USING CONSTRUCTION DEFICIENCY REPORTS AND PRODUCT MODELS AS SYSTEMATIC FEEDBACK TO AVOID DESIGN ERRORS CAUSED BY LACK OF KNOWLEDGE

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ABSTRACT

Design errors cause a big part of the defects occurring in building production and maintenance. Earlier research have shown that the most common cause for design errors is lack of knowledge. Product-model based CAD-systems are increasingly used in structural engineering practice and it is well known that these systems reduce the design errors, mostly through better visualization and collision checks. The design errors caused by lack of knowledge are not prevented using product-model based CAD-systems as we do today. This paper describes a case study of design errors where the structural engineer is involved. The aim of the study was to find new ways to prevent design errors using the product-model based technique. The study supports earlier findings that the use of product-model based CAD-systems have a great potential in preventing design errors, especially co-ordination errors. The study also shows that many of the design errors caused by lack of knowledge could be prevented in future projects if the design errors from earlier projects were systematically documented and made available to the structural engineer in the design process. This could prevent as many design errors as is prevented by using product-model based CAD-systems today. The study shows that about 90% of the design errors that could be prevented in this way were situated where two or more elements meet. It was also found in the study that the information needed about the design errors could be retrieved from construction deficiency reports. Based on these findings it is argued that design errors, caused by lack of knowledge, can be prevented in future projects by making the information from the construction deficiency reports available and retrievable for the structural engineer by indexing them using information about the elements meeting where the design error occurred.

Keywords: Structural Engineering, Design Errors, Product-models, Feedback, Knowledge reuse

1. INTRODUCTION

1.1 Background

The cost of defects occurring during production is stated to be 2-9% of the cost of production (Josephson and Hammarlund 1999). The design is the origin of about 26% of the cost of the defects. From this it can be concluded that it is of great importance to minimize design errors.

Josephson and Hammarlund (1999) shows that the design errors were mainly caused by lack of knowledge (44%) and lack of motivation (35%). They also state that most of the “motivation errors” are due to forgetfulness and carelessness.

1.2 Product model based software (BIM-softwares) and motivation errors

After more than a decade of research into product modeling, where several research efforts have demonstrated the applicability and usefulness of the technique (e.g. CIMSTEEL (Crowley and Watson 1997), COMBINE (Augenbroe 1995)), product models or building information models (BIM) are becoming more and more common in engineering practice. A number of CAD-systems use this technique (e.g. Tekla's Tekla Structure, Autodesk's ADT and Revit). These systems give a number of advantages. Concerning the ability to avoid design errors two means are often mentioned:

- Collision check
- Better visualization.

By performing a collision check a number of errors can be avoided. Using a product-model based software facilitates finding errors by better visualization opportunities. E. g. the partition wall in figure 1 should contain HVAC-installations. These installations have to be transferred trough the hollow core to the lower floor. Due to the placement of the partition wall a hole through the hollow core would result in cutting the strand and in turn reduce the resistance of the hollow core. In Case study A (described below) this problem was found on site when the wall had been half built and the HVAC-installations should be put in place. It was decided necessary to move the wall, causing a great amount of extra work and cost. Using a product-model based software, a collision check should have revealed where the HVAC -installations had to be transferred trough the hollow core. The visualization facility would then help the structural engineer to identify the problem, and the wall could be moved in the design phase, causing a minimum of extra cost.

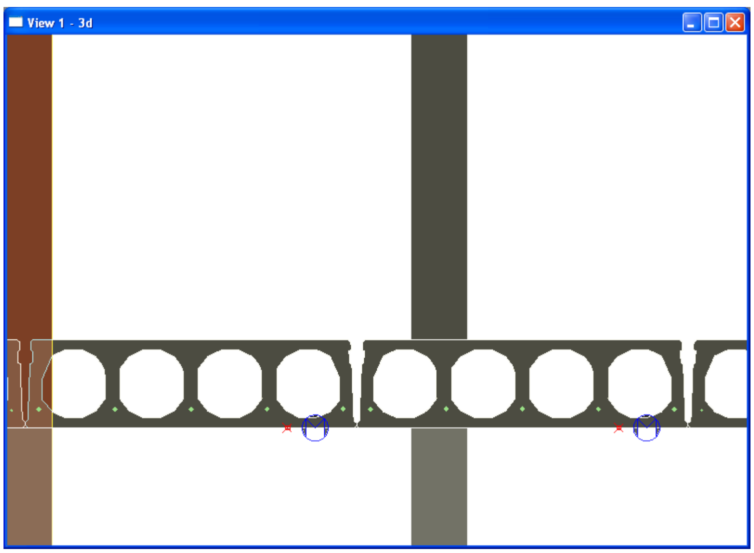

Figure 1: A faulty placement of a partition wall could be avoided if product-model based software was used, thanks to the better visualization possibilities.

By using these means, many design errors can be found and avoided in the design process. Using the categorization of design errors by Josephson and Hammarlund (1999), most design errors that can be avoided in this way are in the category "motivation errors". That is they are caused by forgetfulness and/or carelessness.

1.3 Lack of knowledge and feedback

Lack of knowledge was the other, and the most common, cause for design errors, shown by Josephson and Hammarlund (1999). To reduce design errors caused by lack of knowledge, learning is needed. Argyris and Schön (1978) state that learning is triggered by a detection or correction of errors, and Nevis et al. (1995) conclude that performance gaps are main entrances to continuous learning. From this it can be stated that it is important that information concerning design errors is transferred and made available for the designer. That is, the need for feedback from production to engineering design is of great importance (Roddis and Bocox, 1997).

2. AIM, OBJECTIVE AND RESEARCH QUESTIONS

The **aim** for this study was to study and investigate the benefits of product model based CAD-systems in preventing design errors, and to find new ways to prevent design errors caused by lack of knowledge using the product-model based technique.

As described above, feedback from the production is of most importance to prevent design errors caused by lack of knowledge Bartezzaghi et al., 1997). For this reason the **objective** for the study became to find ways to prevent design errors by creating feedback about defects from the production to the structural engineer by using product-model-based software.

The following central research questions were addressed:

1. How many of the design errors can be attributed to structural engineering (SE-errors)?
2. How many of these SE-errors are co-ordination errors, involving other participants?
3. How many of the SE-errors can be avoided by using product-model-based CAD-systems?
4. How many of the SE-errors can be avoided in the next project if feedback from production was made available to the structural engineer?
5. How can the information needed for feedback (feedback information) be captured?
6. How can the feedback information be made available to the structural engineer using product-model-based CAD-systems?

3. METHOD

To answer these questions two research methods were used:

- Case studies
- Prototyping

Two case studies were performed, where design errors in two projects were studied. The objective for this part was to answer the five first questions. Based on these findings, a hypothesis was formulated to answer the last question. This hypothesis was tested and supported using prototyping.

4. CASE STUDY A: THE FIFTH WING, JÖNKÖPING UNIVERSITY

4.1 Case description

The fifth wing is an enlargement of one of the university buildings at Jönköping University, Sweden. The building is a five story split level house with a total area of 3000m2, containing offices and lecture halls (see figure 2). It was built during 2003 and 2004. The production cost was about 55 million SEK or 5.9 million Euro. The type of contract used was general contract. Both the construction manager and the structural engineer agreed that this project went well and there were no major problems in the project.

Figure 2: The fifth wing project at Jönköping University: a prefabricated concrete building containing offices and lecture halls.

The structure of the building is prefabricated concrete . The structural engineers used ordinary 2D technique (AutoCAD) in the design of the building.

4.2 Case study description

Data was gathered using mainly three sources: drawings, construction deficiency reports, and informal interviews. The **drawings** were studied to get an understanding of the project and to get a geometrical description and the material of the structure. The type of contract, general contract, made **construction deficiency reports** available. By studying the construction deficiency reports, the design errors causing some of them could be identified. A number of **informal interviews** with the construction manager were also conducted. The construction manager was the author of most of the construction deficiency reports The purpose of these interviews was to gain a better understanding of some of the deficiencies. The structural engineer was also interviewed. Both the construction manager and the structural engineer were satisfied with the design process and the outcome of this process.

To be able to investigate the product-model based technique, the building was modeled using Tekla-structures (www.tekla.com).

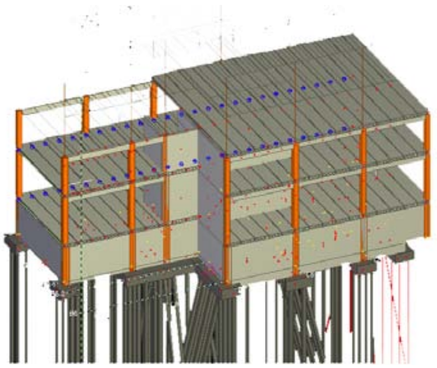

Figure 3: A part of the model created using Tekla (left) , the structure as built (right). The model is some what simplified, e.g. the windows were not modeled.

4.3 Construction deficiencies categorization

Based on the information gathered, the next step performed was to categorize the construction deficiencies in the following categories:

- Design errors (Yes/No)
- Participants involved
- Could be avoided using product-model based CAD-system (Yes/No)
- Could be avoided in the next project using feedback. (Yes/No)
- Situated were two or more element meets (Yes/No)

Not all construction deficiencies are design errors. Some of them are just changes made. This made it necessary to categorize the construction deficiencies so that the subcategory of **design errors** could be identified.

The design errors were in turn categorized according to which **participants** that were **involved** in the design error. The design errors where the structural engineer was involved (**SE-errors**) were investigated further. Each SE-error was investigated to see if it **could have been avoided if a product-model based CAD-system had been used.**

In the same way it was investigated if the SE-errors **could be avoided in the next project, using feedback.** That is, if it could be avoided if the information contained in the construction deficiencies was known by, or were made available to, the structural engineers.

It was noticed early in the case study that most of the defects reported in the construction deficiency reports were situated where two or more elements met. To confirm this finding it was investigated for each defect if it was **situated were two or more element met**.

4.4 Result from case study A

In total, 185 construction deficiency reports were studied and categorized.
57% (106) of these construction deficiencies were categorized as design errors while 43% were caused by other reasons. The involvement of the different participants in these design errors was:

- Architect 19%
- Structural engineer 30%
- HVAC engineer 68%
- Electrical engineer 37%

The HVAC engineer was the designer involved in most of the design errors, 68% (72).

The structural engineer was involved in 30% (32) of the design errors. We will focus on these design errors and they are from now on called **SE-errors**. 75% (24) of the 32 SE-errors also involved other participants.

47% (15) of the SE-errors were categorized as “Could be avoided using product-model based CAD-system” That is, they could probably have been avoided if a product-model based CAD-system had been used in the design process. 8 of these 15 errors also involved the HVAC engineer.

38% (12) of the SE-errors were categorized in the category “Could be avoided in the next project using feedback”.

If the two techniques, both product-model based CAD-system and feedback, were successfully used, 63% (20) of the SE-errors could have been avoided.

82% (26) of the SE-errors were situated were two or more element met**.** Of the 12 SE-errors that could have been avoided in the next project using feedback, as many as 92% (11) were situated where two or more element met.

5. CASE STUDY B: HUSKVARNA CARE CENTRE

5.1 Case description

Huskvarna Care Centre is a six story building with a total area of $10000m^3$. It was built during 2005, with a total cost of about 127 million SEK (13.65 million Euros). The contract type used in this project was all-in one contract. This project was more problematic than case A. The construction manager was rather critical to the structural engineering because much of the information needed was lacking at first, which caused a lot of drawing revisions an extra work for the construction manager.

Figure 4: Huskvarna Care Centre

5.2 Case study description

Data was gathered using mainly three sources. The **drawings** were studied to get an understanding of the project and to get a geometrical description and the material of the structure. The contract type made it impossible to gather design errors using construction deficiency reports. Instead the **drawing revisions** performed by the structural engineer were studied. As in case study A, a number of **informal interviews** were conducted with the construction manager. The purpose of these interviews was mostly to gain a better understanding of some of the drawing revisions. The drawing revisions were categorized using the same categories as in case study A.

5.3 Result from case study B

To identify the defects where the structural engineer was involved (SE-errors), the drawing revisions of the structural engineering drawings were studied. For each of the revisions that could be of interest more information was gathered by interviewing the construction manager. The outcome of this procedure was 57 design errors where the structural engineer had been involved (SE-errors).

Only 11% (6) of the SE-errors were categorized in the category “Could be avoided using product-model based CAD-system”.The explanation for the low figure of this category is the large number of SE-error caused by lack of information in this project, as described above.

44% (25) of the SE-errors were categorized in the category “Could be avoided in the next project using feedback”. If the two techniques, both product-model based CAD-system and feedback, had been successfully used, the same 44% (25) of the SE-errors could have been avoided.

65% (37) of the SE-errors were situated where two or more element met**.** Of the 25 SE-errors that could have been avoided in the next project using feedback, as many as 88% (22) were situated where two or more elements met.

It should be mentioned here that the result of this case study is highly influenced by the viewpoint of the construction manager. A parallel study is being conducted where focus will be on the structural engineer and his viewpoint.

6. ANALYSIS

Table 1 summarizes the results from the case studies to answer the following questions:

1. How many of the design errors could be attributed to structural engineering (SE-errors)?
2. How many of these SE-errors are co-ordination errors, involving other participants?
3. How many of the SE-errors could be avoided by using product-model-based CAD-systems?
4. How many of the SE-errors could be avoided in the next project using feedback from production?

Table 1: Summary of the results from the case studies

Question	Case study A (%)	Case study B (%)
1	30	100
2	75	7
3	47	11
4	38	44

The main difference between the two studies can be found in question number 1, 2 and 3. Looking at question number 1 and 2 it can be stated that the involvement of other participants was much greater in case A than case B. In case B, question number 1, all the information comes from the drawings of the structural engineer. Therefore, the figure is 100 %.

Looking at question number 3, the results indicate that the technique of product-model based CAD-systems is useful in preventing SE-errors, many of which are co-ordination errors.

Comparing the benefits of product-model based CAD-systems with the potential of feedback (question 3 and 4), the results indicate that feedback is at least equally important as using product-model based CAD-systems to avoid SE-errors. This is also in line with the findings of Josephson and Hammarlund (1999) where 44% of the costs for defects attributed to design was caused by lack of knowledge, while 35% was caused by forgetfulness or carelessness. The case studies also illustrates the even greater potential in combining the two methods of product-model based CAD-systems and feedback to avoid SE-errors. In case study A, 65 % of the SE-errors could have been avoided in this way.

It was also evident from the case studies, that almost all SE-errors that could have been avoided in the next project using feedback were situated where two or more elements met (case A: 92 %, case B : 88%).

The capturing of information concerning design errors (research question 5) was different in the two cases because of the different types of contract. In case A (general contract) the capturing was rather straight forward while it was more laborious in case B (all-in-one contract). In case A it was performed by using the construction deficiency reports. The information in these documents is in most cases a good description of the errors. The fact that the construction deficiency reports are legal documents, and that money can be lost if these are not documented correctly, makes a good incitement that enables the creation and in turn capturing of the information. In case B, the drawing revisions performed by the structural engineer were studied for the purpose of capturing information concerning design errors. The descriptions of the errors are in this sense much poorer, and it was in most cases needed to gather more information to make feedback meaningful.

7. FEEDBACK FROM CONSTRUCTION TO DESIGN (A PROTOTYPE)

The last question we like to address in this paper is how the feedback information can be made available to the structural engineer, using product-model-based CAD-systems (research question 6). Based on the findings in the case studies, we formulated an hypothesis that the feedback information concerning design errors could be captured in the deficiency reports. We then designed a prototype to show how this information could be made available by using a product model in the way that the construction deficiency reports were linked to the elements involved.

The construction deficiency reports were created using Microsoft Word. These reports were translated to HTML documents. Having this, the construction deficiency reports could in the prototype be connected to the elements by giving the URL to the HTML document. In the prototype the document is situated in a subdirectory of the project file but it could be placed in a database (fig. 5).

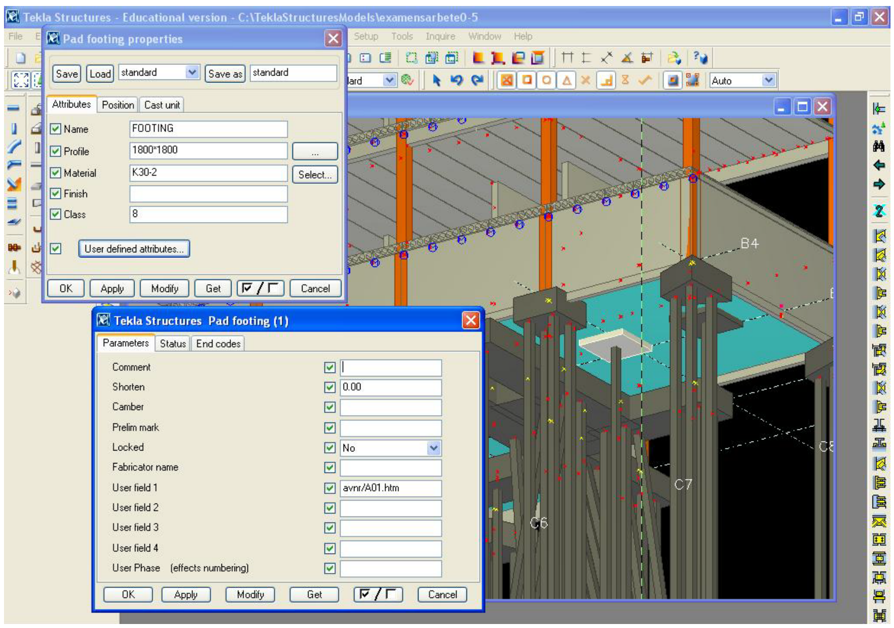

Figure 5: The documentation of the construction deficiency is connected to the elements involved.

The product model is then transferred to the structural engineer, or a common web-based product model could be used. The structural engineer can then browse the elements and study the construction deficiency report together with the elements involved.

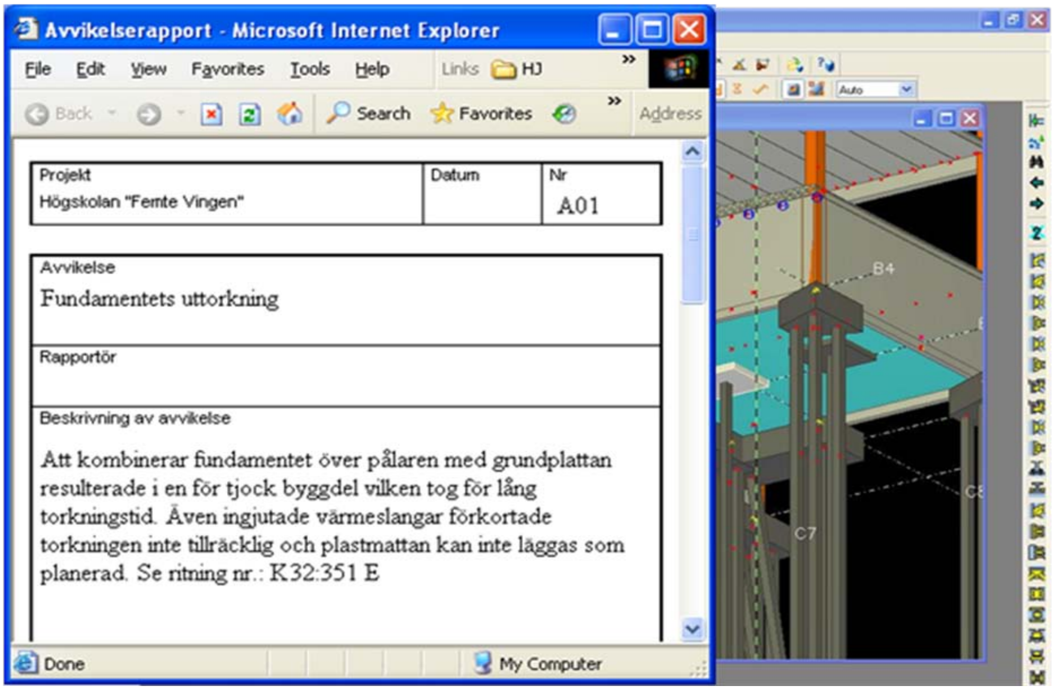

Figure 6: The structural engineer can now browse the elements and investigate the construction deficiency report and the elements involved.

8. DISCUSSION AND CONCLUSIONS

In this paper we argue that the technique of product-model based CAD-systems is useful in preventing SE-errors, many of which are co-ordination errors.

Comparing the benefits of product-model based CAD-systems with the potential of feedback, the results indicate that feedback is at least equally important as using product-model based CAD-systems to avoid SE-errors. The studies also show the even greater potential in combining the two methods of product-model based CAD-systems and feedback.

The prototype illustrates the possibility of connecting information about construction deficiencies to a product model with a minimum of extra work, using construction deficiency reports.

The structural engineer in general likes to solve design problems. For feedback to be of real use, the feedback system should aid the structural engineer in this process. That is, the information about design errors should be presented to the structural engineer when the information is useful.

As shown in the case studies, about 90% of the SE-errors that could be avoided in the next project using feedback were situated where two or more element met. This fact indicates that the elements could be used as indexing for design errors, and that it would be possible to create a feedback system that shows the structural engineer only construction deficiency reports that are of interest in the present design situation.

Johansson and Kliger (2007) describe a prototype for knowledge reuse for structural engineers. They conclude that knowledge reuse is possible if previous structures is represented using a product model-based representation. But to be of real use, the information about previous structures has to include feedback information. The studies in this paper indicate how this can be done, by using the information in construction deficiency reports.

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