DETECTING DESIGN CONFLICTS USING BUILDING INFORMATION MODELS: A COMPARATIVE LAB EXPERIMENT

Timo Hartmann, Assistant Professor, t.hartmann@utwente.nl
VISICO Center – www.utwente.nl/visico, Uniervsity of Twente, The Netherlands

ABSTRACT

One of the applications of Building Information Models (BIM) is Clash Detection: The automated detection of clashes between different elements in a BIM. Clash detection helps design coordinators to detect inconsistencies between different sub-systems in early design stages that would, if not detected early, materialize in expensive change orders and delays during the construction stage. Currently, the existing automated Clash Detections technologies are hampered as they, even for rather simple building designs, usually provide a large amount of clashes of which only a very few are relevant. It is a time consuming and error prone process to filter out the relevant clashes that finally will cause change orders during installation. To help design coordinators with filtering out only the relevant clashes, modelers should organize BIMs according to a breakdown structure that allows a clear distinction between different systems. A good organized BIM then theoretically allows design coordinators to find the relevant clashes more efficient and more accurate by filtering out clashes between different systems that are known to cause expensive field change orders if they are not coordinated well.

We tested this hypothesis with an experiment. We divided 44 undergraduate students in three groups that each had to conduct a Clash Detection. One group used 2D drawings, one group used a standard BIM, and one group used a, with a breakdown structure, organized BIM. The outcomes of the experiment do not show any significant difference in the number of clashes found between any of the groups. Comparing the means directly, students that used the 2D drawings and students that used the organized BIM model found, on average, the same number of relevant clashes. Only students that used the unorganized BIM modeled found, on average, less clashes than the other two groups.

Keywords: BIM, design coordination, clash detection, system breakdown structure, lab experiment

1. INTRODUCTION

In current practice, different parties design different subsystems of a building. The integration of these independent sub-system designs into a consistent overall design is a challenging task because of the existence of so called clashes between the different systems - physical inconsistencies of two sub-systems that, by design, allocate the same space. Clashes between system designs that usually cause delays and cost overruns are for example

- if the ventilation system does not fit between the floor and the false ceiling, or
- if ducts or pipes with large profiles have to penetrate supporting walls.

The detection of such clashes is an important step during the coordination of the designs for different sub-systems of a building (Barton 1983; Tatum & Korman 2000; Staub-French & Khanzode 2007; Plume & Mitchell 2007). If clashes are not found during design coordination efforts, they can lead to delays and cost overruns later on during the physical construction of the building. Additionally, the existence of clashes between systems on virtually every construction site today hinders system installing companies to pre-fabricate parts of their systems.

To reduce risks, most companies prefer to assemble most parts of the system on site which allows for dynamic changes in the original installation system design to circumvent other systems during installation.

To find existing clashes in different system designs, traditionally, engineers coordinate designs by comparing two dimensional (2D) drawings delivered by the different discipline designers. Lately, software companies have developed automated clash detection systems that promise to detect clashes automatically. These applications combine three dimensional (3D) computer models of the different sub-system designs and provide clash detection algorithms that can automatically detect clashes between these models. By now the automated detection of clashes has evolved to one of the major applications of 3D models in practice (Hartmann et al. 2008). Despite these promises, engineers experience problems when they try to apply existing clash detection software in practice. In particular, automated clash detection applications detect large amounts of clashes of which only a few are relevant in that they will cause delays or cost overruns later in the construction phase. Engineers have to manually evaluate each of the automatically detected clashes according to its relevancy. This process is, similar to the manual comparison of 2D drawings, time-consuming and error prone.

Due to this problem, it is not surprising, that except of some anecdotal evidence from cases little is known about the real value of using automated clash detection applications during the design coordination effort. To provide first answers to whether the automated clash detection or the traditional clash detection process allows engineers to more effectively detect relevant clashes in system designs, we, therefore, conducted a lab experiment. During the experiment, we gave 43 Dutch civil engineering students the task to detect clashes in the design of a recently built office building in the Netherlands. To compare different clash detection methods, we divided the students in three groups. Students in the first group used the original 2D design documents of the building. Students in the second group were equipped with an automated clash detection application with a standard 3D model that an engineer modeled using a state-of-the-art Building Information Model (BIM) authoring tool. Students in the third group were also equipped with the same automated clash detection software. In contrast to the second group, however, we organized the 3D model using generally accepted standards that according to Staub-French & Khanzode (2007) should allow for an easy evaluation of the large amount of clashes the automated clash detection process identifies. After the experiment, we compared the number of clashes the three groups found according to the clash detection method the group used and the relevance of the clashes the students in each group found. The outcomes of this experiment show no significant difference in the amount of relevant clashes the students of each group found.

The paper is structured as follows: First we give a short introduction in the existing literature about clash detection and design coordination. We then describe the lab experiment we conducted in detail. Afterwards, we analyze the outcomes of the experiment. The paper concludes with a discussion of the findings from the experiment in light of the practical relevance of the results.

2. MODEL ORGANIZATION AND CLASH DETECTION

Researchers have advocated the benefits of using automated 3D clash detection applications on construction projects. However, so far, researchers have not underlined these benefits with empirical data. One of the few exceptions are the reports of the clash detection software implementation on the Camino Medical Group Project by Stuab-French & Khanzode (2007). We will use this report to outline the benefits that automated clash detection theoretically should offer. In particular, Staub-French and Khanzode (2007) reported the following benefits:

- The possibility to identify most design conflicts prior to construction,
- Improved productivity during construction,
- Less rework,
- Increased opportunity for pre-fabrication,
- Fewer requests for information,
- Fewer change orders,

- The possibility to identify design errors prior to construction,
- The ability to build systems with a less skilled labor force,
- Improved safety performance, and
- Better cost control.

However, from reading this report it gets not clear which of the above mentioned benefits was achieved by using automated clash detection software. This is mainly, because the design management process of this project was characterized by a number of relatively unusual management methods for the construction industry. First of all, the client of the project used a contract form that brought on all design parties relatively early in the process. Additionally, all designers responsible for the design of the building systems worked co-located together independent of their company affiliation. It is hard to identify which of the above benefits can be attributed to the application of the automated clash detection procedure and which to those other management innovations on this project. This example illustrates that it is hard to get a clear understanding of the utility of automated clash detection tools from such anecdotal case descriptions as it is not easily possible to isolate the influencing factors when analyzing case based project data. A consideration of the cost-benefits, in particular, related to the necessary 3D modeling effort to allow for the automated clash detection – the Camino Medical Group Project reported a 30% increase in the required design hours – is even less possible.

3. RESEARCH METHOD

To understand the utility of automated clash detection tools and their relation to the way the organization of BIM models influence the automated clash detection process, we therefore conducted an experiment with a class of third year Bachelor students. The experiment centered around the task to identify design conflicts within the multi-disciplinary design documents of a recently built office building. The overall office building provided approximately 1,500 square meters of office space over three levels and construction activity was mainly in-situ. Overall, three different parties participated in the design of this building and provided design documents: An architect, a structural engineer, and a building installation engineer. We chose this relatively simple case to ensure that all students would be able to identify clashes in the design documents within a relatively short time period.

At the start of the experiment, we divided the students in three groups. We provided the first group with the original set of drawings of the office building process that were provided by the different design parties. These drawings included the designs of the architectural, structural, and building installation systems. Overall, each student in this group received 42 different drawing sheets in the form of DIN A3 print outs. We provided the second group of students with a 3D model of the same building design loaded in the automated clash detection software Navisworks from Autodesk. This 3D model represented the model a designer of the project had created to support the design coordination on the project. The model consists of approx. 3000 3D model objects of different building components, such as walls, columns, ducts, or cable trays, that embodied all relevant systems that the 2D drawings we gave to the first group represented. In its original form the model objects are organized hierarchically using a by the 3D authoring tool pre-defined object breakdown structure. Despite its availability the model had never been used to coordinate designs on the project because engineers preferred their traditional way of working with 2D drawings. To test for the effect of different model organizations on the clash detection process, we, finally, provided the third group with the same 3D model albeit this time additionally organized. We chose a break down structure that we based on a simplified version of the Dutch classification norm's NEN 2634 third detail level. Overall, we organized all objects into nine groups among which the most clashes during the construction of the building occurred. Table 1 describes the break down structure and the classification codes we used for the model organization. We hypothesized that students could use the semantics of the classification codes to easily identify and select groups of objects by trade and building object type. This theoretically should enable them to specifically detect clashes between objects of two such groups and help them with mitigating the large number of clashes that clash detection software usually detect.

Table 1: Break Down Structure we used to organize the 3D model to allow for the clash of specific object groups during the experiment (The abbreviations in the trade columns stand for: A – Architect, C – Structural Engineer, I – Installation Engineer)

Trade	Code NEN 2634	Description of the Object Group
A		Architect
A	2	Construction works
A	2C	Roofs
A	2D	Facades
A	2E	Internal walls
A	2F	Floors
A	2G	Escalators
A	2H	Ceilings
A	3	Installations
A	3C	Elevator and transport
C		Structural Engineer
C	2	Construction
C	2A	Foundation
C	2B	Framework
I		Installer
I	3	Installations
I	3A	Mechanical installations
I	3B	Electrotechnical installations

Before the start of the experiment we provided the students with a number of documents to help them get started with the identification of clashes. Independent of the group membership of the students, we also handed out a general guideline document. We prepared this guideline document together with an experienced design coordinator – the same coordinator that had coordinated the designs for the office building we used for this experiment. In particular, the guidelines recommended that students only look for clashes that will result in change orders during the construction phase and that these clashes usually occur between elements designed by different design parties. Additionally, we provided the students that used the automated clash detection application with a short introductory video of how to generally use the clash detection application, and how to, in particular, clash objects of different systems.

After each of the students had read the general guidelines and the students that were to use the class detection application had watched the video we also asked the students to fill out a questionnaire to understand the experience that each of the students had with design coordination, reading 2D drawings, and with the respective clash detection software. None of the students had ever used the clash detection software Navisworks before the experiment and only one of the students reported that he had seen Navisworks. Students also reported about the time they spend each week using a computer on a three point scale (1=10h or less; 2=10-20h; 3=more than 20h) and they rated their skill of reading 2D construction drawings on a 7-point Likert scale. An initial Analysis of Variance (ANOVA) test for a difference of these values among the groups did not provide significant differences between the mean scores of the groups so that we assume a relatively even distribution of computer skills and skills to read drawings among the students and groups.

After each of the students had filled out the questionnaire, we started the experiment itself. We gave each student group one hour time to detect clashes in the design. To track the results, we asked each student to fill in a table with “the location”, “the names of the elements”, “the elements’ ID”, “the elements’ participants”, and “the distance of overlap” of the clashes they found. Figure 1 illustrates an exemplary clash report one of the students delivered as a result of the experiment.

Name								
Student nr.								
Clash Detection								
Clash nr.	Room	Name component A	Id comp	Responsible	Name component B	Id compo	Responsible participant comp. B	Distance overlap
1	1.05	Sewerdrainage		Plumber	Carrying wall		Constructor	
2		Sewer		Plumber	Carrying wall		Constructor	
3	2.03	PL pipe		Plumber	Carrying wall		Constructor	
4	0.11	Warm/cold water pipes		Plumber	Carrying wall		Constructor	
5	2.05	Waterpipes		Plumber	Carrying wall		Constructor	
6	1.04	Airchannel		Installator	Carrying wall		Constructor	
7	-	Airchannel		Installator	Waterpipes		Plumber	

Figure 1: Example of a clash report from one of the students (We deleted the student's name and number)

After the experiment we analyzed the clashes the students found according to four different clash types according to the severity of the clash. This was possible because the construction of the office building had been completed at the time of the data analysis and we had access to documentation about all problems that occurred during the construction work. In particular, we distinguished between the following three types of clashes:

- Clashes between systems. These are clashes between the different systems of the participating design parties. These clashes did not necessarily lead to any problems during the construction of the building.
- Relevant clashes. Relevant clashes are clashes in the design that reportedly caused coordination problems during the construction of the office building.
- Clashes that caused a change order. These clashes are the relevant clashes that caused a change order during the construction phase because the involved parties with this clash were not able or willing to coordinate the installation work during construction of the office building.

In the next section we will describe the outcomes of this data analysis in detail.

4. RESULTS

Table 2 summarizes the means and standard deviations of the number of clashes the students of each group found during the experiment. Students who used the automated clash detection tools overall found on average more clashes than the students that used the 2D drawings (2D: 2.2143; unorganized: 3.5714; organized: 3.1333). Surprisingly, however, there is no real difference between the three groups with respect to clashes between different systems. Even more, the mean of all identified clashes with respect to clashes between systems for students that used 2D drawings is equal. It seems as if students that used the automated clash detection tool, independent of the input model, also identified a number of clashes that were not really clashes between systems as relevant.

A comparison of the different groups with respect to the means of relevant clashes found shows a difference between the students that used the 2D drawings or the automated clash detection with the organized model and the students that used the automated clash detection tool with the unorganized model. Students with the 2D drawings and the organized model found on average more relevant clashes than the students that used the unorganized model (2D: 1.7857; organized: 1.8000; unorganized: 1.0714). A comparison of the means of clashes that actually caused change orders during the construction does not show a large difference.

Table 2: Types of Clashes Found by Clash Detection Methods based on Clash Detection Method

Clash Detection Method	Clash Detection Type	N	Mean	SD	SE	95% Confidence Interval for Mean	
						Lower	Upper
All Clashes	2D	14	2.2143	1.47693	0.39473	1.3615	3.0670
	BIM unorganized	14	3.5714	1.65084	0.44121	2.6183	4.5246
	Bim organized	15	4.1333	1.92230	0.49634	3.0688	5.1979
	Total	**43**	**3.3256**	**1.84805**	**0.28182**	**2.7568**	**3.8943**
Clashes between Systems	2D	14	2.2143	1.47693	.39473	1.3615	3.0670
	BIM unorganized	14	2.2857	1.93862	.51812	1.1664	3.4050
	Bim organized	15	2.4667	2.16685	.55948	1.2667	3.6666
	Total	**43**	**2.3256**	**1.84805**	**.28182**	**1.7568**	**2.8943**
Relevant Clashes	2D	14	1.7857	1.57766	.42165	.8748	2.6966
	BIM unorganized	14	1.0714	.82874	.22149	.5929	1.5499
	Bim organized	15	1.8000	1.56753	.40473	.9319	2.6681
	Total	**43**	**1.5581**	**1.38534**	**.21126**	**1.1318**	**1.9845**
Clashes that Caused Change Orders	2D	14	.7143	1.13873	.30434	.0568	1.3718
	BIM unorganized	14	.6429	.84190	.22501	.1568	1.1290
	Bim organized	15	.8667	1.18723	.30654	.2092	1.5241
	Total	**43**	**.7442**	**1.04865**	**.15992**	**.4215**	**1.0669**

Table 3: Summary of ANOVA for each of the clash types

Clash Detection Method		Sum of Squares	df	Mean Square	F	Sig.
All Clashes	Between Groups	27.923	2	13.961	4.834	.013
	Within Groups	115.519	40	2.888		
	Total	143.442	42			
Clashes between Systems	Between Groups		2	.247	.069	.933
	Within Groups	142.948	40	3.574		
	Total	143.442	42			
Relevant Clashes	Between Groups	4.919	2	2.459	1.300	.284
	Within Groups	75.686	40	1.892		
	Total	80.605	42			
Clashes that Caused Change Orders	Between Groups	.381	2	.191	.166	.847
	Within Groups	45.805	40	1.145		
	Total	46.186	42			

Next to the above comparison of the means of found clashes we also conducted a single analysis of variance (ANOVA) test using the SPSS data analysis software to evaluate whether the differences we identified above yield any statistical difference. Table 3 and Table 4 summarize the results of the ANOVA. The results show that, despite of the number of all clashes, there is no statistically significant difference between the three clash detection methods with respect to the number of clashes between systems, relevant clashes, and clashes that caused change orders. Considering that the sample size of 43 students is within the range of the suggested 15-20 data points per group, we have to reject the Null-hypothesis that there is a difference between the number of clashes that students can find by applying the different clash detection methods.

In a final analysis step, we used the Temhane comparison test to conduct within group comparison for the means of all detected clashes, the only significant ANOVA result. This analysis explains the significance of this within group difference by a significant difference between the number of clashes the students found that used the 2D drawings and the students that used the organized BIM model. The final results of this data analysis raises a number of interesting questions about the utility of automated clash detection to coordinate construction engineering designs. We will discuss these questions in the next section.

Table 4: Temhane Comparision between clash detection methods per clash type

Clash Detection Method	Comparisions	Mean Weight Difference	Std. Error	Sig.
All Clashes	2D – BIM unorganized	-1.35714	0.59201	0.088
	2D – BIM organized	-1.91905	.63416	.016
	BIM organized – BIM unorganized	.56190	.66409	.789
Clashes between Systems	2D – BIM unorganized	-.07143	.65135	.999
	2D – BIM organized	-.25238	.68471	.977
	BIM organized – BIM unorganized	.18095	.76254	.994
Relevant Clashes	2D – BIM unorganized	.71429	.47628	.385
	2D – BIM organized	-.01429	.58446	1.000
	BIM organized – BIM unorganized	.72857	.46138	.339
Clashes that Caused Change Orders	2D – BIM unorganized	.07143	.37848	.997
	2D – BIM organized	-.15238	.43196	.980
	BIM organized – BIM unorganized	.22381	.38026	.916

5. DISCUSSION

First and foremost the results of the lab test do not show a significant relationship between the number of relevant clashes students were able to identify with respect to which clash detection method they applied. In the controlled environment of the university class setting a clear advantage of using automated clash detection applications did not become evident. Considering that the students neither had experience in identifying clashes using 2D drawings, nor had any experience in using 3D clash detection applications, these findings challenge the common notion that automated clash detection tools have the potential to truly improve the design coordination process, in particular, of inexperienced engineers.

Additionally, despite the general guidelines for the general clash detection process available to the students that clearly suggested to look for clashes between different systems it seems as if students that used the automated clash detection application, independent of the model organization, identified many more irrelevant clashes between single systems than students that used the 2D drawings. In practice, such an identification of clashes as relevant during design coordination efforts that would not cause a change order during the construction of the system will increase the time and effort engineers need to spend in the coordination phase. From a cost-benefit point of view, such extra and unnecessary coordination efforts need to be carefully balanced with the risk that possibly relevant clashes are not detected in the coordination phase that will cause change orders later on. Ideally, engineers should avoid the detection and coordination of clashes, even if relevant, that do not lead to change orders during the construction. In the case, engineers plan to pre-fabricate systems off-site and thus lose their flexibility to find work-abounds to avoid clashes that become relevant during the construction phase, all relevant clashes need to be identified during the design coordination. The results of the experiment show, however that even for the detection of relevant clashes the use of automated clash detection tools did not seem to offer the students much advantage. The ability to detect relevant clashes of the students that used the non-organized model even significantly decrease with respect to the traditional method of using 2D drawings.

6. SUGGESTIONS FOR FUTURE RESEARCH

How relevant this finding is within practical settings remains questionable and only similar experiments that include a number of other possible factors can provide an answer to this questions. It would, for example, be interesting to see how different expertise levels of participants would change the results of the experiment. In the here presented experiment none of the participants had any significant experience with reading drawings or with using automated clash detection software. Further, it would be interesting to explore how project complexity influences the outcomes of the experiment. Currently, the experiment is based on a relatively simple office building. Much of the literature that has described the benefits of clash detection on much more complex projects, such as hospitals. Another point of interest might be the comparison of different structures to organize input models. At the moment, the experiment only uses one, admittedly rather arbitrary choice, classification scheme as basis for the organization of the 3D model. Finally, it would be interesting to explore the influence of different clash detection applications on the experiment results. Such experiments could then, in turn, yield valuable findings about how to best develop clash detection programs and user interfaces. Next to conducting experiments that isolate the above variables, researchers should also follow practitioners closely and critically during the application of automated clash detection tools in practice, best using ethnographic action research methods (Hartmann et al. 2009). Such efforts have the potential to yield in depth findings that account for the real world complexities that practitioners encounter in project settings and that can complement the results of lab experiments, such as the one presented here. For now, unless research as the one outlined above provides different results than the one we provide with our experiment, the utility of applying automated clash detection applications during design coordination efforts should be carefully questioned by practitioners.

Next to these rather practical conclusions that derive directly from the findings, the results of the experiment also open up possibilities for more theoretical discussions and future avenues for research. The findings, for example, point to a shortcoming of the 3D model based process. Due to the increased amount of visual information within a 3D model it gets increasingly hard to understand and navigate 3D models. Additionally, the experiment's results show that it becomes increasingly hard to distinguish between the different systems a specific 3D model object belongs to. Even with an improved model organization the identification of an object's system remains cumbersome and students identified many irrelevant clashes between the same systems as relevant. In contrast to 3D models, 2D drawings are custom build representations of construction designs that engineers specifically generated to communicate designs and to compare different systems. It seems as such purposefully generated 2D drawings seem to be valuable visualizations of project designs that might, in certain cases, exceed the value that information rich 3D models offer.

Further, the findings are, for example, interesting because they point towards a general difference in the underlying search approach between the two methods. The identification of relevant clashes using automated clash detection tools requires search heuristics that allow engineers to identify those clashes that will impede the constructability of the system from a large number of physical clashes between objects that might or might not cause problems. The identification of clashes within 2D drawings require search heuristics that allow engineers to directly identify relevant clashes. What method engineers in practice prefer is questionable, but the experiment shows that the choice of methods does not matter much for laypersons with little experience. Future, researchers should focus on different heuristics that engineers can use to identify system clashes.

7. CONCLUSION

This paper presents the outcomes of a lab experiment that we conducted with a class of Bachelor students to explore the utility of automated clash detection applications during the coordination of building construction designs. One third of the meetings participants tried to identify clashes in the design of an office building using the original 2D design drawings. The other two thirds of the students used an automated clash detection tool (Autodesk Navisworks) to find the same conflicts. Of these two thirds of the students, half used an unorganized 3D model as input to the clash detection software, while the other half used an by us specifically organized 3D input model. The outcomes of the experiment show no statistically different results between the average number of clashes between students of each of the groups. The findings of the experiment challenge the benefits of 3D based clash detection software to improve the design coordination process that the software industry, but also researchers, have put forward in the last couple of years.

Of course, the relevance of one relatively simple lab experiment with students for practical design coordination work should be carefully questioned. We believe that the research community should seriously analyze the outcomes of the experiment and critically question the real benefit of the application of automated clash detection tools in practice. Researchers have put forward the resistance of practitioners as one of the main barriers to the implementation of clash detection tools in practice. Maybe there is some truth to this resistance and the utility of automated clash detection applications is not as good as it is commonly represented by advocates of the technology.

In the same line, researchers and practitioners alike, should be aware of benefits that the application of clash detection software can offer during design coordination efforts that go beyond the technical identification of relevant clashes. One of the big advantages that clash detection software can offer on projects is its use as boundary object that allows a better and more seamless coordination of different disciplines participating on a building project (Evenstein & Whyte 2009). The automated detection of clashes and in particular the possibilities to clearly visualize clashes in 3D makes the process of design coordination transparent to all participants and thus might lead to a better acceptance of the found clashes. This better acceptance, in turn, might lead to a quicker resolution of conflicts and to less discussion among the different design parties about who is responsible to resolve which clash.

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