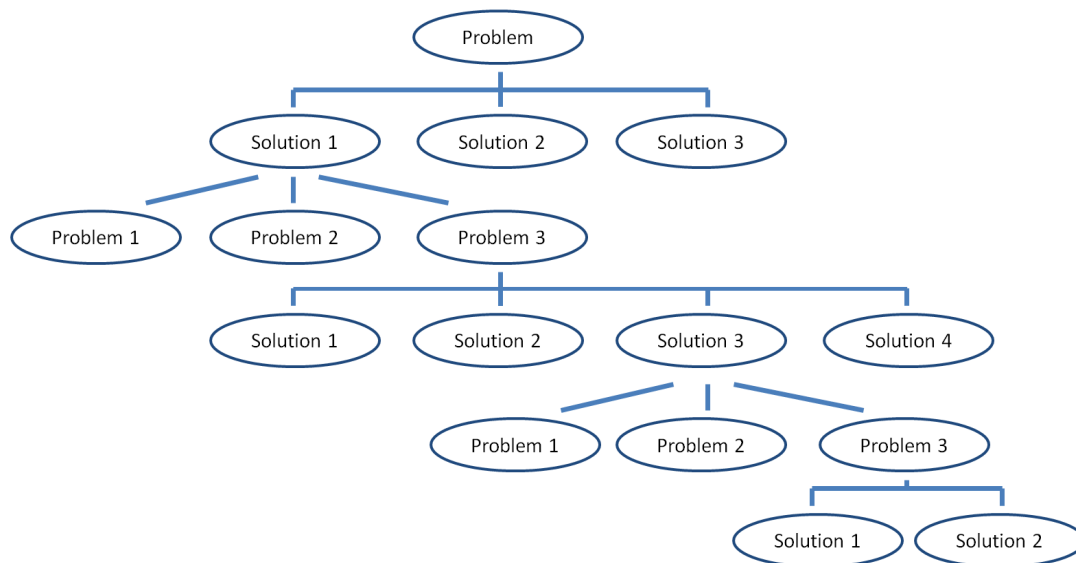


Figure 2. Tree Structure of Problems and Solutions

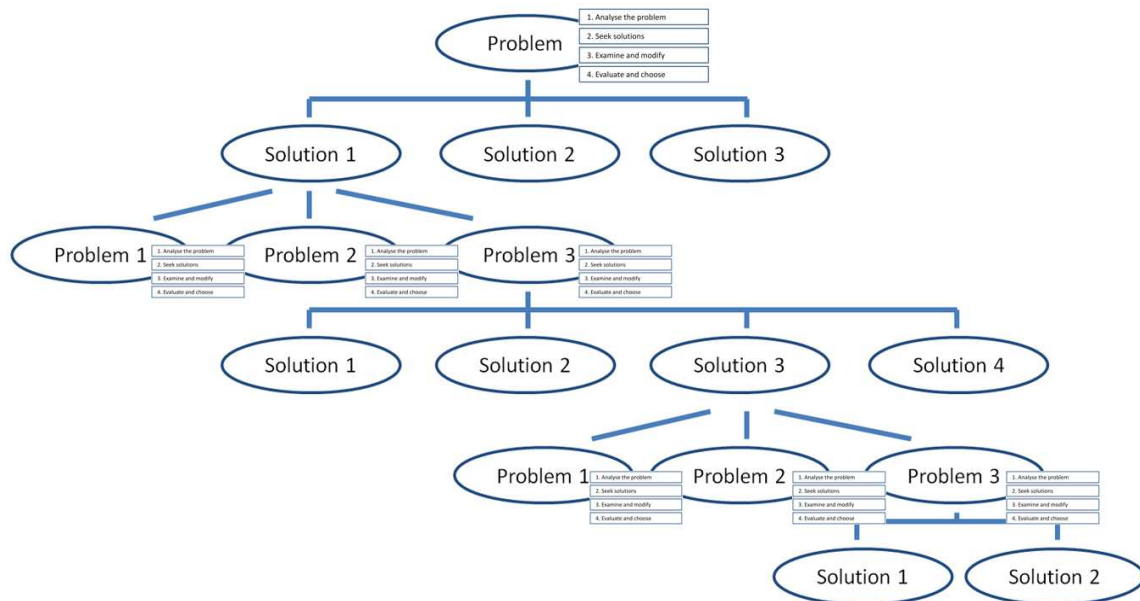


Figure 3. The Problem Analysis Method is Applied for Each Problem Considered

In the design process these two intellectual concepts are combined so that for each problem, beginning at the top, the general problem solving method is applied.

The first step in the general problem solving is the problem analysis. The extent of the problem analysis depends on the type of problem and on how precise the problem is described beforehand. But it is obvious that the problem analysis is decisive for the quality and efficiency of the solution.

First Problem in the Problem Analysis

The problem analysis consists of:

1. Collection of information
2. Analysis of needs
3. Problem formulation
4. Specifications (functional requirements)

The second task in the problem analysis is the analysis of needs. This task can be divided into three subtasks:

- a) Analysis and identification of users and stakeholders
- b) Analysis of activities
- c) Formulation of needs

The analysis and identification of users and stakeholders is basically an analysis of where to seek information. It consists of answering the following questions:

- Which users and stakeholders will be affected of – or could have interest in – how this problem is solved?
- Who are the most important?
 - Who has most influence?
 - Who has – directly or indirectly – the most interesting information’s on this problem?

Stakeholders may include construction, repair and cleaning personnel.

Information on activities can be obtained in a number of ways. In the literature on product design interviews, questionnaires and focus groups are dominant (Ulrich and Eppinger 2008; Otto and Wood 2001). But if we want to have the opportunity to identify needs that people are not aware of, and hence to invent new functions/products, we must focus on the user and stakeholder activities. Then we must analyse the activities and derive needs from these. This is exactly what is done by a new type of consultant firms. They are using anthropologists and sociologists to make observations and interpretations of customer - or future customer - activities and to report these (Bernsen 2014).

The analysis of activities consists of at least one of the following tasks:

- Interviews, questionnaires or focus groups meetings
- Observation of activities
- Imagination of activities (perhaps by an expert)
 - From experience
 - From an articulated vision or ideal

Interviews, questionnaires, focus groups meetings and observations are useful only if the situation and circumstances are somehow similar to the solution from which the considered problem arises. If the solution is new we cannot use observations and then we must use imagination. This is discussed in next section.

When the information is collected the last subtask is to formulate the needs. This includes:

- Analysis and interpretation of the information
- Formulation of needs
- Prioritising of needs

How to Control the Quality?

Now let the scientific scheme of the experiment be applied to this process. This scheme consists of three parts taking place one after each other:

- Observation
- Hypothesis (on how different entities are connected and influence each other)
- Experiment / Test of hypothesis

In this case the “hypothesis” is the list of needs. In a design project it is hard, time consuming and costly, to make experiments and test needs. This is especially the case in the beginning of the project. It will for example often require a number of prototypes, but prototypes will not be ready until much later in the project.

In civil and architectural engineering often just a single object is designed and in that case a complete test is impossible until the structure is built. And even then often only time can show if the needs was well chosen. This means that the testing has to be done in other ways.

Off course interviews, questionnaires, focus group meetings can be made once more, but now with focus on the clarification of some specific questions. And later in the project testing on prototypes will become an option. But in the beginning of the project when the consequences of mistakes are most critical the quality has to be ensured in other ways.

The inherent dilemma is that the choice of observations to report or questions to ask, the interpretations of the reported activities or answers as well as the formulation of needs, is based on the viewpoints and intensions of the observer and the interpreter. This means that the formulation of needs is completely dependent on the focus and mindset of the persons involved whether they are aware of this or not. The voice of the costumer may just be the echo of our own voices.

This leaves us with two general methods for quality control of specifications: critical thinking and reviews.

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 derived from the premises or could other conclusions be drawn just as well?

Critical thinking can actually be used on each part of the problem analysis process, but also on the whole problem analysis process. Critical thinking is in fact a structured method that can be used in every part of the design process.

Review

A review could in this context consist of considering the following questions:

- Do 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 nonexistent problem – or to a problem of less importance?
- Do the solutions found and the process leading to these indicate that the original problem was not completely understood / somehow misunderstood, so that the specifications - or some of them - have to be reconsidered?
- Do the large number of technical problems that we have to solve at this stage of the process indicate that we have not fully understood the concepts and solutions that we have chosen at earlier stages?

Second Problem in the Problem Analysis

In order to describe the second problem we first have to examine the consequences of the independence axiom for the problem analysis. The independence axiom was formulated by Suh (1990). It means that ideally each functional requirement is fulfilled by just one single design element. If two design elements fulfil the same two requirements they become interdependent and we don't want this because interdependence makes the actual design more complicated and vulnerable than it would be if the requirements were fulfilled independently. (Actually it is caused by anticipation a solution on a lower level than the actual level). If one design element fulfils two requirements we call it integration. If we need two design elements to fulfil one requirement then either we can do without one of the elements or the functional requirement is in reality demanding two functions, and then has to be reformulated into two requirements.

For the process of determining requirements, the independence axiom has the effect that:

- We may very well have several observations leading to just one need, but a single observation cannot lead to several needs.
- We can have one need leading to one functional requirement, but we cannot have two or more needs leading to just one requirement, because the needs should be the basic elements from which requirements are derived.
- In the same way we cannot have a single need leading to two requirements. Because if so we would anticipate a solution on how this need is met.

Considering the tree structure of problems and solutions (figure 2) and translating design element to design solution, it is seen that the tree structure fulfils the independence axiom.

Furthermore it is seen that needs and requirements have to fit the level of the actual considered problem. This means that the solutions on the levels above have to be determined before the needs and requirements at the considered level can be specified.

It also means that you cannot set up a requirement if you by doing so, assume a specific solution on a lower level. In that case you would violate what Suh (1990) calls solution neutrality.

Example: If a need for hot water has been identified, we cannot conclude that we have two functional requirements: 1) Water 2) A heating device. Because by doing so we would presuppose a two step solution and then ignore all possible one step solutions, like for example water from a hot spring.

The problem is that by anticipating a solution, other solutions are automatically eliminated. And since the best solutions could be among these, we reduce the efficiency of the process and the possibility of success.

In practice this means that we cannot specify anything but very general needs in the beginning of a project without anticipating specific solutions to fulfil the considered needs. Only when the particular solutions are defined we can obtain more specific needs.

Example: If a need for fast transportation of human beings between cities is identified, it makes no sense to specify more detailed needs or functional requirements until a mean is specified. Possible means could be: walking, horse riding, train, bus, car, bicycle, airplane, etc. A more detailed need could be a need to sit down when the transportation is taking place.

Since it is not practical to make observations, interviews etc. at each level of problem solving, the information's collected during the project must be seen as a reservoir of knowledge from which needs and requirements can be extracted.

Often most of the information on the user activities and needs is collected in the beginning of the project. This means that the concept of this information as a reservoir makes the demands for this collection process; it has to provide a fund of information for identifying and formulation of needs at all levels in the whole design process.

Third Problem in the Problem Analysis

If the considered type of solution already exists we can make observations. But if we invent a new solution fulfilling the identified need, we cannot use observations to generate the specific needs and requirements, but have to use our imagination, experience and general knowledge of human behaviour.

This indirectly defines three types of engineering design projects:

1. Improvement of an existing solution
2. Invention of a new solution to an existing problem
3. A new solution to a new problem

Improvement of existing solution may involve invention of a new solution to a problem on a lower level. This solution may just be new in this context, but known in other contexts. In that case observation from these may provide useful information.

Invention of a new solution to an existing problem may be based on new observations or new interpretations of activities, but also on new technical ideas or possibilities.

A new solution to a new problem may very well be based on a vision. Ideally it is a vision for a better life. Since a vision often describes a new set of activities it may be a good basis for formulation of needs.

Conclusion

In practice it is hard, time consuming and costly, to make experiments to test if the specifications comply with the stakeholders needs. In civil and architectural engineering it is often impossible. This leaves us with two methods for quality control of specifications: critical thinking and reviews. The hierarchical structure of the complete solution implies that needs and requirements cannot be specified on the level of the actual considered problem until the solutions on the levels above have been determined. The information collected during the project must therefore be seen as a reservoir of knowledge from which needs and requirements can be extracted for each specific problem. Finally, if we invent a new solution that fulfills the identified general needs, we cannot use observations to generate the specific needs and requirements, but have to use our imagination, experience and general knowledge of human behaviour.

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