DESIGN ERRORS CAUSED BY LACK OF INFORMATION

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ABSTRACT

Design errors is the cause to a large 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 two case studies 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. The study also argue 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. In the case studies many of the design errors were caused by lack of information. That is, the information transferred to the structural engineer and from the structural engineer to the building production was not sufficient. It is argued in this paper that the use of BIM-manuals/IDM:s should be able to reduce much of the information lack noticed in the case studies, partly because the information required is more precisely described but also because of the analysis on the structural model that is required in these documents. This paper also shows that more than 80% of the design errors caused by the Structural Engineer could have been avoided using BIM-manuals/ IDM:s together with knowledge feedback from the building production to the Structural Engineer.

Keywords: Design Errors, Lack of information, Product-models, Feedback, Information delivery manuals.

1. INTRODUCTION

1.1 Design Errors

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 BIM and Design 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 Structures (Tekla 2011) and Revit (Autodesk 2011). 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.
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 BIM-manuals/Information Delivery manuals and Design Errors

The development and implementation of BIM in the construction industry have created a need to formulise and structure the building information process. A number of BIM-Manuals/BIM guidelines have been developed e.g. (Statsbygg 2011, Senate Properties 2007, NIBS 2007). These documents often contains information about goals for the use of BIM, a process model describing how to achieve these goals and to some extend how to model. They also describe **what information that should be modelled** by the different participants, and **how this information should be transferred** to other participants. These documents also show **which simulations that should be performed on the models**. Lately the focus in these documents have somewhat changed from being more software focused to more information focused and the term Information Delivery Manuals (IDM) is more and more used for these documents, coming from the development of buildingSMART (buildingSMART 2011a).

In Sweden the principle for BIM-Manuals/BIM guidelines can be found within *Bygghandlingar 90 : byggsektorns rekommendationer för redovisning av byggprojekt. Del. 8: Digitala leveranser för bygg och förvaltning* (SI 2008). This document contains guidance on the administrative aspects of BIM with reference to other Swedish standards. Based on these guidelines, a development of IDM:s have started, mainly for the project handover to the facility management (FFI 2011). Concerning the information delivery between the structural engineer and the building production, which is the focus of this paper, the development of IDM is still in its infancy.

One of the goals for the development of BIM-manuals and IDM:s is to be able to define “detailed specification of the information that a particular user (architect, building services engineer etc) needs to provide” (buildingSMART 2011a). “In doing so, the intent is to provide a basis for reliable information exchange for users so that they can be confident that the information they are receiving is accurate and sufficient for the activities they need to perform” (buildingSMART 2011b). That is, the use of BIM-manuals and IDM:s should be able to reduce the information lack from the Structural Engineer. This category of design errors were rather common in the case studies described below.

1.4 Lack of knowledge and feedback

Lack of knowledge is 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 defects in building production caused by design errors is studied, captured, 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 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 using the product-model based technique.

The following central research questions were addressed:

- How many of the design errors can be attributed to structural engineering (SE-errors)?
- How many of these SE-errors are co-ordination errors, involving other participants?
- How many of the SE-errors can be avoided by using product-model-based CAD-systems?
- How many of the SE-errors can be avoided in the next project if feedback from production was made available to the structural engineer?
- How many of the SE-errors is due to lack of information from the structural engineer to the building production.
- How can the use of BIM-manuals and IDM:s avoid design errors caused by lack of information.

3. METHOD

To answer these questions two research methods were used:

- Case study
- Comparative study between BIM-manuals and design errors categorized as lack of information.

Two case studies were performed. In these two studies the same project was studied. In the first case study the main aim was to get the viewpoint of the construction (Case Study B1). In the second one the aim was to capture the viewpoint of the structural engineer (Case Study B2). The objective for this part was to answer the five first questions. To answer the last question, BIM-manuals, especially Statsbygg (2011), were studied and compared to the results from the case studies.

4. THE CASE STUDIES PROJECT: HUSKVARNA CARE CENTRE

1.5 Case description

Huskvarna Care Centre is a six story building with a total area of 10000m3. 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 a turnkey contract.

Figure 1: Huskvarna Care Centre

The structural system of the building is foundation piles and concrete cast in situ at the buildings first level, and at the other levels hollow core floor elements on a steel structure, se figure 1. The structural engineers used ordinary 2D technique (AutoCAD) in the design of the building.

This project was not straight forward. 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 and extra work for the construction manager. The structural engineer in turn said that the main reason for the problems in the project were lack of design co-ordination and that a change in the projects time-schedule made it hard to perform a good work due to lack of time.

1.6 Case study description

Data was gathered using mainly three sources: drawings, drawing revisions, 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. As a complement the structure of the building was modeled using the product-model based CAD-system Tekla Structures (Tekla 2011). This gave an opportunity to understand the project even better, and also to investigate the product-model based technique.

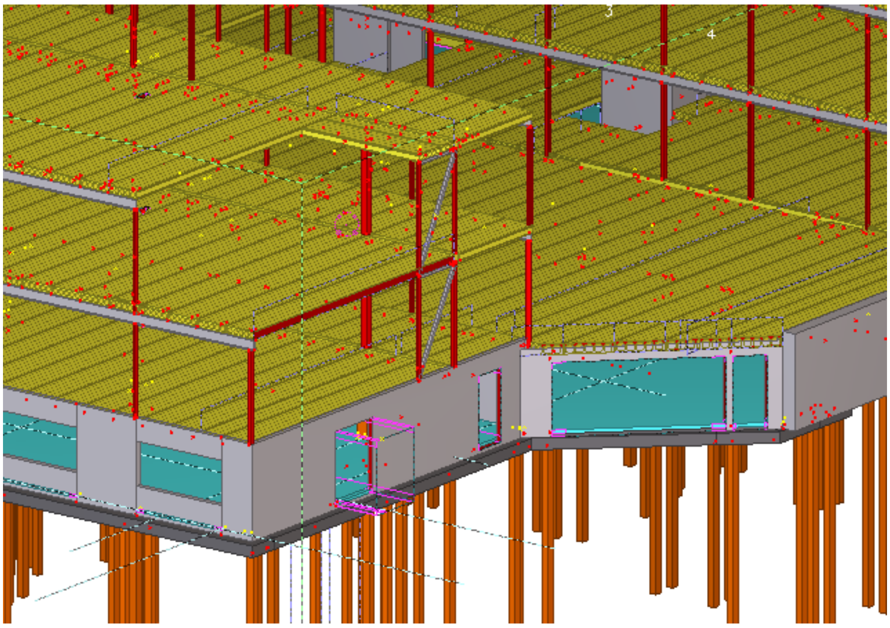

Figure 2: A part of the model created using Tekla. As shown the structural system is concrete cast in situ at the first level on a foundation of foundation piles, and at the other levels hollow core floor elements on a steel structure.

The **drawing revisions** performed by the structural engineer were studied in detail. By studying the drawing revisions, the design errors, causing some of them, could be identified. A number of **informal interviews** were also conducted. The purpose of these interviews was mostly to gain a better understanding of some of the drawing revisions.

1.7 Drawing revisions categorization

Based on the information gathered, the next step performed was to categorize the drawing revisions 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)
Caused by lack of information from the structural engineer (Yes/No)

Not all drawing revisions were caused by design errors. Some of them are just changes made. This made it necessary to categorize the drawing revisions 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 many of the SE-errors 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**. Another thing that was noticed was that the main reason for many of the revisions were lack of information from the structural engineer. For this reason the drawing revisions were categorized using the category **lack of information**.

The study of the drawing revisions and the informal interviews were performed in two different studies, with two different viewpoints. In the first one the aim was to catch the viewpoint of the building production. This was performed by interviewing the construction manager of the project and to categorize the drawings revisions according to the information from these interviews. This study is from now on called B1. The second case study (B2) was performed with the aim to catch the viewpoint of the structural engineer.

1.7.1 Result from case study B1

As described above the case study B1 was performed with the aim of getting the viewpoint of the building production and for that reason a number of informal interviews were conducted with the construction manager and the drawing revisions was categorized according to the information gathered from these interviews.

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).

7% (4) of the SE-errors were co-ordination errors, involving other participants.

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.

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.

1.7.1.1 Lack of information as a design error

The construction manager was rather critical to the structural engineer because much of the information needed was lacking at first, which caused a lot of drawing revisions and extra work for the construction manager.
In the opinion of the construction manager as much as 49%(28) of the revisions were caused by **lack of information**.

To get a better picture of these revisions they were categorized further in the following categories:

- Element missing
- Information about a detail missing
  - Information about reinforcement missing
- Information about dimensions missing
- Text instructions missing

Only 4% (1) of the 28 revisions that were categorized as missing information were caused by the fact that information about an element was missing.
39% (11 of 28) of the revisions were categorized as missing information about details.
5 of these were categorized as missing information about reinforcement.
18% (5 of 28) were categorized as missing information about dimensions and
11% (3 of 28) were categorized as missing text instructions.

Studying the category “lack of information” it became rather clear that most of the SE-errors were either in the category “lack of information” or “could be avoided in the next project using feedback” This was the case for as many as 86% (49) of the SE-errors.

1.8 Result from case study B2

The case study B1 was performed with the aim of getting the viewpoint of the structural engineer. This was conducted in the same way as in the case study B1. To identify the defects where the structural engineer was involved (SE-errors), the drawing revisions of the structural engineering drawings were studied in the same way as in B1. For each of the revisions that could be of interest more information was gathered by interviewing the structural engineer. The outcome of this procedure was that only 25 revisions were categorized as errors and of those 25 only 16 were categorized as design errors where the structural engineer had been involved (SE-errors). Comparing this result with the result from B1 it can be concluded that the number of revisions that were categorized as design errors were dramatically reduced. If the type of contract used had been general contract there may have been a negotiation about this difference. Since the aim of this study was to get the viewpoint of the structural engineer, this was not performed. The structural engineer stated that the main reason for the problems in this project was lack of design co-ordination. According to him, as many as 60% (15) of the errors were caused by lack of design co-ordination. He also pointed out that a change in the project time-schedule made it hard to perform a good work due to lack of time.

25% (4) of the SE-errors were categorized in the category “Could be avoided using product-model based CAD-system”.
31% (5) 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 37,5% (7) of the SE-errors could have been avoided.

44% (7) of the SE-errors were situated where two or more element met**.** Of the 5 SE-errors that could have been avoided in the next project using feedback, as many as 60% (3) were situated where two or more elements met.

1.8.1.1 Lack of information as a design error

In the interviews with the structural engineer the revisions were discussed. In these discussions the structural engineer argued that many of the design-errors that in the case study B1 were labeled as “caused by lack of knowledge”, actually were caused by the structural engineer not delivering drawings containing all information needed for the production. To investigate this, the SE-errors also were analyzed to see if they were caused by lack of information or not.

Of the SE-errors that were categorized as lack of information (11), 5 were categorized the same in B1. But four of them were instead categorized as “Could be avoided in the next project using feedback”.

In the same manner as in B1 the SE-errors that were categorized as “lack of information” were categorized further using the same sub-categories and with the following results:
27% (3) of the 11 revisions that were categorized as missing information were caused by the fact that information about an element was missing. That was two more than in the case study B1.
91% (10) of the revisions were categorized as missing information about details.
4 of these were categorized as missing information about reinforcement.
None of the 11 were categorized as missing information about dimensions and
9% (1 of 11) were categorized as missing text instructions.

As many as 81% (13) were either in the categories “lack of information” or “could be avoided in the next project using feedback”.

5. ANALYSIS

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

How many of the design errors could be attributed to structural engineering (SE-errors)?
How many of these SE-errors are co-ordination errors, involving other participants?
How many of the SE-errors could be avoided by using product-model-based CAD-systems?
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 B1 (%)	Case study B2 (%)
1	100	64
2	7	25
3	11	25
4	44	31

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 B2 than in case B2. From the construction managers point of view the structural engineer was responsible for all the revisions while the structural engineer had another point of view and in many cases had more information about the cause of the revision.

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.

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 B1: 88% and in case B2 60%).

1.9 Lack of information and BIM-manuals

One of the main problems in the project of the case studies was lack of information. One of the main goals with BIM-manuals and IDM:s is to "provide a basis for reliable information exchange for users so that they can be confident that the information they are receiving is accurate and sufficient for the activities they need to perform" (buildingSMART 2011b). These facts made it interesting to conduct a comparative study between BIM-manuals and design errors categorized as lack of information.

This was performed by studying BIM-manuals, especially (Statsbygg 2011) and analysing how the use of these could avoid the SE-errors categorized as "lack of information. The reason for focusing on the BIM-manual from Statsbygg was that it is the newest one, to the knowledge of the authors, and that the construction industry and the BIM-use in Norway is rather similar to the situation in Jönköping/Sweden where the case studies were performed. The result from this analysis is described below using the same sub-categories as in the case-studies.

1.9.1 Elements missing

In the case study B2, 27% (3) of the 11 revisions that were categorized as missing information were caused by the fact that an element was missing. To avoid this, Statsbygg (2011) states that:
"All load-bearing vertical and horizontal structures shall be modeled holding type, material, geometry, location, joining and structural dimensioning data."
This statement could be translated to a IDM and further on to model view definitions (MVD). This statement alone should prevent the structural engineer from missing an element, but an MVD do not find out if an element is missing. The only thing that an MVD can be used to is to find out if the elements is of the right type but it can be used to control if some element is missing. Statsbygg (2011) also suggest that the structural model shall be analysed in a number of ways e.g. ocular analysis, consistency check and clash detection. These analyses of course also make an opportunity to find out of elements are missing.
A load bearing analysis using a 3D-analysis tool is also suggested and this would make missing load-bearing elements rather obvious. Unfortunately there is still an interoperability problem between structural design- and analysis tools, hence today a consistency check between these two models is a manual process (Statsbygg 2011). This can lead to missing elements yet.

1.9.2 Information about details missing

In the case study B1 there were 39% (11 of 28) of the revisions that were categorized as missing information about details. In B2, 91% (10) of the revisions were categorized as missing information about details. That is, it was in this category that most information was missing in both the studies.

To avoid that information about details missing Statsbygg states:
"All types of joining shall be modelled (also for visualization purposes). I.e. it is not required to model all occurrences/instances of the connection point/joining types, but it must be clear where the types are intended used." (Statsbygg 2011)
Having these requirements should be sufficient to avoid missing information about details. But as stated above the demands on what information should be available does not exclude the possibility that some details are missing. This has to be controlled by hand, by looking at each possible location of a detail and then to look if there is a reference of that type of detail is modelled. The reference is in most cases found only on the drawings and not in the model which makes this a rather tedious work and for that sake it will probably not be properly performed in all projects.

Today it is possible to model each detail in 3D, using BIM-software's as Tekla structures. If this is required as indicated in Senate (2007) the process of controlling if details are missing could be performed by looking at the 3D-model and studying the connections and other details. This makes the control easier. Such controls ought to be included in the quality management system of the structural engineering firm, using checklists for instance. (In Tekla Structures missing details are also detected when creating collision checks). It is possible to model the reinforcement in detail today with the same advantages as for modelling details.

Statsbygg (2011) do not suggest that a structural analysis of the hole structure that also includes the details should be performed. As today it is hard to perform such a analysis mostly due to lack of software's and lack of time.

1.9.3 Information about dimensions and text instructions missing

Requirements on this kind of information is not normally included in BIM-manuals and IDM:s because this type of information is not specific for BIM, although the use of BIM may change these requirements.
In case study B1, focusing on the viewpoint of the construction manager, 29% (8) of the SE-errors were categorized as missing information about dimensions or missing text instructions.
In case study B2, focusing on the viewpoint of the structural engineer, just 9% (1) of the SE-errors were categorized as missing information about dimensions or missing text instructions.
This is a dramatic difference and it is rather clear that the construction manager and the structural engineer did not have the same opinion concerning these revisions. Some of the differences depend on the fact that the structural engineer did not in turn receive information from other participants but some of them were also due to the fact that the structural engineer did not find it necessary to put the information into the drawings. That is, he did not have the knowledge what information were needed for the building production. To avoid this problem, feedback from the building production to the structural engineer, about dimensioning for instance, is needed.

6. 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.

One of the main problems in the project of the case studies was lack of information. One of the main goals with BIM-manuals and IDM:s is to "provide a basis for reliable information exchange for users so that they can be confident that the information they are receiving is accurate and sufficient for the activities they need to perform" (buildingSMART 2011b).

It can be concluded from this study that the use of BIM-manuals and IDM:s should be able to reduce the information lack from the Structural Engineer to the building production, partly because the information required is more precisely described but also because of the analysis on the structural model that is required in these documents. Concerning information lack about details, which was the most common category of information lack, it is argued that detailing in 3D, using BIM-software's as Tekla structures, together with a good quality management system should be able to reduce the lack of information.

Also concerning lack of information from the Structural Engineer to the building production it was shown that knowledge has to be transferred from the building production to the structural engineer. That is, also concerning information feedback is needed.

It can be concluded that the most of the revision that was categorized as design errors where the structural engineer was involved were either in the category "lack of information" or in the category "could be avoided in the next project using feedback", over 80%. This paper shows that most of them can be avoided using BIM-manuals/ IDM:s together with knowledge feedback from the building production to the structural engineer.

ACKNOWLEDGMENTS

The work reported here was funded by Jönköpings Läns Byggmästareförening.

REFERENCES

Argyris, C. and Schön, D. (1978) “Organisational learning: A theory of action perspective” Reading, Mass: Addison Wesley. Augenbroe, G. (1995) “The Combine Project: A Global Assessment” CIB Proceedings 180, W78 Workshop on Modeling Building Through Their Lifecycle, Stanford, CA, 163-171.

Autodesk (2011) www.autodesk.com, (last accessed on 01-08-2011).

Bartezzaghi, E., Corso M. and Verganti R. (1997) “Continuous improvement and inter-project learning in new product development”, International Journal of Technology Management, 14(1), 116-138.

buidlingSMART (2011a) “Process - Information Delivery Manual (IDM), http://buildingsmart.com/standards/buildingsmart-standards/idm, (last accessed on 29-04-2011).

buidlingSMART (2011b) “Information Delivery Manual”, www.iai.no/idm/, (last accessed on 29-04-2011).

Crowley, A.J. and Watson A.S. (1997) “Representing Engineering Information for Constructional Steelwork” Microcomputers *in Civil Engineering*, 12, 69-81.

East, W. (2011) “Construction Operations Building Information Exchange (COBie)” http://www.wbdg.org/resources/cobie.php?r=om

FFI (2011) Informationsleveranser Digitala Informationsleveranser till och från Förvaltning http://www.fi2.se/documents/public/Informationsleveranser/Tillämpningsanvisning_ver2011_FFi_publG5_110309.pdf

Josephson, P.E. and Hammarlund, Y. (1999), “The causes and costs of defects in construction: a study of seven building projects”, *Automation in Construction*, 8 (6), 681-687.

Nevis, C., DiBella, J. and Gould, M. (1995) “Understanding organizations as learning systems” *Sloan Management Review*, Winter, 73-85.

NIBS (National Institute of Building Sciences). (2007), *National Building Information Modeling Standard - Version - Part 1- Overview, Principles, and Methodologies*, NBIMS, US.

Roddis, W. M. K. and Bocox J (1997) “Case-based approach for steel bridge fabrication errors”. Journal of Computing in Civil Engineering, 11(2), 84-91

Senate Properties (2007): “BIM Requirements” Volume 5: Structural design, www.senaatti.com/tiedostot/BIM_2007_Vol_5_Structural_BIM.pdf.

SI, Swedish Standards Institute (2008), Bygghandlingar 90 : byggsektorns rekommendationer för redovisning av byggprojekt. D. 8, Digitala leveranser för bygg och förvaltning, Stockholm : SIS Förlag AB.

Statsbygg (2011) “Statsbygg Building Information Modeling Manual - version 1.2” http://www.statsbygg.no/FilSystem/files/prosjekter/BIM/StatsbyggBIMmanual1-2PublicBeta1.pdf

Tekla (2011) www.tekla.com, (last accessed on 01-08-2011).