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Enhancing buildings with engineering design methods

Sebastian Schneider, Elmar Erdell, Udo Lindemann

Technical University of Munich, Department for Product Development
Sebastian.Schneider@pe.mw.tum.de

Abstract
A view in statistics about defects in civil engineering shows that in industry high costs arise to repair defects at buildings. The reason for these defects can be found mostly in the planning of the building: Over 50% of the faults can be ascribed on that. Engineering design methods help to enhance the quality of products and beside improve the product development processes. Nevertheless they are implemented only rarely in civil engineering yet. Hence transferring methods from engineering design to civil engineering design should improve the design of buildings. In a research project funded by BayForrest the transfer and implementation of engineering design methods to civil engineering was investigated. To better understand why and how methods in civil engineering should be adapted similarities and differences of civil and mechanical engineering will be described. For the implementation of methods approaches were established and are presented in this paper. The results should be documented at two complete exemplary development processes: The planning of a semidetached house and the design of a façade element.

Keywords: Method implementation, civil engineering, quality faults.

Introduction
A huge part of the whole waste can be assigned to civil engineering (see Figure 1). This construction waste results mostly out of reparations from defects in the construction phase of the building and the tear-off of old buildings.

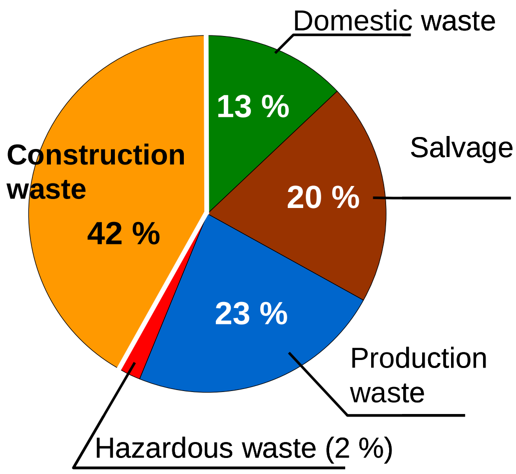

Figure 1Composition of waste [14]

The third report over damages at buildings of the Federal Government of Germany [2] numbers the avoidable building damages at new civil works (Building construction) for the year 1992 of 1,74 billion €. Here damages through mistakes during the planning, carrying out and material production are registered. With reference to the building construction volume at new buildings from the same year in height of 76,13 billion € [2] a loss ratio of approximately 2,3 % results from that. The costs for avoidable building damages are for a building approximately on the average 9.700 € with reference to the buildings finished in the year 1992 (179.151 buildings) [2]. The part of which planning faults are at least a part problem of the damages becomes in this report only for the damages with deficient repair and modernization measures (Volumes approximately 1,69 billion € for the year 1992; [2]) indicated. According to several studies [5, 8] the part of the planning errors conducts approximately 56 %. The exact number and the partitioning can be seen in Figure 2.

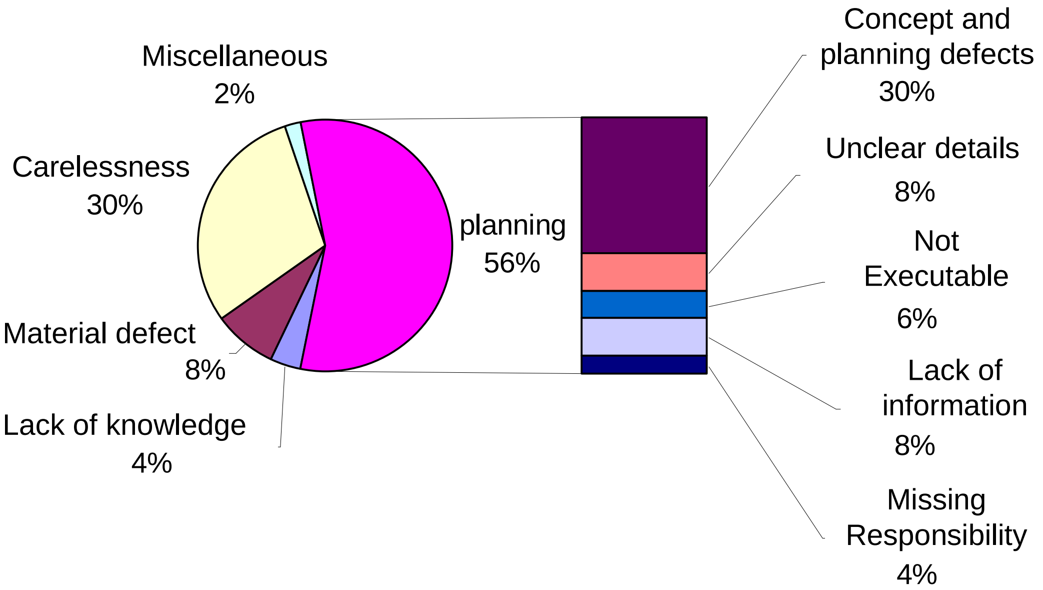

Figure 2. Cause of defects (after [5])

The numbers show that there is considerable potential for saving expenses in the field of the avoidable building damages. A reduction of the building damages means a reduction of the pending waste. With the implementation of quality enhancing methods in the planning process planning errors should be reduced. At the moment methods are only implemented for project management [6].

Overview on the research project

The research project "Method transfer to civil engineering" was part of a research network called "Stock flow management construction" which was funded by BayForrest. It consisted of ten single projects which can be assigned to one of the four topics (see also Figure 3):

- Materials
- Models
- Old buildings, actual stock
- Evaluation concept

At one demonstration project - the refurbishment of the "Alter Hof", an old building in the downtown of Munich – all single projects should evaluate their theoretical results. The results were concluded in a guide "Sustainable construction" which is available in the internet (http://www.sfm-bauwerke.de).

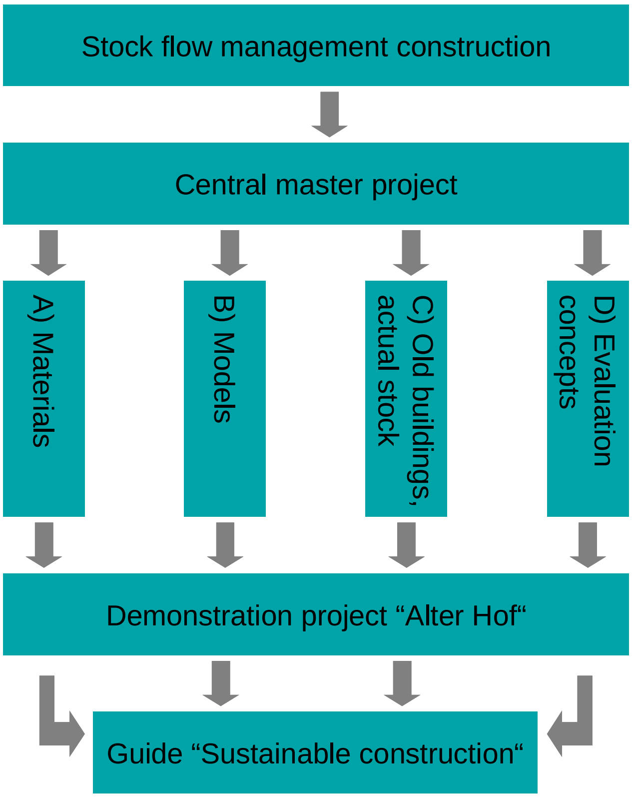

Figure 3. Overview of the research network

Within the project “Method transfer to civil engineering” further on the following tasks were carried out:

- Implementation of methods at an industry partner
- a student product development seminar
- observation of an architectural challenge
- interviews with architects and prefabricated house suppliers

The main parts were conducted at the industry partner, a mid-size company which develops and builds up one- and multi family-houses, business houses and octaeders. Two projects, the development of a semidetached house and the student product development seminar of a façade element – both conducted in collaboration with the company – will be described in detail later on to visualize concrete results. Beside an extract of a method implementation will be described to visualize theoretical insights at a practical example.

Similarities and differences of civil and mechanical engineering

To better understand why and how methods and processes have to be adapted similarities and differences of civil and mechanical engineering should be presented in this section, most of them are results from the practical work of the research project.

When considering the method use the general problem solving / working steps as well as the general procedures (like the Munich Procedural Model [7]) are the same, only the product is different. In mechanical engineering products are often based on moving parts and hence physical effects are decisive. In contrast in civil engineering, as buildings are static, building materials and principals are from great importance. Hence several methods which focus especially on these physical effects (like parts of TRIZ or the list of physical effects) are not usable in civil engineering. For further methods the knowledge of civil engineering is necessary to be successful (i.e. during the search for solutions). Similar are connection techniques and principals (i.e. screws, catch outs) which can be looked up in design catalogues.

Other similarities and differences concern the products/buildings and the general industrial processes. In mechanical engineering the products are developed in different numbers, starting with only a few (i.e. special purpose machine like printing machines) over some dozen (i.e. locomotives, airplanes) up to some (ten) thousand exemplars (i.e. cars, mobile phones). In contrast in civil engineering the lot size in civil engineering is nearly one, only a few buildings are to mass-produce. This means that for each building a new development process is conducted. The steps in this process as well as the amount of money the architect gets for each step and on the whole are fix prescribed [8], which is quite different to mechanical engineering. Here the processes are free customizable and depend mostly on the product (i.e. complexity, lot size, costs, life duration …) and the company. Beside there are no guidelines regarding the development costs.

Also the life duration differs quite a lot: while buildings exist usually some decades (at least 50 years or longer), mechanical engineering products are usually used shorter: the times vary from some months/a few years (i.e. mobile phones, household appliances) over about ten years (i.e. cars) up to about 30 years (i.e. locomotives, air planes, ships). Depending on that the technology change differs a lot. In general the differences in the processes resulting from the differences of mechanical and civil engineering can be viewed at two examples:

For a one-family house (costs about 200.000 €) around 360 hours of a civil engineer and 300 hours of an architectural planners are necessary, the fee (after HOAI [8]) is 21.587 €. In contrast for a high-pressure cleaner the development time for a adaptation design is around 1,5 years with in average two engineers what is equal to about 6.600 hours.

An approach for method transfer to civil engineering

The approach can be regarded on different levels of abstraction:

- The method level
- The implementation process level within the company

They will be described in detail in the order above.

For the selection, adaptation and application of methods in mechanical engineering Lindemann [7] defined the following model (see Figure 4). When transferring methods from engineering design to civil engineering several further points depending on the differences in the chapter before have to be taken into account. They will be described according to the several steps of the model and visualized at an example.

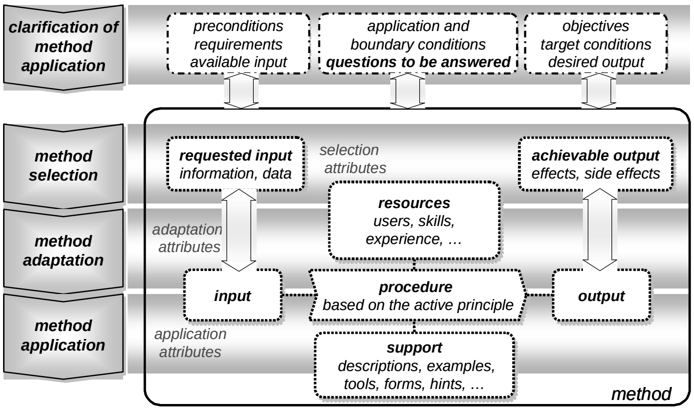

Figure 4. Munich Method Model [7]

For selecting the appropriate method the problem which should be solved or the situation which should be improved must be described in an abstract domain independent way. As mentioned above the solution/working steps are the same, nevertheless processes, terms, definitions, problems, and descriptions differ between both disciplines. Hence the formulation of the problem or situation happens on an abstract domain independent level. There are several ways for describing the situation/problem in which the method should be used. Methods can be classified and hence selected according to these different attributes. These selection attributes correspond to the abstract formulation of the situation/problem. Several of these attributes are known from method applications in engineering design [12, 13, 14]. Some, like elementary methods (like compare, vary, document [16]) or DFX (i.e. Design for Environment), are domain independent, as they describe general attributes of methods. Other attributes must be described for the specific discipline (i.e. the stage in the product development process). As the product development processes in civil and mechanical engineering design differ they have been compared. A scheme how to translate the different steps from civil to mechanical engineering is shown in Figure 5.

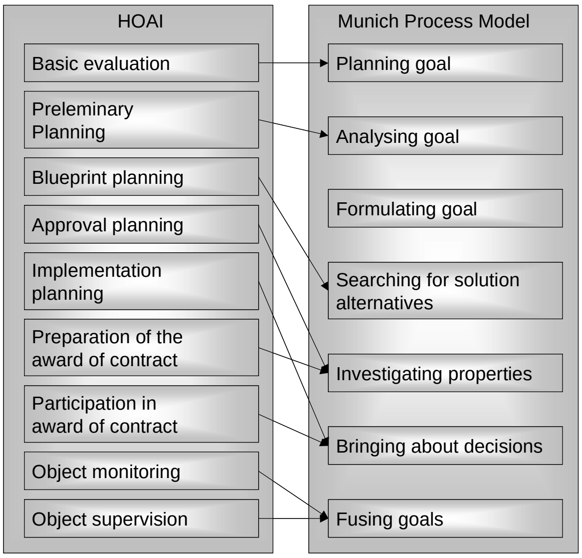

Figure 5. Comparison of the different development processes [8, 7]

For the description of development processes several approaches can be found in the relevant literature. In this comparison the two following models were chosen out of huge variety: the HOAI (Fee Structure for Architects and Engineers, [8]) for civil engineering and the Munich Process Model for engineering design [7]. In the HOAI the basic steps during the development of a building are described. All steps have to be carried out as noted in the chapter before. Here it must be considered that different disciplines (civil engineers, architects) in general have to work together. Whereas in mechanical engineering there is only one discipline participated. As it can be seen in Figure 5 some steps are clear attributable (analyzing goal, searching for solution alternatives), others intersect (investigating properties, bringing about decisions, fusing goals) and some exist only in one discipline (formulating goal). The processes are only models which can differ in practice. Hence this is only a model for selecting the right model for the right situation/problem. It should be noted that the Munich Process Model allows a flexible adaptation to the specific design problem. In some practical examples it was observed that this is also appropriate for civil engineers. Beside templates have to be prepared and adapted to the other discipline and the specific problem. Here especially terms have to be checked and implemented.

For the method adaptation the usual boundary conditions (time, number of persons, distribution of persons, tools) have to be considered. In a method application in civil engineering domain-specific terms have to be changed or adapted to the new discipline. Some terms may have different meanings in different disciplines or different terms are used for the same circumstance. Also different disciplines link different problems with one term for example i.e. when civil engineers speak of a façade wall it is clear that it should contain heat insulation, awning, and the possibility to mount something inside building. Also special elements which exist only in one discipline have to be added (i.e. laws, norms). Here an intensive literature research within the other discipline might be helpful to avoid forgetting special issues. Beside domain-specific checklists are helpful.

At the beginning an extensive introduction is helpful to point out the sense and the aim of the method. The civil engineers will only accept the methods if they are convinced of the sense and the benefit. Examples can be helpful to demonstrate the benefit of the method. The procedure of the method and the several working steps should be explained. Hints which could enhance the result or problem that could happen should be mentioned and discussed. Templates for the support of the method application need to be introduced and explained. During the application it is necessary to consider the terminologies. Many problems result from different understandings of terms. To avoid misunderstandings it is meaningful to clarify difficult circumstances with all involved participants.

Implementation process of a method

The implementation of a method is further more than just the usage of the method. The exact goal should be defined, boundary conditions have to be considered and the procedure should be planned. In mechanical engineering there are different approaches [12, 13] which were adapted for this project. The whole process can be viewed in Figure 6 and will be presented at one exemplary implementation.

First of all the project should be prepared. Therefore the strength and the optimisation potential is identified. The involved employees are sensitised, a project team is formed and the employees are trained. The next step is the clarification of the problem. Therefore information should be collected and the problem should be analysed and structured. In this case the problems at the actual building were analysed and the main problems elaborated. Then the goal and the goal values should be declared. Here the exact values for the reduction of faults and costs were defined. Afterwards the selection and adaptation of an adequate method is carried out. Therefore methods like interviews with experts and inquiries as well as creativity methods could be helpful. It was foreseeable –according to the information of the owner of the company- that experts like architects and representatives of building material suppliers have big know-how and could generate enough solutions. Hence creativity methods were not implemented. To introduce a method pilot projects or special method implementation with coaches should be carried out. Interviews with workmen are helpful to analyse the problem during the mounting of the building. Some interviews were conducted successful. After that the owner of the company decided to regularly carry out interviews to systematically collect and avoid faults. At the end the goal should be controlled and method implementation continually improved. In the vase of the interviews after the successful implementation they were anchored in the planning process. Beside checklists for the interviews were created.

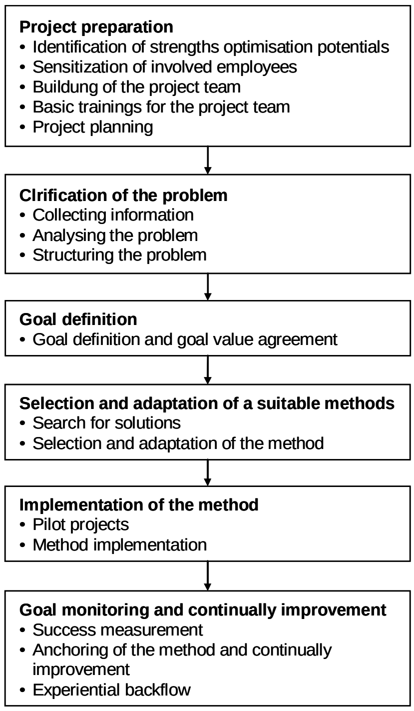

Figure 6. Implementation process of a method [11]

Examples

To show all details which have to be considered at the method transfer two complete product development projects, both conducted within the research project, will be described:

- Planning of a semidetached house
- Removable façade element

Planning of a semidetached house

In Figure 7 the whole development process, divided into the different steps of the Munich Process Model [7]. The methods are assigned to the different steps of the Munich Process Model [7]. To better visualize the interaction the methods which influence the costs of the building are suitable signed in Figure 9.

To plan the goal a project plan was created in the form of a mind map. Interviews with experts (the owner of the company) were carried out to define the strategic orientation of the project. For analyzing the goal existing projects were analyzed, parallel interviews were conducted, both with the aim to derive weaknesses. Beside all requirements were collected and documented in a list of requirements, which was afterwards basis for a cost-benefit-analysis. A pareto-analysis and interviews with experts helped to structure the target. Out of these two methods the main development goals were derived: reducing the costs and number defects at the building. For the search for solution interviews with experts – architects, representatives of building material suppliers and workmen- completes by an extensive search for further solutions were conducted. The collected solutions were documented in a morphological chart.

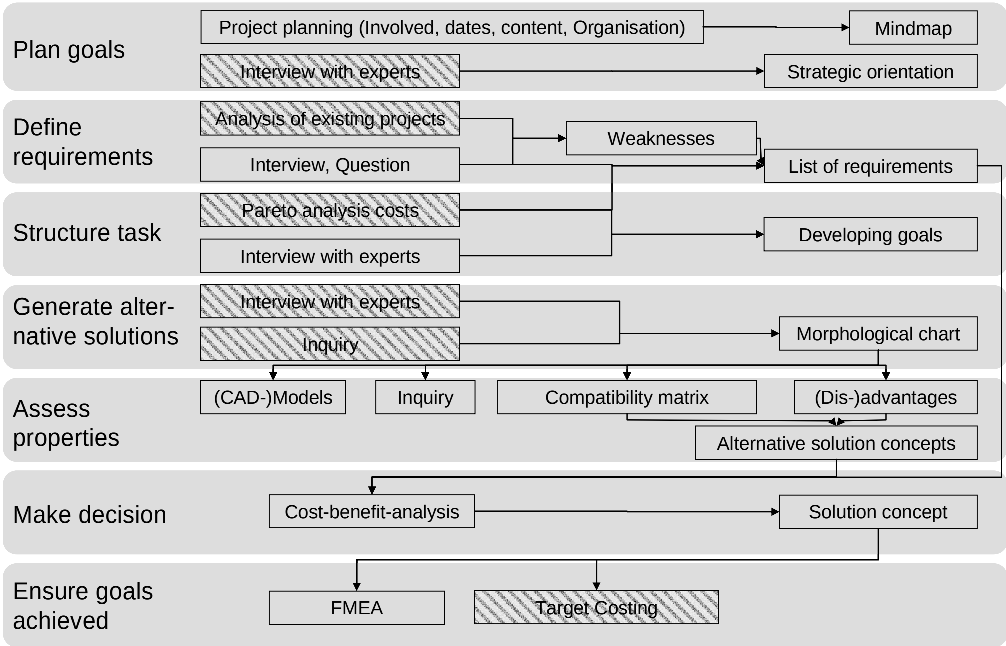

Figure 7. Interaction of the methods

To assess the properties four methods were implemented: With real and CAD-models the functionality of different constructions of the frame and the walls was tested. Inquiries were conducted to get concrete values for the different solutions. In a compatibility matrix of different solutions concerning i.e. the frame and the shutter was investigated. An advantage/disadvantage comparison was basis for a pre-selection of some solutions. Out of this some concept alternatives were derived which were afterwards evaluated with a cost-benefit-analysis. A FMEA and Target Costing were finally used to ensure the goal of the solution concept.

Removable façade element

In a product development seminar a group of four students developed a façade element for a removable building. With several methods (i.e. mind maps, list of requirements, 6-3-5, brainstorming, cost-benefit-analysis …) and also according the MPM they developed a concept. In this case it was obvious that expert knowledge is necessary: the students which were all mechanical engineers would have been lost especially during the search for solutions without the help of a civil engineer. It was interesting that design catalogues from mechanical engineering were very helpful to find solutions for the fastening of the façade element. The resulting concept can be seen in Figure 8: a wooden sandwich element with a fill (for the isolation). Outside a rubber padding is mounted as protection and wall paper. The elements are mounted on the building with a L-profile and catch outs of plastics.

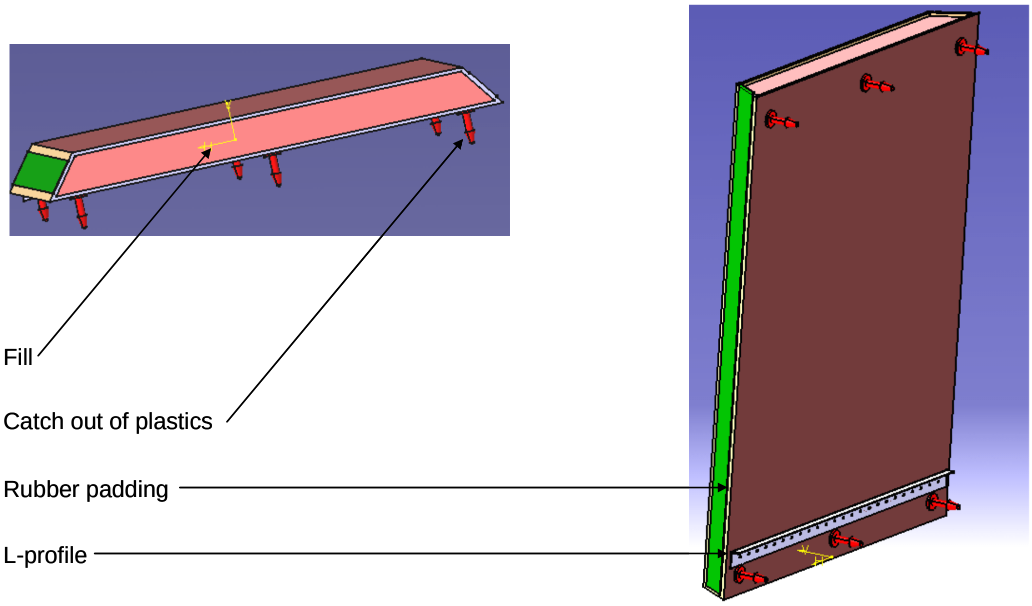

Figure 8. Design of the new façade element

Conclusion

Despite a huge amount of quality faults methods are only used rarely in civil engineering. In a research project methods from mechanical engineering were now successful implemented in civil engineering. The implementation was conducted together with a company to validate the theoretical contributions, all within a research network. For the implementation and transfer of methods in civil engineering as well as for the industrial implementation of methods models were elaborated and validated. At the beginning a comparison of civil and mechanical engineering was carried out to derive similarities and differences. To visualize the results two exemplary product development projects were presented.

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