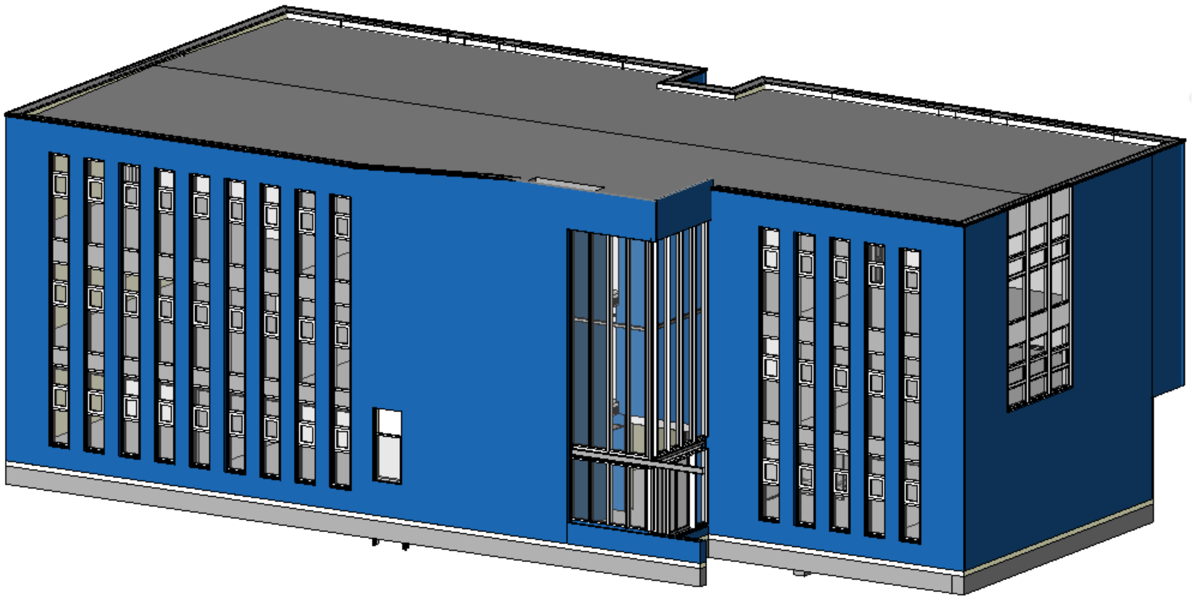
Organizing 3D Building Information Models with the help of Work Breakdown Structures to improve the Clash Detection process



Final Report

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Summary

Lately, there are more and more experts who advocate the advantages of Building Information Modeling. A 3D Building Information Model (BIM) gives a clearer insight in the composition of the different building systems such as the architectural, structural, and installation system. One of the applications of Building Information Modeling is Clash Detection; the automated detection of clashes to control systems coordination. Conducting a Clash Detection generates a collection of clashes which occur between elements in the 3D BIM. Khanzode et al (2006) claim that using a 3D BIM gives better results in finding relevant clashes after conducting a Clash Detection than comparing and controlling 2D drawings. When BIM coordinators who care for a good system coordination within 3D BIMs conduct a Clash Detection and find relevant clashes before the execution stage they will avoid change order costs and delays.

However, BIM coordinators who conduct Clash Detections using 3D BIMs experience problems. Because of complex designs Clash Detections can provide large amounts of clashes. Therefore, filtering out the relevant clashes that cause change orders is a cumbersome process. To filter out clashes BIM coordinators select groups of elements out of the 3D BIMs to clash with each other. However, if 3D BIMs don't have a clear organization structure it is difficult for BIM coordinators to make useful selections.

To make it easier to focus on relevant groups to clash with each other and find relevant clashes I developed a new classification based on the properties of a Work Breakdown Structure. To develop a new classification I used the standard groups of the Dutch NEN 2634 construction classification for cost calculation. To create a better organization structure according to Work Breakdown Structures I assigned to each standard group a responsible participant. After analyses I rearranged these groups according to their responsible participant and composed a schematic WBS. To apply this WBS as classification for organizing 3D BIMs I converted the standard WBS to table format and implemented it in the modeling software.

Having installed the new WBS based classification in modeling software such as Revit Architecture modelers will be able to organize the 3D BIM elements based on the new WBS based classification. When BIM coordinators conduct a Clash Detection to clash the different specialty designs with each other using an organized BIM they theoretically should find the relevant clashes more efficient and more accurate. I tested this hypothesis with an experiment based on one project concerning the construction of a new office building.

In the experiment 43 students, divided in three groups, conducted a Clash Detection in which one group used 2D drawings, one group used the unorganized 3D BIM, and one group used the organized 3D BIM. The results of this experiment show that the students who used the organized 3D BIM were able to find more clashes which caused change orders than students who used the two other forms. Besides, the students who used the unorganized 3D BIM scored a far lower average number of relevant clashes.

These results provide evidence for the benefit of an organized 3D BIM conducting a Clash Detection compared to the two other forms of Clash Detection. Using the new developed classification modelers have a better overview of what they are modeling and BIM coordinators benefit from the organized structure during the Clash Detection. BIM coordinators who conduct Clash Detections with organized 3D models don't experience cumbersome processes to trace the relevant clashes but are

able to clearly focus on groups of elements which are related to participants. This will create a more efficient and accurate Clash Detection process which results in less change orders.

Introduction

A new innovation in the construction industry is Building Information Modeling (BIM). This new project management form prescribes the creation of 3D Building Information Models to which construction participants as an architect, structural engineer, and installer add their system designs. Then, these Building Information Models function as the main source of information for the participants of the project. According to Hartmann, T., J. Gao, et al. (2008) the application of Building Information Modeling (BIM) in the construction industry leads to benefits in several areas during the project life cycle through improved visualization, systems coordination, cost calculation, and collaboration. However, Staub-French, S. and A. Khanzode (2007) claim that without demonstrating the benefits and providing guidelines for implementation it is difficult for participants to invest the resources necessary to adopt innovations such as Building Information Modeling.

The Clash Detection tool is an application of BIM which is useful for the coordination of systems within a 3D Building Information Model. It detects the clashes between different elements within a 3D Building Information Model. Traditionally, job preparators are responsible for the preparation activities for the execution stage as forming contracts with contractors, purchasing materials, and ensuring a good coordination and assembly order of the different systems of a project. To ensure a good system coordination job preparators compare 2D designs to find conflict situations/clashes between the specialty designs. Because the specialty participants develop their designs separately, comparing the designs on different drawings is a cumbersome process in which job preparators easily miss clashes. Some of these clashes result in change orders which cause delay and extra costs. Using a 3D Building Information Model and the Clash Detection application job preparators would be able to find these clashes better and more efficient.

However, during Clash Detections using 3D Building Information Models, job preparators experience problems. Because the large number of detected clashes it is difficult to find the relevant clashes. These relevant clashes are clashes that cause change orders that job preparators want to avoid. Organizing 3D Building Information Models may help job preparators to be able to better focus on these relevant clashes.

To test the finding of clashes three groups of students have conducted three different forms of Clash Detection during an experiment. One group used 2D designs on drawings, the second group used an unorganized 3D Building Information Model, and the last group used an organized 3D Building Information Model. After the experiment I analyzed and compared the results of the different Clash Detection forms.

I structured the paper as follows. Chapter 1 describes the research background and problem description. Then chapter 2 describes the research goal and method. In chapter 3 I present the results of the research which I discuss in chapter 4. Also I describe the limitations of the research in chapter 4. Chapter 5 gives the theoretical contributions of the research and in chapter 6 I describe practical conclusions. In chapter 7 I give some suggestions for future development and development.

1 Research background and problem description

1.1 Background

In the construction industry participants have to collaborate to successfully finish a project. In many projects the participants develop their designs according to the following order. The architect develops several designs based on the requirements of the principal. After the principal chooses and approves one design a structural engineer develops a structural system which corresponds to the architectural design. When these two system designs are ready the installation advisor develops an installation system design which integrates with the other two system designs.

According to Plume, J. and J. Mitchell (2007) many system coordination problems arise because the specialty participants develop their design separately and have an individual focus. Therefore, traditionally, job preparators compare and control the different specialty designs for conflict situations. In general, job preparators are responsible for the preparation activities for the execution stage as forming contract with contractors, purchasing materials, and ensuring a good coordination and assembly order of the different systems of a project. According to Khanzode et al (2006), ensuring a good coordination by comparing and controlling drawings is a cumbersome process in which job preparators easily make failures since they don't have a clear overview of the designs and their coordination related to each other. Missed conflict situations between different systems in the design stage can result in change orders during execution, which cost a lot of money and cause delay.

A Building Information Model (BIM) provides a better visualization by combining the specialty system designs in one 3D model. According to Azhar, S., A. Nadeem, et al. (2008) a Building Information Model is an object oriented digital representation of a facility. This makes it easier for job preparators to compare the different specialty systems to achieve a good system coordination. Having a project designed using 3D Building Information Modeling the task of system coordination transfers from the job preparator to the BIM coordinator. BIM coordinators can use the Navisworks Clash Detective tool to conduct a Clash Detection to realize a good system coordination. To realize useful results of a Clash Detection BIM coordinators follow a general Clash Detection process. In paragraph 1.2 I will outline this Clash Detection process and the problems which can occur, using 3D BIMs.

1.2 The Clash Detection process and occurring problems

During a Clash Detection job preparators in case of designs on 2D drawings and BIM coordinators in case of 3D designs compare the different system designs to detect clashes. In both cases not all clashes are relevant to find. The real important clashes job preparators and BIM coordinators must find are the clashes which cause change orders during the execution stage. These clashes I will call relevant clashes. A relevant clash is a clash which occurs between at least two elements and results in a change order in the execution stage in case the BIM coordinator does not detect the clash and/or the responsible participant does not solve the clash. To find these relevant clashes job preparators and BIM coordinators focus at points in the designs where different systems interfere with each other. Examples of relevant clashes which can occur are:

- The ventilation system does not fit between the floor and the false ceiling and clashes with the false ceiling (Figure 1);

- Ducts/pipes which cross supporting walls have a profile that causes problems to cut off such large openings (Figure 2);
- Different installation systems run through each other.

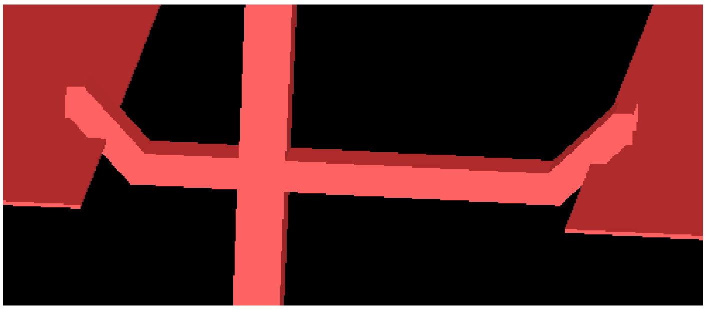

Figure 1 Clash between ventilation shaft and false ceiling

Figure 2 Clash between ventilation shaft and supporting wall

When these clashes occur during the execution stage this will cause change orders which delay the project and cost extra money. Then, executing contractors have to solve the clash in practice. Besides the delay and extra costs the decisions are pressurized and result in unsatisfied solutions. Therefore, it is necessary for job preparators and BIM coordinators to avoid these clashes by finding them during the design stage by conducting a Clash Detection. After finding the relevant clashes job preparators and BIM coordinators are able to give specialty participants the assignment to adjust their design at the clash location.

However, unless the benefits of Clash Detections using BIMs, during the Clash Detection processes using a 3D BIMs, BIM coordinators experience some problems. When BIM coordinators conduct Clash Detections the automated Clash Detection often detects large amounts of clashes which are not all relevant. The large amount of irrelevant clashes retains BIM coordinators to easily find the relevant clashes. Besides, when BIM coordinators conduct Clash Detections it is not always immediately clear to which responsible participant the elements within the 3D BIM belong. This hinders BIM coordinators when they have to assign responsible participants to change their design after the identification of relevant clashes.

To solve or reduce the described problems around Clash Detections BIMs may need an organization structure. Having organized Building Information Models may improve the performance of BIM coordinators conducting Clash Detections. An organized BIM would result in faster tracing of relevant clashes and tracing relevant clashes more accurate. This organization structure offers modelers the opportunity to assign each element to a certain standard group which relates to the responsible participant of that element. Then it is possible for BIM coordinators to more efficiently extract useful information out of 3D Building Information Models during Clash Detections. The Systems Engineering (SE) approach may be an appropriate method to organize 3D BIMs. According to the book Fundamentals of Systems Engineering of the Department of Defense (pages 45-60 and 85-140) (2001) the SE approach builds up/decomposes a project in manageable parts (systems/subsystems/etc.) and prescribes "system analysis and control" tools which guide the preconstruction route. One of these system analysis and control tools is the Work Breakdown Structure (WBS).

1.3 Work Breakdown Structure (WBS)

The Work Breakdown Structure is an appropriate tool which may contribute to organize a 3D Building Information Model. According to Bachy and Hameri (1997) a project organization benefits from a Work Breakdown Structure (WBS) because the WBS forms the central activity tree which reflects the activities to execute in order to complete a project. To compose a WBS a project organization needs to take several steps. According to Bachy and Hameri (1997) the steps to develop a Work Breakdown Structure are the following:

1. Product Breakdown Structure (PBS; physical object tree)
2. Assembly Breakdown Structure (ABS)
3. Work Breakdown Structure (WBS)

To develop a Work Breakdown Structure step 1 is to develop a Product Breakdown Structure (PBS) or physical object tree. In the PBS the project organization divides the final object in physical systems, components, and elements. When the PBS is complete the assembly analysis of the different PBS objects results in step 2: the Assembly Breakdown Structure (ABS). The ABS provides information for the order of activities to achieve the final goal. At this point project managers are able to compose the Work Breakdown Structure by merging the PBS and ABS. The WBS starts with the project or end objective and subdivides the project objective in objectives. Then, the objectives contain sub objectives which consist of the activities. These activities combine the information of the PBS and ABS while describing how an executing team should create a physical system or sub system (PBS) in which order (ABS)(Figure 3).

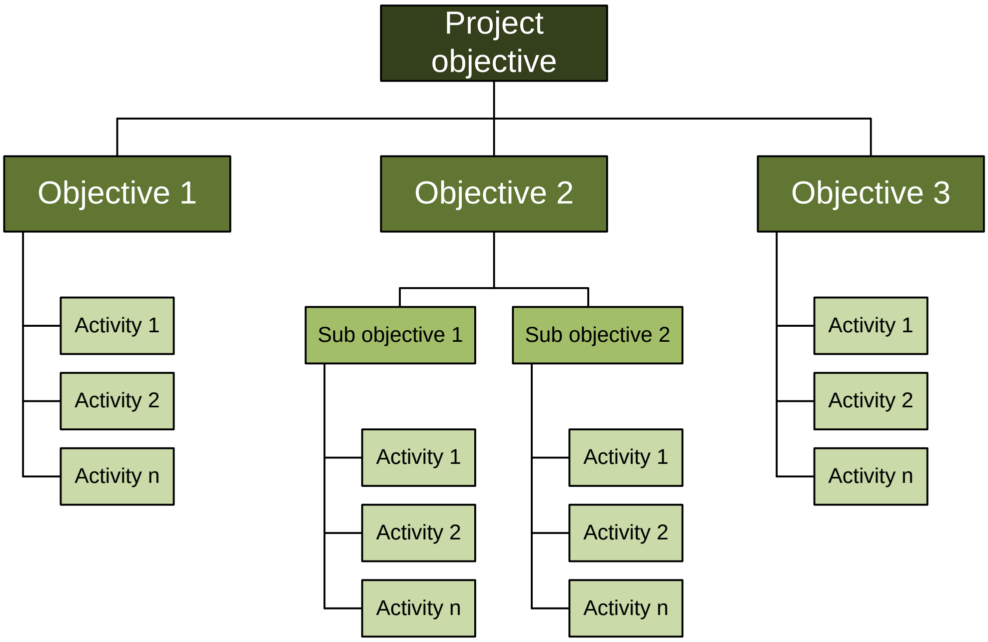

Figure 3 Work Breakdown Structure

When the composition of the objectives and activities is complete the WBS developer can assign the responsible participants to the activities to complete the WBS. After assigning the responsible participants to the activities step 4 is to develop the Organizational Breakdown Structure (OBS). Combining the WBS and OBS results in step 5: the project schedule (Figure 4).

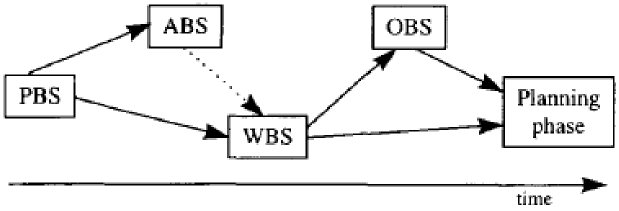

Figure 4 Steps to develop the project schedule (Bachy and Hameri, 1997)

1.4 Developing a WBS

Before developing the WBS I reconsidered the problem situation during the Clash Detection process. The WBS should contribute to the organization structure of 3D Building Information Models.

In modeling software such as Revit Architecture it is possible for modelers to assign model elements to standard groups of a standard classification by giving the elements an Assembly Code. The classification used in Revit contains the following standard main groups: ’Substructure’, ‘Shell’, ‘Interiors’, ‘Services’, ‘Equipment and furnishings’, ‘Special construction and demolition’, and ‘Building sitework‘. These groups do not focus on systems or responsible participants. To create a better organization structure two aspects are necessary: a participant information containing structure of the WBS and a division of standard groups. The combination of these two aspects should create the ideal classification to organize a 3D Building Information Model with to contribute to improve Clash Detections.

In fact, the Revit classification represents a Product Breakdown Structure composed by the standard Revit classification groups. According to Bachy and Hameri composing a Product Breakdown Structure is **step 1** to develop a Work Breakdown Structure. To create a Product Breakdown Structure which improves the structure compared to the Revit classification but still reflects standard groups I started to analyze other classifications. Because a Dutch company provided the project to do research to I analyzed two Dutch construction classifications of which the NEN 2634 pointed out to be the most appropriate. Just like the Revit classification I consider the NEN 2634 classification, developed for cost calculation of house and utilitarian construction projects, as a standard Product Breakdown Structure in table format. This means that the NEN 2634 contains standard groups and sub groups at several levels which are comparable to the systems, subsystems, and elements of a standard PBS. The NEN 2634 classification divides house and utilitarian construction projects in manageable parts. Table 1 reflects the construction classification of the eight main groups the NEN 2634 prescribes.

<table>
<tr><th colspan="10">Construction classification according to NEN 2634</th></tr>
<tr><td rowspan="3">Soil (1)</td><td colspan="7">Costs of construction</td><td rowspan="3">Unfixed accomodations and industrial equipment (7)</td><td rowspan="3">Additional costs (8)</td></tr>
<tr><td rowspan="2">Construction works (2)</td><td colspan="3">Installations (3)</td><td rowspan="2">Fixed accomodations (4)</td><td rowspan="2">Site (5)</td><td rowspan="2">General execution costs (6)</td></tr>
<tr><td>Mechanical installations</td><td>Electrical installations</td><td>Elevator and transport</td></tr>
</table>

Table 1 Construction classification according to the NEN 2634

Table 2 reflects further details of the NEN 2634 construction classification of the groups Soil (1) and the subgroups 2A, 2B, and 2C of Construction works (2). This detailed classification splits the main groups into subgroups (level 2) by giving the code an extra letter. Those subgroups consist of element groups (level 3) and these element groups have a code with an extra number for each element group.

Code NEN2634	Description
1A	Procurement
1B	Infrastructural facilities
1C	Prepare site for building
1	Total soil
2A(11)	Soil facilities
2A(13)	Floors on foundation
2A(16)	Foundation constructions
2A(17)	Pile foundations
2AU	General Execution Costs
2A	Total foundation
2B(21)	Supporting external walls
2B(22)	Supporting internal walls
2B(23)	Supporting floors
2B(27)	Supporting roofs
2B(28)	Main carrying constructions
2BU	General Execution Costs
2B	Total framework
2C(27)	Roof completion structure
2C(37)	Roof openings
2C(47)	Roof completions
2CU	General Execution Costs
2C	Total roofs

Table 2 Building classification NEN 2634 detail level 3

This classification divides a construction project in several standard groups which embrace the construction activities based on categories, such as “Soil”, “Construction” and “Installation” (see Table 1 for the complete overview of the groups)

According to the steps of Bachy and Hameri, composing the Assembly Breakdown Structure would be **step 2**. However, the NEN 2634 classification which also functions as standard Product Breakdown Structure contains standard groups which are relevant for assigning modeled elements to. To create a clear organization structure in the 3D BIM it is not necessary to know the exact assembly order of the different 3D BIM elements during the execution stage. Therefore, step 2 was not relevant for this research.

During **step 3** I developed a WBS. Normally a Work Breakdown Structure consists of objectives, sub objectives, and activities/work packages. However, these objectives and work packages are project related. Besides, the NEN 2634 classification provides a standard Product Breakdown Structure containing standard groups which are appropriate to assign BIM elements to. Therefore, it is redundant to rewrite these standard groups in objectives. Thus, the standard PBS containing the standard NEN 2634 classification groups formed the basis of a standard WBS. To create a better organization structure I analyzed the structure of the standard PBS.

Analyzing the groups of the standard PBS the groups did not clearly relate to a specialty participant. To make clear which participant is responsible for which standard group I assigned the corresponding specialty participants (Principal, Architect, Stuctural Engineer, and Installation advisor/executor) to the groups of the standard PBS. To make directly clear which participant is responsible for a certain standard group I added an extra symbol to the NEN codes to start the codes with:

- O = Principal (Dutch: Opdrachtgever)
- A = Architect (Dutch: Architect)
- C = Structural engineer (Dutch: Constructeur)
- I = Installation advisor/executor (Dutch: Installateur)

During the assigning of the responsible participants to the standard groups I remarked that the NEN 2634 classification shares the group 'Elevator and transport' under the Installation advisor/executor. However, during the design stage of a construction project architects have the responsibility for the group 'Elevator and transport' because they have to take account for enough space for the installation of elevator and transport systems. Therefore, I adjusted the classification by adding the group A3 Installations to the Architect and sharing the group 'Elevator and transport' with code 'A3C' under A3 Installations. Also I inserted extra groups named Structural Engineer with code 'C' and Structural design with code 'C2'; the Structural Engineer is responsible for the construction works 'Foundation' and 'Framework'. Table 3 reflects the adjustments and shows the division of the new classification based on participant information according a WBS.

Division of standard groups according to the NEN 2634		
A	2	Construction works
C	2A	Foundation
C	2B	Framework
A	2C	Roofs
A	2D	Facades
A	2E	Internal walls
A	2F	Floors
A	2G	Escalators and
A	2H	Ceilings
I	3	Installations
I	3A	Mechanical installations
I	3B	Electrotechnical installations
A	3C	Elevator and transport

New classification based on WBS structure		
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

Table 3 Adjustments to the standard groups of the NEN 2634

After rearranging the groups I finished step 3 and created a new standard classification based on the properties of a WBS that modelers can use as classification after implementation in Revit Architecture (for implementation see Appendix 9.1).

Having the combination of the standard groups of the NEN 2634 and the added corresponding participants I also composed a schematic form of the standard Work Breakdown Structure. Figure 5 reflects the first tree levels of this standard WBS which divides projects at the second level in four participants. The third level contains the first level standard groups of the NEN 2634 implying the main responsibilities which I shared under the corresponding participant.

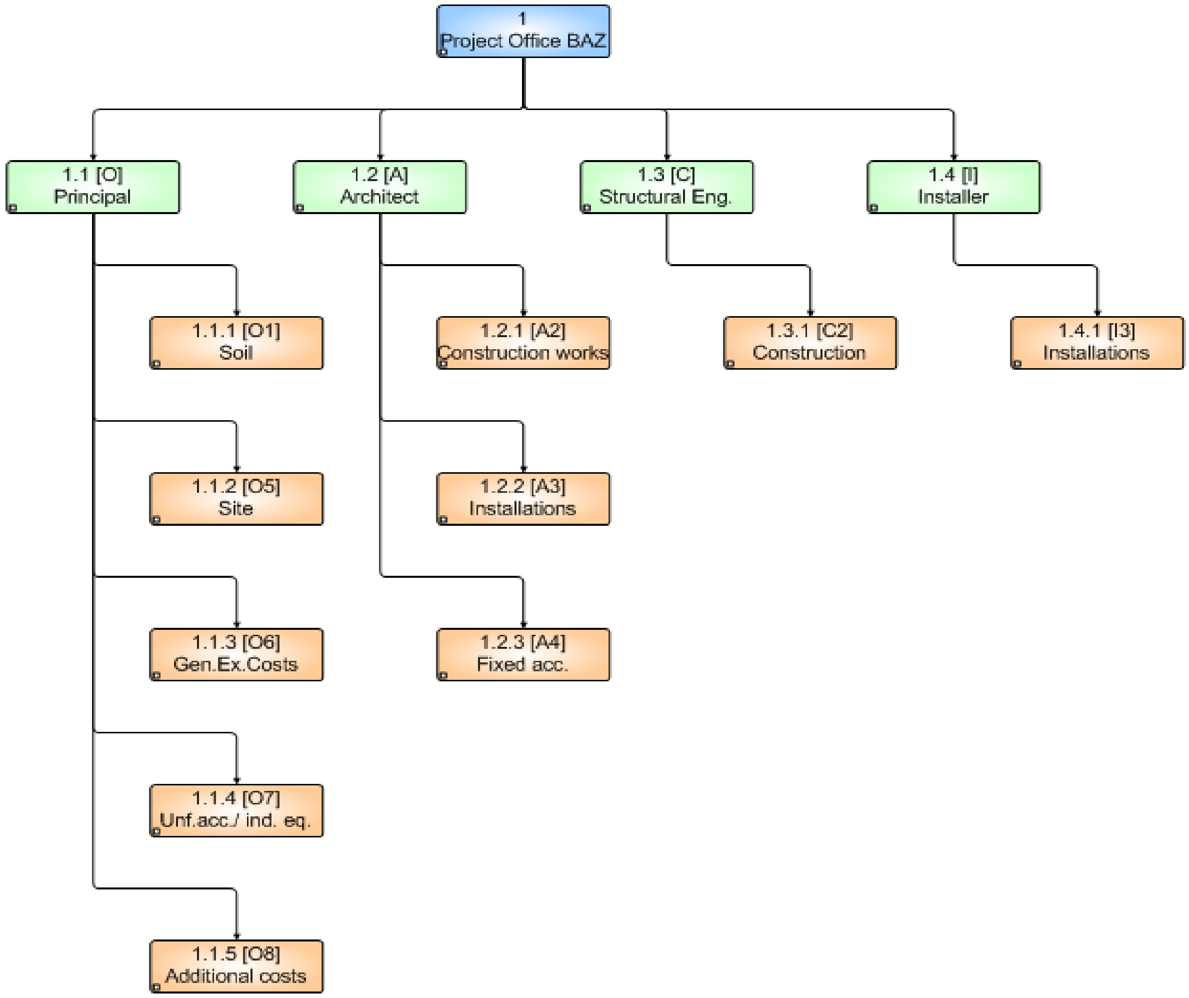

Figure 5 WBS containing the levels project, participants and main responsibilities

The new developed WBS based classification consists of five levels standard groups which all originate from the NEN 2634 classification (For the total overview of the new classification see Appendix 9.3). The standard WBS involves the division of participants at the second level instead of linking a participant to a work package.

Having installed the new classification based on the developed WBS in Navisworks modelers will be able to build up their 3D BIM and organize the elements according to the new classification containing participant related standard groups. When BIM coordinators conduct Clash Detections and clash the different specialty designs with each other using an organized 3D BIM they are able to focus on participant related systems and sub systems. Therefore, they theoretically should find the relevant clashes more efficient and more accurate. In this research I tested this hypothesis by carrying out an experiment. Chapter 2 presents the goal and the method of this research.

2 Research goal and method

2.1 Research goal

During the research I compared three different Clash Detection forms: a Clash Detection using 2D drawings, a Clash Detection using an unorganized 3D Building Information Model (3D BIM A), and a Clash Detection using an organized 3D Building Information Model (3D BIM B). To compare the different forms of Clash Detection 43 students conducted the Clash Detection forms using the same project. A Dutch construction advisory company lately finished their own office building project.

For the office building design the company attracted an Architect, a Structural Engineer, and an Installation advisor. Those three participants developed their specialty system design. The office building has a length of 33,3m, a width of 18,3m, and a height of 11,7m and consists of three floors with large open plan office spaces. In the office project the construction advisory company coordinated the participants who developed their system designs in 2D. After the execution stage an intern modeler developed a 3D BIM of the office based on the 2D designs. The 3D BIM is almost similar to the 2D drawings except of the installation system; the modeler only designed the Heating, Ventilation and Air Conditioning system (HVAC) in the 3D BIM. The modeler did not add the plumbing, sprinkler, electricity, and gas installation system.

The reason to choose for this project is that there are not so many projects available which have the specialty designs on drawings and have a similar designed 3D Building Information Model. Because the office project was the company's property these two designs were available for research which made the office project appropriate to use for the experiment. Furthermore, the building is not a complex building. A too complex project would be more difficult for students to overlook. Then it would be too hard for the students to create a perception of which clashes are important.

Having 2D designs on drawings, the unorganized 3D Building Information Model the internal modeler developed, and the 3D Building Information Model organized according to the new classification based on the standard WBS, it was possible to compare three different ways of Clash Detection on the same project.

The goal of this research is to test the hypothesis that BIM coordinators find relevant clashes more efficient and accurate when they conduct a Clash Detection using an organized 3D BIM compared to an unorganized 3D BIM and 2D drawings. To compare the different Clash Detection forms three groups of students (total of 43 students) each conducted a different Clash Detection form during an experiment.

2.2 Research method: the Clash Detection experiment

During a one hour lasting experiment three groups of students conducted each a different Clash Detection form in which they had the assignment to note the important clashes they found. The 43 students who participated to the experiment were all unprepared and unprejudiced. The students did not get information about the project or the activities they would do during the experiment, before the start of the experiment. Now all students had the same point of departure at the start of the experiment which ensures better comparable results compared to a situation in which the 43 students were partly prepared and/or prejudiced because of pre knowledge.

Before the experiment I gave the students a general Clash Detection guideline derived from experts of the construction advisory company which would help them to find important and relevant clashes. The Clash Detection guideline explained that a clash is relevant when the clash would result in a change order when not solved. The guideline recommended to clash different building systems and subsystems with each other to find relevant clashes. Further, the guideline prescribed 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, to process the clashes for further actions and to be able to trace back the clashes (For the guideline see Appendix 9.1).

For the students who executed the Clash Detection experiment using 2D drawings the designs of the Architect, Structural Engineer, and Installer were available in 2D. The students who had to use 3D BIMs had to conduct a Clash Detection using Navisworks software. Navisworks contains a Clash Detective application which detects clashes between elements of the model. Each student had to find out which conflict situations occurred in the Building Information Model that the internal modeler developed. For both 3D BIMs an extra guideline about Navisworks informed the students how to clash different groups with each other.

3 Results

After the experiment all the students submitted the most important clashes and noted the location, the names of the elements, the elements’ ID’s, the elements’ participants, and the distance of overlap. Having this information I traced back every clash they found. Analyzing these clashes I distinguished the clashes based on relevancy of the clash by dividing the clashes in four categories; “overall number of clashes”, ”number of clashes between different systems”, “number of relevant clashes”, and “number of clashes which caused a change order in the execution stage”.

After analyzing and distinguishing the clashes I calculated the averages of each category. Figure 6 and Table 4 reflect the results of these averages for each clash category based on the Clash Detection form.

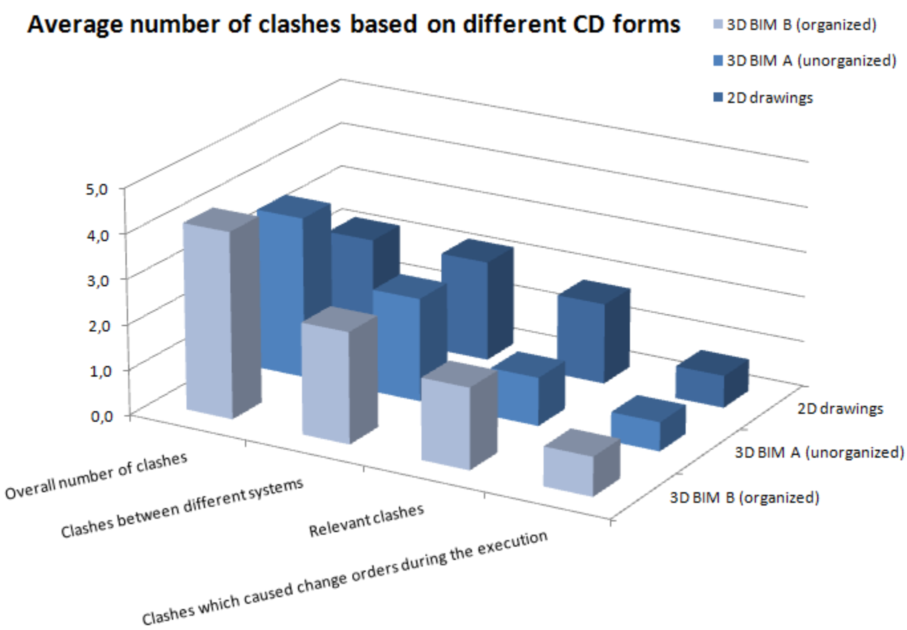

Figure 6 Average number of clashes based on different Clash Detection forms

Table of average numbers of clashes	Overall clashes	Clashes between different systems	Relevant clashes	Clashes caused change orders
Av. nr. of clashes 2D drawings	**2,2**	**2,2**	**1,8**	**0,7**
Av. nr. of clashes 3D BIM A (unorganized)	**3,6**	**2,3**	**1,1**	**0,6**
Av. nr. of clashes 3D BIM B (organized)	**4,1**	**2,5**	**1,8**	**0,9**

Table 4 Average number of clashes based on different Clash Detection forms

From these averages, the following results are important to take into account:

- *The average overall numbers of clashes of students who used the 3D BIMs A and B (respectively 3,6 and 4,1) are higher than the average number of clashes of students who used 2D drawings (2,2);*

- *The average number of clashes between different systems of students who used 2D drawings is almost the same (2,2) as the average numbers of clashes between systems of students who used the 3D Building Information Models A and B (respectively 2,3 and 2,5);*

- *Students who used 3D Building Information Model B found the same average number of relevant clashes as the students who used 2D drawings (1,8.) These averages of relevant clashes are higher than the average of relevant clashes the students found who used the 3D BIM A (1,1);*

- *Students who used 3D Building Information Model B were able to find an average of 0,9 clashes which caused a change order in reality. The students who used the 2D drawings and 3D Building Information Model A scored lower averages (respectively 0,8 and 0,6) of clashes which caused change orders in reality.*

4 Discussion

After collecting the data of the experiment, the results which I summed up in chapter 3 are interesting to discuss. The italic parts reflect the results of chapter 3 which I will discuss in this chapter.

- *The average overall number of clashes of students who used the 3D BIMs A and B (respectively 3,6 and 4,1) are higher than the average number of clashes of students who used 2D drawings (2,2);*

During the one hour experiment the students who conducted a Clash Detection using one of the two 3D BIMs first had to find out how to handle the 3D software with help of a short guideline. After learning the 3D software their Clash Detections produced large amounts of clashes. Then, they had to find a way to focus on relevant clashes and make a selection of the clashes to fill in the table. The students who used the 2D drawings had to find out which drawings were comparable and how they should compare the drawings to find clashes. Thus, both groups experienced starting up problems.

Although both groups had the same amount of time to conduct the Clash Detection, and both groups experienced starting up problems, the Clash Detections using 3D BIMs provide more results of clashes than finding clashes using 2D drawings. Students who used the Navisworks Clash Detection could passively search for clashes because they only had to make two selection groups and wait for the automated Clash generation of the software. Afterwards, the students could filter out the important clashes. The students who compared the 2D drawings actively had to find clashes. This process results in a slower clash generation and resulted in the lower value of overall number of clashes found by students who used 2D drawings. This is probably the reason of the higher average numbers of overall clashes of the students who used 3D BIMs.

- *The average number of clashes between different systems of students who used 2D drawings is the same as the average overall number of clashes of students who used 2D drawings (2,2), and this value is almost the same as the average numbers of clashes between systems of students who used the 3D Building Information Models A and B (respectively 2,3 and 2,5);*

At first, it is not surprising that the averages of the overall number of clashes and the number of clashes between different systems of the students who used 2D drawings have the same value (2,2). The attached general Clash Detection guideline recommended the students to search for clashes between different systems. Therefore, the students who used the 2D drawings actively searched for clashes comparing the drawings of different systems/participants and generated clashes which only occurred between different systems.

The average numbers of clashes between different systems concerning the three Clash Detection forms only have a small difference which has the following reasons. Despite of the ease of the automated clash generation by using the Navisworks Clash Detection applied on 3D BIMs, the students who used the unorganized 3D BIM A were apparently not able to find many clashes between different systems. This is a result of 3D BIM A not having a clear structure containing different systems. Therefore several students who used the unorganized 3D BIM A did not have clear opportunities to search for groups of elements of different systems to select and clash these groups with each other. Therefore the Clash Detections using 3D BIM A consisted of many clashes within a system.

The students who used the organized 3D BIM B had better opportunities to distinguish the different systems. However, it was still possible to clash groups within the same system. Probably, students also thought they found important clashes within systems or forgot/ignored the implications of the general Clash Detection guideline. Therefore, the percentage of the average numbers of clashes between different systems in relation to the overall average number of clashes of the students who used 3D BIMs (unorganized 3D BIM A: 64% and organized 3D BIM B: 61%) is lower than that percentage of the students who used 2D drawings (100%). Therefore, probably, the average numbers of clashes between systems of students who used 3D BIMs exceed the average number of clashes of students who used 2D drawings less than I expected (See Table 4).

Despite of the inability to make a selection out of organized groups, the students who used 3D BIM A still managed to find the average of 2,3 clashes between different systems. Compared to the average of 2,5 clashes between different systems of students who used 3D BIM B, this is quite a good result. The reason for this can be that the students who used 3D BIM A generated a lot of clashes and chose to write up the clashes between different systems as the most important clashes, having in mind the general Clash Detection guideline recommendations.

Nevertheless, the students who used the 3D BIM B found the highest average number of clashes between different systems which is a result of the organization structure of 3D BIM B.

- *Students who used 3D Building Information Model B found the same average number of relevant clashes as the students who used 2D drawings (1,8.) These averages of relevant clashes are higher than the average of relevant clashes the students found who used the 3D BIM A (1,1);*

The students who used the organized 3D BIM B scored a higher average number of relevant clashes than the students who used the unorganized 3D BIM A (1,8 vs. 1,1). The students, who used the 3D BIM B, easier found relevant clashes, because of the organization structure of 3D BIM B. Therefore, compared to students who used 3D BIM A, they could easier focus on certain groups of elements within different systems to select, which often involved in relevant clashes. This makes the process of finding relevant clashes more efficient. Students who used 3D BIM A did not have a clear structure to focus on systems or participants for the selection of groups to clash with each other. Therefore the students who used the unorganized 3D BIM A generated many clashes and had trouble in finding relevant clashes in these large amounts of clashes during a Clash Detection.

Besides, the average number of relevant clashes of students who used 2D drawings and the average of relevant clashes of students who used the 3D BIM has the same value of 1,8. Because of the Clash Detection guideline the students who used 2D drawings did not look for clashes within a drawing. Because in this experiment a drawing belonged to one participant, it was not logical for students to look on one drawing for clashes within a system. Therefore, all clashes which students found on 2D drawings were clashes between different drawings and therefore between different systems. Because the most relevant clashes occur between different systems, the average number of relevant clashes for students who used 2D drawings is high compared to the average number of clashes of students who used the organized 3D BIM B.

- *Students who used 3D Building Information Model B were able to find an average of 0,9 clashes which caused a change order in reality. The students who used the 2D drawings and 3D Building Information Model A scored lower averages (respectively 0,7 and 0,6) of clashes which caused change orders in reality;*

This result provides evidence for the benefit of an organized 3D BIM conducting a Clash Detection. The students who used the organized 3D BIM B found the highest average number of clashes which occurred in reality and caused change orders compared to students who used 2D drawings and the unorganized 3D BIM A. The outcome of the experiment indicates that using an organized BIM during a Clash Detection avoids more change orders than using 2D drawings or an unorganized 3D BIM (respectively 0,9 vs. 0,7 and 0,6).

To provide an overview of the frequency of the number of clashes found in different categories of Clash Detection forms I presented the outcome in a histogram. Figure 7 and Figure 8 give the histograms in which the different Clash Detection forms are given by the colored groups; blue group: 2D drawings; green group: unorganized 3D Model A; red group: organized 3D Model B. To make a distinction between the clash categories, I chose for a light/dark division for each group in four subgroups.

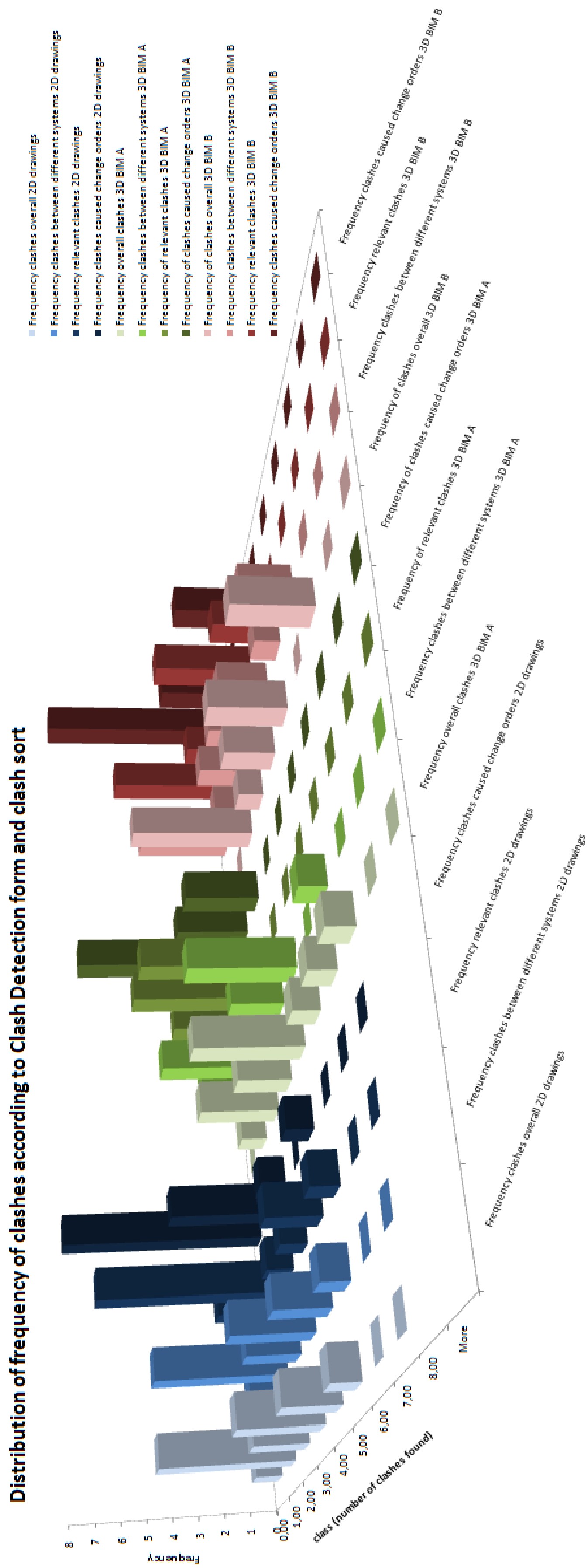

Figure 7 3D histogram; frequency of clashes found using different Clash Detection methods

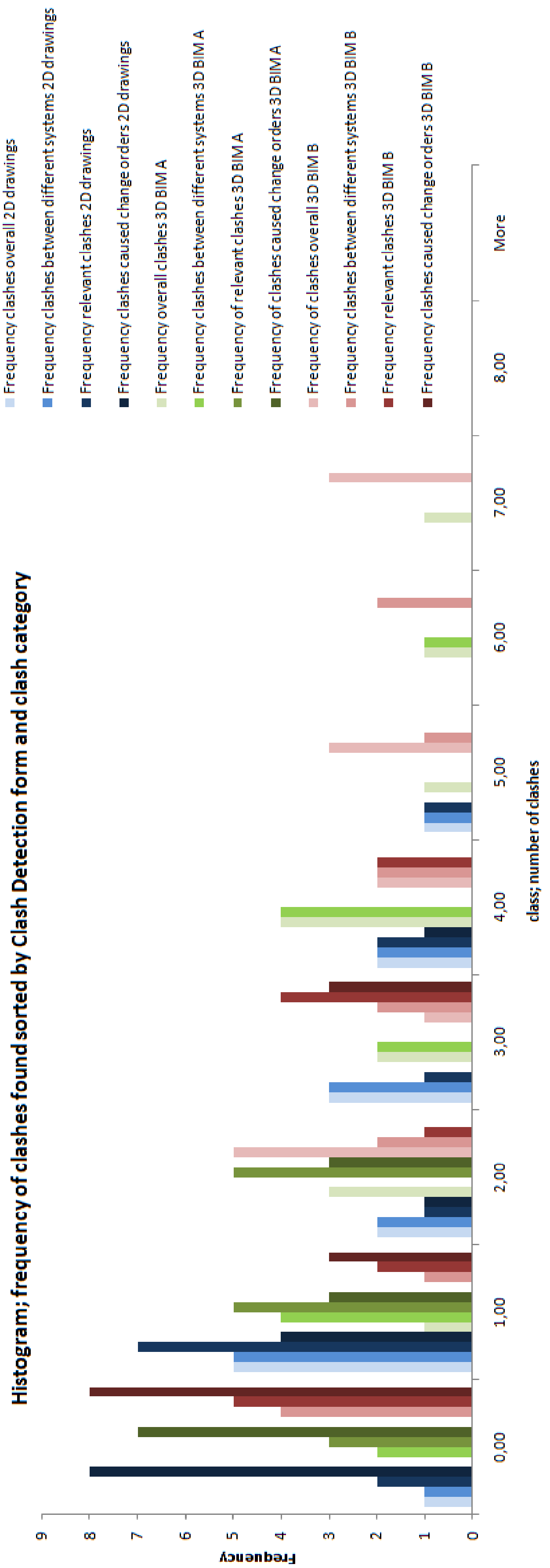

Figure 8 2D histogram; frequency of clashes found using different Clash Detection methods

Figure 8 provides the distribution of the blue, green and red group combined which indicates a positively skewed normal distribution (Howell, 2002). This means that the distribution's tail aims to the right indicating that the median value is larger than the mean value because there are many low values and a few extreme values. Apparently, several students had difficulty in finding clashes. Possible reasons for this can be time pressure, low skillfulness about technical drawings of 3D software or a lack of confidence to note the results they found.

The second aspect which is remarkable is that the extreme values belong to the Clash Detection forms which students conducted by using 3D BIMs. Apparently, some students who used 3D BIMs had the ability to learn fast or were already more familiar to 3D software and found more clash results and/or had more confidence to note these clashes.

In general, the total outcome has a positively skewed normal distribution. When you only look at the subgroups, which represent a clash category within a certain Clash Detection form, the distribution shows an irregular pattern. Using the population number of 43 students it is not possible to recognize a certain pattern in the outcome data when you first distinguish the results in Clash Detection forms and second divide the data of each Clash Detection form in clash categories. To be able to make more statistically valid conclusions, based on a certain pattern of the outcome, the population of students should be higher.

4.1 Limitations

The experiment, in which the students participated, had some limitations. The 3D Building Information Model which the students used for Clash Detection during the experiment did not contain the whole installation system. The internal modeler only designed the Heating Ventilation and Air Conditioning (HVAC) system. The only clashes that caused change orders during the execution that were traceable in the model were the clashes with the HVAC system involved. When the modeler would have implemented the whole installation system in the 3D BIM, the students would probably have found more clashes, and the conclusions would depend on the outcome of a larger number of (relevant) clashes.

Concerning the Clash Detections, the experiment consisted only of detecting hard clashes. A hard clash is the consequence of intersecting elements. In practice, there also exist clashes which occur because elements are too short for example. In Clash Detection software such as Navisworks these clashes are traceable by making special rules in the software but due to time limitations this seemed unfeasible.

Another limitation is the duration of the experiment. When the experiment had lasted for example 2 hours instead of 1 hour, the students who used the 2D drawings may have been able to find a few extra clashes. However, most of the students who conducted the Clash Detection using 2D drawings already found many clashes in relation to the clashes that were traceable. When I had prolonged the experiment with an extra hour, students would lose their focus and would also note clashes that are not valuable or that do not occur. The students who used the 3D BIMs would have generated better results by having an extra hour. Because the software and also conducting a Clash Detection was new to them, they did not have much time left to test the opportunities of the software. Besides, they did not have much time for comparing the clashes they generated and selection of the most important clashes. Nevertheless, during executing the experiment of one hour the students were all fully focused conducting a Clash Detection. Therefore, the one hour lasting experiment generated valuable outcomes of the students of all three groups, because all students needed their time and they were fully focused to conduct their Clash Detection form and to note their results.

This organization structure is especially necessary for Building Information Models that individual modelers have composed and which consist of one Revit file. Ideally, a Building Information Model should contain different systems designed by different specialty modelers. It is then possible for the BIM coordinator to load the different files in Revit and clash the different system designs with each other. This solution would result in a Clash Detection with only the clashes between different systems. When the modelers organize the specialty BIMs according to the new classification based on WBS properties, BIM coordinators have the opportunity to clash different sub groups within a specialty design with each other. Many relevant clashes could occur between two sub groups within a system, for example clashes between the electrical system and the HVAC system within the installation system. With an organized BIM it is also possible to focus on certain groups between different specialty systems ignoring the irrelevant clashes between those systems, for example clashes between the mechanical installation system with the walls and ceilings of the architectural system and thus ignoring isolation, roof, and floors. A BIM coordinator is now able to focus on groups between which relevant clashes probably occur.

5 Theoretical contributions

Because of the new classification based on the standard WBS, modelers are able to better organize 3D Building Information Models according to specialty systems and subsystems. The organization structure of the new classification originated from the structural properties of the Work Breakdown Structure and the addition of the standard classification groups of the NEN 2634. Because the new classification is general developed on standards every modeler is able to use it to structure 3D BIM's of every project.

However, the main goal is that organizing 3D BIMs has to be beneficial for BIM coordinators to detect the important clashes during a Clash Detection. The results of the Clash Detections which the students conducted during the experiment provide evidence for the improvement of the Clash Detection process. The students who conducted a Clash Detection using the organized 3D BIM detected more clashes which caused change orders during the execution stage than the students who conducted the other forms of Clash Detection. The students never conducted or observed Clash Detections before. This point of departure ensured a reliable comparison between the different ways of conducting a Clash Detection. However, in practice, not students but BIM coordinators should achieve better results because of organizing 3D BIMs. Because of the participant related system structure also BIM coordinators would be able to find relevant groups of elements or participant related subsystems/systems easier compared to an unorganized 3D BIM. Because of expertise BIM coordinators are better able to select these relevant groups to clash with each other than students and therefore have the ability to extract easier, more and better information of especially an organized 3D Building Information Model during a Clash Detection. When the different participants all design their system design according to the WBS based classification structure, BIM coordinators know what to expect about how the specialty modelers have composed their designs. In conclusion, having an organized 3D BIM ensures that BIM coordinators conduct Clash Detections more efficient and more accurate.

Another benefit of the new classification is that because of the WBS properties, a project organization can easier use the Building Information Model to create output specified to the different project participants. These outputs could be cost calculations, assembly orders, supply orders etc.

6 Practical implication

As I described in the introduction, several experts are convinced about the advantages of Building Information Modeling for the construction industry. When companies want to invest in this new way of working, they can benefit from BIM on at least the area of Clash Detection. The experiment with unprepared students showed that the students found more relevant clashes conducting a Clash Detection using the organized 3D model than the students who used the normal 3D model or 2D drawings.

Using this new classification, modelers have a better overview of what they are modeling and BIM coordinators benefit from the organized structure during the Clash Detection. BIM coordinators who conduct Clash Detections with organized 3D models don't experience cumbersome processes to trace the relevant clashes but are able to clearly focus on groups of elements which are related to participants. When BIM coordinators load Revit files in Navisworks, the Clash Detective tool in Navisworks is able to read the information of the Revit model. In case of an organized 3D BIM, Navisworks shows the Assembly codes which the modeler has assigned to all elements. The codification provides a clear overview and the modeler is able to easily distinguish the systems and subsystems of different specialty participants during a Clash Detection. Therefore, conducting a Clash Detection using a 3D Building Information Model organized by the new classification, results in a more efficient and accurate way to trace relevant clashes.

Besides, every project manager can use the new classification in the schematic standard WBS format to create a clear organization view of a project. The schematic standard WBS provides a clear view of the composition of the project. When modelers assign the elements of the model to the new classification, they could also place them as a new level in the standard WBS. When the BIM coordinator has filtered out the relevant clashes during a Clash Detection he is able to trace the clash causing subgroups in the schematic WBS. Then, the schematic WBS provides information about the clashing subgroups and the related subgroups. The clear overview of the WBS may help BIM coordinators in finding solutions for the clashes that are relevant.

7 Suggestions for future research and development

This research provides evidence for the positive contribution of the WBS as Systems Engineering tool to structure 3D BIMs. Based on literature research, the WBS pointed out to be the most appropriate Systems Engineering tool to apply for organizing 3D BIM's to improve the results of Clash Detection. However, it can be useful to do further research to the implementation of Work Breakdown Structures or other organizing (Systems Engineering) tools in 3D models. Because projects become more complex BIM coordinators will have more problems in finding all relevant clashes. Organizing 3D BIM's will provide a clear base which BIM coordinators can use to efficiently find important information. Because there are also relevant clashes which occur because of a wrong assembly order of elements this could also be a research area to analyze further. Because of these assembly clashes current project organizations develop 4D Building Information Models adding a time-component to the BIM. Using 4D BIMs, the BIM needs an adapted classification which also divides the standard groups according to the time of assembling of that element. The development of an Assembly Breakdown Structure would help to develop a new classification including the time aspect.

Furthermore, during this research I based the new developed classification on properties of a Work Breakdown Structure and the Dutch construction classification NEN 2634. Recently, Stabu, another Dutch construction classification innovated their classification by renewing the codification and detailed the groups further. When modelers are going to use the new Stabu classification they can change the new developed WBS based classification according to the standard groups that Stabu uses. I recommend to structure these standard groups also according to the participant related composition based on the properties of Work Breakdown Structures (Figure 5). While developing a classification using Stabu standard groups I suggest to do research to the detail of the classification a 3D Building Information Model still provides benefits to the Clash Detection process.

8 References

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Dutch construction directive NEN 2634

Dutch construction directive Stabu

9 Appendices

9.1 Experiment Clash Detection assignment

In 2007 BAZ started to develop plans for a new office. As process coordinator, BAZ functioned as job preparator and executor. In the execution stage, BAZ guided the contractor's employees as executor. For the project, every participant delivered their designs on 2D drawings.

When the execution stage started, BAZ decided to develop a 3D Building Information Model (BIM), to show the advantages of using a 3D BIM. Normally, when a principal wants to execute the project using BIM, the architect, structural engineer and the installation advisor/executor have to deliver their designs in 3D. A BIM coordinator then controls the integration of those designs in one 3D BIM. Doing so, a BIM coordinator conducts a Clash Detection using software such as Navisworks. Using a 3D BIM the BIM coordinator should be able to clearly compare the different designs and identify conflict situations between elements of the architectural, structural and installation designs.

For the BAZ office, an internal BIM modeler developed the office in 3D by modeling the drawings in Revit Architecture. The modeler could start the 3D modeling after the final designs were ready, and at the same time the execution stage started. Therefore BAZ could not use the 3D model for a Clash Detection before the execution stage. Unfortunately, because during the execution, there occurred several conflict situations, for which BAZ had change orders with costs of about € 20.000,-.

9.1.1 Indications to conduct a Clash Detection

During this experiment one group of students will execute a Clash Detection according the traditional way of building (traditional contract), which means to execute a Clash Detection using 2D drawings of the office. One other group has to execute a Clash Detection using the existing 3D model of the BAZ office. The third group has to execute a Clash Detection using a 3D model organized according to the structure properties of a Work Breakdown Structure. To know how to identify important clashes, I made a general Clash Detection guideline, derived from experts within the company of BAZ.

General Clash Detection guideline

In advance, it is necessary to have a good understanding of how a job preparatory or BIM coordinator conducts a Clash Detection in general. There are some standard rules which can help to execute a sound Clash Detection and the following overview reflects a guideline:

- To extract useful information out of a Clash Detection, it is recommended to clash relevant groups of elements to each other; clash different building systems to each other. A clash is relevant when the clash would result in a change order when not solved. Examples of relevant clashes which regularly occur:
    - Installation system element with architectural element;
    - Installation system element with structural element;
    - Structural element with Architectural element.
- To process a clash for further actions note the following information about a clash:
    - Location's;
        - Level;
        - Room/part of the level

- Elements';
    - Name;
    - Element's ID;
    - To which participant belongs the element?
- Measure/note distance of overlap.

When you use this guideline to conduct a Clash Detection, you will find more relevant clashes.

9.2 Installation of the new classification

9.2.1 How to install the new classification

The developers of Revit have integrated a standard Uniformat Classifications WordPad file in Revit. Modelers normally can choose the classification groups of this file. To be able to use the new developed classification containing participant related standard groups based on the structure of Work Breakdown Structures, I converted the new classification to a WordPad file. To enable Revit to read this file, you need to rename the old Uniformat Classification file to Uniformat Classifications_original. Then you have to save the new file as Uniformat Classifications in the map C/Program files/Autodesk Revit Architecture 2010/Program/.

9.2.2 How to use the new classification

9.2.2.1 Assign Assembly codes to the project elements

When BIM coordinators want to clash the designs of the different participants to each other, or they want to clash a group of elements of one responsible participant with a group of elements of another responsible participant, the modeler in Revit needs to assign the right Assembly Codes to each element. When there are more designing participants, it is recommended to convince them of assigning an Assembly Code to each element and using the same new developed classification.

Assigning an Assembly Code to an element is not a cumbersome activity. When the modeler has drawn an element in the design, the modeler rightclicks on the element and navigates to properties. When the modeler clicks on Type properties Figure 9 shows up.

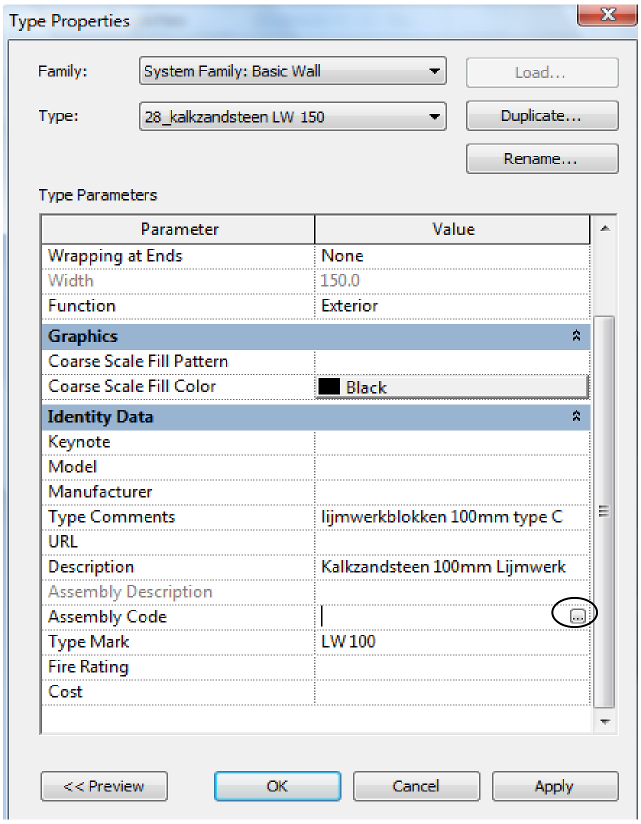

Figure 9 Type properties

Click on the encircled button. Then Figure 10 shows up.

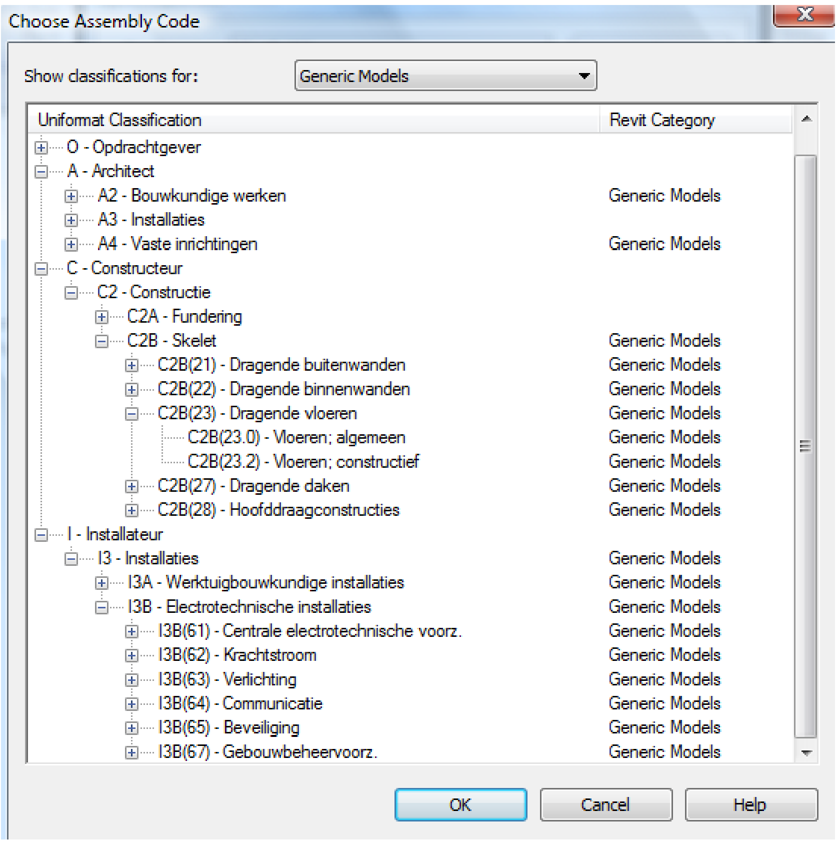

Figure 10 Choose Assembly Code

The modeler has to choose the right group out of the Classifications tree to assign to an element. Now the modeler has assigned an Assembly Code to the element which shows the responsible participant by the first letter:

- O = Principal (Dutch: Opdrachtgever)
- A = Architect (Dutch: Architect)
- C = Structural Engineer (Dutch: Constructeur)
- I = Installation advisor/executor (Dutch: Installateur)

9.2.2.2 Clash Detection in Navisworks

When modelers assigned an Assembly Code to each element, it is possible for BIM coordinators to conduct a Clash Detection in Navisworks by choosing Assembly groups. When you open the Clash Detective tool, go in both windows to the tab properties. Then choose for Revit Type and then Assembly Code. There you are able to choose which Assembly Code groups you want to Clash with other groups of elements in the right window (see Figure 11). Each Assembly Code represents a group of elements. In the appendix 9.3 you can find out which Assembly Codes represent which groups.

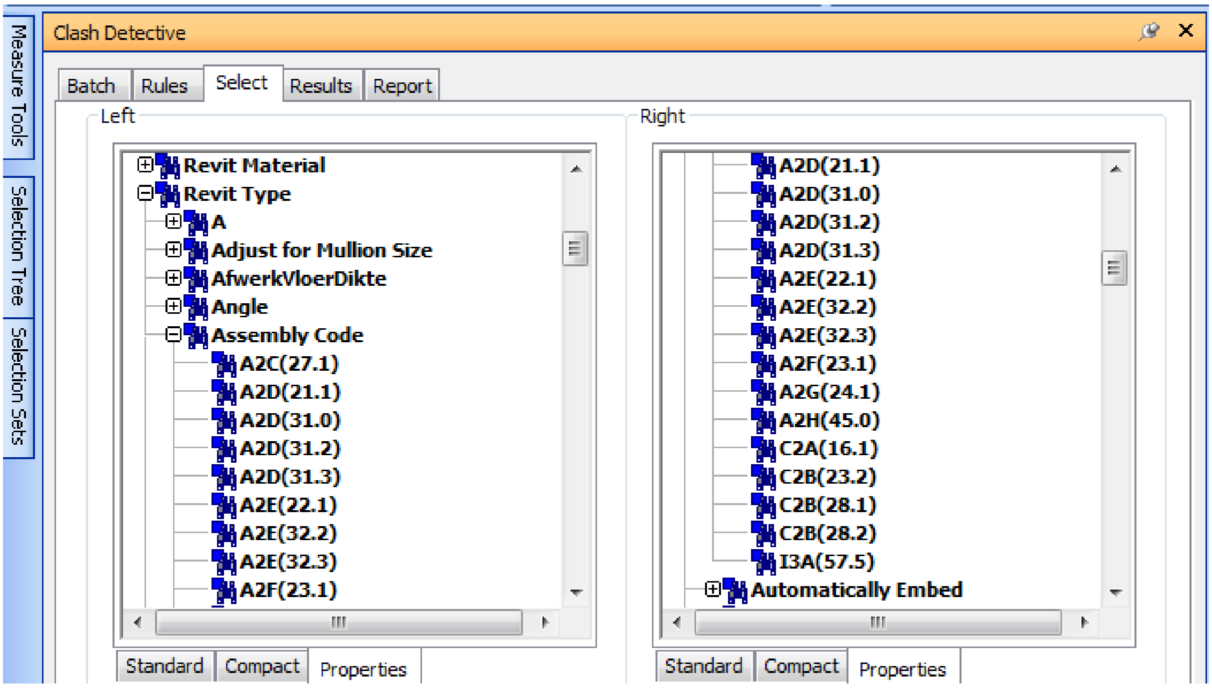

Figure 11 Navisworks Clash Detective tool

It is easy to read for the BIM coordinator, which Assembly Codes are of the responsibility of a certain participant because of the codification. Now it is easy to select for example the groups which start with an A (Architect) and clash them to the groups which start with a C (Structural Engineer, Dutch: Constructeur) in the right window.

9.3 New Classification based on WBS properties

The table below reflects an overview of the standard groups of the NEN2634 and compared to those groups the standard groups and codification of the new classification with WBS structure.

Code NEN 2634	Code new Classification	Omschrijving	Niveau
	O	Opdrachtgever	1
1	O1	Grond	2
1A	O1A	Verwerving	3
1B	O1B	Infrastructurele voorzieningen	3
1C	O1C	Bouwrijp maken	3
5	O5	Terrein	2
5A	O5A	Terrein, bouwkundig	3
5A(90)	O5A(90)	Terrein, bouwkundig	4
5A(90.0)	O5A(90.0)	Terrein	5
5A(90.1)	O5A(90.1)	Grondvoorzieningen	5
5A(90.2)	O5A(90.2)	Werkterreininrichting	5
5A(90.3)	O5A(90.3)	Omheiningen	5
5A(90.4)	O5A(90.4)	Terreinafwerkingen	5
5A(90.7)	O5A(90.7)	Terreininrichtingen; standaard	5
5A(90.8)	O5A(90.8)	Terreininrichtingen; bijzonder	5
5B	O5B	Terrein, werktuigbouwkundige installaties	3
5B(90)	O5B(90)	Terrein, werktuigbouwkundige installaties	4
5B(90.5)	O5B(90.5)	Terreinvoorz.; werktuigbouwkundig	5
5C	O5C	Terrein, electrotechnische installaties	3
5C(90)	O5C(90)	Terrein, electrotechnische installaties	4
5C(90.6)	O5C(90.6)	Terreinvoorz.; elektrotechnisch	5
6	O6	AUK	2
6U1	O6U1	AUK geheel gebouw	3
6U2	O6U2	AUK project/bouwplaatsinrichting	3
6U3	O6U3	AUK project/werkvoorbereiding en uitvoering	3
60-.0	O60-.0	Indirecte projectvoorzieningen	3
60-.1	O60-.1	Werkterreininrichting	3
60-.2	O60-.2	Materieëlvoorz.	3
60-.3	O60-.3	Risicodekking e.d.	3
60-.4	O60-.4	Projectorganisatie	3
60-.5	O60-.5	Bedrijfsorganisatie	3
7	O7	Losse inrichtingen en bedrijfsinstallaties	2
7A	O7A	Losse inrichtingen	3
7A(81)	O7A(81)	Losse verkeersinventaris	4
7A(81.0)	O7A(81.0)	Losse verkeersinventaris; algemeen	5
7A(81.1)	O7A(81.1)	Losse verkeersinventaris; standaard	5
7A(81.2)	O7A(81.2)	Losse verkeersinventaris; bijzonder	5
7A(82)	O7A(82)	Losse gebruikersinventaris	4
7A(82.0)	O7A(82.0)	Losse gebruikersinventaris; algemeen	5
7A(82.1)	O7A(82.1)	Losse gebruikersinventaris; standaard	5
7A(82.2)	O7A(82.2)	Losse gebruikersinventaris; bijzonder	5
7A(83)	O7A(83)	Losse keukeninventaris	4
7A(83.0)	O7A(83.0)	Losse keukeninventaris; algemeen	5
7A(83.1)	O7A(83.1)	Losse keukeninventaris; standaard	5
7A(83.2)	O7A(83.2)	Losse keukeninventaris; bijzonder	5
7A(84)	O7A(84)	Losse sanitaire inventaris	4
7A(84.0)	O7A(84.0)	Losse sanitaire inventaris; algemeen	5
7A(84.1)	O7A(84.1)	Losse sanitaire inventaris; standaard	5
7A(84.2)	O7A(84.2)	Losse sanitaire inventaris; bijzonder	5
7A(85)	O7A(85)	Losse schoonmaakinventaris	4
7A(85.0)	O7A(85.0)	Losse schoonmaakinventaris; algemeen	5
7A(85.1)	O7A(85.1)	Losse schoonmaakinventaris; standaard	5
7A(85.2)	O7A(85.2)	Losse schoonmaakinventaris; bijzonder	5
7A(86)	O7A(86)	Losse opslaginventaris	4
7A(86.0)	O7A(86.0)	Losse opslaginventaris; algemeen	5
7A(86.1)	O7A(86.1)	Losse opslaginventaris; standaard	5
7A(86.2)	O7A(86.2)	Losse opslaginventaris; bijzonder	5
7B	O7B	Bedrijfsinstallaties	3
8	O8	Bijkomende kosten	2
8A	O8A	Voorbereidings- en begeleidingskosten	3
8B	O8B	Heffingen enz.	3
8C	O8C	Verzekeringen	3
8D	O8D	Aanloopkosten	3
8E	O8E	Financieringskosten	3

8F	O8F	Risicoverrekeningen	3
8G	O8G	Onvoorziene uitgaven	3
8H	O8H	Onderhoudskosten van het verworven terrein	3
8I	O8I	Omzetbelasting	3
8J	O8J	Onvoorzien	3
8K	O8K	Veiligheidscoördinator	3
8L	O8L	Coördinatie van de verschillende disciplines	3
	A	Architect	1
2	A2	Bouwkundige werken	2
2A	A2A	Fundering	3
2A(11)	A2A(11)	Bodemvoorzieningen	4
2A(11.0)	A2A(11.0)	Bodemvoorzieningen, algemeen	5
2A(11.1)	A2A(11.1)	Bodemvoorzieningen, grond	5
2A(11.2)	A2A(11.2)	Bodemvoorzieningen, water	5
2C	A2C	Daken	3
2C(27)	A2C(27)	Dakafbouwconstructie	4
2C(27.1)	A2C(27.1)	Daken; niet constructief	5
2C(37)	A2C(37)	Dakopeningen	4
2C(37.1)	A2C(37.1)	Dakopeningen; niet gevuld	5
2C(37.2)	A2C(37.2)	Dakopeningen; gevuld	5
2C(47)	A2C(47)	Dakafwerkingen	4
2C(47.1)	A2C(47.1)	Dakafwerkingen, afwerkingen	5
2C(47.2)	A2C(47.2)	Dakafwerkingen, bekledingen	5
2D	A2D	Gevel	3
2D(21)	A2D(21)	Buitenwandafbouwconstructie	4
2D(21.1)	A2D(21.1)	Buitenwanden; niet constructief	5
2D(31)	A2D(31)	Buitenwandopeningen	4
2D(31.0)	A2D(31.0)	Buitenwandopeningen; algemeen	5
2D(31.1)	A2D(31.1)	Buitenwandopeningen; niet gevuld	5
2D(31.2)	A2D(31.2)	Buitenwandopeningen; gevuld met ramen	5
2D(31.3)	A2D(31.3)	Buitenwandopeningen; gevuld met deuren	5
2D(31.4)	A2D(31.4)	Buitenwandopeningen; gevuld met puien	5
2D(41)	A2D(41)	Buitenwandafwerkingen	4
2D(41.0)	A2D(41.0)	Buitenwandafwerkingen; algemeen	5
2D(41.1)	A2D(41.1)	Buitenwandafwerkingen	5
2E	A2E	Binnenwanden	3
2E(22)	A2E(22)	Binnenwandafbouwconstructie	4
2E(22.0)	A2E(22.0)	Binnenwanden; algemeen	5
2E(22.1)	A2E(22.1)	Binnenwanden; niet constructief	5
2E(32)	A2E(32)	Binnenwandopeningen	4
2E(32.0)	A2E(32.0)	Binnenwandopeningen; algemeen	5
2E(32.1)	A2E(32.1)	Binnenwandopeningen; niet gevuld	5
2E(32.2)	A2E(32.2)	Binnenwandopeningen; gevuld met ramen	5
2E(32.3)	A2E(32.3)	Binnenwandopeningen; gevuld met deuren	5
2E(32.4)	A2E(32.4)	Binnenwandopeningen; gevuld met puien	5
2E(42)	A2E(42)	Binnenwandafwerkingen	4
2E(42.1)	A2E(42.1)	Binnenwandafwerkingen	5
2F	A2F	Vloeren	3
2F(23)	A2F(23)	Vloerafbouwconstructie	4
2F(23.0)	A2F(23.0)	Vloeren; algemeen	5
2F(23.1)	A2F(23.1)	Vloeren; niet constructief	5
2F(33)	A2F(33)	Vloeropeningen	4
2F(33.0)	A2F(33.0)	Vloeropeningen; algemeen	5
2F(33.1)	A2F(33.1)	Vloeropeningen; niet gevuld	5
2F(33.2)	A2F(33.2)	Vloeropeningen; gevuld	5
2F(43)	A2F(43)	Vloerafwerkingen	4
2F(43.0)	A2F(43.0)	Vloerafwerkingen; algemeen	5
2F(43.1)	A2F(43.1)	Vloerafwerkingen; verhoogd	5
2F(43.2)	A2F(43.2)	Vloerafwerkingen; niet verhoogd	5
2G	A2G	Trappen en hellingen	3
2G(24)	A2G(24)	Trap- en hellingconstructie	4
2G(24.0)	A2G(24.0)	Trappen en hellingen; algemeen	5
2G(24.1)	A2G(24.1)	Trappen en hellingen; Trappen	5
2G(24.2)	A2G(24.2)	Trappen en hellingen; hellingen	5
2G(24.3)	A2G(24.3)	Trappen en hellingen; ladders en klimijzers	5
2G(34)	A2G(34)	Balustrades en leuningen	4
2G(34.0)	A2G(34.0)	Balustrades en leuningen; algemeen	5
2G(34.1)	A2G(34.1)	Balustrades en leuningen; Balustrades	5
2G(34.2)	A2G(34.2)	Balustrades en leuningen; leuningen	5
2G(44)	A2G(44)	Trap- en hellingafwerkingen	4
2G(44.0)	A2G(44.0)	Trap- en hel lingaf werkingen; algemeen	5

2G(44.1)	A2G(44.1)	Trap- en hellingafwerkingen; trapafwerkingen	5
2G(44.2)	A2G(44.2)	Trap- en hellingafwerkingen; hellingafwerkingen	5
2H	A2H	Plafonds	3
2H(45)	A2H(45)	Plafondafwerkingen	4
2H(45.0)	A2H(45.0)	Plafondafwerkingen; algemeen	5
2H(45.1)	A2H(45.1)	Plafondafwerkingen; verlaagd	5
2H(45.2)	A2H(45.2)	Plafondafwerkingen; niet verlaagd	5
3	A3	Installaties	2
3C	A3C	Lift en transport	3
3C(66)	A3C(66)	Lift en transport	4
3C(66.0)	A3C(66.0)	Transport; algemeen	5
3C(66.1)	A3C(66.1)	Transport; liften	5
3C(66.2)	A3C(66.2)	Transport; roltrappen en rolpaden	5
3C(66.3)	A3C(66.3)	Transport; goederen	5
3C(66.4)	A3C(66.4)	Transport; documenten	5
4	A4	Vaste inrichtingen	2
4(71)	A4(71)	Vaste verkeersvoorz.	3
4(71.0)	A4(71.0)	Vaste verkeersvoorz.; algemeen	4
4(71.1)	A4(71.1)	Vaste verkeersvoorz.; standaard	4
4(71.2)	A4(71.2)	Vaste verkeersvoorz.; bijzonder	4
4(72)	A4(72)	Vaste gebruikersvoorz.	3
4(72.0)	A4(72.0)	Vaste gebruikersvoorz.; algemeen	4
4(72.1)	A4(72.1)	Vaste gebruikersvoorz.; standaard	4
4(72.2)	A4(72.2)	Vaste gebruikersvoorz.; bijzonder	4
4(73)	A4(73)	Vaste keukenvoorz.	3
4(73.0)	A4(73.0)	Vaste keukenvoorz.; algemeen	4
4(73.1)	A4(73.1)	Vaste keukenvoorz.; standaard	4
4(73.2)	A4(73.2)	Vaste keukenvoorz.; bijzonder	4
4(74)	A4(74)	Vaste sanitaire voorz.	3
4(74.0)	A4(74.0)	Vaste sanitaire voorz.; algemeen	4
4(74.1)	A4(74.1)	Vaste sanitaire voorz.; standaard	4
4(74.2)	A4(74.2)	Vaste sanitaire voorz.; bijzonder	4
4(75)	A4(75)	Vaste onderhoudsvoorz.	3
4(75.0)	A4(75.0)	Vaste onderhoudsvoorz. algemeen	4
4(75.1)	A4(75.1)	Vaste onderhoudsvoorz. standaard	4
4(75.2)	A4(75.2)	Vaste onderhoudsvoorz. bijzonder	4
4(76)	A4(76)	Vaste opslagvoorz.	3
4(76.0)	A4(76.0)	Vaste opslagvoorz.; algemeen	4
4(76.1)	A4(76.1)	Vaste opslagvoorz.; standaard	4
4(76.2)	A4(76.2)	Vaste opslagvoorz.; bijzonder	4
	C	Constructeur	1
2	C2	Constructie	2
2A	C2A	Fundering	3
2A(13)	C2A(13)	Vloeren op grondslag	4
2A(13.0)	C2A(13.0)	Vloeren op grondslag; algemeen	5
2A(13.1)	C2A(13.1)	Vloeren op grondslag; niet constructief	5
2A(13.2)	C2A(13.2)	Vloeren op grondslag; constructief	5
2A(16)	C2A(16)	Funderingsconstructies	4
2A(16.0)	C2A(16.0)	Funderingsconstructies; algemeen	5
2A(16.1)	C2A(16.1)	Funderingsconstructies; voeten en balken	5
2A(16.2)	C2A(16.2)	Funderingsconstructies; keerwanden	5
2A(17)	C2A(17)	Paalfunderingen	4
2A(17.0)	C2A(17.0)	Paalfunderingen; algemeen	5
2A(17.1)	C2A(17.1)	Paalfunderingen; niet geheid	5
2A(17.2)	C2A(17.2)	Paalfunderingen; geheid	5
2B	C2B	Skelet	3
2B(21)	C2B(21)	Dragende buitenwanden	4
2B(21.0)	C2B(21.0)	Buitenwanden; algemeen	5
2B(21.2)	C2B(21.2)	Buitenwanden; constructief	5
2B(22)	C2B(22)	Dragende binnenwanden	4
2B(22.0)	C2B(22.0)	Binnenwanden; algemeen	5
2B(22.2)	C2B(22.2)	Binnenwanden; constructief	5
2B(23)	C2B(23)	Dragende vloeren	4
2B(23.0)	C2B(23.0)	Vloeren; algemeen	5
2B(23.2)	C2B(23.2)	Vloeren; constructief	5
2B(27)	C2B(27)	Dragende daken	4
2B(27.0)	C2B(27.0)	Daken; algemeen	5
2B(27.2)	C2B(27.2)	Daken; constructief	5
2B(28)	C2B(28)	Hoofddraagconstructies	4
2B(28.0)	C2B(28.0)	Hoofddraagconstructies algemeen	5
2B(28.1)	C2B(28.1)	Hoofddraagconstructies kolommen en liggers	5

2B(28.2)	C2B(28.2)	Hoofddraagconstructies wanden en vloeren	5
2B(28.3)	C2B(28.3)	Hoofddraagconstructies ruimte-eenheden	5
	I	Installateur	1
3	I3	Installaties	2
3A	I3A	Werktuigbouwkundige installaties	3
3A(51)	I3A(51)	Warmte-opwekking	4
3A(51.0)	I3A(51.0)	Warmte-opwekking; algemeen	5
3A(51.1)	I3A(51.1)	Warmte-opwekking; lokaal	5
3A(51.2)	I3A(51.2)	Warmte-opwekking; centraal	5
3A(51.3)	I3A(51.3)	Warmte-opwekking; toegeleverde warmte	5
3A(51.4)	I3A(51.4)	Warmte-opwekking; warmte-krachtkoppeling	5
3A(51.5)	I3A(51.5)	Warmte-opwekking; bijzonder	5
3A(52)	I3A(52)	Afvoeren	4
3A(52.0)	I3A(52.0)	Afvoeren; algemeen	5
3A(52.1)	I3A(52.1)	Afvoeren; regenwater	5
3A(52.2)	I3A(52.2)	Afvoeren; faecaliën	5
3A(52.3)	I3A(52.3)	Afvoeren; afvalwater	5
3A(52.4)	I3A(52.4)	Afvoeren; gecombineerd	5
3A(52.5)	I3A(52.5)	Afvoeren; speciaal	5
3A(52.6)	I3A(52.6)	Afvoeren; vast vuil	5
3A(53)	I3A(53)	Water	4
3A(53.0)	I3A(53.0)	Water; algemeen	5
3A(53.1)	I3A(53.1)	Water; drinkwater	5
3A(53.2)	I3A(53.2)	Water; verwarmd tapwater	5
3A(53.3)	I3A(53.3)	Water; bedrijfswater	5
3A(53.4)	I3A(53.4)	Water; gebruiksstoom en condens	5
3A(53.5)	I3A(53.5)	Water; waterbehandeling	5
3A(54)	I3A(54)	Gassen	4
3A(54.0)	I3A(54.0)	Gassen; algemeen	5
3A(54.1)	I3A(54.1)	Gassen; brandstof	5
3A(54.2)	I3A(54.2)	Gassen; perslucht en vacuüm	5
3A(54.3)	I3A(54.3)	Gassen; medisch	5
3A(54.4)	I3A(54.4)	Gassen; technisch	5
3A(54.5)	I3A(54.5)	Gassen; bijzonder	5
3A(55)	I3A(55)	Koude-opwekking en distributie	4
3A(55.0)	I3A(55.0)	Koude-opwekking; algemeen	5
3A(55.1)	I3A(55.1)	Koude-opwekking; lokaal	5
3A(55.2)	I3A(55.2)	Koude-opwekking; centraal	5
3A(55.3)	I3A(55.3)	Koude-opwekking; distributie	5
3A(56)	I3A(56)	Warmtedistributie	4
3A(56.0)	I3A(56.0)	Warmtedistributie; algemeen	5
3A(56.1)	I3A(56.1)	Warmtedistributie; water	5
3A(56.2)	I3A(56.2)	Warmtedistributie; stoom	5
3A(56.3)	I3A(56.3)	Warmtedistributie; lucht	5
3A(56.4)	I3A(56.4)	Warmtedistributie; bijzonder	5
3A(57)	I3A(57)	Luchtbehandeling	4
3A(57.0)	I3A(57.0)	Luchtbehandeling; algemeen	5
3A(57.1)	I3A(57.1)	Luchtbehandeling; natuurlijke ventilatie	5
3A(57.2)	I3A(57.2)	Luchtbehandeling; lokale mechanische afzuiging	5
3A(57.3)	I3A(57.3)	Luchtbehandeling; centrale mechanische afzuiging	5
3A(57.4)	I3A(57.4)	Luchtbehandeling; lokale mechanische ventilatie	5
3A(57.5)	I3A(57.5)	Luchtbehandeling; centrale mechanische ventilatie	5
3A(57.6)	I3A(57.6)	Luchtbehandeling; lokaal	5
3A(57.7)	I3A(57.7)	Luchtbehandeling; centraal	5
3A(58)	I3A(58)	Regeling klimaat en sanitair	4
3A(58.0)	I3A(58.0)	Regeling klimaat en sanitair; algemeen	5
3A(58.1)	I3A(58.1)	Regeling klimaat en sanitair; specifieke regelingen	5
3A(58.2)	I3A(58.2)	Regeling klimaat en sanitair; centrale melding, meting en sturing	5
3B	I3B	Electrotechnische installaties	3
3B(61)	I3B(61)	Centrale electrotechnische voorz.	4
3B(61.0)	I3B(61.0)	Centrale elektrotechnische voorz.; algemeen	5
3B(61.1)	I3B(61.1)	Centrale elektrotechnische voorz.; energie, noodstroom	5
3B(61.2)	I3B(61.2)	Centrale elektrotechnische voorz.; aarding	5
3B(61.3)	I3B(61.3)	Centrale elektrotechnische voorz.; kanalisatie	5
3B(61.4)	I3B(61.4)	Centrale elektrotechnische voorz.; energie, hoogspanning	5
3B(61.5)	I3B(61.5)	Centrale elektrotechnische voorz.; energie, laagspanning	5
3B(61.6)	I3B(61.6)	Centrale elektrotechnische voorz.; energie, zeer lage spanning	5
3B(61.7)	I3B(61.7)	Centrale elektrotechnische voorz.; bliksemafleiding	5
3B(62)	I3B(62)	Krachtstroom	4
3B(62.0)	I3B(62.0)	Krachtstroom; algemeen	5
3B(62.1)	I3B(62.1)	Krachtstroom; hoogspanning	5

3B(62.2)	I3B(62.2)	Krachtstroom; laagspanning, onbewaakt	5
3B(62.3)	I3B(62.3)	Krachtstroom; laagspanning, bewaakt	5
3B(62.4)	I3B(62.4)	Krachtstroom; laagspanning, gestabiliseerd	5
3B(62.5)	I3B(62.5)	Krachtstroom; laagspanning, gecompenseerd	5
3B(63)	I3B(63)	Verlichting	4
3B(63.0)	I3B(63.0)	Verlichting; algemeen	5
3B(63.1)	I3B(63.1)	Verlichting; standaard, onbewaakt	5
3B(63.2)	I3B(63.2)	Verlichting; calamiteiten, decentraal	5
3B(63.3)	I3B(63.3)	Verlichting; bijzonder, onbewaakt	5
3B(63.4)	I3B(63.4)	Verlichting; standaard, bewaakt	5
3B(63.5)	I3B(63.5)	Verlichting.; calamiteiten, centraal	5
3B(63.6)	I3B(63.6)	Verlichting; bijzonder, bewaakt	5
3B(63.7)	I3B(63.7)	Verlichting; reklame	5
3B(64)	I3B(64)	Communicatie	4
3B(64.0)	I3B(64.0)	Communicatie; algemeen	5
3B(64.1)	I3B(64.1)	Communicatie; signalen	5
3B(64.2)	I3B(64.2)	Communicatie; geluiden	5
3B(64.3)	I3B(64.3)	Communicatie; beelden	5
3B(64.4)	I3B(64.4)	Communicatie; data	5
3B(64.5)	I3B(64.5)	Communicatie; geïntegreerde systemen	5
3B(64.6)	I3B(64.6)	Communicatie; antenne inrichtingen	5
3B(65)	I3B(65)	Beveiliging	4
3B(65.0)	I3B(65.0)	Beveiliging; algemeen	5
3B(65.1)	I3B(65.1)	Beveiliging; brand	5
3B(65.2)	I3B(65.2)	Beveiliging; braak	5
3B(65.3)	I3B(65.3)	Beveiliging; overlast	5
3B(65.4)	I3B(65.4)	Beveiliging; sociale alarmering	5
3B(65.5)	I3B(65.5)	Beveiliging; milieu-overlast, detectie en alarmering	5
3B(67)	I3B(67)	Gebouwbeheervoorz.	4
3B(67.0)	I3B(67.0)	Gebouwbeheersvoorz.; algemeen	5
3B(67.1)	I3B(67.1)	Gebouwbeheersvoorz.; bediening en signalering	5
3B(67.2)	I3B(67.2)	Gebouwbeheersvoorz.; automatisering	5
3B(67.3)	I3B(67.3)	Gebouwbeheersvoorz.; regelinstallaties klimaat/sanitair (op afstand)	5