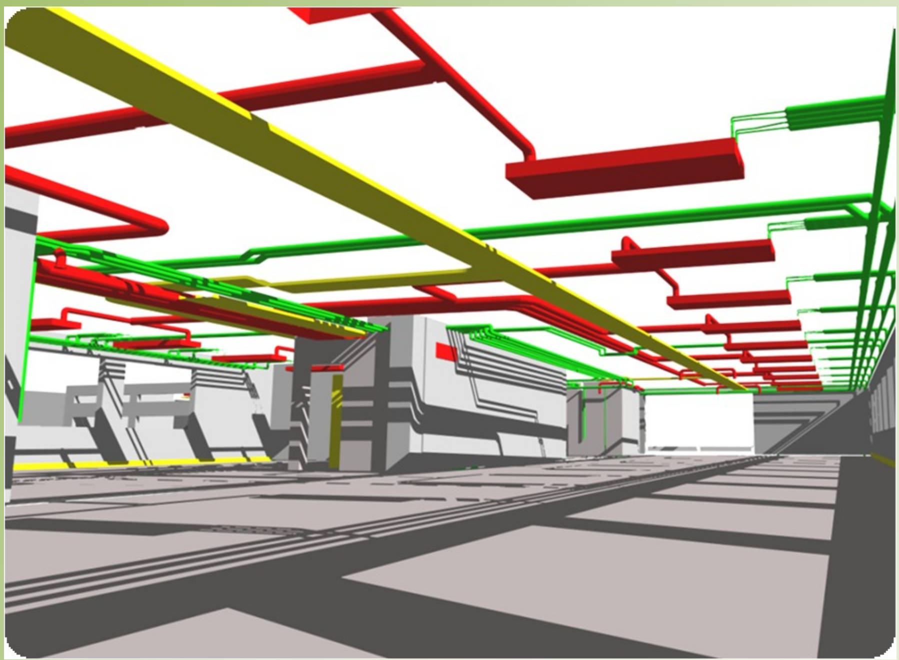
Use of 4D BIM for general contractors

With focus on constructability analysis through clash detection and 4D simulation



Master thesis - April 2012

Technical University of Denmark

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Title sheet

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Preface

This thesis was written and submitted in partial fulfillment of the requirements for the degree of Master of Science in Engineering (M.Sc.) at the department of Civil Engineering of the Technical University of Denmark.

It has been done during a 6 month period spanning from October 2011 to April 2012 and corresponds to 35 ECTS points.

A CD is part of the hand in. It contains more or less all models used by the author in his tests.

The models are in the same conditions as they were, before they were imported to Navisworks, Solibri, Tekla BIMsight and Vico Office. A reader that wants to reproduce the author's results can therefore open the files in Revit and export them to IFC, DWG and NWC. Furthermore, the attached CD contains; the project files, clash reports and diverse documents performed during the thesis.

The author would like to thank all the people that have contributed to this thesis.

Thanks to my supervisors Jan Karlshøj, Salman Sagdosh Pey and Mads Møller-Nielsen for their feed backs.

A special thank to my girlfriend Jerine, for always being there for me.

Moreover a special thank to my; parents: Hendrik and Lise, sisters: Lida and Helena for always supporting me.

Finally I would like to thank all those who helped and inspired me during my master study and research work.

Abstract

This thesis will look into how General Contractors should utilize Building Information Models for performing clash detection and 4D modeling in the early stages of a construction project. The utilized applications are evaluated for whether they are capable of promote more efficient work processes utilizing the BIM methodology. Clash detections are performed for reviewing constructability issues and 4D methods are equally tested to prove whether the methods are capable of securing quality of project schedules.

The utilized BIM applications are tested in terms of mapping synergies for whether or not these tools promote and improve cooperation and communication among employees, in order to create desired quality in the design and pre-construction phase of a construction project.

The study will furthermore show innovative BIM tools for the purpose of remodeling and model reviewing and schedule management optimization.

This thesis investigates whether clash detectives are capable of identifying discipline models for constructability issues for the case of MTHøjgaard's project PFA Nørgaardsvej. Each application is tested for its capabilities for identifying clashes by adjusting sets of rules, parameters or by comparing entire discipline models against each other.

A great finding within this research related to reporting of clashes by extracting information out from an IFC specification is shown, as well as other interoperability features.

The best practice for solving conflicts is demonstrated by showing how direct clash report import or automatic switchback to the native design application can be performed.

The thesis will show how BIM models can be linked with time and activity based information from any type of Gant-chart based schedule. This test will moreover show how a Gant-chart based schedule can be converted to a BIM based LOB schedule.

Finally, the produced 4D simulation will be tested and analyzed for whether subcontractors can benefit from the final 4D product.

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List of abbreviations

Abbreviation	Meaning	Description
2D	Two-dimensional drawing	A 2D drawing
3D	Three-dimensional model	A 3D model containing geometrical information about a building
4D	3D + time	A 3D model linked to time or scheduling data.
5D	4D + cost	A 3D model linked to cost data.
AEC	Architecture, Engineering and Construction	Used when referring to the whole industry which are surrounding building construction projects
BATID	Element Identity	IFC specification based Element ID
BCF	BIM Collaboration Format	A pre release, submitted to buildingSMART under the new "Affiliation Scheme" to become an official buildingSMART specification
bcfzip	Zipped BCF file	Compressed BIM Collaboration file Format
BIM	Building Information Model / Modeling / Management	Concept and method of generating and administrating building data
BIPS	Byggeri, informationsteknologi, produktivitet, samarbejde	Membership driven, non-profit association working for the Danish construction companies
bSI	buildingSMART International	A neutral, international and unique non for profit organisation supporting open BIM through the life cycle.
CIFE	Center for Integrated Facility Engineering	Academic research center for Virtual Design and Construction of AEC industry projects
CII	Construction Industry Institute	A consortium which purpose is to measurably improve the delivery of capital facilities.
CAD	Computer Aided Design	The use of computer technology for the design of objects
CD	Compact Disc	Unit for storing of data
DTU	Technical University of Denmark	Technical University which educate B.sc. and M.sc. in engineering
DWF	Drawing format	A compressed 2D/3D drawing format developed by Autodesk. Contain design data, graphics, and text
DWG	Drawing	A binary file format used for storing 2D and 3D design data
FM	Facility Management	Interdisciplinary field devoted to the coordination of business support services, associated with maintenance functions in buildings
GC	General Contractor	Responsible for the day-to-day oversight of a construction site, management of vendors and trades, and communication of information to involved parties throughout the course of a building project
GUID	Globally Unique Identifier	A 128-bit number used by programs to uniquely identify the location of a data object.
HVAC	Heating, Ventilation and Air Conditioning systems	Heating, ventilation and air conditioning systems used in buildings
HTML	Hyper Text Markup Language	A web-browser based clash detection report, which allows images and data to be stored
ICT	Information & Communication Technology	Demands aimed to ensure increased and improved knowledge-sharing between the parties of the construction sector
ID	Identity	Term used for object or item uniqueness

Abbreviation	Meaning	Description
IFC	Industry Foundation Classes	Open file format that is being developed with the goal of becoming a universal information exchange standard in the AEC industry
ITO	Information Takeoff	Data gathering and capturing of information's available within BIM model
LBS	Location Breakdown Structure	Relates to a physical or logical breakdown of the project
LOB	Line-Of-Balance	A graphical scheduling method focusing on continuous resource utilization in repetitive activities
MEP	Mechanical, Electrical and Plumbing	Mechanical, electrical, plumbing building services or the engineering disciplines associated with them
MTH	MT Højgaard	One of the leading general contractors in the Scandinavia with core competences in; Civil works, Construction, Mining, Offshore
NW12	Navisworks Manage 2012	Autodesk software package used for engineering design review and 4D
NWC	Navisworks Cache File	File containing geometry and metadata in the native format for Navisworks. Enables models to load more quickly.
NWD	Navisworks Published Data File	File format which stores all project assets in a standalone document for review
NWF	Navisworks Review File	Master file format containing NWC file(s)
PDF	Portable Document Format	A compacted file that captures document text, fonts, images, and even formatting of documents from a variety of applications
PFA	PFA Ejendomme A/S	The owner/client for the building case described in this thesis
QA	Quality Assurance	Set of procedures intended to ensure that a product or service under development meets specified requirements
QC	Quality Control	Set of procedures intended to ensure that a product or performed service adheres to a defined set of quality criteria or meets the requirements of the client or customer
QTO	Quantity Take-Off	Model based quantity of a material needed to complete a specified work
RFI	Request For Information	Primarily used to gather information to help make a decision on what steps to take next
ROI	Return Of Investment	A performance measure used to evaluate the efficiency of an investment.
RVT	Revit project file	Architectural/Structural/MEP design project created with Revit
SMC	Solibri Model Checker	Model checking software from Solibri
TBS	Tekla BIMsight	Clash detective software from Tekla
TOI	Take-Off Items	Model based selection of objects needed to QTO
TXT	Text	Standard text document that contains unformatted text
VVS	Varme, Ventilation og Sanitet	Danish term of building services (heat, ventilation and plumping) or the engineering disciplines associated with them
XML	Extensible Markup Language	Used to define documents with a standard format that can be read by any XML-compatible application

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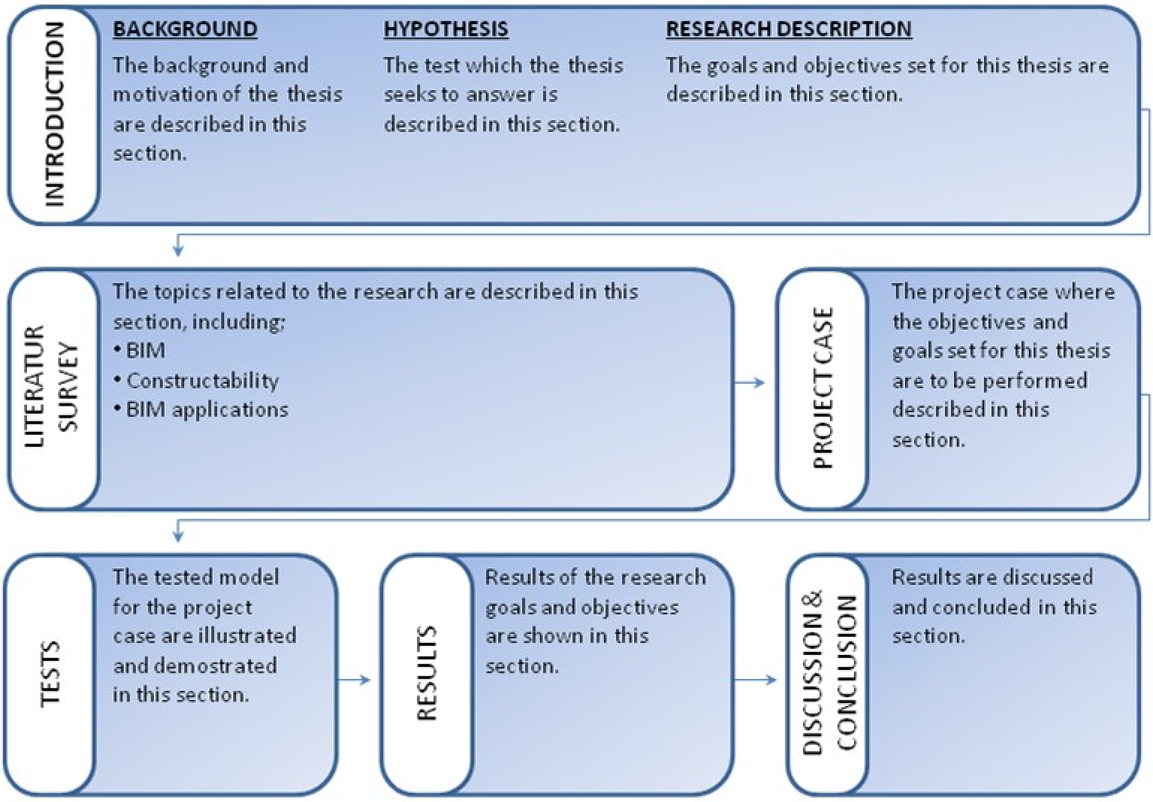
Chapter 1

Introduction

1. Introduction

The overall structure of the current thesis is illustrated below;



1.1 Background and motivation

The construction industry has over the last 40 years not been able to improve its general productivity, where other industries such as the non-farm industries have rose over 200 %. [2] In fact, the construction industry have seen a steadily declining productivity, yet during this time period many labor-saving machines and design tools have been implemented, including Computer Aided Design, Spreadsheets and PC database - just to mention a few. The problem is not caused by a shrinking or booming construction market - increasing productivity and coordination is imperative. A key method for accomplishing this issue is process optimization, adaption and implementation of proven manufacturing techniques and concept from other industries. The construction industry has due to these characteristics become more focused and aware on the actual construction process and turned their attention for innovative tools, industrialized concepts and methods in order to improve the process. Another reason for this increased attention is also caused by the fact that project teams face ever increasing pressure to deliver projects as quickly as possible within the time and cost limits set by the client. In order for the contractors to meet these demands they need to explore various construction strategies to be able to optimize and to assure themselves of achievability, constructability, bidability and thereby guarantee quality of construction projects. The issue of performing construction feasibility has due to this development become vital and essential for assuring projects are designed and executed smoothly. Utilization and improvement of constructability analysis has, for these reasons become a key focus and concern for several of the major operators within the AEC sector [18]. General contractors, designers and owners have particularly turned their focus on this methodology, as they seek to decrease construction costs, deliver complex project on-time and improve their overall construction operations practices - since it benefits all members of a project team [17]. Recognizing constructability issues in the early stages of a construction project is review by many to help to identify design limitations that prevents a contractor's ability to plan and perform construction operations effectively. [17]

Building Information Modeling (BIM) is one of the most promising concept developments in the AEC sector. This concept enables performance of constructability analysis by automatic detection clash detection. It enhances the level of coordination allowing contractors to perform substantially more prefabrication and less onsite adjustments.

CII has reported a potential return on investment of 10:1 by applying constructability reviews. Other studies have proved savings as much as 10.2 % in construction time and 7.2 % in project costs, only by applying constructability practices [30].

This concept is predicted to be one of many tools and techniques when implemented correctly to help the construction industry to increase its general productivity and optimize the way thing are currently being done. The concept will change the way construction are delivered, but there are some hurdles and barriers to clear before the industry will experience many of its true benefits. Recent surveys have moreover indicated that approximately 40 % of the top 400 contractors are using BIM on more than 10 % of their work. [31]

According to [2] "BIM facilitates a more integrated design and construction process that results in better quality buildings at lower cost and reduced project duration". Moreover McGraw Hill Construction SmartMarket Report highlights that Western European BIM users has identified following as the highest-value project benefits; Improved collective understanding of design intent, improved overall project quality and reduced conflicts during construction. These benefits are small steps in the path to increase the productivity, but they represent huge steps in improving the actual processes within the industry.

The BIM capabilities range much beyond than the ability to performance clash detection and it is where BIM gets really interesting. Another promising development within BIM is the so-called fourthdimensional modeling or 4D BIM. This method allows design and construction teams to test different design and sequencing alternatives in accordance with scheduled plans. 4D models works by linking each object based unit to its corresponding time schedule. The object oriented 4D model has according to report by CIFE “the potential to support automated constructability reasoning and helping a project team in identifying constructability issues early in the design and construction stages”.

The ability to visualize and animate the construction sequence in the perspective of the actual project site provides design teams, owners, contractors or other interested parties with a bird’s eye view of the process. This process simplifies the understanding of the activities or events to occur on the project site. Furthermore it help improving the understanding of project installation progression and assists the decision making process often required when scheduling works or activities in logistically challenging environments.

1.2 Hypothesis

This study will test whether constructability analysis through BIM based clash detection and 4D simulation is capable of identifying severe and moderate buildability issues. The paper will for this purpose investigate whether conflicts between building components installed by different trade disciplines can be located in time and solved by best practice BIM methods. The study will moreover test whether the theoretical BIM process and concept corresponds with the features of some of the actual BIM tools and applications available in the market are capable of coordinating constructability issues in an efficient way. The proclamation of interoperability of the BIM concept and process concerning clash detective reports will furthermore be investigated, in order to authenticate the theoretical statements.

1.3 Research description

This section provides an overview of the research behind this thesis. It includes following subsections; research purpose, objectives, approach and scope.

1.3.1 Purpose

The purpose of this study is to look at how General Contractors should utilize Building Information Models for performing clash detection and 4D modeling in the early stages of a construction project. The focus of the study is to evaluate whether various BIM tools can lead to more efficient work processes, within performance of clash detection for reviewing constructability issues and utilization of 4D methods as a tool to secure quality of project schedules as well as build-up scenario.

In addition, the study will search of mapping synergies from the aforementioned topics to look for areas where cooperation and communication among employees could be improved in order to create desired quality in the design and pre-construction phase of a construction project.

Additionally, the aim of the study is to investigate the need and extent of required level of information and detailing in relation to the creation of a BIM model, in the view of utilizing the models for performing clash detection and 4D simulations.

The core of the study is subsequently to test and assure the quality of how a 3D model should be developed and progress in order for the model to be utilized to perform clash detection and 4D simulation.

The aim of the study will furthermore look into innovative new BIM tools for the purpose of remodeling and model reviewing and schedule management optimization within mentioned phases of a construction project.

There study will seek to answers the following questions, which in principle are indirectly included in the above mentioned description:

- How to perform constructability analysis using 3 different BIM applications from different software vendors at different price categories?
- What are the advantages and disadvantages of the investigated clash detectives in terms of interoperability, key features, retail price and support?
- How should the clash detective reports be shared and mapped in terms of project collaboration in order to simplify cooperation and communication process?
- What is the best practice process for developing, remodeling or reengineering discipline models in terms of altering issued clashes from clash detectives?
- How should BIM models be linked with time and activity based information from a master schedule, in order to visualize the scheduled construction assemblies?
- How 4D BIM methods should be used as a planning tool in the design and pre-construction phase, in the view of General Contractor cooperation with subcontractors?
- How to make sequencing of project activities simpler and more intuitive by providing visualization of the construction process at an early planning stage?
- How a Gant-chart schedule can be converted to a LOB schedule?
- How to link non-model based information to a LOB schedule?

1.3.2 Objectives

The following bulleted list shows which objectives are strived to be clarified in this study. All objectives are aimed to be performed on the case of MTH project PFA Nørgaardsvej.

- Perform constructability analysis using following clash detectives; Autodesk Navisworks Manage 2012, Solibri Model Checker v.7, Tekla BIMSight v. 1.4.1.
- Report identified clashes using data exchange formats; BCF, HTML
- Utilize Autodesk Navisworks Manage 2012 Switchback functionality to modify, fix and rectify issued clashes in Autodesk Revit Architecture 2012.
- Develop an exchange scenario of file sharing for clash reports using recommended workflows of investigated clash detectives
- Perform 4D sequencing of construction activities using Vico Office Release 3.2
- Convert a master schedule based on Gant-chart to BIM based LOB schedule and report the schedule visually by utilizing 4D BIM animations techniques

1.3.3 Research approach

The following list shows the research approach taken into consideration for solving the goals and objectives set for the study. The list is presented in a chronological way and signifies which topics and tools are to be described, highlighted and clarified in the following sections.

1. **Literature review:**
   A literature review was conducted in the field of;

   - Building Information Modeling, including; the BIM concept, BIM planning, BIM and construction and BIM process
   - Construction feasibility, including; constructability analysis, coordination and constructability review using clash detective applications
   - BIM integration applications, including; essentials, features and properties and software descriptions of; Autodesk Navisworks Manage 2012, Solibri Model Checker v.7, Tekla BIMSight v. 1.4.1 and Vico Office R.3.2.

2. **Building Information Modeling:**
   MTH provided the research with 3 different discipline models created and merged using Autodesk Revit Architecture 2011. The models contained following disciplines;

   - Heating Ventilation Air Condition (HVAC)
   - Mechanical, Electrical, Plumping (MEP)
   - Superstructure

   For the purpose of this research Autodesk Revit Architecture 2012 was used as a model design application and as platform to export/import IFC discipline models. Additionally, the application was used to utilize BCF and NW12 Switchback functionalities for the purpose of modifying and rectifying issued clashes found in used clash detectives.

3. **Clash detection application development**
   Constructability analysis for the case of MTH project PFA Nørgaardsvej was performed using following clash detectives;

   - Navisworks Manage 2012
   - Solibri Model Checker v.7
   - Tekla BIMSight v. 1.4.1

   Using SMC and BIMsight was BCF reports generated, whereas report in the form of XLM and HTML was generated using NW12. NW12 Switchback was furthermore utilized as part of the rectification and modification of issued clashes.

4. **4D BIM application development**
   The sequencing of construction activities for the case of MTH project PFA Nørgaardsvej was performed using Vico Office Release 3.2

   MTH provided a Gant-chart based master project schedule which was utilized as reference for time inputs to the 4D modeling of planed duration of construction activities. Resources assigned to each activity were based on actual crew sizes. The BIM based LOB schedule was developed by splitting the overall construction site into zones and areas. QTO's where extracted from the BIM model itself and TOI where adjusted to match specific activities.

5. **Documentation**
   Some of the issued clashes found in the clash detectives are compared to the on-site installations by comparing clash visualizations with pictures. This approach is conducted in order to validate whether identified constructability issues actually did occur during the construction phase and to see how the issued clashes where solved.

   The BIM based LOB schedule is compared to the actual Gant-chart based schedule to see whether the master schedule can be optimized. The optimization are based on the ability to adjust following; increase productivity of specific activities by increasing crew size, analyze whether a location breakdown could have an effect on saving time by moving and splitting specific activities into zones and adjust their sequence progression.

6. **Software review**
   A formal software review was performed of the utilized clash detectives. This approach was conducted in order to analyze the advantages and disadvantages of each clash detective in terms of interoperability, key features, retail price and support.

1.3.4 Scope

This study focuses on two key BIM topics for successful utilization of BIM models for GC's at an early stage of a construction project. The BIM topics are;

1. Clash detection including coordination and collaborative BIM methods
2. Sequencing of project activities by 4D simulation including abilities to optimize schedules trough BIM based LOB scheduling

Performing clash detection of discipline models involves coordination at a high level. This is because identified constructability issues need to be reported to responsible team member(s). The reported issues need to be solved before a given deadline. This rectification process can require coordination between different AEC members. This study does not take this process into consideration. The author takes all AEC responsibilities for fixing and modifying clashed issues - in order to simplify and show how this method should be performed by GC's and their collaborative partners or subcontractors.

Scheduling of construction projects involves defining construction methods and tasks, sequencing of tasks, resource allocation, resource leveling, activity duration estimating, cash flow analysis, and calendar and staff allocations. This study is limited only to activity sequencing because of time and resource constraints.

The outputs produced in each utilized application are limited to focus only on key objectives set for the thesis. Outputs are to be stored in an attached CD, where the readers of the hard copy can see the products. The results of the performed works are also not to be attached in the form of appendixes, since the outcome could become too extensive.

1.4 Target audience

This primarily target group of this thesis is my supervisors and external examiner since this paper represents the work of achieving the acquisition of Master's degree in civil engineering.

Secondly the target group is people with interest in BIM, especially within the field of; constructability analysis, clash detectives and 4D methods.

Chapter 2

Literature survey

2. Literature survey

The following chapter introduces;

- BIM in the AEC sector, including; BIM in Denmark, the meaning of BIM, the concept, intends, process and why the AEC sector, especially the GC's should utilize BIM
- BIM and construction feasibility, including; constructability analysis, coordination, clash detection and clash detective applications
- BIM integration applications, including; general features and properties together with software descriptions of NW12, SMC and TBS

The aim of the literature reviews is not to describe an exhaustive study of listed topics, but to introduce them in a way that should make it easier for the readers to understand why the statement of this study is interesting.

The content has been selected, based on what is interesting to put into perspective with the obtained results in the tests section.

2.1 BIM in the AEC sector

The following chapter covers various BIM related themes and topics. The aim of this chapter is to highlight and identify following subjects;

1. BIM in Denmark
2. The meaning of BIM
3. The BIM concept, its intends and process
4. General opportunities of BIM in all phases of a construction project

Several litterateurs have already performed similar research and studies within mentioned topics. The following chapters are inspired and part-reviews from [1, 2, 4].

2.1.1 BIM in Denmark

The Danish government initiated a structured political plan in 2003 that resulted in the establishment of "Digital Construction". The aim of the project was to improve the overall productivity within the Danish construction industry. Moreover the mission of the project was to contribute to the digitalization of the construction sector and to utilize modern exciting systems for data storage and interoperability among different AEC disciplines. [3]

The vision of the project has since been implemented in the Danish law [7]. The law requires among others that governmental construction projects ranging more or equal to 5 million DKK, the construction industry should use ICT to communicate in the following areas:

- Electronic tendering
- Project web
- Building Information Model
- Electronic hand-over

Furthermore the law requires that governmental owners should make a number of demands related to ICT. These demands aim to ensure increased and improved knowledge-sharing between the parties of the construction sector.

In addition guidelines have been developed, e.g. "CAD-manual 2008 anvisning C102" by BIPS to ease the implementation process and facilitate the adaption of the governmental requirements. BIPS is a membership driven, non-profit association working for the construction companies in Denmark.

Finally, a recent Danish report [3] conducted by COWI concludes, that full digitalization of all new and existing buildings in Denmark have a potential to save 17 billion DKK per year.

Other countries are also working on national standards for the same reasons, e.g. US, Germany, France, Finland, Norway, Sweden, Singapore among others. [3]

2.1.2 The meaning of BIM

According to bSI is BIM an shortened buzz-word which represents three separate but linked functions;

- ***Building information Modeling*** *is a business process for generating and leveraging building data to design, construction and operate the building during its lifetime. BIM allows all stakeholders to have access to the same information at the same time through interoperability between technology platforms.*
- ***Building Information Model*** *is the digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility, forming a reliable basis for decisions during its life-cycle from inception onwards.*
- ***Building information Management*** *is the organization & control of the business process by utilizing the information in the digital prototype to effect the sharing of information over the entire lifecycle of an asset. The benefits include centralized and visual communication, early exploration of options, sustainability, efficient design integration of disciplines, site control, as built documentation etc. – effectively developing an asset lifecycle process and model from conception to final retirement.*

Furthermore the Associated General Contractors of America defines BIM as; "*the development and use of computer software model to simulate the construction and operation of a facility. The resulting model, a Building Information Model, is a data-rich, object oriented, intelligent and parametric digital representation of the facility, from which views and data appropriate to various users' needs can be extracted and analyzed to generate information that can be used to make decisions and improve the process of delivering the facility."*

2.1.3 BIM intends & process

BIM is not any software! It is a procedure of getting relevant information about any construction project in the design and pre-construction phase.

BIM is used in more and more disciplines as a tool to structure and share information and knowledge. The BIM process is one of the newest construction concepts enabling innovative methods to generate and gather all necessary information for a given process.

The process of developing BIM models enables better design integration, constructability analysis, coordination for construction, building performance analysis and also facility management. [2]

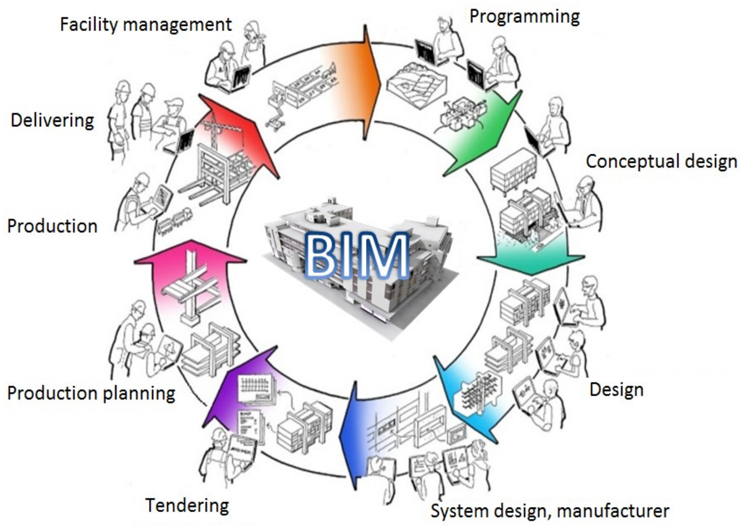


Figure 1 – The BIM concept and how all phases of a construction project contribute to the process. Source; Vestergaard, 2007.

The BIM model is a container or database containing the information needed to manage various processes such as procurement, construction or operation of buildings, facilities and civil works. In short terms, it describes a building design and its life cycle, modeled and maintained by digital tools. The aim of utilizing BIM is to get some common guidelines and standards, a common model and a common tool where it is possible to handle and manage the entire construction process. Figure 1 illustrates how all phases of a construction project contribute to the BIM process. The process enables to bring together the different threads of information used in construction into a single operating environment - thus reducing, and often eliminating, the need for the many different types of paper document currently in use. This current practice involves multiple communication ways, which is prone to error, inaccurate and inefficient in terms of productivity. Figure 2 illustrates the current practice;

Figure 2 – Traditional communication patterns in the AEC sector. Source HFB, 2008

Figure 3 illustrates on the other hand, the communications ways using BIM. It helps to bring all project members on a cooperative and object based model. This process is the result of a reorganized process where all project members work on the same data structure. This enables that information is shared on a database from where data is born, used, updated, and reused for the further work.

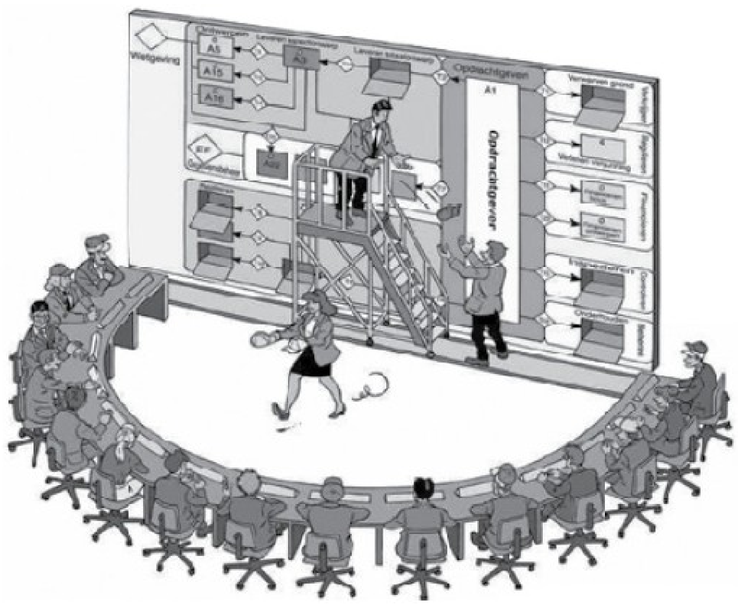


Figure 3 – Way of communicating using BIM. Source HFB, 2008

2.1.4 Opportunities and benefits of BIM

A BIM model is based on 3D objects, which initially contains all information about the modeled building. They are made of intelligent building components which includes data attributes and parametric rules for each object. Each object is moreover associated with properties and various forms of informations which together define the particular object. The various objects relate themselves to each other parametrically, e.g. change in one object will automatically be reflected in all other relevant objects. BIM models are modeled or designed in computer based software applications. These tools contain a parametric modeling engine, which automatically define the behavior of a graphical unit and characterizes its relationship to other model components. [2]

The BIM methodology allows all relevant parties of a construction project the opportunity to pull information out of the model. The extraction of information can be adjusted in a systematically structured pattern or outline, enabling users to pull out data containing just what they have an interest in. This feature ensures that all project member’s works on the same database of information, avoiding confusions and misinterpretations.

BIM opens up to a better way for coordination and communication among the designers, architects, engineers, contractors, building owner and stake holders. The project team members share the useful information along with the electronic models with each other.

There are many other opportunities or benefits than just the parametric modeling, coordination and communication aspects mentioned above. Utilization of this methodology helps the users to be able to see into the building with all of its components. Users are furthermore able to view the building from all sides and can even observe how the building looks at different times of day and night. Additionally different users can take a 3D tour within the building and all its facilities, improving the understanding of how the building would like when build and finalized.

Utilization and implementation of BIM can be a very effective tool for any contractor. The contractor can use the BIM process either by collaborating with a consultant or perform the actual modeling and extracting the needed information by themselves. The tools can especially by very useful during the construction stage, since ongoing activities can be arranged, assured and managed by BIM application monitoring following; quality assurance, logistics, construction progress, schedules and finances ect. In other words is BIM applicable in all aspects of the contractors work during the construction stage.

The individual project partners, such as subcontractors, can build their own models for their own intensions and purposes, e.g. modeling MEP or HVAC components. This model represents then the discipline model of an actual construction project - which the subcontractor is in charge of. The different discipline models can then successfully be integrated or merged into a single master model, containing all disciplines models, e.g. Superstructure, MEP etc.

Combining discipline model opens up to the ability of decreasing conflicts, errors, omissions and changes in construction documents during construction. This is however only achievable by utilization of BIM tools, these tools easily recognize potential problems in advance in the building process. Fixing constructability related problems early results in fewer issues in the plans, fewer disturbs in the field and finally reduces rework. This topic is described in more details in the succeeding chapter, (BIM and Construction feasibility).

According to [1] aids BIM improvement of the quality and speed for decision making in relation to; manage supply chains, sequence workflow, progress correctness of data, diminish time spent on data entry, cut down design and engineering clashes and consequent rework and recover lifecycle management of buildings and infrastructure.

At last, several litterateurs state [1, 2, 4], that implementation of BIM can provide;

- Improve the jobsite by cooperate with people, processes, materials, equipment and information more effectively
- Enhance productivity, by increasing quality project outcome with fewer RFIs and field coordination problems
- Experience positive ROI on overall investment during an economic recession

Finally, seeing BIM from a contractor’s perspective, it enables - among others;

- Early insight into complex assembly and installation details
- Simulate the building performance and thereby gain a greater insight into the processes
- Achieve better flow by utilizing the methods in logistics planning
- Assist in prefabrication, preassembly, modularization, and off-site fabrication techniques and processes.

Some literature reviews have identified the following as some of the most common BIM uses on typical construction projects, across different stages of a construction project.

Design phase

- Compare and analyze different design alternatives (Kymmell, 2008)
- Generate 2D drawings (Gilligan and Kunz, 2007)
- Visualization/ walkthrough (Kymmell, 2008)
- Clash detection/ design coordination (Gilligan and Kunz, 2007)
- Constructability analysis (Kymmell, 2008)
- Cost analysis and estimation (5D) (Kymmell, 2008)
- Construction schedule modeling (4D) (Brandon and Kocaturk, 2008)
- Energy/performance analysis (Eastman et al, 2008)
- Linking of methods statement to model (Brandon and Kocaturk, 2008)
- Planning of construction sequences (Eastman et al, 2008)
- Resolution of coordination issues during regular coordination meetings (enhanced visualization) (Kymmell, 2008)

Construction phase

- Replacement of fabrication shop drawings by 3D model (Gilligan and Kunz, 2007)
- Automated Quantity Take-offs (Brandon and Kocaturk, 2008)
- Cost tracking (cash flow analysis) (Kymmell, 2008)
- 3D analysis of safety issues (Brandon and Kocaturk, 2008)
- Installation procedures at congested areas (Brandon and Kocaturk, 2008)
- Analysis of construction sequences (Khanzode et al, 2008)
- Purpose built models for specific problem solving (Kymmell, 2008)
- Optimization of crew(s) productivity (Gilligan and Kunz, 2007)
- Construction mobilization procurement (Khanzode et al, 2008)

Operations phase

- Generate "as-built" models (Gilligan and Kunz, 2007)
- Repair strategy development (Brandon and Kocaturk, 2008)

2.2 BIM and construction feasibility

The following chapter covers various themes and topics within construction feasibility, BIM coordination and clash detection. The aim of this chapter is to highlight and identify following subjects;

1. The need for performing constructability analysis, as well as the purpose and meaning of the term constructability, including; struggles and resistances encountered to perform constructability reviews. When the analysis and review should be performed? Who should perform the analysis? and new processes and practices this method covers.
2. Building information modeling coordination, including; Challenges within BIM projects and typical coordination procedure.
3. What is clash detection? Including; Clash detective abilities. Ignoring errors and consequences of inaccurate models, along with, early involvement of project team members.
4. Clash detection applications, including; Detectives within BIM design tools and detectives through BIM integration tools

Several authors and organizations have already performed similar research and studies within mentioned topics. The following chapters are inspired and part-reviews from [4, 17, 18, 25].

Figure 4 – Outcome of poor constructability analysis

Figure 5 – Outcome of poor coordination

2.2.1 Constructability analysis

As construction projects are getting increasing more complex, and timeframes get shorter and shorter. The issue of performing construction feasibility has become even more vital and essential - especially for construction companies. Utilization and improvement of constructability analysis has, due to this development, become a key focus and concern for several of the major operators within the AEC sector [18]. General contractors and owners have turned their focus on this methodology, as they seek to decrease construction costs, deliver complex project on-time and improve their overall construction operations practices [17].

Design constraints are a frequent source which causes rework or inappropriate construction progression, causing constructions delays, re-engineering and even the risk of decreasing the crew productivity. The consequences of these issues are in a worst case scenario; higher costs and a suboptimal project performance. [17] Such issues can be avoided if constructability analyses are utilized by engineering departments and construction companies.

Utilizing constructability (review/analysis) requires however, consciousness by GC in-house design teams and constructability consultant firms, since they need to be aware of the potential issues and claims implied by a design's constructability or buildability profile.

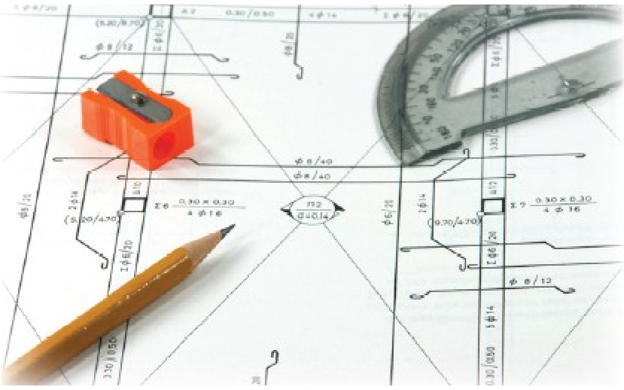


Figure 6 - Constructability review of construction drawings

When a project has various constructability issues, the consequences could be litigation, involving delay claims, change order issues and disputes as well as owners dissatisfaction with delivery. [18]

In a worst case scenario, direct claims may be made against a design team for poor plans, specifications, or estimates or schedules that have made a project difficult to build, more costly or more time consuming than anticipated. These types of issues are well-known in the construction industry, but what is not so well recognized is; when to do constructability reviews, who should perform them and how they should be done.

Subsequent sections provide a litterateur survey of ideas and methods for performing constructability analysis. It is important to note that constructability issues not only involve issues of buildability, but also the sequence of construction and integration of systems in a logical sequence using standard building elements.

The meaning and objectives of constructability reviews

A general search in books [1, 2, 4], papers [18, 20, 22] and scientific articles [17] revels that the term ***constructability*** does not have a clearly defined meaning.

The term constructability and buildability are terms which are specific to the construction industry and have meaning only to those operating within the limits of the industry.

The term ***constructability*** have different meanings within the AEC disciplines; [4]

- *To an **architect**, constructability means the ability for the design to be constructed as envisioned.*
- *To an **engineer** constructability means that the actual construction meets the performance criteria set forth.*
- *To a **constructions manager**, constructability issues can affect many components of a project including costs, schedule, materials and labor. In many cases, the contractor is responsible for the way and methods of constructing a project, based on the design intent documentation.*

These meanings/definitions are however only general clarifications and does not fully cover the term. Constructability analysis, buildability and project construction feasibility all refers to the evaluation of; whether the project design can actually be built by a construction team and how it will be done. [4]

According to [17] the technique is a construction management related method, enabling project managers the ability to review all construction processes from start to finish.

"It is an inspection for practicality, which purpose is to spot potential design and assemble difficulties".

The assessment is a formalized ongoing and repeating process that utilizes a team with broad technical construction knowledge to ensure that project design is buildable while being cost-effective, bidable and maintainable with reduced overruns and delays. [22]

Bid-ability assessment is a review of contract documents to identify errors, omissions and conflicts in plans, specifications, quantities, work items/activities, operational constraints and appropriate basis of payment. This topic is part of a constructability process, but is not covered in this thesis.

According to [18] constructability is referred to as:

- *The extent to which the design of a building facilitates ease of construction, subject to the overall requirements for the completed building*
- *A system for achieving optimum integration of construction knowledge and experience in planning, engineering, procurement and field operations in the building process, and balancing the various project and environmental constraints, to achieve overall objectives*
- *A system for achieving optimum integration of construction knowledge in the building process, and balancing the various project and environmental constraints to maximize achievement of project goals and building performance*

The overall aim of the assessment is to identify and correct potential conflicts related to the construction plan, before a project is initiated and built on-site. The key objectives are according to [20];

- *Enhance early planning*
- *Minimize scope changes*
- *Reduce design related change orders*
- *Avoid cost overruns*
- *Improve contractors productivity*
- *Develop construction friendly specifications*
- *Enhance quality*
- *Reduce delays / meet schedules*
- *Improve public image*
- *Promote construction safety*
- *Reduce conflicts / disputes*
- *Decrease construction and maintenance costs*

Typical implementation goals for GC's are usually, "*an effort to improve the total quality of construction bid packages*" & "*optimize the use of construction knowledge and experience in planning and design to achieve the overall project objectives*" [20]

The review can be initiated during late design and can last until preconstruction. [4]

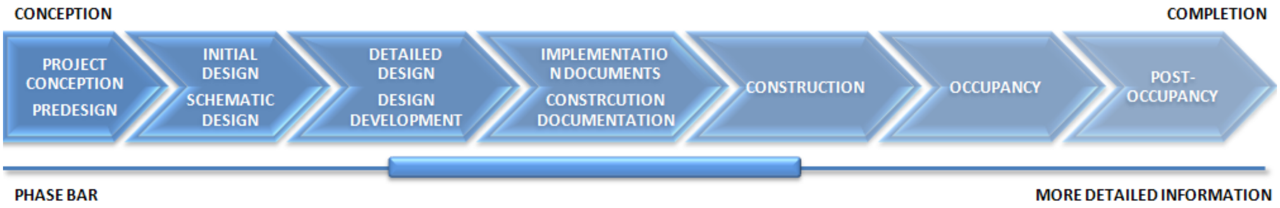


Figure 7 – Constructability reviews usually begin during design and can last until construction. Source of inspiration [4]

The reason why constructability analysis and reviews are usually performed after the conceptual design, is to make sure that the construction knowledge and extracted data is integrated in succeeding phases of a construction project, especially during the design stage. [17] The commencement of such review is described later in section 2.2.1.

How does one really know if a design is buildable? And how much can one determine about how building components and objects will clash, when looking at a BIM model. Best practice and several pilot projects has shown, that the best way to know if a design is truly buildable, is to investigate it by testing it. 4D BIM allow design and construction managers to test different design and sequencing alternatives.

Barriers

Several factors prevent the commencement and initiation of constructability reviews. This is to some extent caused by the fact, that the AEC sector is well-known for being conservative and often displaying resistance towards new processes and methodologies [4]. This is especially common, when the techniques require high level of training and organizational changes - including implementation of new tools, skills and routines. [JK]

The following list shows other struggles and resistances encountered to perform and improve constructability reviews; [18, 20]

- *Complacency with status quo*
- *Resistance by designers, who tend to see such efforts as an intrusion*
- *Unwillingness to invest additional capital and effort in the early stages of a project*
- *Limitations of "lump-sum" and "design-build" contracts*
- *Lack of construction experience in the design firm*
- *The designers perception and opinion that they already performed an analysis*
- *Lack of mutual respect between constructors and designers*
- *Construction input that is requested too late to be of value*

To overcome the above mentioned struggles and resistances requires changes in procedures, company culture and awareness of potential constructability issues both at the corporate and project level [18, 20].

Litigation usually involves the claim starters listed below, which clearly include issues relating to constructability. According to [18] "*The list (below) provides an insight as to why constructability claims arise because almost all of these factors relate to inadequate communication, lack of coordination, and inexperienced project teams that do not obtain guidance from those who have previously handled similar projects*".

- *Site responsibilities are not clear and coordinated*
- *Client differences are not resolved immediately*
- *The construction schedule and budget are not tied to scope*
- *The clients project representative is inexperienced*
- *The firm accepts the project with uncompensated risks*
- *There are infrequent site observations*
- *The client has difficulty making decisions*
- *Key issues are resolved after the agreement is signed*
- *The firm has a high professional staff turnover rate*
- *The consultants project staff are inexperienced*
- *The firms project manager is inexperienced*
- *Construction contract administration services are not in the contract*
- *Project agreements are not well coordinated*
- *The project is fast tracked*
- *The construction budget is inflexible*
- *There is a high volume of change orders*
- *The construction schedule is inflexible*
- *Client decisions are not systematically documented*
- *The consultants project manager is inexperienced*
- *The client is a committee*
- *The client has a high public profile which generates public attention, putting pressure on design decision-making processes*

Other factors which prevents utilization of the reviews is lack of common firm regulations of the project managers and design engineers employment contracts. The performance of this types of works are rarely required, neither specified in the employers daily-, weekly- or monthly work schedules and routines. [JK]

Additional obstacles and barriers to commence such review are also the lack of knowledge and request for performing such analysis - coming especially from the owners and stakeholders. According to [21] "*the initial investment in such reviews has the potential to generate savings far greater than the expenditure. The risk of problems with the design belong to the owner under most delivery methods, though this risk is generally shifted to the GC in a design-build scenario. But even in such a delivery model, the owner must communicate its intent and requirements.*"

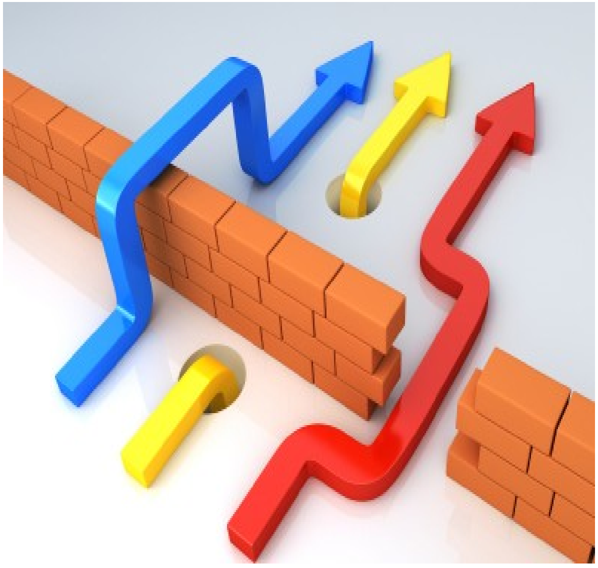


Figure 8 – Avoid barriers.

The constructability review provides a mechanism where the owner can be protected against the risk of increased costs due to conflicts between the design and construction considerations. [20]

When to perform constructability reviews

Constructability issues often occurs as a result of; (communications issues) between the owner, the architect or the designer and the construction company (before construction commences). These issues are well known to be a common problem, particularly for design-bid-build projects. [1, 2, 4] More on this matter subject later.

The problem with constructability issues are usually caused by the fact that architects and design-engineers by their nature are not experts and endure "know-how" within the construction methods and practices. For these reason and "*for liability reasons, most plans and specifications tend to be performance oriented, specifying the end result and materials to be used*". [18, 20] The lack of communication and collaboration between designer and construction companies is often covered or hidden by the use of performance specifications. While the use of performance specifications is justified, it cannot be overused in the name of risk management. [18]

Awareness of constructability issues early in the project delivery process, helps project teams to identify design constraints which limit a contractors ability to plan and perform construction operations efficiently. Incorporation of constructability analysis into the design process and practice at an early stage, will furthermore result in less post-construction disputes and have a positive impact on the project delivery. Explicitly due to improved and more assured project deliverance. [17]

According to [2] and paper [18] the constructability reviews should be performed for all construction projects, regardless of their size and complexity. Tweaking, adaption and use of the methods, should only be adjusted in accordance with the design intent documentation and project delivery method.

Other books [1] and paper [22] that constructability analysis should only be considered for projects with complex MEP installations and fire protection designs. The arguments in such cases are, that these tools and techniques are too comprehensive and time consuming for simple projects.

Other construction risk management specialist [C4] state "*the Constructability Review process must be established, scheduled and tailored to each design phase*".

There is also in general, different opinions for when, and how frequently the analysis should be performed. Some paper [18] and scientific articles [14] state, that projects in the region of $2 million or less, a simple constructability analysis should be performed at initiation, then again at approximately 90 % design stage. For others, in the $25 million region or less, constructability reviews should be done at initiation, then again at the 30, 60 and 90 % design stages. For projects over $25 million the constructability review process should be more or less continuous during the entire design phase.

Other ministry guidelines [22], suggests that reviews should be performed by internal and external teams. According to [22] the internal review should be conducted in a workshop format at *"specified milestones completion(s) and will result in specific observations or recommendations for implementation in design. At this time, internal review may be considered* *at 50 and 80 % stages of design*". The external reviews should be conducted either by collaborative firms or consulting companies. The review is suggested to be conducted at an agreed schedule and at approximately 80 % stage only.

Firms and associations within the construction industry do however also have their own opinions for when to perform the reviews.

- "*The most beneficial time to perform a Constructability Review is prior to final completion of design (whenever possible) or prior to bidding the construction contract (at a minimum)*". [C1]
- *"The review should take place at about the 50% design stage".* [C2]
- *"reviews to be conducted during the early stages of a project design. Reviews conducted early in the design process have the best potential for providing meaningful benefits without having an adverse affect on project schedules. Performing the first constructability review at the 90-95 % plan completion is not recommended. At this stage, plan changes will without a doubt, result in costly schedule delays".* [C3]

Apart from the different opinions in relation to frequency and when to perform the reviews. It is the common opinion; that the reviews should be conducted for the first time at the early design stage. Several sources [1, 2, 18] require, that this process should be part of the design stage and should be performed routinely. Furthermore numerous sources [9, 12, 23] state, that final reviews of the plans and specification should take place, at or near the completion of the design phase of a project. This is due to the fact that conducting reviews in the preconstruction phase is not effective, since by this time significant costs have been incurred in developing the design. "*Plan and preparation changes at this late stage are costly to put into operation since they have a significant effect on the project schedule and may conflict with already approved permits and commitments, and furthermore will be perceived by many involved in the process as an attack on their credibility*". [23]

Who should perform the reviews

Litterateur surveys of [1,2, 4, 18, 20] signifies, that constructability reviews, must be conducted by all types of contractors. The majority of the journals and articles also suggest, that the reviews should be project specific, where the extent and scope of the assessments should correspond to the complexity and project size.

Figure 9 – The puzzle of who does what and when?

The reviews have to be performed by a mix of technical skilled personnel, construction managers and construction specialists. The experts could be composed of people who are experienced in the contracting industry on specific construction operations. The technical skilled employees should be composed of; BIM experienced personnel, with different engineering discipline backgrounds, tendering-, scheduling- and material specialists. The team size will vary, depending on the construction complexity.

Some journals [9, 18, 23] and scientific article [17] recommend contactors to perform the analysis internally and externally. Meaning that the contractor should set up a team within their own company, but also hire, either a collaborative company or a consulting company - to perform a review at a specified and agreed design stage.

According to [18] the performance and execution of who is to be responsible of such analysis is however depending on the contracted project delivery method. On the other hand implementation and completion of constructability reviews are typically easily managed, but only when a contractor is determined to perform the analysis beforehand. The preferred or chosen general contractor is usually engaged at the first client briefing stage and is involved all the way through the design phases. The contractor is for any type of project delivery methods an essential part of all design meetings and reviews all documents, plans, drawings, specifications, tender documents and procurement schedules.

For ***design-bid-build*** projects, the contractors involved in the tendering phase must conduct a constructability analysis before pricing the bid documents [18]. This is generally very difficult since there has been no prior communication about the design. This is due to the fact, that construction companies does not get involved in the design phase, as it is unlikely for them to be contracted at that time [4]. The best solution and a way to overcome this obstacle and make use of constructability analysis at an early stage is to hire reviewer consultants. These consultants need to be construction specialists with significant experience in construction methods. Furthermore they need to have the ability to run projects in corporation with the architects and engineers during the intense design process phases [18].

According to [4, 18] is this type of task not easily performed and such consultants rare. A different approach is according to [18] "*to identify the likely tendering construction companies (perhaps four to six candidates) and ask them to each provide an experienced construction engineer or construction manager to form a team to help the designers develop a buildable solution from the outset. This team could serve again and again, and lessons learned on one project could be leveraged into new projects as time goes by*".

The proposed taskforce or team requires unsurprisingly some expenditure from the construction companies, but there could be a lot of interest from the clients perspective to grant or offer a considerable consulting payment for this process [23]. This approach may also be seen as an investment that returns no construction overruns or time delays and fewer litigation issues. The outcome of this approach may also help project teams to eliminate the risks of generating poor plans, drawings, specifications etc.

According to [18] "*Constructability reviewers working for the construction company have to be very experienced and fast on their feet in order to advise the bidding company on the constructability issues that are likely to affect costs and schedules*". Furthermore it is noted that severe constructability issues on design-bid-build projects can bankrupt a construction company, if constraints and issues are not identified up front, or if uncompensated constructability risks are not properly analyzed. A constructability analysis must for that reason be a principal part of a construction company's integrated approach to risk management. According to [18] "*Construction companies that do not undertake a constructability analysis and review increase* *their risk profile, as the idea is to identify, categorize, quantify and then reduce or eliminate the risk*". Design risk is, by its very nature, an expression of constructability.

For ***build-own-operate-transfer*** projects (where the construction company is entirely responsible for all project design and construction), the construction company have to perform the reviews by themselves [4]. In the absence of some internal constructability reviewers, the company must bring in external constructability know-how to establish an accurate and cautious design review that is fully buildable, without excessive costs or time delays. According to [18] requires this approach " *designers to provide their designs for external review at all levels, something that some architects are unwilling to do*".

A constructability review is also easy to implement for projects operating on the ideology of alliancing and partnering, mainly those related to large public works which by their nature employ a JIT design process [23]. It is easily achieved, as the entire project team (from designers and engineers to those involved in construction and commissioning) are all on the same side - sharing project "gain and pain". For these types of relationship, communication pathways are very strong and cooperative, and all project members can contribute expertise to the constructability review. Furthermore, there are usually few litigation issues related to the constructability, as problems and concerns are worked out at an early stage - resulting in none or few constructability surprises [18].

According to [18] for construction project running on such delivery methods the constructability reviews should commence at the client brief stage, and run through the design process stages, as well as into construction. The assessment should be conducted regardless of construction options, project timeframe or size. The constructor must therefore be active and influential in the reviewing process during the entire design stage [23].

According to numerous source [1, 2, 4, 18], when conducting these reviews (for whatever project delivery method) it is essential that the contractors integrate information source system which capture the lessons learned throughout all project phases. This includes what went wrong, what went right, change orders, variations and commissioning reports. The teams needs to provide a continuous stream of information into a database, which initially will benefit the contractor, when the next project is initiated. Since the constructability review "know-how" and procedure is up to date.

The review process

A project team should meet to discuss constructability issues throughout the planning and design process. During the development of the Project Assessment, an intensive effort should be made to identify specific constructability items and determine their impact on the conceptual design [20]. A project manager should then be assigned to the task, where his/hers responsibility is to ensure that constructability issues have been given adequate attention and are continuously resolved during the review process. This task can be accomplished by holding one or more constructability review sessions, organized and managed by the Project Manager [8].

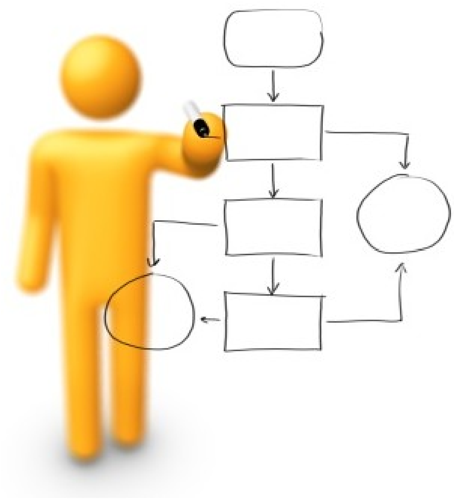


Figure 10 – The process.

The review members should attend a so called "kick off meeting" held at the start of the design stage. Follow up meetings should then be held at a specified and agreed design stages. For example at the 30% and 60% design phase. (See previous section; When to perform constructability reviews)

Identified and critical items/objects should be given at the midway stage (E.g. 60 %), since they both can have an effect on the final design and on-site installation methods. During this period, this may be the last opportunity that any design changes can be considered, without major negative impact to the project. When the midway review is finalized and reported items/objects has been resolved, the Project Manager should decide whether a final review is necessary at the design end stage, (E.g. 90 or 95 % stage). It is furthermore up to a Project Manager to decide on the amount of time necessary to be used for each review [18, 20].

According to [18, 20] is a Project Managers responsible (each meeting) to share and collect info about;

- *Evaluation of documentations and their completeness and adequacy for a specific ongoing tasks*
- *The analysis of buildability*
- *Logical construction sequence*
- *Scheduling and complexity of project objects and elements.*

Complexity analysis determines whether or not elements can be simplified or split into smaller individual standard components. This assessment is particularly vital for infrastructural system elements, such as piping and cabling, e.g. in large buildings with a complicated service function[18]. Rising MEP and cableways and similar systems should also be analyzed to see if a simpler installation system could save cost, time and reduce uncertainties, during the construction period [8]. For example, a rising service duct channel may be sized by the designer, so that the construction company cannot use a standard support system and a special one must be fabricated. If several hundred rising duct channels are required then a case could be made during the constructability analysis to simplify this element by redesigning the rising channel so that a standard support system can be used.

Workforce & management tools

Best practice and utilization of constructability reviews [1, 2, 18] signifies that the correct workforce and tools are necessary to effectively execute the review. According to [18, 2] is a common approach to:

- *Establish a multidisciplinary review team with construction experienced personnel*
- *Create comprehensive constructability management tools which are provided to the reviewers*
- *Conduct constructability audits on projects either under construction or completed to ascertain and prevent recurring bid document errors*
- *Conduct site visits to verify site topographic, utility, easement, surrounding public utility and other existing conditions*

Individuals with direct construction field experience, should be selected to perform constructability reviews. According to [18] "*the most qualified constructability reviewers are those individuals that have dealt with the by-product of bid document errors and omissions in the field. Supervisors, inspectors, or managers who have been involved in resolving unclear construction conditions or settling change orders and claims have an excellent background that can be applied in the upfront constructability reviews*". Their knowledge, combined with some form of a constructability checklist derived from reviews of previous projects necessary for a comprehensive and successful constructability review.

The initial reviews are usually completed by architects and engineers, and are viewed from a designers perspective. These reviews should afterwards, as early as possible, be edited towards the contractors/builders perspective in order to fully incorporate preferred solutions. [22]

It is essential that a team is capable to continually build upon, and access a "know-how" or previous "lesson learned" database of specific troublesome areas. According to [18] "*the review team needs to have management tools that act as a guide to finding missing or uncoordinated contract document information, including a detailed constructability scope of work*". The detailed constructability scope of work defines areas to be reviewed in the documents and assigns multidisciplinary team members responsible for completing them. In practice, each reviewer is responsible for catching comments such as “see structural”, “provided by others” or “provide as required” and frequently repeated errors or omissions that have resulted in variations or change orders on previous projects [18].

A log-book is also an important tool for the engineer engaged to perform a constructability review. The engineer can use the booklet to log the “lessons learned” during construction and follow the output of the review process. This logging process has according to [25] two key benefits;

- Data and information can be incorporated into other subsequent projects
- Back-checking is enabled

Several meeting and follow-ups with the architects and design engineers are necessary to resolve all identified issues. The project team should reach an agreement on whether or not to incorporate each constructability comment. The constructability review will pay for itself if it is conducted properly and focused on the issues that affect buildability. It can be difficult to quantify the financial savings delivered by the review as the stage of construction, in which an error is discovered has the biggest impact on its cost. However, only a few of the major and frequent issues need to be identified to realize its true value. According to [18] *"it is essential that the review and analysis process is systemized so that it follows a set procedure".*

Benefits

Several articles and books promote constructability analysis. [1, 2, 4, 17, 18]

An effective constructability review process will accomplish several goals that are important to any construction company. In general a constructability review process should assure;

1. *The project, as detailed in the plans and specifications, can be constructed using standard construction methods, materials and techniques;*
2. *The plans and specifications provide the contractor with clear, concise information that can be utilized to prepare a competitive, cost-effective bid; and*
3. *The work when constructed in accordance with the plans and specifications will result in a project that can be maintained in a cost-effective manner by a FM agency over the life of the project.*

Figure 11 – Benefits

According to the CII "*Early constructability efforts result in a significant payback to the project*". CII research has cited cost reductions of between 6 and 23 percent, benefit/cost ratios of up to 10/1, and large schedule reductions.

The intangible benefits are equally as important as the quantitative benefits and must be recognized accordingly. These are; more accurate schedules, reduced design omissions, enhanced quality of the contract documents for bidding, reduced volume of RFI's, reduced change orders, increased productivity, improved sequence of construction, enhanced quality, decreased maintenance and safer job.

An additional material advantage is the development of teamwork and employees sense of contribution to a reliable project. This can be explained by, when construction personnel are involved early in the design stages, a sense of teamwork is developed, which ultimately could continue through the construction phase with positive outcome.

BIM and Constructability

Utilization of BIM models unlocks the technical aspects of conducting constructability reviews. This is due to BIM models are capable of checking construction projects for coordination, buildability and even bidability [4]. BIM models contains design data for all disciplines, which mitigate risks throughout construction process greatly - due to the models ability to visually see every significant error and inconsistency in the drawings and specifications. Design flaws and logistics problems come to light, and coordination is maintained due to automatic clash detection features [2]. (The topic is described in further detail in the subsequent chapter). When the overall design is nearly complete and the BIM is approaching the final construction documentation level, a constructability review can be performed to find any high-level/high-cost issues. Upon completion, the final product of a BIM-based review include:

- *Detailed, data rich model reflecting an as-planned design*
- *A inconsistency report listing each error and omission in the drawings discovered during the development of the BIM*

- *A clash report listing each cross-disciplinary interference in the construction documents*
- *An constructability report of any high-level or high-cost issues*

Furthermore a BIM model can according to [9] "*be a valuable tool for enhancing existing systems with respect to construction sequence, equipment access, completed work and assembling difficulty components".* This ability can provide additional links between the site and the design to collaboratively solve constructability issues that may arise during construction. Modeling the building in a 3D environment would point to any of the missing information in the building, certain components or systems and the sequence of assembling the components can be easily determined. In this way all the misunderstandings can be solved and identified, before the construction starts, since all the important design details already has been clarified and solved [9].

2.2.2 Coordination

One of the fundamental goals of the utilization of BIM is the coordination between discipline BIM models. The outcome of this essential process is multiple trade and system coordination. Trade coordination using BIM requires diverse construction related skills, experience, technical BIM modeling skills and most importantly, understanding of the technology, including its methods of interaction. Tasks within this field are usually a major portion of any BIM coordinators and project managers' responsibilities. [4] The tasks usually involve work and communication with designers, subcontractors, material suppliers and fabricators, among others. [4] When the BIM concept is to be fully utilized the trade coordination process usually involve; clash detections, constructability analysis and coordination meetings with AEC members. It is also essential to create a trade coordination management plan, to create shop/coordination drawings. The work process includes updating and renewal of BIM models in accordance with located interferences, until reaching a zero conflict status.

The coordination between the BIM related trades can be really challenging, especially when projects are running on traditional 2D based CAD. Identification and resolution of issues requires great deal of technical skill and experience. [19] This is due to 2D CAD clash detection is performed manually by overlaying individual system drawings on a light table to identify potential conflicts. Other commonly used interference detection for 2D CAD based projects is the use of digital CAD drawings and overlay of these layers to visually and manually identify potential clashes. These CAD drawings which lack a z-axis, allow for mistakes in interpretation. For them to be completely accurate, the top and bottom elevations of all the components in a project need to be shown in order to coordinate these layered CAD files. [4] According to [2] are both manual approaches slow, costly, and prone to error and depend on the use of up-to-date drawings.

The only real way to complete a useful coordination is to create a BIM model in which all files are 3D, linked, and intelligent during the design phase. According to [4] is trade coordination one of the areas where BIM really shines. BIM makes this process easy to understand for all project members. Issues and constrains can be quickly identified and presented, which initially help project team to facilitate communication among trades and leads to more proactive interference resolution. The trade coordination process is a valuable process that is to be performed during the preconstruction stage and especially during the HVAC/MEP coordination process in the construction phase.

The coordination procedure is as following;

1. Designers and subcontractors create BIM models of their respective scope of work based on their design documents.
2. The discipline models are uploaded to a common server, which then are subsequently combine the designs and trade specific BIM models into one merged 3D BIM model.
3. The merged BIM model is then used to perform clash detection, from where reports are generated.
4. The clash reports and the BIM model are then reviewed in a coordination meeting, attended by designers and subcontractors. Identified problems are discussed, to find appropriate solutions.
5. Based on the decided solutions, the designer and subcontractors modify and adjust their own designs and resubmit the new BIM models for next iteration.
6. The process is repeated until all involved parties have confidence in the constructability of the coordinated designs.

2.2.3 Clash detection

One of the major advantages of the BIM process is the possibility for designers, contractors, and developers to visualize and explore the tree dimensional model, rapidly, efficiently and instantly. Designs modifications can simply and efficiently be changed and successively visualized, in order to view altered design objects. The BIM process does not only allow designers better parametric design and visualization options, it also offers users automatic interference detection features.

Entire AEC BIM models can be checked for interferences, where inconsistencies and lack of design information are identified, either through simulation of the construction process to a certain degree or by utilizing systematic clash detection. [10] Some of these abilities within the BIM have been one of the major advances and leading factors of the implementation of the BIM process in the AEC industry. A vast drive and effort of systematizing and utilizing interference detections functionality between several AEC BIM models have been developed over the last decades. [4] These automatic detection of conflicts are excellent methods for identifying design errors, e.g. where objects either occupy the same place, or are too close for suitable or applicable access, insulation, safety, maintenance, and so forth. [2] The degree of precision, accuracy and the overall ability to layer multiple models or information data sets into a single file are in a broad-spectrum new in the construction industry. [4] The capabilities and supported services or features show where BIM can provide - through software solutions - some astonishing tools. Which the conventional 2D CAD processes and methods cannot live up to, neither challenge in terms of consistency.

Options and features

In general, entire BIM project models can be tested against other discipline model in order to spot, locate and observe what the scope of interference is. Virtually anything in the model can be tested against another set of objects, elements, or selection criteria. [4] Besides these options, several clash detection software tools allow automatic geometry based clash detection to be combined with rule-based clash analysis for identifying qualified and structurally organized clashes. Subsequently it is possible to selectively check and control clashes between stated or specified systems, such as isolating clashes between mechanical and structural systems. Working with rules in clash detectives are very useful since they give the users some parameters to run against clash groups or batches. These features unlocks the possibilities to ignore certain types of geometry or certain items contained within the same model. Rules can also be created and modified as needed, giving the users flexibility for running separate detailed detections for different purposes. Utilizing rules when running a clash, can therefore help the users to reduce or filter the number of clashes that might be found in a given run. This brings the users closer to the desired results. [1] These options are only possible because each component within the BIM models is associated with specific type of systems or identification information. Consequently, the clash detection process can be performed at any level of modeling detail and across any number of building systems and trades. [2] E.g. a contractor can search for conditions where the clearance or space (soft clash) between mechanical components and the subfloor is less than a given height, e.g. 65 cm. Such types of clash detection analysis are only possible with well-defined and structurally organized BIM models. Regardless of the BIM models accuracy, the GC or subcontractor must ensure that the BIM model is finalized with suitable level of detail. E.g. it must contain sufficient geometric and grouping information about the piping's, ducts, structural steels, concrete elements and connections including other structurally critical components, so that clashes can be accurately detected. [2]

Ignoring errors & consequences of inaccurate models

In many cases very small modeling errors cause clashes which initially would not cause a big problem during construction phase. Such errors or clashes can be quickly identified and ignored, but if the detailing is incorrect, a significant amount of problems will not be encountered until the building is at the construction stage. Such errors could ultimately lead to costly and time consuming reworks or re-engineering in order to solve the errors, triggered by inaccurate BIM models. [2]

Involvement of project team members

Accurate and proper detailing of the BIM models, by all project team members responsible for the design of each engineering discipline, is vital and essential. The project team members need to participate in the model development process as early as possible, especially the contractors.

According to [2] a possible resolution could take place in a common project site office, where large a monitor can be used to display each issue, and each discipline can contribute their expertise to the solution. Agreed upon changes can then be entered into the appropriate design model prior to the next clash detection cycle. Utilization, experience and know-how within this form of workflow has shown that there is no such thing as a minor change that does not require clash detection. [2]

Other collaboration techniques used in the AEC sector is the so called "big room" or "i-room" approach. This workflow involves designer, specialty contractors and other critical members. These project members has to share the same work space to improve access to one another.

The goal is to create a collaborative work environment where the decision-making latency can be reduced. This is similar to the "Extreme Collaboration" approach that is used by NASA scientists in designing space missions. The central idea is to put all the project team members who need to collaborate, together in one room, and allow them full access to each others knowledge, so that they can work out their coordinated design solution together. [2]

Subcontractors, who are outsourcing modeling and coordination, are not exempt from this requirement. Outsource detailers are also required to work in the big room, not remotely. Having detailers working side by side shortens the overall time for modeling and coordination and is more economical in the end for all concerned. Because it eliminates the need for detailers to wait for postings to see what others are doing. The big room need not be at the jobsite, it can be in another location more convenient for the detailers. [2]

The idea is excellent and has worked as well as could be expected in various attempts to implement it in the construction industry. [2]

It is clearly a challenge to bring individuals together from various companies and have them placed for a longer time, for working out the design of a complex construction project. In practice it has been the GC's who has been able to organize such efforts successfully. [2]

The i-room is an idea that came from CIFE. The concept was developed out of a research of collaboration techniques in parallel industries, such as automotive or aeronautic engineering. The automotive industry in Japan uses the big room concept, which is very similar to the i-room. [2]

2.2.4 Clash detective applications

There are in general two dominant applications types of clash detection technologies in the AEC industry, they can be subcategorized into the following;

- Clash detection add-ins within BIM application design tools
- BIM integration tools that perform clash detection (build for purpose)

Clash detection within BIM design tools

The BIM design tools, such as Autodesk Revit, Bentley Microstation and Graphisoft Archicad includes basic interference detection features that allow designers to check for “hard” clashes during the design phase. The lack of supported features and filtering options makes the tools poor in terms of identifying interferences, such as; clearances, applicable access, insulation, safety, maintenance and so forth. The design tools also lack interoperability, e.g. they do not support the competitors software solution file formats. The lack of interoperability causes file exchange problems when different engineering discipline models are to be combined or when BIM models are to be upgraded, reengineered or extended by external project team members. Nevertheless, these tools give the designers the most optimal editing options since the tools are performed within BIM design tools, in other words, the workflow of editing BIM models and performing hard clash detection is interconnected and linked.

Clash detection through BIM integration tools

Professional clash detection technologies, build for purpose, are also available in the AEC industry. These applications work externally, as BIM integration tools. The applications allow designers to import a 3D model from a third parties modeling software (mentioned earlier) and visualize it as an integrated model. Examples of this kind of software are Autodesk Navisworks Manager, Bentley Navigator, Tekla BIMsight and Solibri Model Checker. See section 2.3 for more information about some of the mentioned applications. These, build for purpose, part clash detection tools supports the IFC exchange file format, and some of them are entirely based upon this exchange format, e.g. Tekla BIMsight and Solibri Model Checker.

The interference detection analysis that these tools offer have a tendency to be more sophisticated and are capable of identifying more types of clash types, such as; clearances, soft and hard clashes.

The disadvantage of mentioned applications is that identified clashes cannot be fixed instantaneously, because the integrated model (often through IFC file format) is not directly associated with the original model. The information and data stream is therefore only one way and not bidirectional. E.g. when a Revit 3D model is exported to Navisworks and once the interferences are located, the users must check the element ID for each clash and then go back to Revit, use the “Select By ID” function, manually type the ID to find the issued element. This workflow is very time consuming and immature since it is not always possible to find the correct element with the extracted ID tag information. [16] Newly released applications have integrated state of art technology, which avoids some of the mentioned drawbacks, e.g. Solibri Model Checker (through Issue Locator) and Navisworks Manager (through SwitchBack). Both systems are described in section 2.3. However the applications are all supporting the OpenBIM collaboration file format XML and are continuously being upgraded and developed, in order to make the systems more easy to use and improving their performances. The XML file format allows designers or other CAD coordination managers the options of generating automated feedback and reporting options, created directly from the clash detection applications. These collaborative reporting options can then be imported to other design tools, such as Autodesk Architectural Desktop, Tekla and Graphisoft ArchiCAD that identifies the reported issues, and provide a camera location for viewing. From here designers are able to directly modify issued interferences and make corrections as necessary. Other BIM design tools, such as Autodesk Revit and Bentley MicroStation have also made commitments to support this new cross-platform communication method. This drawback is also stated in [2] and followed by subsequent statement; “*These capabilities must be introduced into the originating systems or upstream modeling tools and also the receiving, downstream models. This new capability can be used to potentially provide two-way communication for any pair of clash detection or rule-checking tools, as part of a design tool or standalone checking tool*”.

2.3 BIM integration applications

This chapter discusses the functionalities of various chosen and project relevant software tools utilized and exploited in this master thesis. The aim of the chapter is to aid the understanding of typical characteristics and uniqueness of common tools used in the BIM process. The focus is primarily to clarify which tools GC's should use in their efforts to perform 4D simulations, sequencing, general model checking and interference detections. It is important to note, that this chapter is not favoring or does not preference any specific software product and the applications described and represented here are not the only ones in the AEC software market. The application descriptions are intended to acts as guidelines for GC's who wish to perform the above mentioned actions.

The aim of this chapter is to highlight and identify following subjects;

1. General features and options;
2. Software describtion; NW12, Tekla BIMsight, Solibri Model Checker, Vico Office
3. File exchange, collaboration, 4D Simulation and clash detection comparison

Several BIM books [1], [2], [4] has already conducted similar research and descriptions within this topic. The following section is therefore inspired and reviews from those.

2.3.1 General features and properties

The applications mentioned in this section are all dynamic collaborations tools typically used by a variety of designers, construction managers, CAD coordinators, architects etc. The systems are engineered principally for coordination and cooperation purposes, executed by extracting and managing information within BIM model. They are used by several engineering disciplines, working within construction of buildings, infrastructures, plants, offshore structures, and so forth. Through these applications project teams are able to interactively view, analyze and augment project information. The tools leverages the interactive nature of information stored inside BIM models for high performance visualization. They enable in return, greater project transparency, awareness and most importantly insight knowledge to help project teams to avoid costly onsite errors.

The tools are capable of doing much more than perform clash detection, in addition, teams can simulate project scenarios virtually to resolve clashes and optimize project schedules. They are capable of enriching models and project workflow by saving comments, notes and reporting issues to third parties project members. Furthermore they are capable of producing 2D and 3D PDFs for consumption of a wider audience. In other words, the applications are capable of analyzing BIM models for integrity, quality and physical safety. [1]

The systems offer easy to use visualization with intuitive walk-in functionalities. With a single mouse click, users are able to see X-rays, transparent systems or semi-faded objects of a BIM model and thereby reveal potential flaws and weaknesses in the design. The systems also offers the possibility of highlighting clashing object based components and checks that entire models meet the terms with used building codes or best practices within organizational agreements.

The mentioned BIM integration applications are BIM products from different software vendors. Each system comes with their own series of features and capabilities. Some of the applications are similar in term of their supported features and abilities, whereas some are more sophisticated, advanced and support other options, such as QA, QC, FM and ITO. [1]

All applications are aiming towards adding value and business benefits for whomever using the tools. The missions of the software's are to improve the quality of BIM models and make the entire design process more productive.

With the help of the applications, the users can save time and money in deploying BIM and enjoy a fast ROI.

According to [1] following project value addition can be obtained;

- *Saves building costs by decreasing design related flaws*
- *Enables more accurate and up-to-date cost estimates*
- *Provides time savings in architectural design*
- *Supports transparent and more reliable planning process*
- *Saves labor and time through automated quantity takeoff*
- *Decreases the risk involved in BIM pilot projects*

More over [1] state that "the building industry has a potential of saving up to 30% of building costs through improving efficiency and eliminating mistakes and delays".

2.3.2 Software Descriptions

The following descriptions are just samples of some of the characteristics and abilities of utilized softwares in this thesis.

Autodesk Navisworks

Navisworks helps architecture, engineering, and construction teams to improve and gain control over the outcome of AEC projects. By utilizing the application solutions, detailed design models can be aggregated and reviewed by all project stakeholders, helping users to benefit from the competitive advantages of BIM workflows. BIM processes allow team members to explore a projects key physical and functional characteristics digitally - before it is built, helping to deliver projects faster more economically and with reduced environmental impact. [Autodesk]

Studies of [1] state that "*Navisworks is the best place to begin an initial exploration in integrating BIM applications. For anyone who has not been exposed to 3D models, it is a great place to begin to learn to view, navigate, and understand virtual environments*".

Navisworks is a viewer of BIM models and has many useful applications in almost all phases of the deployment of a BIM model. The application works much like a video game and since it is not a modeler it also limits the severity and number of things that can go wrong in a BIM analysis [1]. According to [1] is the main purpose or primary function of Navisworks is to provide; 3D model interoperability for the building designers and construction field managers. Allot of different design tools are being used by many different engineering and design disciplines that all create and produce basic or advanced 3D model in various file formats. Most of these tools do not import or export one another's native file formats, thus Navisworks has provide a model viewer that can read almost any 3D file format. According [5] the application is capable to read up to 48 different 3D based CAD and laser scan file formats, varying from the IFC to Google SketchUp, AutoCAD and even Pro/Engineer, Solidworks and Rhino, just to mention a few.

According to [1] not everyone will ever be using the same software for everything; thus the need for interoperability is fundamental to the successful implementation of the BIM process. Any project team using BIM is faced with four major challenges that Navisworks addresses:

- *It can read different file types from various sources*
- *It can import and handle huge files*
- *It can combine, merge and append different file types into the same file together, and*
- *It facilitates graphical communications across the entire project team*

The reason that Navisworks can handle huge files and navigate through the virtual environments so effortlessly is that all solid 3D models are translated into surface models; i.e., the solids will be represented by all their surfaces only. This translation allows the application to manipulate the information faster, thus making navigating through the model in Navisworks faster and more practical for the users [1]. The import of model data from a solids modeler will thus be limited to the 3D information that is critical to the functionality of Navisworks; the nature of import and export functions between software tools is often limited, and relates to interoperability [6]. It is the translator that determines exactly what information is brought across to the other platform, and how it is manifested in that new platform.
This translation unavoidably removes some of the information and most of the intelligence from the original model, but that is generally not a particular problem. What is left is all the geometries and spatial information's, and that should be enough to sustain all the visual data and perform sequence and clash analysis [1]. This automated file translation and ability to combine a variety of file types and sizes ultimately result in a whole-project view that helps all project stakeholders to make better design decisions, increase accuracy of construction documentation, and predict performance and planning [Autodesk].

Navisworks software is offered by Autodesk in three different products varieties. This is according to Autodesk due to "*provide project stakeholders with the right tools to help collaborate, coordinate, and communicate more effectively*".

Beside all mention capabilities, Autodesk state that the applications is able to increasing project teams productivity when working between Revit and Navisworks. This is because the software package includes features such as;

- *Transition between views in Revit and Navisworks applications for easy navigation and visualization with the Switchback feature (described in subsequent section)*
- *Pass construction components created with new Revit into Navisworks for 4D simulation*
- *More accurately create 4D sequences to demonstrate constructability with support for Revit properties, including areas, volumes, and points, along with Revit-linked files and split regions*

Products requiring a license can be purchased as a network license, meaning, that anyone are able to use the product regardless where it is used within the firms server borders and within the limited licensed products.

The products are listed and described in order of their capabilities, starting with the most basic. The products are not described in full details, but are brief explanation of the products.

Navisworks Freedom

Navisworks Freedom is a free viewer, this application can look at already prepared composite (or single) models in the correct file format (NDW and 3D DWF files) [Autodesk]. Freedom is for users who do not wish to analyze or manage projects, but simply wish to have visual access to the models. It will allow the user to view the 3D model hierarchy, object properties, and even animations for a single file. However, it is a viewer only and does not allow editing or markup capabilities [Autodesk].

This is a good product to provide users who need or desire to see the result of many different files brought together into a combined project model. Other project team members with advanced Navisworks solutions (subsequently described) can publish an NWD file that is shared with others utilizing Navisworks Freedom [Autodesk].

Navisworks Simulate

Navisworks Simulate allows users to assemble different 3D models into one combined project model file [Autodesk]. The assemble of a Navisworks project file can (described previous) be a mix of various 3D design modeling file types. After assembling the various files into one combined project file, users can perform construction sequencing also called 4D BIM, by scheduling tasks with the model items and/or objects. A review of a construction sequence is conducted in the so called "TimeLiner" function, by either importing a construction schedule from an outside software or building a new schedule in TimeLiner. The 3D model components can be linked to a scheduled task, and thus can be seen appearing (or disappearing) in timed sequence. This is an excellent way to communicate construction progress visually [1]. Users can import schedules from a variety of scheduling applications such as, Microsoft Project and Primavera [1]. The imported schedules can externally be updated or altered and subsequently imported back to Navisworks, where a 4D analysis then can be performed. The 4D playbacks extracted by the TimeLiner can then be published in a video and shared to other team members for further evaluation and acceptance of the sequence build scenario. Users can furthermore create animations and rendering with the model for visualization purposes [Autodesk]. A huge drawback of this product is that it is not capable of performing interference checking.

Navisworks Manage

Navisworks Manage is the most expensive of all the Navisworks family packages. However it is also the one that is capable of performing all previous mentioned functions (combining files, simulation, animation, visualization), but also interference checking and other coordination features [6]. The clash detection and interference checking provides the ability to detect not only hard clashes between objects, but also check for items or objects that interfere with required clearances around objects. This is invaluable for the coordination among building systems [6]. The clashes are not only found and listed, but also manageable through the same software until they are dismissed or resolved [1]. Reports can be generated and tracked for the detected problems enabling all of the project team members to be made aware of problems. Furthermore a 4D simulation can be attached with a clash detection to perform a time and space conflict analysis [6]. This features allows users to identify sequencing mistakes or possible problematic temporary construction part such as; crane placement, scaffolding, support systems (soldater), pre-stressing equipment and so forth. For further information about the products please see appendix A1 and A2; Autodesk Navisworks 2012 product brochure and Navisworks 2012 Product Description.

Following table sums-up and shows the difference of each described Navisworks product;

	Navisworks Manage	Navisworks Simulate	Navisworks Freedom
Project viewing	✓	✓	✓
Project review	✓	✓	✗
Combine files	✓	✓	✗
Sequence simulation	✓	✓	✗
Animations	✓	✓	✗
Visualization	✓	✓	✗
Clash detection	✓	✗	✗
Interference Management	✓	✗	✗
Coordination	✓	✗	✗

Table 1 – Key diversities of Navisworks products

Clash detection

Studies of [6] signifies following, *"with Navisworks clash detective features, you can save time and money by finding errors and omissions in your project virtually".* Furthermore it states that "*Clash detective offers the ability to work with coordination teams to help you identify where changes need to occur so that you can respond accordingly*". Navisworks clash detective goes therefore beyond the steps of simply clashing objects together in any giving BIM project. With this application project teams can create reports, set up predefined batch items (saved clashes), set rules, and group clashes [6].

According to [Autodesk] is Navisworks clash detective capable of helping project teams to *"foresee and avoid potential problems before construction, reducing expensive delays and rework".* Furthermore, it states that the clash detective is capable of;

- *Perform clash detection tests against specified geometry to find and resolve conflicts*
- *Check as-built laser scan data against 3D designs*
- *Open current clash in many original design software applications*
- *View clashes in context with geometry in the model and in relation to other clashes*
- *Make all non-clashing items transparent to easily locate clashes in the model*
- *Transition between clash results to maintain orientation in the model*
- *Create Hard, Clearance, and Duplicate clash tests to support multiple coordination scenarios*
- *Analyze space and time by linking clash tests to 4D simulations and object animations*

Subsequent description will only focus on performing clash detection working with rules. Other features within the clash detective package can be found in [6], chapter 8.

The batch tab (see Figure 12) is basically the starting point for clash detection. This gives the users a tab, where they can keep tracks of saved clashes. From the Batch tab users are able to see the project's clashes and keep tracks of when items have been updated and how many active items remains [6].

There are eleven predefined rules templates that users can use. The first six are default rules and the remaining five are customizable rules templates - where users can specify their own information, such as Selection Sets (group of objects/items) or other specified properties (e.g. item name, category, thickness and so forth). The default rules which are listed in the Rules tab are not customizable. According to [6] *"the actions and items that they ignore are already defined by templates and cannot be changed (although you can add and delete them as needed)".* The default rules include;

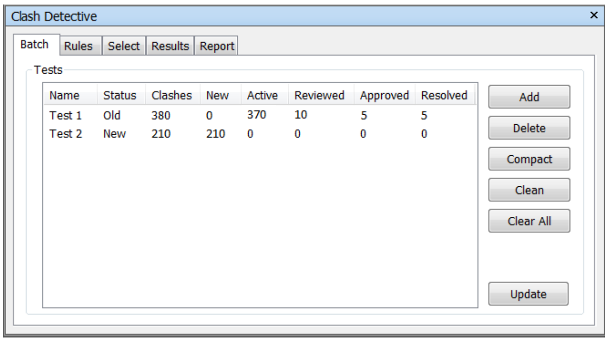


Figure 12 – Navisworks Clash detective, Batch tab

- Items in same group/block/cell
- Items in same file
- Item in previously found pair of composite objects
- Items in same composite object
- Items with coincident snap points
- Items in same layer

The five customizable rules templates include;

- Insulation thickness
- Same property value
- Same selection set
- Specified selection sets
- Specified properties with the same value

The customizable rules allows, in general, to filter out specified items in order to view interferences and control results. (E.g. filter out items such as slabs, columns, walls, from the clash tests or filter out items with same value or perform clearance clash test). The customizable rule templates are described in further details in [6] chapter 8.

Navisworks clash detective main engine is found under the "Select" tab. This tab is equipped with two separate panels, labeled with "Left" and "Right", which allows users to select criteria's, properties, selection sets or entire models to run against each other in order to run clash analysis. Both panels are capable of performing the same thing. A selection criteria is selected on each panel, whereas the clash detection will subsequently find clashes in accordance with chosen rules [6].

Other options within the "Select" tab is the so-called geometry type and self intersect.

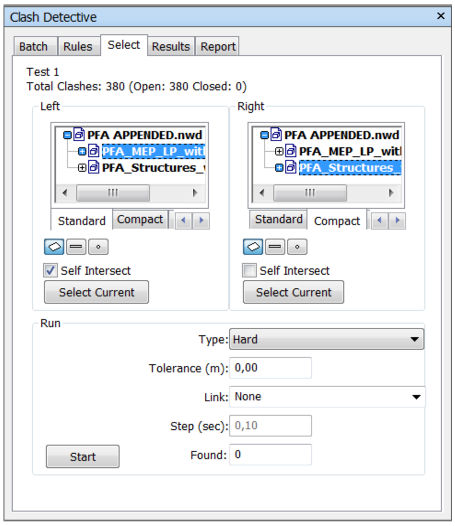


Figure 13 – Clash detective, Select tab

The geometry type functions are capable of changing the set up for clashing the objects against each other. This functionality is separated into tree different options. The first and default option is enabling to run clash detection only for surfaces. The second option is enabling running clashes only for lines (usually used for pipes) and the third option is to enable tests for points only (usually utilized for point cloud data from laser scans) [6].

Self intersect provides a unique opportunity to clash selected geometry against itself as well as against the other selected geometry [6]. E.g. running a test of a structure model with self intersect in one of the panels and MEP model in the other panel. The result of such test would clash structure against MEP as well as perform self intersect for structure. Self intersect can be performed simultaneously in both panels if needed [6].

Furthermore, the "Select" tab also includes a run panel where users must decide which clash analysis they want to perform. According to [6] is Navisworks capable of performing following clash types;

- *Hard clash (is where two physical objects intersect with each other)*
- *Hard conservative (gives you an additional clash option in which the geometry intersections are clashed in more of a theoretical intersecting clash. In Navisworks terms, the two objects are treated as intersecting even though the geometry may not be)*
- *Clearance clash (gives the intersecting objects a specified distance that they must remain from apart from each other)*
- *Duplicate clash (helps you to find intersecting objects of identical position and type. The object have to have both type and position to be considered duplicate)*
- *Tolerance (controls the severity of the clashes and lets you filter out what could be considered minor (fixed in the field) clashes. Tolerance is used for all types of clashes (Hard, Clearance, Duplicate). Be aware, however, that some materials such as ductwork created in CAD MEP might have thickness of .001 and pipe going through that pipe will only clash .001. The most conservative tolerance is 0)*

Finally the Clash detective window contains two other separate tabs that is "Results" and "Report". In the "Results" tab is where things start to get interesting and where Clash Detective begins to shine [6]. In this tab is users able to see clash results virtually - where colliding objects are highlighted and auto revealed. This area is filled with lots of options and information to be considered when exploring the results. The following list describes key features [6];

- **Name** — *Displays the name of the clash.*
- **Status** — *Each clash has a status associated with it. Following conditions can be marked; **Reviewed** (indicates that a clash was previously found and marked as reviewed). **Active** (refers to a clash found in a test that has not yet been resolved). **Approved** (indicates that a clash was previously found and marked as approved). **Resolved** (indicates that a clash was previously found, but not in the current run)*
- **Distance** — *Displays the distance or depth of the clash*
- **Description** — *Indicates the type clash (hard, hard conservative, clearance or duplicate)*
- **Assigned to** — *Assign clash result to specific team members for resolution*
- **Approved by** — *Name of approver along with date and time*

The "Report" tab gives the users the ability create reports and share the data with other team members. Each report can be customized giving the users the ability to control what information is to be contained in each report. According to [6] is Navisworks capable of creating reports in different formats such as XML, HTML, TXT or viewpoints. The HTML report can be opened by programs like Excel and the XML report can be imported to other databases such as Autodesk Constructware.

Switchback

The newest generation of Navisworks (Autodesk Navisworks Manage 2012) comes with a variety of new features and options focusing on workflow, collaboration and interoperability [24]. Many of these new features enhances the workflow between Navisworks and other BIM designing products, such as; Revit (version 2012 or later), AutoCAD (version 2004 or later) and Microstation-based CAD products (/J and v8).

This ability is referred within Navisworks workflow as Switchback. The feature allows the user in Navisworks to select an element and literally, switchback to the native design software and make corrections as necessary. Navisworks will automatically launch the native design application (including model file) and then locate and zoom into the selected object in Navisworks in the native CAD package. This feature saves design staffs for huge amounts of time when working between Navisworks and other design or CAD based modeling applications. [5, 24]

With Switchback functionality users are able to run clash detections in Navisworks and select each interfering element, item or object and then switchback to e.g. Revit to make changes or correct the issued clashing construction part. However users will still have to re-export the Revit file as an updated NWC file to see the corrected changes. When re-exported file is imported into Navisworks the clash detection should be initiated once again and the previous clash will appear as "resolved" in the database history.

This feature enables the ability to track and manage issued interferences. Furthermore the ability to assign responsibilities for each clash is also unlocked, enabling project managers or BIM coordinators to specify who and when the issued interference should be corrected.

In previous versions of Navisworks, users export their Revit model to nwc file and open it in Navisworks to perform clash detection. Once the interferenced elements are located, reports in the form of XML or html are generated containing information about the clasing objects element ID’s. When the responsible team or person gets the report, the user open the discipline model in Revit, and use Select By ID function to find the element. This procedure is very time consuming, and sometimes, users can not find the correct element with the reported ID [Autodesk].

Navisworks file formats

It is important to know the Navisworks file formats to properly utilize the applications capabilities and features in terms of interoperability and cooperation.

According to [5, 6] a usual Navisworks workflow utilizes a combination of NWD, NWC, and NWF files. It is recommended (during ongoing project), that the NWF file format should be used, since the original source files can be updated and re-cached. This is because the NWF format is a kind of a container that links out to the different source files. It is capable of recalling and capturing all graphical overrides, such as, changing model element colors, hided object, faded items and transparencies etc. This allows projects running on either NWD or NWC format (e.g. where updates have been made), the NWF project file will remember all applied graphical settings. This in-coded file organizer principle is very similar in the NWC format, however the NWD format only incorporate all geometry and object property data, but is not capable of saving changes including graphical overrides to the model. The primary difference is that NWD files cannot update or re-cache if changes have been made to the original source data. This file format (NWD) is intended to be utilized as a static representation of models, since it is useful when project teams needs to archive specific milestone events, but also because this format contains all necessary geometry. It is therefore a suitable file format to share with other users, without worrying about supplying the associated source files.

Using Navisworks file formats in a typical workflow

According to [6] best practice for utilizing Navisworks file formats in a typical workflow is to append original source 3D data files from specific trades on a project (e.g., Architecture, MEP, Structure, Civil, or Existing Conditions) to Navisworks. Afterwards a project coordinator should then converts these files to the NWC format and places the NWC files in the same directory as the original source files. Note that certain files types, such as Revit (.rvt) cannot be appended directly in Navisworks but must be converted to an NWC file first. This concept will not be covered in this thesis, however it can be found in [6] Chapter 2, section "File Exporters". When the project coordinator saves a Navisworks session, the project should be saved as an NWF format, which captures the link to the saved source and NWC files. In the period in-between, the architect, MEP coordinator, structural engineer, and civil engineer are able make changes, such as moving objects or adding/removing components, to their original 3D data files. When the project coordinator opens the project saved as an NWF, Navisworks will look for the linked files and do a quick comparison to determine if any of the original 3D data files are newer than the NWC files. If all original data sources were modified, Navisworks re-cashes those files and overwrites the original NWC files with the new data. The project coordinator may save or publish the model to the NWD file format to archive specific milestone events or to share with external users who do not have access to the original source data files (see Figure 14).

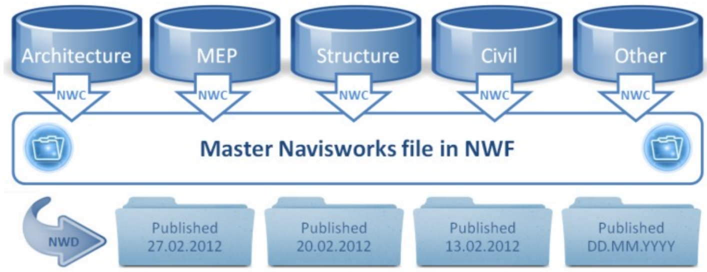


Figure 14 – Typical project workflow. Source of inspiration [6]

If the original source files are renamed or moved to other folders, Navisworks will alert and request the users for their new locations. If the associated NWC files (in the NWF file) are moved or deleted, Navisworks automatically re-caches the files and creates a new NWC file based upon original sources in a given folder. When a NWF file is resaved it will remember the new location for these files. Also, it should be noted that Navisworks uses a relative path structure when saving files. E.g. If a project folder contains several subfolders for the various disciplines (Architect, MEP Engineer, Structural Engineer, etc.), users can share this project folder without breaking any of the links.

Procedure for creating internal file alteration record

The main (NWF) Navisworks model will unavoidably be changed continually, as design teams progresses, finalize and change their models - especially during design phase, preconstruction and possibly in constructions stage. Many different models will be uploaded, and the BIM modeling will repetitively be updated with different discipline models.

The question that arises to many utilizing Navisworks is, how to manage this process and what the best practice is for archiving older files.

According to [6] is one way to achieve the best manageable BIM workflow is to receive updated models on weekly basis, from either subcontractors or in-house personnel (GC). The project team should create a series of working folder with names of each discipline (e.g. Architect, MEP, Structural and Civil). Models should then be uploaded with date naming convention including discipline model identification and updates should be handed-in using the same filename as the original submission. Hereby the project team will easily distinguish new, old and each discipline model from one another. Furthermore the project team should create a new folder, named after each discipline and place the uploaded model in that folder (see Figure 15).

When the files are imported into Navisworks, the generated NWC file should then be saved in the same file as the original data source. As updated files are uploaded and received, the project team should rename the working folder with the date to designate the date it was archived. This should initially also become the date of the current model in the project. The new models should then be saved in the discipline named working folder; thus the links in the NWF file remained intact.

When the NWF file is opened, the new models should automatically be loaded and a new NWC file should be generated and placed in the folder. Any changes such as display overrides, viewpoints, and markups will hereby be retained and applied to the new models. In addition to the archiving of the NWC files, the project team should make a weekly NWD file, which represents a snapshot of the project. Since this is to be an archive of the project to date, the project team should use the date in the naming convention for easy identification.

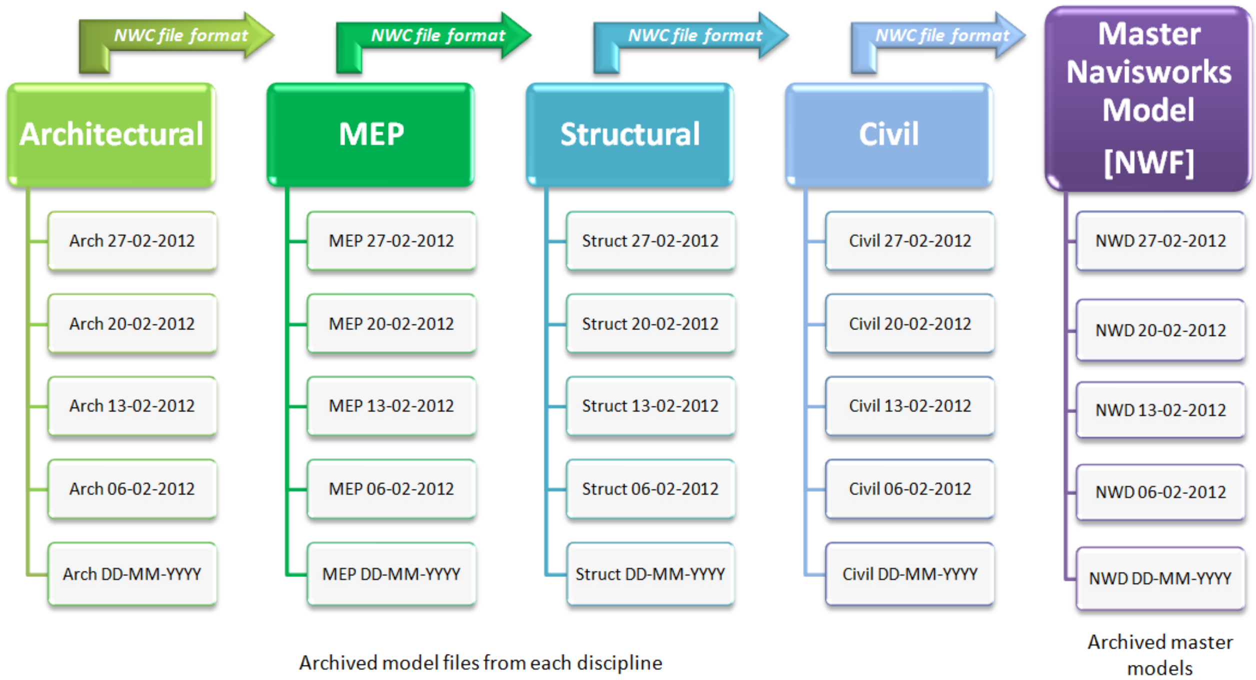


Figure 15 – Procedure for creating internal file alteration record. Source of inspiration [6]

Tekla BIMsight

Studies of [26, 27, 28, 29] signifies that Tekla BIMsight is a BIM software aimed for model-based project cooperation. The software is available free of charge for anyone to install. The software is according to [Tekla] “*an easy-to-access application which promotes data sharing for all types of construction projects, including all necessary building information from different construction disciplines*”.

The application enables project teams to communicate using BIM models with anyone. Contractors, designers, architects, MEP detailers, fabricators and anyone within the AEC sector are capable of combining models and subsequently check for interferences, perform spatial coordination and collaborate [29].

According to Tekla Inc. Managing Director Hans Ehrnrooth the mission behind Tekla BIMsight to ”*enable BIM for everyone, multiplying the users' potential to think and achieve big in their projects and businesses*" and “*leveraging BIM as a centralized process rather than 'just a 3D model' requires cooperation and goodwill between the construction disciplines*."[29]

See appendix A3 for a review for this application.

Solibri MC

See appendix A4 for AEC Bytes review for this application.

Chapter 3

Project case

3. Project case MTH PFA

The following chapter introduces the case of project MTH PFA Nørgaardsvej. This case was used as a basis for studying and investigating the research goals set for this thesis.

The intention of the chapter is to introduce the building case, by describing the building in a way that should make it easier for the readers to understand the scope and complexity of the building. The aim of this chapter is to highlight and clarify followings;

- General information about the building
- BIM models, including; Description of the discipline BIM models covering HVAC, MEP and Superstructure and finally the purpose behind the BIM modeling for each discipline model.

3.1 Project description

The project case MTH PFA is situated in Nørgaardsvej 32, Kgs. Lyngby, Denmark. The construction project is an extension of an existing domicile owned by PFA property. The project is conceptually designed by KHR Architects, design, developed and constructed by the General Contractor MTH.

The construction was initiated 11-07-2011 and should according to the schedule be finalized 21-05-2012.

The construction cost is according to M. Nielsen (MTH) approximately 10.500 DKK/m^2.

The architectural design is illustrated in Figure 16.

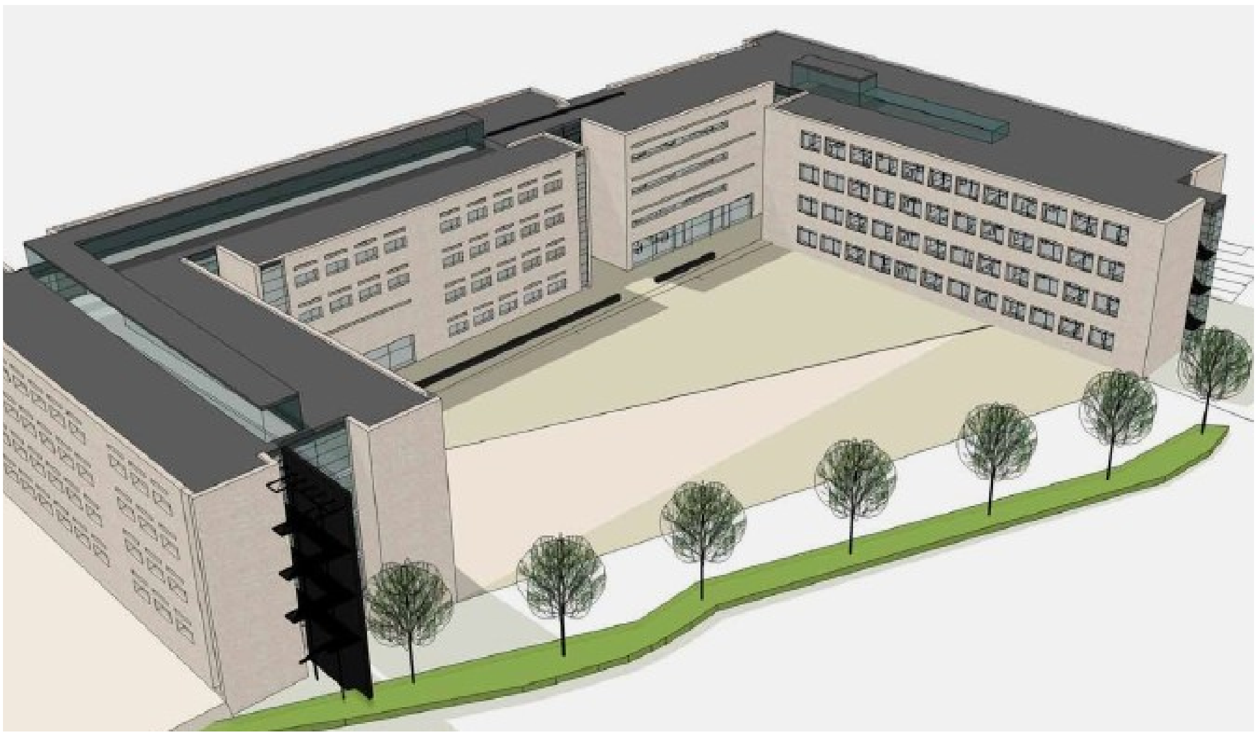


Figure 16 – The architectural design intend of PFA Nørgaardsvej.

The facility has a gross area of 4881 m^2 including a 1500 m^2 basement with a large technical room and 44 parking spaces. The building itself is designed as 2 4-storey buildings connected by an intermediary passage around the common areas. The connection serves moreover as an integrated emergency escape route, constructed based on the western existing emergency staircase.

The facility is designed to accommodate 250 persons. It houses 30 offices in the ground floor, 73 offices in the first to the third floor and 4 separated workplace offices housing 1-4 workstations per floor.

Figure 17 illustrates the floor plan of the ground floor. The red colored dashed line specifies the extension.

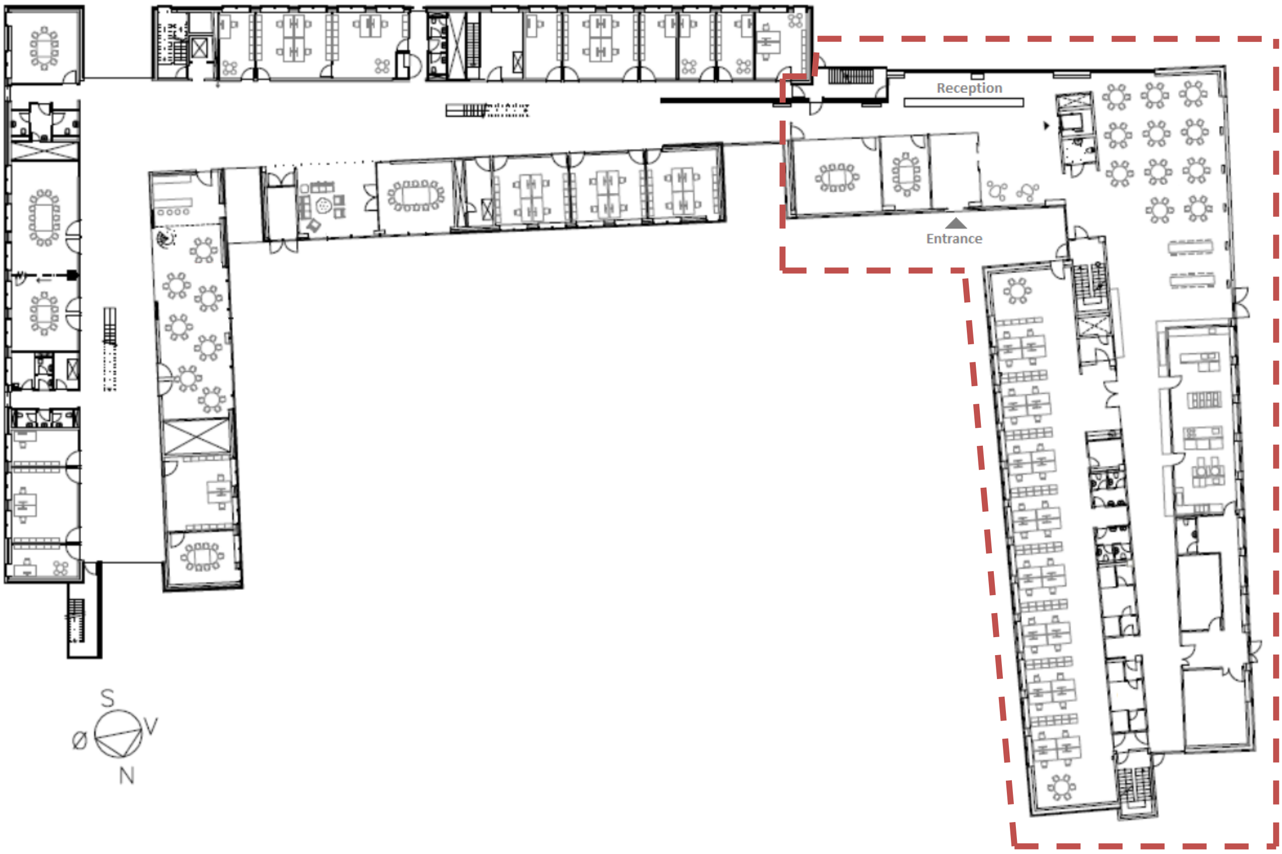


Figure 17 – Project overview of PFA Nørgaardsvej. The dashed red colored line shows the building extension

Floor plans of basement to 3rd floor, showing the room distributions are found in appendix A5

Part of the construction program developed by MTH is found in appendix A6. This document describes the general scope, level of quality including clarification of chosen solutions and materials for the planned construction.

3.2 PFA MTH BIM models

The BIM models for the case of MTH PFA Nørgaardsvej are separated into 3 files. Each model is representing one or more engineering disciplines. The models contains following disciplines;

- Structural model represent the structural engineering discipline
- VVS-model represents the mechanical HVAC and plumping disciplines
- EL model represents the electrical discipline

The structural model is modeled in Autodesk Revit Structure 2011. All objects or families (called families when modeling in Revit) within the model are custom made, either based on template families or modified existing families. The model is depicted in Figure 18.

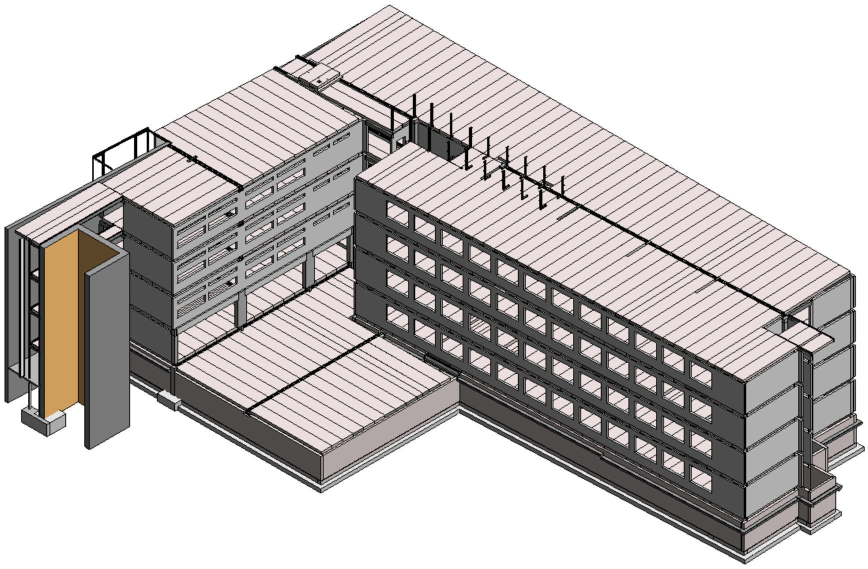


Figure 18 – Structural model of MTH project PFA Nørgaardsvej

The VVS-model is partly modeled in Autodesk Revit MEP 2011. Standard Revit MEP families have been utilized for the creation of the plumping installations. The model contains linked DWG based models for the mechanical ventilation installations which are modeled in MagiCAD. The model is depicted in Figure 19

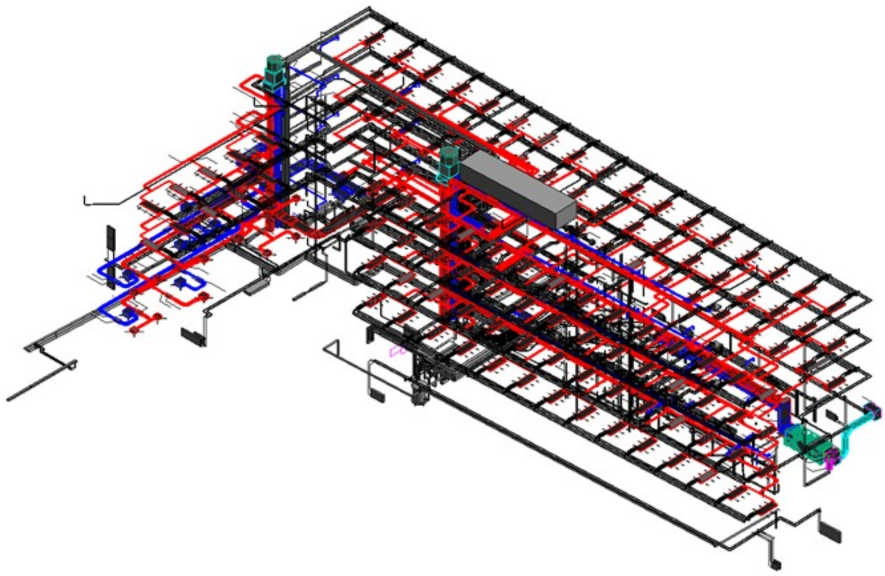


Figure 19 – HVAC and plumbing model of MTH project PFA Nørgaardsvej

The electrical model is modeled in Autodesk Revit MEP 2011. Standard Revit MEP families are also utilized for the creation of the electrical installations. The model is depicted in Figure 20

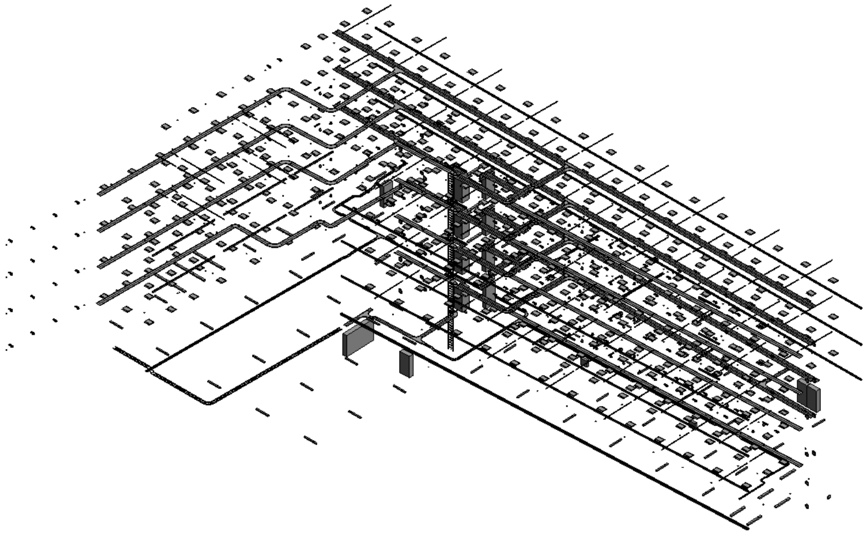


Figure 20 – Electrical model of MTH project PFA Nørgaardsvej

All BIM models where created for the purpose of utilizing the 3D models to generate 2D based construction drawing. The Structural model is however also developed to be utilized for procurement as well as structural analysis purposes. Figure 21 illustrates a merged model of all mentioned discipline models.

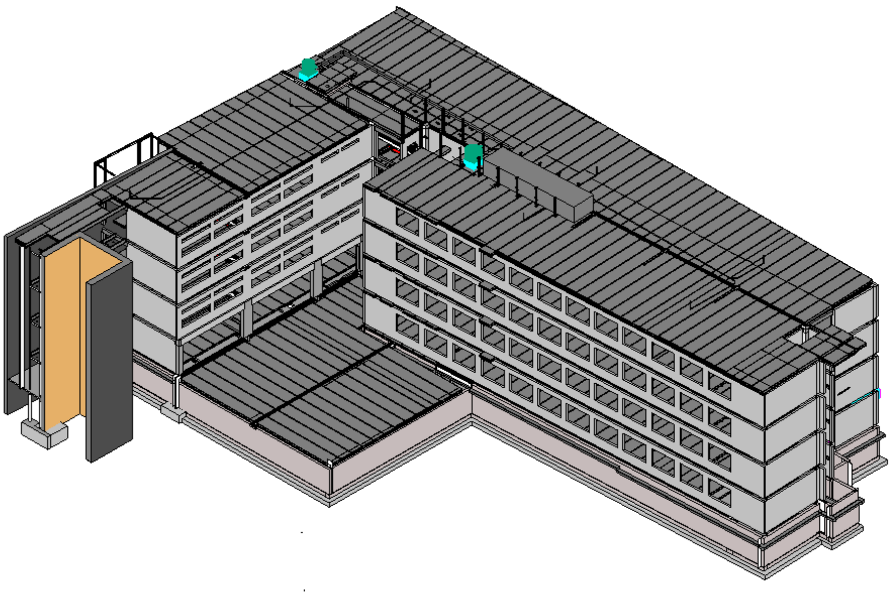


Figure 21 – Merged discipline models of MTH project PFA Nørgaardsvej

Chapter 4

Test

4. Test

In the following chapter the research goals and objectives set for this thesis will be tested in accordance with the defined approaches.

The chapter is structured to firstly deal with clash detection and constructability reviewing capabilities of; Autodesk Naviswork Manage 2012, Solibri Model Checker v.7 and Tekla BIMsight v. 1.4.1, including utilization of; Rules and parameter, clash reports, and finally how to make use of interoperability features within each clash detective.

Subsequently the 4D BIM subject is tested using Vico Office R.3.2 application, where the construction sequence and constructability analysis are reviewed in accordance with issues declared in the research goals and objectives.

All tests are based on the Autodesk Revit based models, provided by MTH for their design and construction of PFA Nørgaardsvej 32.

4.1 Clash detection

Constructability analysis through clash detection is presented in this chapter. In order to distinguish the tests and the utilized clash detectives is each test defined with a number followed by the application name.

4.1.1 Using rules and parameters

The following tests will highlight how clashes can be diminished by utilizing rules of ignorance and parameters. These features are important tools for any BIM coordinator utilizing the clash detectives, since it provides the users the opportunity to search or sort out minor or insignificant interferences. Moreover they provide the ability to ignore or sort several occurring clashes to a single object.

Since the amounts of clashes identified for the building case are numerous, the following demonstrated results will be limited to focus on specified disciplines.

Test 1 – Navisworks

The test demonstrated in following section is performed on the MEP vs. HVAC disciplines. It will illustrate the necessity of exploiting following 2 rules;

- Standard template rule; Items in Previously Found Pair of Composite Objects
- Custom made rule; Ignoring clashes from specified levels

The model-based test can be found in the attached CD, in following directory; //PFA/Clash/Navisworks/PFA Clash detection with rules.nwf

Following models are utilized for this test; MEP.nwc vs. El.nwc (HVAC vs. Electrical)

1. An initial run on identifying clashes without use of rules, results in 69 interferences.
   The clash detection is set to identify clashed with a tolerance of 1 cm.
   - The clash report can be found in the attached CD. It is named ''HVAC-MEP None Rules.html''
     Directory; //PFA/Clash/Reports/

2. A 2nd run, applying the rules set;
   Items in Previously Found Pair of Composite Objects
   Results in 55 interferences and 14 ignored clashes.
   - The rule set ignores and does not report; any items found clashing that are part of composite objects (items composed of multiple parts of geometry) that have previously been reported in the test. In other words, objects/items composed of multiple parts are not reported several times, once one clash is found per object. Other parts within same object are ignored.
   - The clash report can be found on the attached CD. It is named ''HVAC-MEP rule1.html'' Directory; //PFA/Clash/Reports/
   - Figure 23 and Figure 24 show the issue

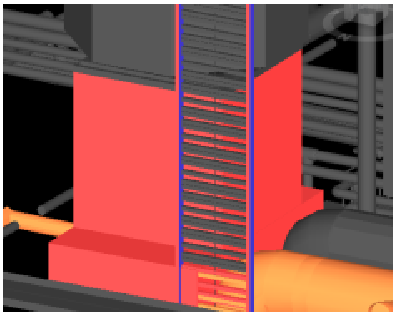


Figure 23 – Previously detected clash; Items that are a part of a composite objects containing several clashes. All identified clashes (colored in red and orange) are reported.

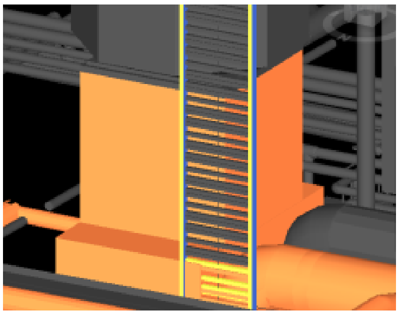


Figure 22 – Clash detection with rule; Item found clashing that are apart of composite objects that have previously been reported (colored yellow) in the test are not reported.

3. A 3rd run, applying the previous rule, combine it with a custom made rule;
   Ignore clashes between HVAC/MEP from basement to 2nd floor
   Results in 16 interferences and 53 ignored clashes.
   - The rule set ignores and does not report; any items found clashing from basement to 2nd floor. Clashes found in 3rd floor are reported.
   - The clash report can be found in on the attached CD and has the name ''HVAC-MEP rule2.html''
   - Figure 24 and Figure 25 shows the issue

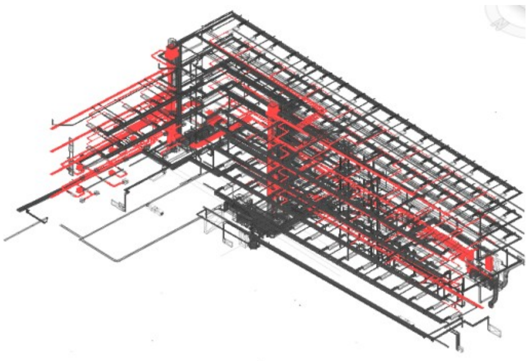


Figure 24 – Clash detection without rules. All identified clashes (colored in red) are reported.

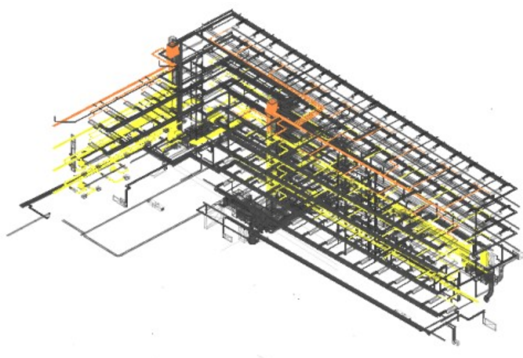


Figure 25 – Clash detection with custom made rule. Clashes in 3rd floor are reported (colored in orange).

4. The interference detection utilizing 2 rules have reduced identified clashes from 69 to 16, by ignoring 53 clashes. From this point coordination and management of reporting the issues to the responsible person(s)/team members be initiated.
   - Out of the 16 clashes are 2 clashes reported to be solved by the HVAC team.
   - The rest (14 clashes) are reported to be solved by the electrical team.
   - Report to both discipline teams is found on the attached CD. It has the name ''HVAC-MEP Report to HVAC and Electrical Team.html''
   - Figure 26 and Figure 27 show some of the reported issues

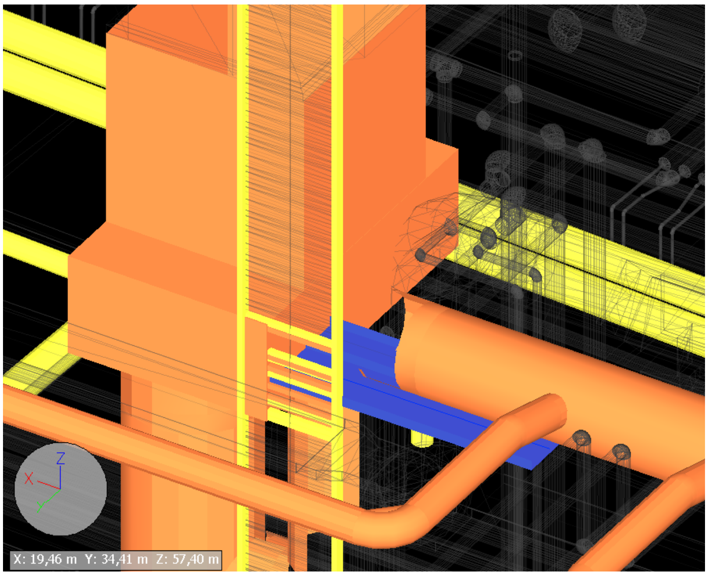


Figure 26 – Reported issue to the electrical team; Cable tray (colored in blue) collide with ventilations vent aggregate (colored in orange).

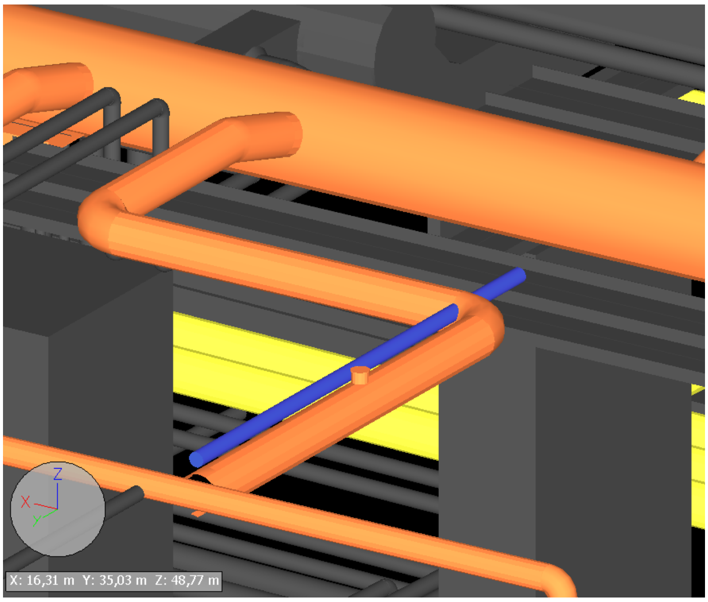


Figure 27 – Reported issue to the HVAC team; Plumbing pipe (colored in blue) collide with HVAC duct (colored in orange).

Test 2 – Navisworks

The test demonstrated in following section is performed on the MEP vs. Superstructure disciplines. It will illustrate the necessity of exploiting same rules as the previous test. However other combination of discipline models is used.

The model-based test can be found on the attached CD in following directory; //PFA/Clash/Navisworks/PFA Clash detection with rules.nwf

Following models are utilized for this test; MEP.nwc and El.nwc vs. superstructure.nwc

1. An initial run on identifying clashes without use of rules, results in 450 interferences.
   The clash detection is set to identify clashed with a tolerance of 1 cm.
   - The clash report can be found on the attached CD. It is named ''MEP vs. Structure None Rules.html''

2. A 2nd run, applying the rules sets, as described in test 1.
   Results in 101 interferences and 349 ignored clashes.
   - The clash report can be found on the attached CD. It has the name ''MEP vs. Structure rule2.html''
   - Figure 29 and Figure 28 show some of the reported issues

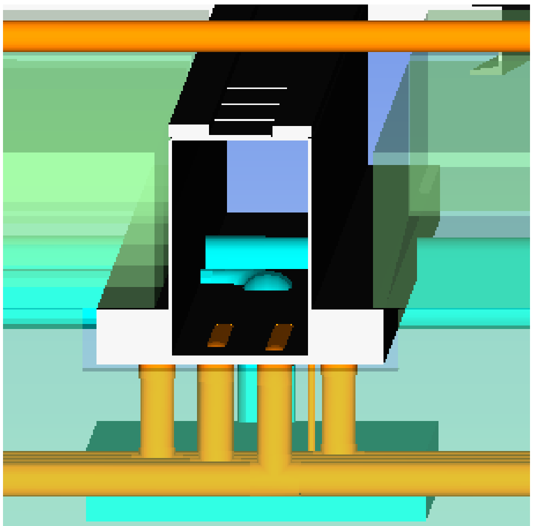


Figure 29 – MEP installations in the 3rd floor (colored cyan and orange) intersects with the SWT beam (colored black/grey).

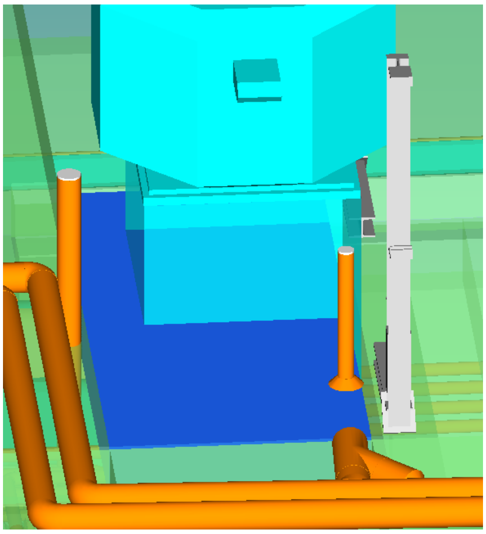


Figure 28 – The HVAC chimney (colored cyan) intersects with roof hollow core slab (colored blue).

Comments to test 1 and 2

It is fairly easy and simple to perform clash detection using various combinations of discipline models. The sorting and ignoring of clashes can also be easily be managed by applying simple rules. These features enable a simple procedure of reporting clashes to the responsible person(s)/team(s). The process of reaching a zero conflict status for any given project can easily be structured by utilization of rules. A BIM coordinator can start with identifying clashes in a specified level and subsequently move to the level above, when issued clashes in the specified level are resolved.

Test 3 – Solibri MC

The test demonstrated in following section is performed on the Superstructure. It will illustrate the necessity of exploiting a self intersection rule, based on;

- Intersection – Different Kind of Components, restrictions based on;
    - Beam Intersections, with following parameters;
        - Include intersections of; Duplicate, Inside and Overlapping
        - Intersection tolerances; Horizontal 1 cm, vertical 1 cm

The model-based test can be found on the attached CD, in following directory;
//PFA/Clash/SolibriMC/XXXX.smc

Following model is used for this test; Structure.ifc

An initial run, on specified parameters results in 940 interferences. A formal check of the interferences indicates that all prefabricated slabs (beams within structural terms) have been wrongly exported to the IFC format.

- SMC Information Takeoff, of the 940 interferences, based on the beams verifies the formal check. 687 slabs of the 940 interferences are based on the incorrectly exported IFC beams.
- The Information Takeoff is found on the attached CD in a file named ''Beam Information Takeoff.xls''
- The corresponding clash report is found on the attached CD in a file named ''Beam Intersections.pdf''
- Figure 30 illustrates the beam Information Takeoff items

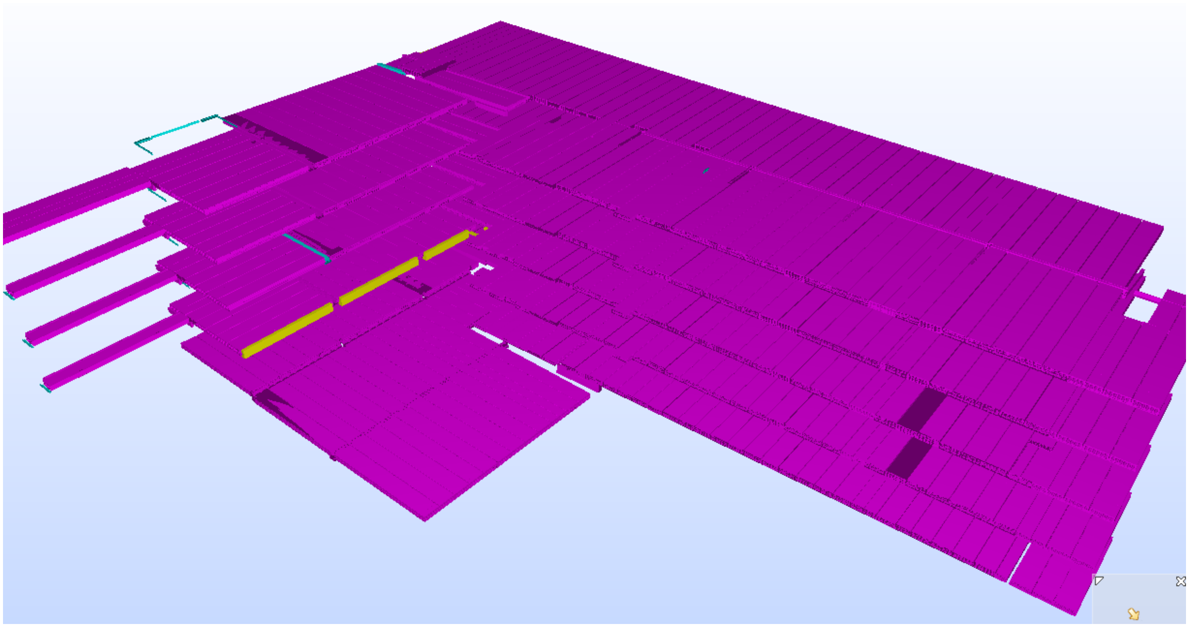


Figure 30 – Information Takeoff items of incorrectly exported IFC beams/slabs.

An IFC re-export from Revit Structure and Architecture followed by installation of 2 different IFC translator add-ins to Revit (IFC exporter from Tekla and ArchiCAD) was investigated - however the issue was not solved. The Autodesk Revit Structure based slabs are family based objects, which geometry is only exported correctly when exporting to NWC or DWG.

Test 4 – Solibri MC

The test demonstrated in following section is performed on the Electrical vs. HVAC disciplines. It will illustrate the necessity of exploiting following rule;

- General Intersection Rule, based on;
  - Intersections, with following parameters;
    - Lightning Fixtures vs. Objects
    - Include intersections of; Overlapping
    - Intersection tolerances; Horizontal 1 cm, vertical 1 cm

The model-based test can be found in the attached appendix CD, in following directory; //PFA/Clash/SolibriMC/El vs. HVAC.smc

Following models are used for this test; PFA_MEP.dwg and El.ifc

An initial run, on specified parameters results 46 interferences.

- The clash report can be found on the attached CD. It is named ''El vs. HVAC Intersections.pdf''
- Figure 32 and Figure 31 shows some of the reported issues

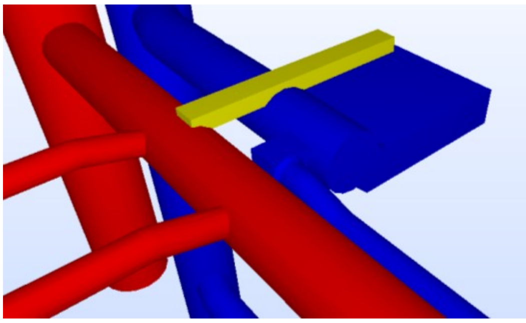


Figure 32 – Light Fixture clash with HVAC

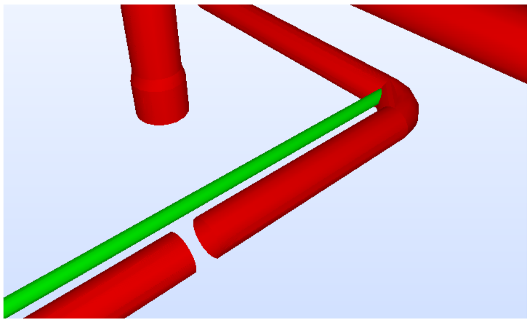


Figure 31 – Cable pipe clash with HVAC duct

Comments to test 3 and 4

The IFC export of the slab geometries from the structural model performed in Revit Architecture and Structure was insufficient and prone to error. However the abilities of the clash detective proved to be sufficient, in terms of detecting structural interferences. The self intersection is fairly easy and the overall structure of the clashes is simple, since each clash is reported in accordance with it level, type and discipline. However, identifying intersections within Solibri MC requires that the imported models contain the necessary information in order for the application to run the specified clash detections. As long as the information within the models is insufficient, the application will not understand what the user what to perform. The converted HVAC model does not contain the required level of information and due to these circumstances the identification of clashes cannot be performed sufficiently. The HVAC model is based on a dwg format, where all objects within the model are considered as “dummy” objects. E.g. pipes, ducts, and fittings are all considered as objects. Moreover the model is incorrectly modeled, since the entire HVAC system is grouped per level, thus separated in 2 functions; air intake (see figure 32 colored in blue), air-supply (see figure 32 colored in red). This means, that all HVAC objects within a single floor is connected to each other per system. This issue causes lot of problems, since the grouped object is identified as a collision several times.

Test 5 – Solibri MC

The test demonstrated in following section is performed on the Electrical vs. MEP disciplines. It will illustrate the necessity of exploiting following rule;

- General Intersection Rule, based on;
  - Intersections, with following parameters;
    - Lightning Fixtures vs. Pipe
    - Include intersections of; Overlapping
    - Intersection tolerances; Horizontal 1 cm, vertical 1 cm

The model-based test can be found on the attached CD, in following directory; //PFA/Clash/SolibriMC/El vs. MEP.smc

Following models are used for this test; El.ifc and MEP.ifc

An initial run, on specified parameters results 7 interferences.

- The clash report can be found on the attached. It is named ''El vs. MEP Intersections.pdf''
- All reported issues are addressed to the electrical discipline and concerns only light fixtures.
- The associated Information Takeoff can be found on the attached CD. It is named ''Information Takeoff - El vs. MEP.xls''
- Figure 34 and Figure 33 show some of the reported issues

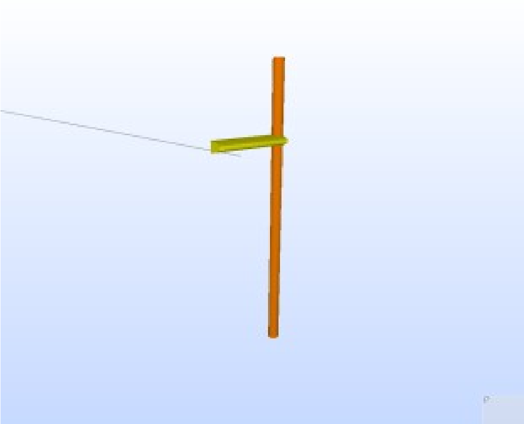


Figure 34 – Light fixture (colored yellow) clash with plumbing pipe (colored orange).

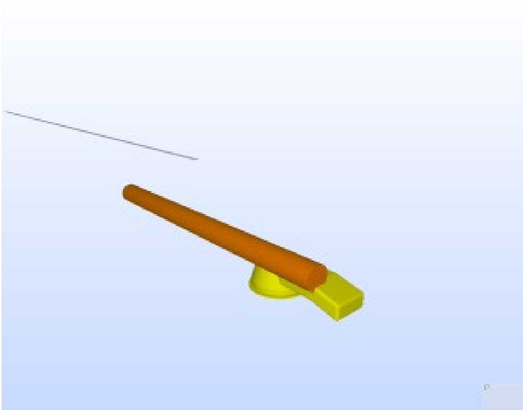


Figure 33 – Light fixture (colored yellow) clash with plumbing pipe (colored orange).

Comments to current test

It is rather easy and simple to perform clash detection using various combinations of discipline models. The search and sorting of clashes can also be easily managed by applying simple rules based on parameters. These features enable a simple procedure of reporting clashes by extracting the information to the responsible person(s)/team(s). The process of reaching a zero conflict status for any given project can also easily be structured by utilizing the existing file mapping of IFC files. A BIM coordinator can start with identifying all clashes in the project and report only those related to a certain level and subsequently move to the level above, when issued clashes in the reported level are resolved.

Test 6 – Tekla BIMsight

The test demonstrated in following section is performed on the Electrical vs. MEP disciplines. It will illustrate the process of finding conflicts between mentioned disciplines.

- The search parameters are based on;
  - Overlap tolerance of 1 cm

The model-based test can be found on the attached CD, in following directory;
//PFA/Clash/TBS/Electrical vs MEP.tbs
The current test is saved in the tab; "Conflict Checking", group; El ifc vs MEP ifc
Following models are used for this test; El.ifc and MEP.ifc

An initial run, on specified parameters results 7 interferences.

- All reported issues are addressed to the electrical discipline and concerns only light fixtures.
- Figure 36 and Figure 35 show some of the identified clashes

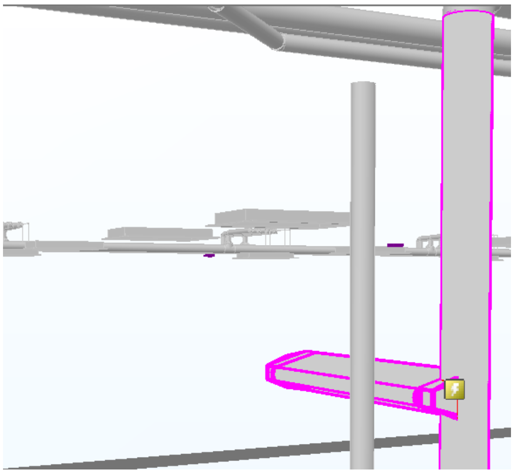


Figure 36 – Light fixture clash with pipe (objects colored grey with purple perimeter).

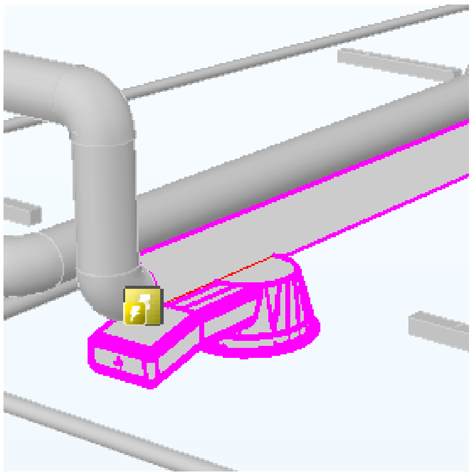


Figure 35 – Light fixture clash with pipe (objects colored grey with purple perimeter).

Test 5 and 6 are based on the same criterions for identifying clashes between the electrical and MEP disciplines - but performed under different clash detectives. The number and type of identified clashes are identical.

Test 7 – Tekla BIMsight

The test demonstrated in following section is performed on the MEP vs. Structural disciplines. It will illustrate the necessity of finding conflicts by a selection criterion.

- The search parameters are based on;
  - Utilization of clipping planes, enabling partial selection of objects in the basement.
  - Overlap tolerance of 1 cm

The model-based test can be found on the attached CD, in following directory;
//PFA/Clash/TBS/PFA Tekla BIMsight clash detection.tbs

The current test is saved in the tab; “Conflict Checking”, group; Selection Basement
Following models are used for this test; Structure.dwg and MEP.ifc

An initial run, on specified parameters results in 52 interferences.

- The majority of identified clashes must be addressed to the MEP discipline and concerns in general only piping issues, such as; pipes are inside walls and pipes are misplaced in relation to prefabricated concrete element openings
- Figure 37 and 38 shows some of the identified clashes

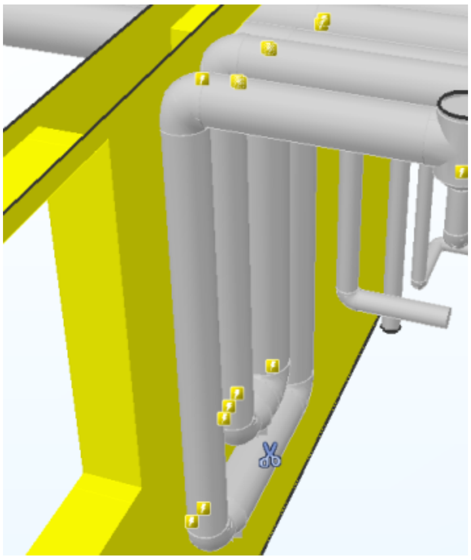


Figure 38 – Pipe clash with structural wall

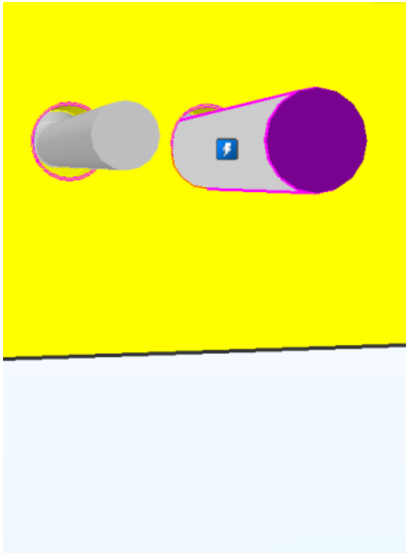


Figure 37 – Pipe clash with basement wall

Comments to test 6 and 7

It is very easy and simple to perform clash detection using various combinations of discipline models. However, the application does not support any kind of document based reporting features. It can only provide clash reports in the form of BCF. This subject is tested in the subsequent section.

Clash detection can only be performed by; identifying clashes between 2 or more disciplines, by a selection criterion or by adjusting the visibility graphics. Moreover the application does only support 2 different adjustable rules sets; overlap tolerance and minimum distance. The searching and sorting of clashes is very complicated and time consuming. The users must manually assign each clash to a clash group in order to manage clashes which are to be addressed to a specific discipline. The process of reaching a zero conflict status for any given project is influenced by the inefficient clash management - however this management is partially assisted by the existing file mapping of IFC files. A BIM coordinator must start with identifying all clashes in the project and manually sort clashes related to a certain level and discipline. The BIM coordinator can subsequently move to another manually managed level and discipline, when issued clashes in the previously managed level are resolved.

4.1.2 Clash report

The following tests will show how clash reports are used for modifying or fixing issued clashes from clash detective reports. Reports from Navisworks and Solibri MC are used in this section. Tekla BIMsight does only support reports generated in the BFC format. The BFC topic is tested in the test 11.

Test 8 – Navisworks

The test demonstrated in following section is performed on the electrical discipline.

Clash report generated in test 1 will be used as basis for fixing issued clashes addressed to the electrical discipline. The clash report is found on the attached CD and it is named ''HVAC-MEP Report to HVAC and Electrical Team.html''

The report contains 14 different clashes addressed to the electrical discipline. A single issue appears in the html report as;

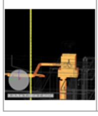
									Item 1					Item 2					
Image	Clash Group	Clash Name	Status	Distance	Description	Date Found	Assigned To	Clash Point	Item ID	Layer	Path	Item Name	Item Type	Item ID	Layer	Path	Item Name	Item Type
	*Electrical*	Clash58	Active	-0.01	Hard	2012/2/19 13:24.41		x:51.55, y:11.82, z:37.51	*Element ID:* 3756459	<No level>	File > File > EL_1.nwc > <No level> > Trough Cable Tray > Solid	Trough Cable Tray	Solid	:	ARB - UK - A	File > File > MEP_1.nwc > ARB - UK - A > location <Not Shared> > M.V.3.3.01.dwg > Mesh	M.V.3.3.01.dwg	Mesh

Figure 39 – Example of html based clash report to the electrical discipline

The electrical personnel/team will start fixing issued clashes by extracting Item ID related to their model.

The Element ID is then copy pasted into the native design application, where the issued object can be found by searching for the specified element ID number. Figure 40 illustrates the issue;

The technical team behind the electrical discipline can then fix the issue by moving the object as specified in the clash report. For this test the clash detective personnel have indicated that the cable tray should at least be moved downwards by 3 cm. The issue is then fixed in the native design application by doing so.

When all of the issued clashes have been identified and fixed a new NWC model file is sent to the BIM coordinator for new iteration of clash detection. This process continues until a zero state of conflict is reached or when the identified clashes are regarded as minor and insignificant clashes.

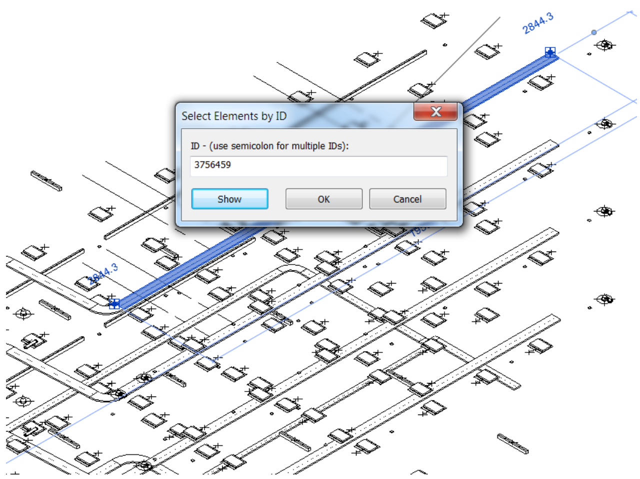


Figure 40 – Element ID search within Autodesk Revit Architecture, Structure and MEP.

Issued clashing object is found by copy pasting the Element ID number in the search field.

Test 9 – Solibri MC

The test demonstrated in following section is performed on the Electrical vs. MEP disciplines.

Clash report generated in test 5 will be used as basis for fixing issued clashes addressed to the electrical discipline. The Information Takeoff for the clashing lightning fixtures is found on the attached CD. It is named ''Information Takeoff - El vs MEP.xls''

The Information Takeoff contains 7 different clashes addressed to the electrical discipline. A single issue appears in spreadsheet as shown in Figure 41;

The electrical personnel/team will start fixing issued clashes by extracting BATID number related to their model. See Figure 41, column A, row 3 to 9.

	A	B	C	D
1	Ruleset 'RuleExamples.cset' has rejected issues.			
2	BATID	Type	Count	Color
3	3234204	Dom 402CWH 1xTL-D15W	1	
4	3439733	PM II 136 HF	1	
5	3691863	PM II 249 T5 "L"	1	
6	3749349	Dom 402CWH 1xTL-D15W	1	
7	3749534	PM II 249 T5 "L"	1	
8	3756707	Dom 402CWH 1xTL-D15W	1	
9	3765323	CHALICE 190H 218 HF	1	

Figure 41 – Example of spreadsheet based Information Takeoff addressed to the electrical discipline

The BATID number is then copy pasted into the native design application, where the issued object can be found by searching for the BATID number within the search field of Element ID. Figure 42 illustrates the issue;

The technical team behind the electrical discipline can then fix the issue by moving the object as specified in the clash report. For this test the clash detective personnel have indicated that the cable tray should be moved in accordance with clash depth plus a few cm.

Since this information is rather imprecise the technical team can link the MEP model to their original electrical model and move the issued objects by utilizing the linked model as reference and visual navigation guide.

When all of the issued clashes have been identified and fixed a new IFC model can subsequently be sent to the BIM coordinator for new iteration of clash detection. This process continues until a zero state of conflict is reached or when the identified clashes are regarded as minor and insignificant clashes.

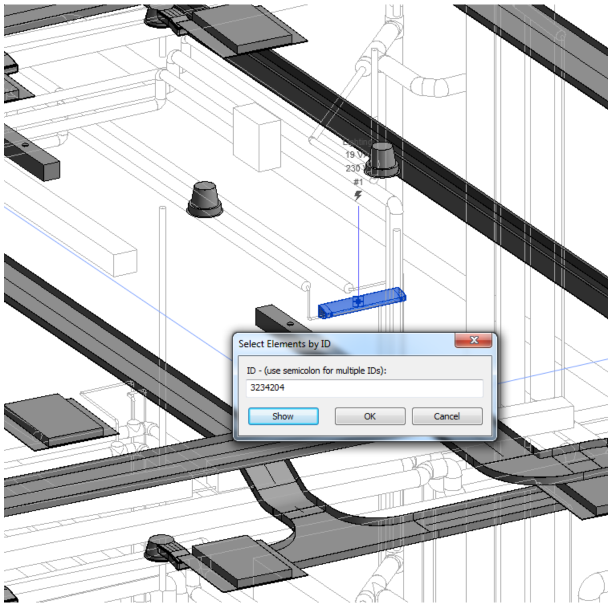


Figure 42 – BATID search of Element ID within Autodesk Revit Architecture, Structure and MEP.

Issued clashing object is found by copy pasting the BATID number in the search field.

4.1.3 Interoperability

The following tests will demonstrate how clashes can be solved by utilizing interoperability features within investigated clash detectives. The interoperability features enables BIM coordinators to send clash reports to different trades or engineering disciplines, responsible to fix or modify issued clashes by utilizing automatic object identification within the native design application.

Since the amounts of clashes identified for the building case are numerous, the following demonstrated results will be limited to focus on specified trades/disciplines.

Test 10 – Navisworks SwitchBack procedure

The test demonstrated in following section is performed on the MEP vs. HVAC disciplines. It will illustrate the working procedure for resolving issued clashes, utilizing the SwitchBack functionality of NW12.

The model for the current test can be found on the attached CD, in following directory;
//PFA/Clash/Navisworks/SwitchBack/PFA El vs MEP-HVAC.NWF

The use of Navisworks SwitchBack works like following;

1. Export all discipline models to Navisworks file format nwc.
2. All discipline models are appended, and subsequently saved as Navisworks file format nwf.
3. Clash detection between MEP (Electrical separated) and HVAC components are prepared by turning the superstructure model temporary off.
4. Within the Batch tab is the interference detection assigned.
5. Rules for performing the clash detection are defined. (None rules are applied in this test)
6. Within Select tab is the MEP/HVAC model selected in the left side, whereas the Electrical model is selected in the right side.
7. Run the test and view the clashes in the “Results” tab.
8. See the amount of clashes in the “Batch” tab. Notice that 53 clashes are active. See Figure 43.

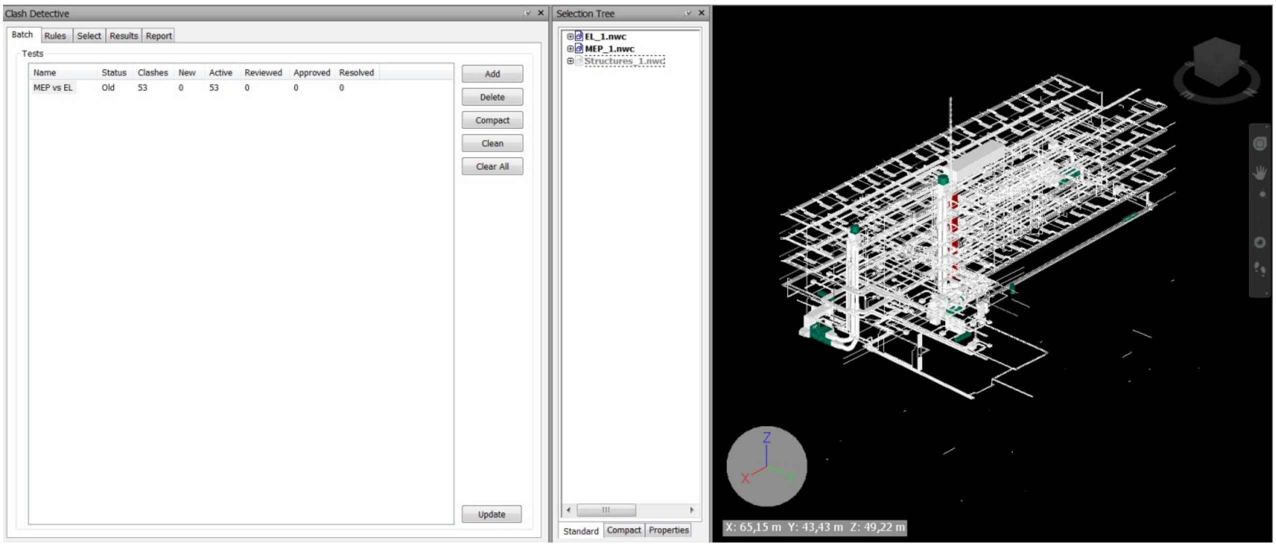


Figure 43 – Illustration of “Batch” tab, showing amount of identified clashes

9. Select any type of clash in the “Results” tab.

10. Rename the clash, where SwitchBack is to be executed.
11. Markup and redline. See Figure 44

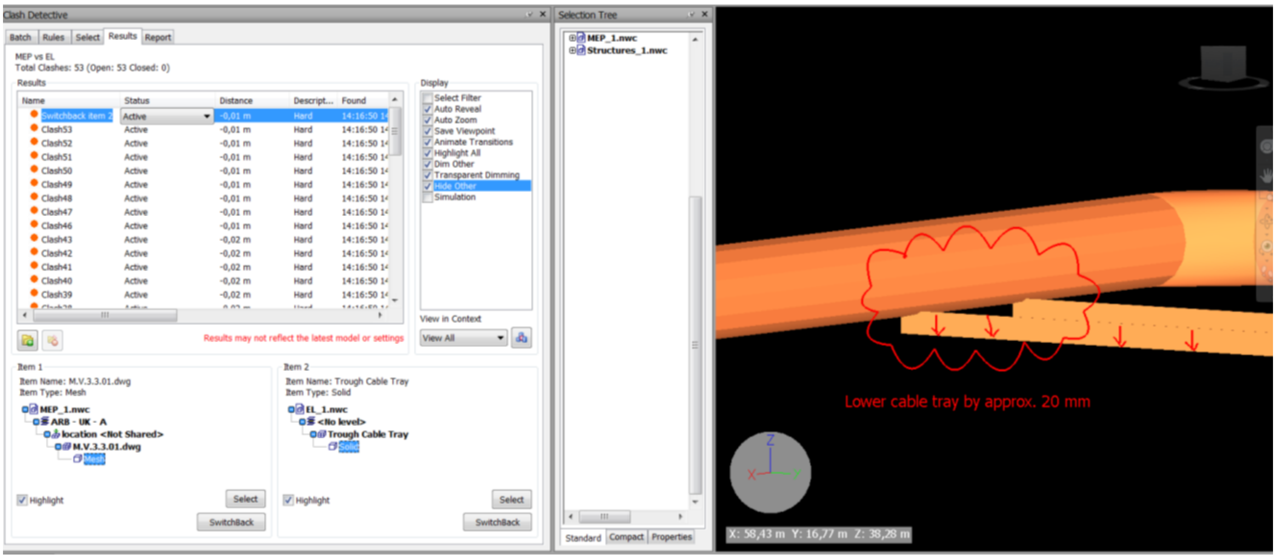


Figure 44 – Markup and redlining

12. Open Revit and the related model. (In this example El.rvt)
13. Click the Switchback button in the right side or Item 2 box. See Figure 44.
14. The El.rvt model opens and the issued object is automatically selected. Needed modifications can be applied. Figure 45 and Figure 47 illustrate the issue.

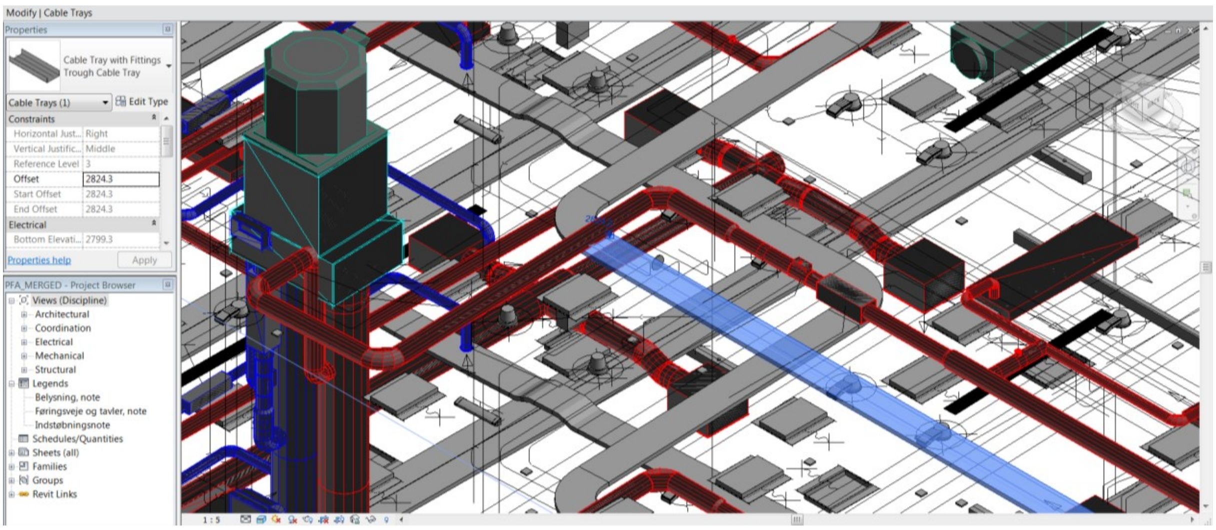


Figure 45 – 3D view of selected SwitchBack item in Revit Architecture

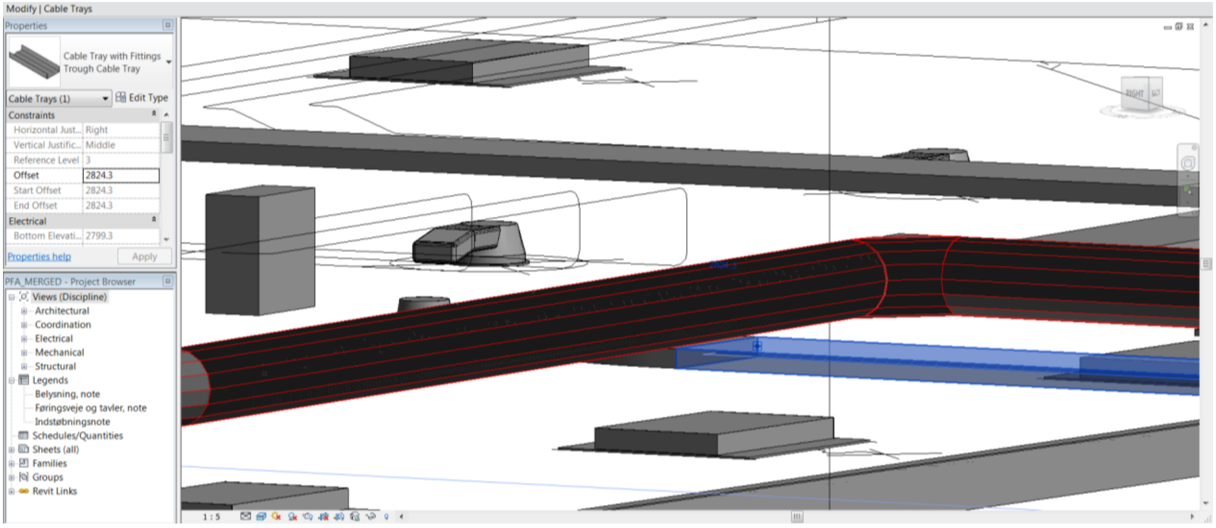


Figure 47 – 3D view of selected SwitchBack item in Revit Architecture (showing the intersecting objects)

15. After fixing the cable tray a re-export is performed to Navisworks where the old model is overridden by the new nwc file for the El model.
16. Push the refresh button, go to clash detective, update the Batch tab, and see the results. Figure 46 illustrates the issue. Note; Notice that 2 issues are solved, and 51 clashes still are active

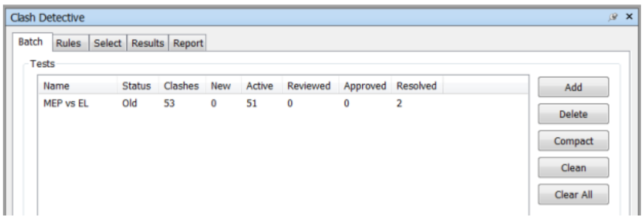


Figure 46 – "Batch" tab showing updated status of clashes Notice that 2 issues are resolved and 51 clashes still are active

17. View the resolved issues, by opening the "Results" tab and mark the "Resolved" clash types. Figure 48 depicts the issue.

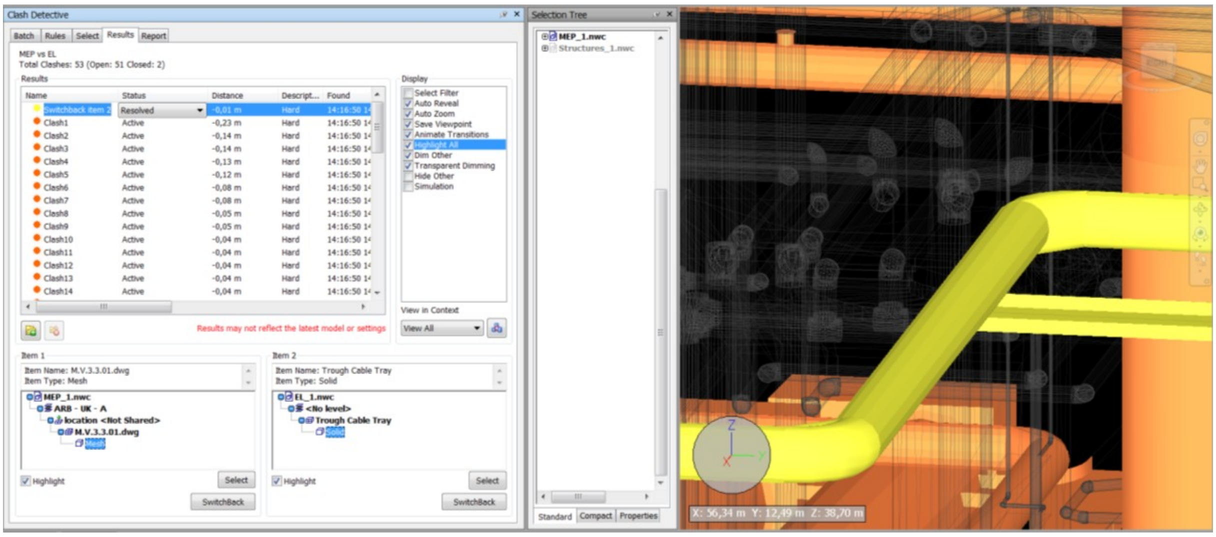


Figure 48 – View of resolved clash status. Notice the yellow colored items.

Test 11 – Solibri MC, BCF procedure

The test demonstrated in following section is performed on the MEP vs. HVAC disciplines. It will illustrate the working procedure for resolving issued clashes, utilizing the BCF reporting functionalities of SolibriMC.

The models for the current test can be found on the attached CD, in following directory;
//PFA/Clash/Solibri/BCF/PFA El vs MEP-HVAC.smc

Following models are used for this test; MEP.ifc, El.ifc and HVAC.dwg

The use of BCF works like following;

1. Export the MEP models to IFC and HVAC model to dwg
2. Add models to Solibri MC
3. Save the Solibri MC project
4. Rules for performing clash detection are defined. For the current test is the General Intersection Rule utilized, based on parameters shown in figure X.
5. Run the intersection check
6. View the results in the “Results” tab.
7. Select the issues which are to be reported in the BCF. For the current test are 2 intersections rejected and comments are noted in the “Results Details…” Figure 49, Figure 50 and Figure 51 show reported issues.

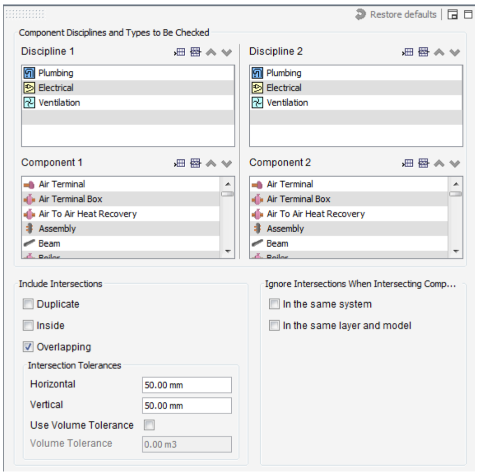


Figure 49 – Intersection parameters

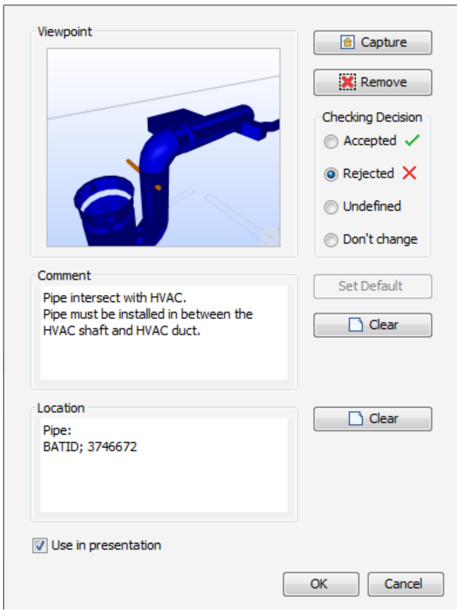


Figure 51 – Results details of pipe intersection with HVAC duct.

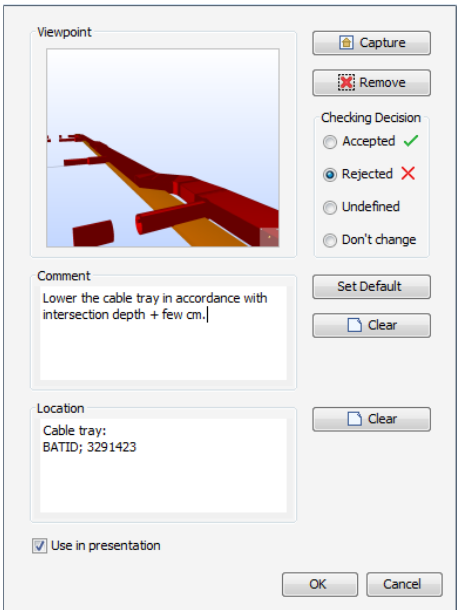


Figure 50 – Results details of cable tray intersection with HVAC duct.

8. Select the “Presentation” tab within the modeling interface.

9. Create new presentation. Name the presentation and make use of rejected issues by checkmarking “Convert Slides from Checking Results (Viewpoints)”. See Figure 52.
10. Create a report by selecting the Report button. Checkmark the BCFzip and save the report to a folder.
11. Save the Solibri MC project and close the program.

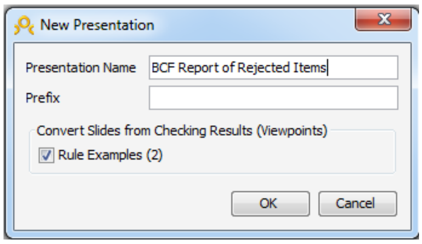


Figure 52 – Creation of presentation

The fixing of object related to the electrical discipline is described from point 12 to 20. Modification of objects related to the plumbing discipline is described from point 21 to 29.

12. Launch Revit Architecture or MEP and open following IFC model; El.ifc
13. Link the HVAC.dwg to the Revit project in order to view the intersection between each discipline model. This is performed in Revit under the “Insert” toolbox, “Link CAD” tab.
14. Select the toolbox where BCF import is located. For the current test is the “CQTools” utilized where the BCF tools is found under the BCF Import tab.
15. Import the BCF report, named “BCF Report of Rejected Items.bcfzip”. See Figure 53.

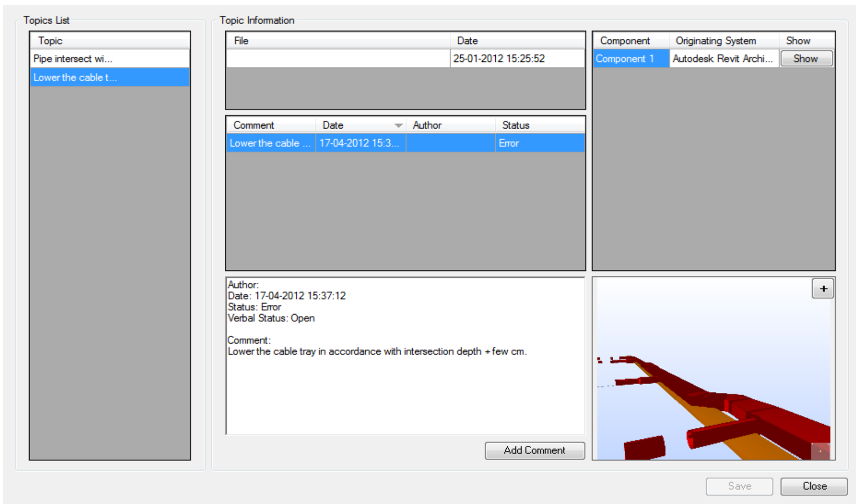


Figure 53 – CQTools BCF Import panel within Autodesk Revit Architecture

16. Push the “Show” button for Component 1 in order to select the issues object in Revit. See Figure 54.

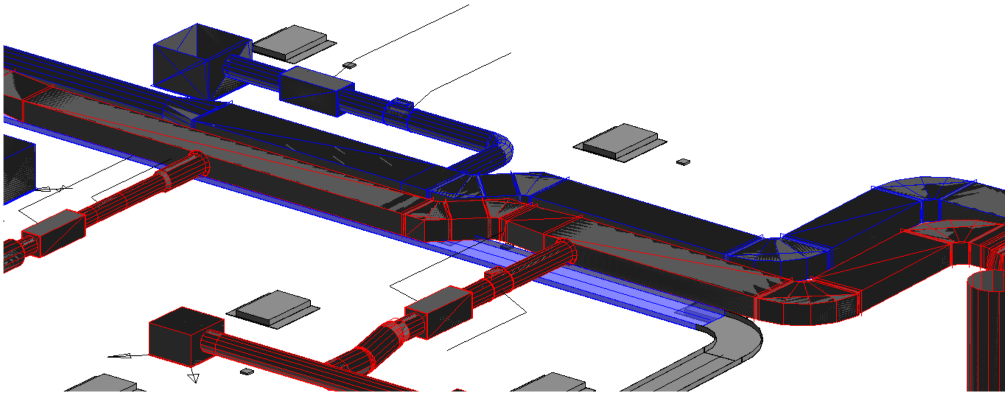


Figure 54 – Selection of Component 1 (cable tray), based on BCF report

17. Collect the necessary information's within the IFC based project interface for fixing the issued object. Comments from the BCF report can be used as a reference, e.g. lowering the cable tray.
18. Open the original Revit model (El.rvt). Find the issued object and copy paste the information generated for adjusting and rectifying issued object from point 17.
19. After fixing the cable tray a re-export of the IFC is performed.
20. The fixing and modification process continues until reaching zero conflict status.

The following description repeats the point 12 to 20. It demonstrates the procedure for fixing intersections addressed to the plumbing discipline.

21. Launch Revit Architecture or MEP and open following IFC model; MEP.ifc
22. Link the El.rvt model to the Revit project in order to view the intersection between each discipline model. This is performed in Revit under the "Insert" toolbox, "Link Revit" tab.
23. Select the toolbox where BCF import is located.
24. Import the BCF report, named "BCF Report of Rejected Items.bcfzip". See Figure 55.

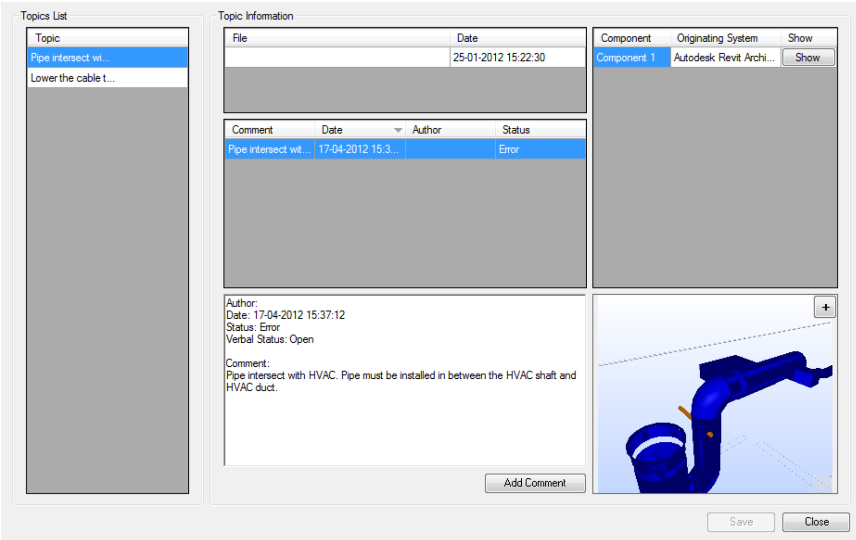


Figure 55 – CQTools BCF Import panel within Autodesk Revit Architecture

25. Push the "Show" button for Component 1 in order to select the issues object in Revit. See Figure 56.

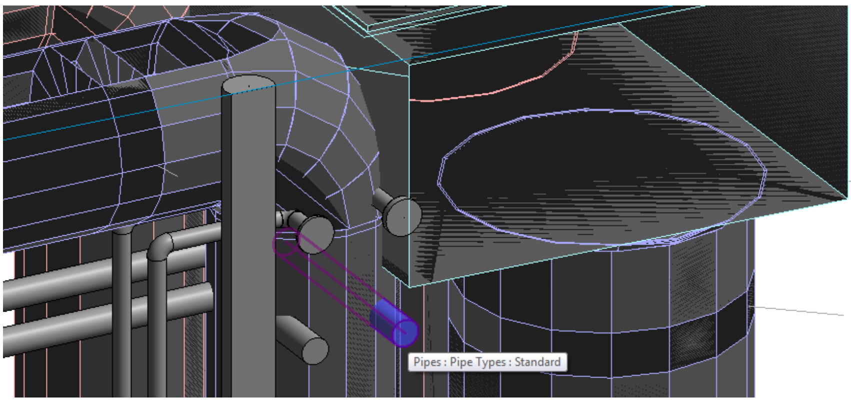


Figure 56 – Selection of Component 1 (pipe), based on BCF report

26. Collect the necessary information's within the IFC based project interface for fixing the issued object. Comments from the BCF report can be used as a reference, e.g. pipe must be installed in between the HVAC shaft and HVAC duct.
27. Open the original Revit model (MEP.rvt). Find the issued object and copy paste the information generated for adjusting and rectifying issued object from point 26.
28. After fixing the pipework a re-export of the IFC is performed.
29. The fixing and modification process continues until reaching zero conflict status.

Test 12 – Tekla BIMsight, BCF procedure

The test demonstrated in following section is performed on the MEP vs. HVAC disciplines. It will illustrate the working procedure for resolving issued clashes, utilizing the BCF reporting functionalities of SolibriMC.

The models for the current test can be found on the attached CD, in following directory; //PFA/Clash/TBS/BCF/PFA El vs MEP-HVAC.tbs

The current Tekla BIMsight test is saved in the tab; "Conflict Checking", group; MEP vs HVAC

Following models are used for this test; MEP.ifc, El.ifc and HVAC.dwg

The use of BCF works like following;

1. Export the MEP models to IFC and HVAC model to dwg
2. Add models to Tekla BIMsight
3. Save the TeklaBIMsight project
4. Rules for performing clash detection are defined. For the current test is all discipline models checked against each other, based on parameters shown in Figure 57.
5. Run the conflict check
6. View the results in the in the "View" tab.
7. Select the clashes which are to be reported in the BCF. For the current test is 9 intersections rejected and marked as critical. Figure 58 shows reported issues.

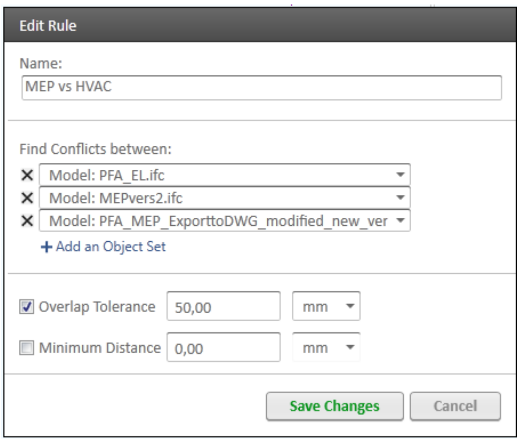


Figure 57 – Clash detection rule parameters

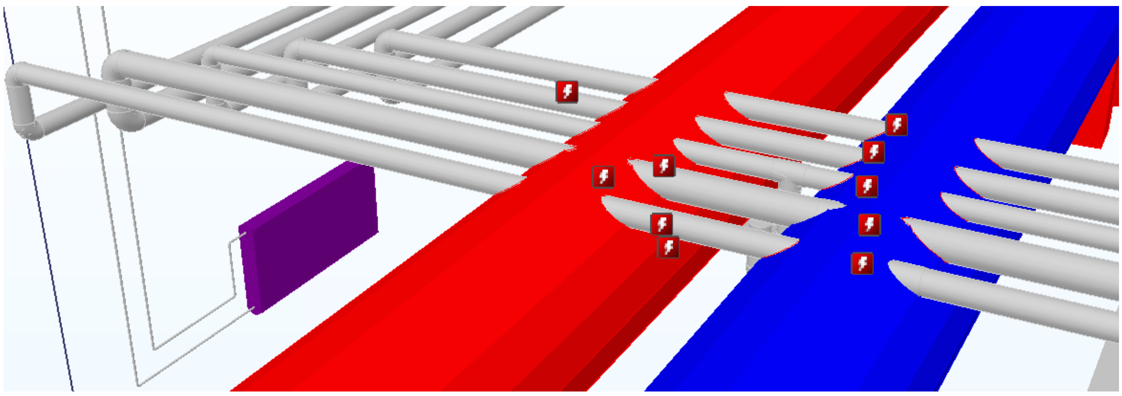


Figure 58 – Selected conflicts to be reported in the BCF

8. Notes to the conflicts are applied by selecting all the "Critical" issues in the "Conflict" tab. See Figure 59.
9. Create a BCF report by selecting the "Sharing" button followed by selecting "Save to file".
10. Save the Tekla BIMsight project and close the program.
11. Launch Revit Architecture or MEP and open following IFC model; MEP.ifc
12. Link the HVAC.dwg model to the Revit project in order to view the intersection between each discipline model. This is performed in Revit under the "Insert" toolbox, "Link CAD" tab.
13. Select the toolbox where BCF import is located.
14. Import the BCF report, named "BCF Report of Critical Items.bcfzip". See Figure 60.

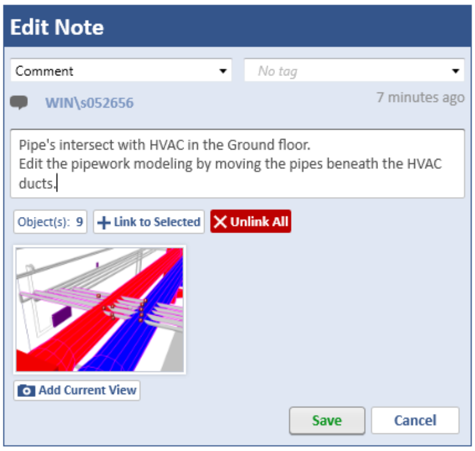


Figure 59 – Notes related to identified conflicts

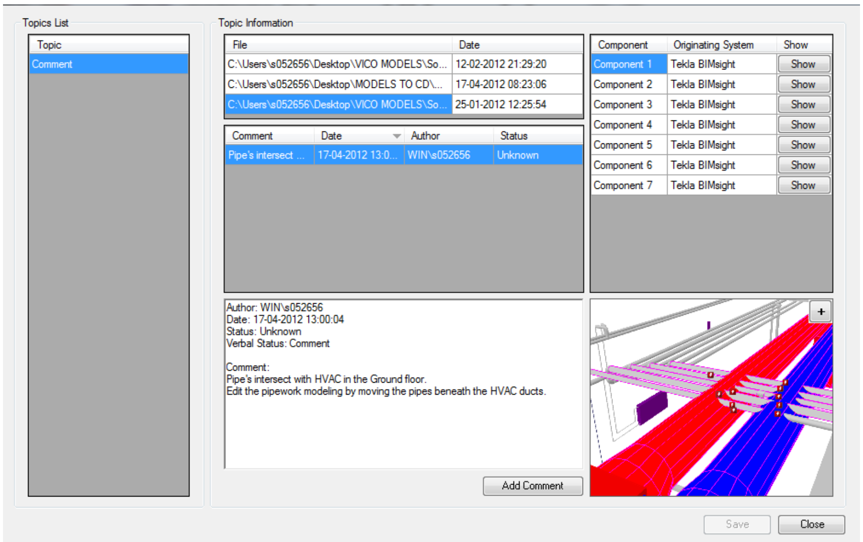


Figure 60 – CQTools BCF Import panel within Autodesk Revit Architecture

15. Push the "Show" button for Component 1-7 in order to select the issued objects in Revit. See Figure 61.

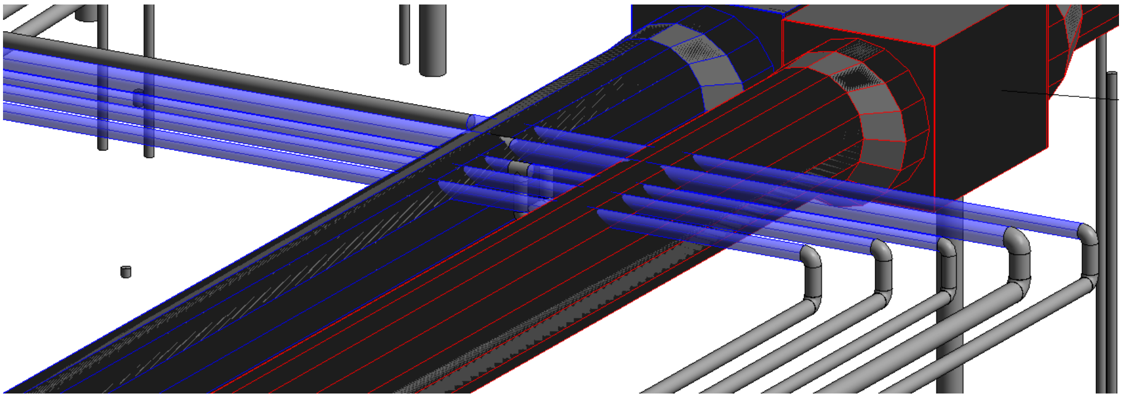


Figure 61 – Selection of Component 1-7 (pipes), based on BCF report

16. Collect the necessary information's within the IFC based project interface for fixing the issued objects. Comments from the BCF report can be used as a reference, e.g. Pipe's intersect with HVAC in the Ground floor. Edit the pipework modeling by moving the pipes beneath the HVAC ducts.
17. Open the original Revit model (MEP.rvt). Find the issued object and copy paste the information generated for adjusting and rectifying issued object from point 16.
18. After fixing the pipework a re-export of IFC model is performed.
19. The fixing and modification process continues until reaching zero conflict status.

Comments to test 11 and 12

The BCF report contains information about the two or more intersecting objects. This data is generated on basis of the information's available within the IFC specifications (model imported to Solibri MC or Tekla BIMsight). The IFC specification uses a globally unique identifier (GUID) for all object instances. This data storage (IFC GUID) is created only when IFC models are exported from all Autodesk Revit based platforms. The IFC GUID is however created when objects are modeled in Revit, but the software is not capable of identifying the GUID when working on the original model. This issue is however not a problem when using the IFC models in Revit, since the IFC GUID is stored within the IFC specifications. Figure 62 and Figure 63 depict the subject.

This procedure is on the other hand not the correct way to fix and modify objects within a model, since the IFC models are not aimed to be first generation models - or in other words, main models. The Revit based model should in all cases serve as the main model, but since they are not capable of utilizing the IFC GUID the purpose of utilizing BCF reports do not give any sense. This issue was furthermore verified by the Revit application add-in developer CADQ. See appendix A8 for documentation about the issue.

The procedure for utilizing the BCF reports is as a result of this issue, not working optimal since users are not capable of editing and modifying intersecting issues directly in their main models. However the procedure shows that IFC specifications can be used as guiding models for identifying issued objects within the original/main models in all Revit platforms.

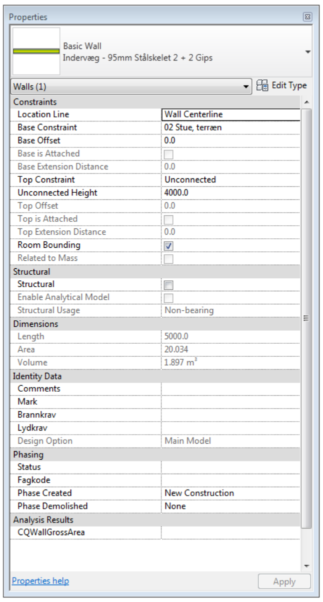


Figure 62 – Revit based wall properties without IFC GUID information.

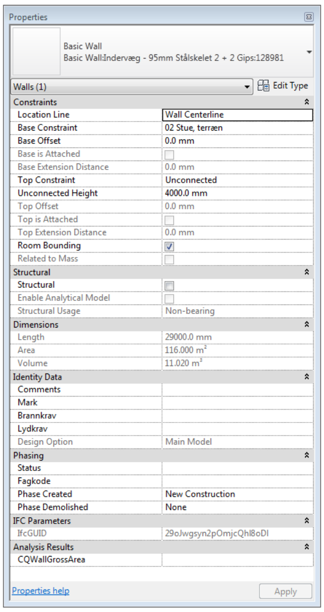


Figure 63 – IFC based wall properties with IFC GUID information in Revit.

4.2 4D modeling

4.2.1 Introduction

The purpose of the 4D modeling for the case of MTH project PFA Nørgaardsvej is to investigate how 3D BIM models can be utilized to create LOB schedules and sequence animation of the build-up scenario. The focus of the study is to explore, how a 3D model containing time and location information can be made useful for analyzing and optimizing an existing Gant-chart schedule.

Following questions are considered to be investigated;

- Converting an existing Gant-chart to LOB schedule utilizing BIM
- Amount of information needed to perform a BIM based LOB schedule
- Creating a build-up sequence animation using the time and location information within a LOB schedule
- Look for areas were activities could be optimized by using the final LOB schedule

4.2.2 Assumptions

Several assumptions were made to ease the process of creating the LOB schedule, these includes;

- Production rate of each activity are based on; model based QTO of a specific activity divided by the planed duration of same activity in hours. [QTO unit/hours]
- Crew size of any activity equals actual crews size per week divided by the duration of activity in weeks [average crew size per activity]

4.2.3 Procedure

The Revit based discipline models for the case of MTH project PFA Nørgaardsvej are used for the 4D modeling investigation. All BIM models are exported to Vico Office and added with time and resource information from an existing master project schedule and crew plan.

Vico Office "LBS Manager" was utilized to define locations inside the model viewer to drive the location based QTO and starting point for location based schedule planning. "LBS Manager" made it possible to create locations (E.g. floors, zones and areas), without having to go back to the native BIM application.

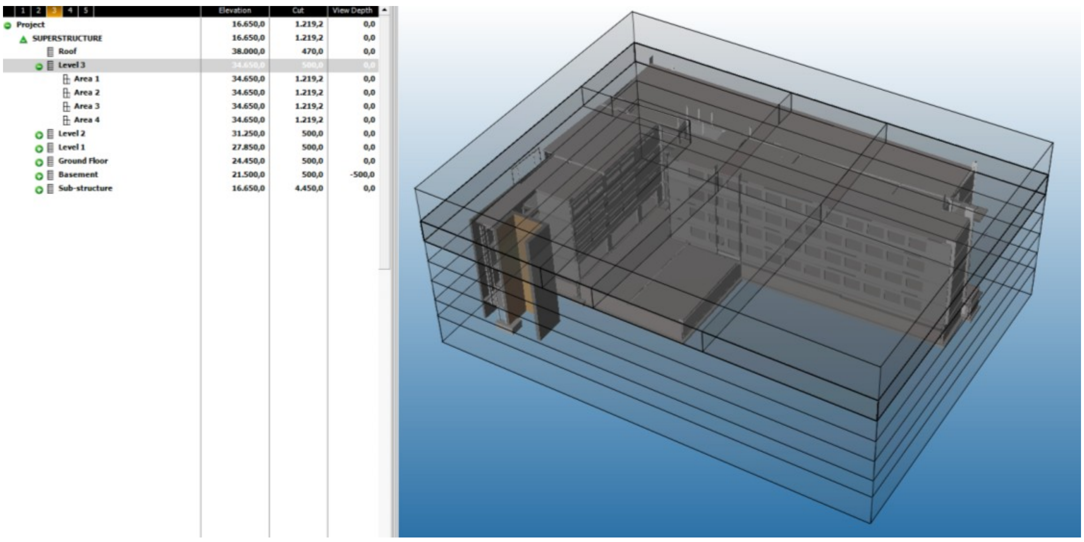


Figure 64 – Vico Office LBS Manager, bounding box with elevations, zones or areas

The LBS is set to separate each floor and each floor into 3 or 4 zones. The foundation and basement is separated into 3 zones whereas the rest of the building (ground floor to the 3rd floor incl. roof) is separated into 4 zones.

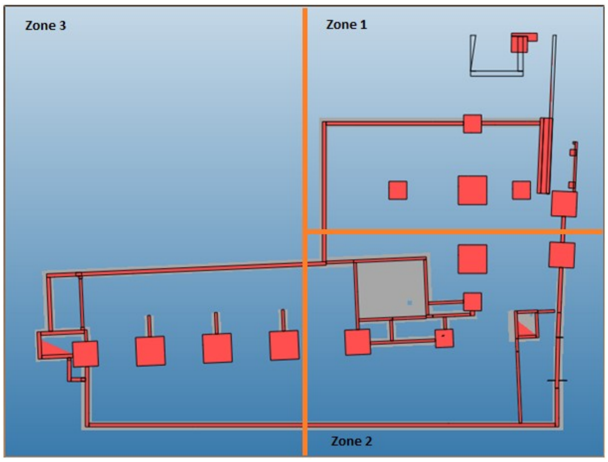


Figure 66 – LBS of foundation and basement

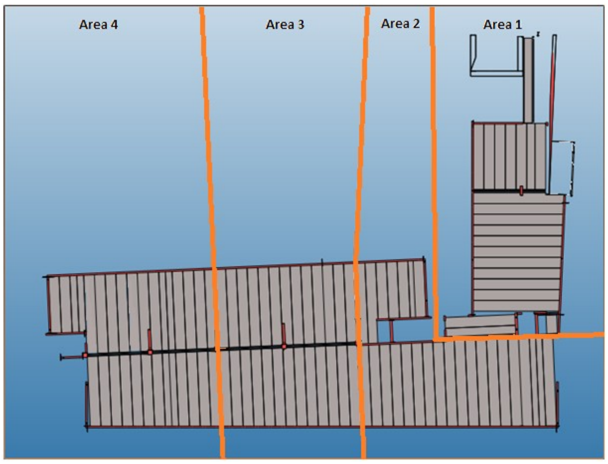
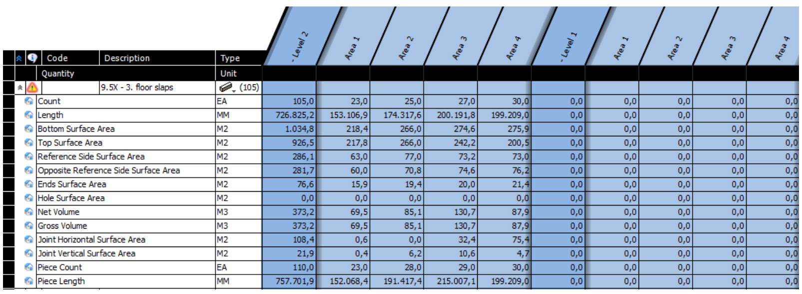


Figure 65 – Typical LBS of Level 1 to 3

The schedule planning modules in Vico Office are capable of using quantities per location to calculate; labor, material and equipment amounts. These information's are normally subsequently used for determining number of work hours per location. However, this procedure was not utilized, since the duration of each activity was known in the PFA Nørgaardsvej master project schedule. The common procedure gives the option that quantities are recalculated and updated at the end of the location editing process. This procedure makes it possible to analyze and optimize the phasing and zoning of a project to get to the best schedule for the project.

When the LBS are defined the next step is to check or verify the QTO's are accordingly to desired configuration of the LBS. This is to be performed, since QTO's in Vico Office are defined as QTO's by location. The application automatically uses the locations of the used BIM and stores the quantities of TOI for each of these locations. Overviews of the quantities per location are found in the "Manage Takeoff" view. A grid system with TOI's and QTO's presented as rows with the projects locations as columns. See Figure 67.



Code / Quantity	Description	Type / Unit	- Level 2	Area 1	Area 2	Area 3	Area 4	- Level 1	Area 1	Area 2	Area 3	Area 4
	9.5X - 3. floor slaps	(105)										
Count		EA	105,0	23,0	25,0	27,0	30,0	0,0	0,0	0,0	0,0	0,0
Length		MM	726.825,2	153.106,9	174.317,6	200.191,8	199.209,0	0,0	0,0	0,0	0,0	0,0
Bottom Surface Area		M2	1.034,8	218,4	266,0	274,6	275,9	0,0	0,0	0,0	0,0	0,0
Top Surface Area		M2	926,5	217,8	266,0	242,2	200,5	0,0	0,0	0,0	0,0	0,0
Reference Side Surface Area		M2	286,1	63,0	77,0	73,2	73,0	0,0	0,0	0,0	0,0	0,0
Opposite Reference Side Surface Area		M2	281,7	60,0	70,8	74,6	76,2	0,0	0,0	0,0	0,0	0,0
Ends Surface Area		M2	76,6	15,9	19,4	20,0	21,4	0,0	0,0	0,0	0,0	0,0
Hole Surface Area		M2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Net Volume		M3	373,2	69,5	85,1	130,7	87,9	0,0	0,0	0,0	0,0	0,0
Gross Volume		M3	373,2	69,5	85,1	130,7	87,9	0,0	0,0	0,0	0,0	0,0
Joint Horizontal Surface Area		M2	108,4	0,6	0,0	32,4	75,4	0,0	0,0	0,0	0,0	0,0
Joint Vertical Surface Area		M2	21,9	0,4	6,2	10,6	4,7	0,0	0,0	0,0	0,0	0,0
Piece Count		EA	110,0	23,0	28,0	29,0	30,0	0,0	0,0	0,0	0,0	0,0
Piece Length		MM	757.701,9	152.068,4	191.417,4	215.007,1	199.209,0	0,0	0,0	0,0	0,0	0,0

Figure 67 – Manage Takeoff view of 3rd floor slabs. TOI and QTO's are presented as rows whereas the locations as columns.

When and if the QTO's are incorrectly configured according to desired LBS, Vico Office makes it possible to redefine TOI manually, giving the option to move location based takeoffs to desired locations. (E.g. part of the foundation contains QTO's for basement and substructure. This issue can be solved by manually linking foundation TOI's to substructure - giving the substructure hierarchy locations the desired QTO's).

When the TOI's and more importantly the QTO's are configured according to desired LBS, the duration of each activity can be defined under the "Cost Planner". Cost issues are not covered in this thesis, however it is an essential feature to recognize – especially for the creation of a LOB schedule. Cost and work hour issues are all incorporated within this spreadsheet, since activity or task based durations (labor) are a part of the calculated total costs. The task based work hours are however extracted from the master project schedule of PFA Nørgaardsvej making the "Cost Planner" module containing only work hour related information.

Costs planning within Vico Office are typically developed phase by phase, in which more specific and more accurate cost information are added throughout the design and pre-construction phases. This process enables users to replace assumptions that were made in the initiation and early design phases. According to Vico Software the "Plan Cost" view supports this process and is capable of providing continuous cost feedback throughout all project phases. "*You can start with a costing scheme at the business development phase, and gradually increase granularity as more specific data and accurate quantities become available from the 3D BIM model or manually entered quantities*" [Vico Software]. Furthermore Vico Software state that; "*The Plan Cost view contains an n-tiered 3D spreadsheet; a graphic scheme which emphasizes the hierarchical structure of the cost estimate. Every line item (Assembly) can be further refined with additional Components, providing flexibility, and enabling you to gradually develop your cost plan from a basic abstract level to a highly-detailed cost estimate*" [Vico Software]

Vico Office is capable of planning costs and schedules in three deferent ways:

1. As spreadsheet, by manually entering quantity and cost/time information in place (non-model based)
2. With separated QTO, using a formula in the cost line items (import QTO's)
3. With model-based QTO, using quantities extracted from the BIM files as input for the cost line items.

The three supported cost/schedule planning techniques can be combined as desired.

For the case of PFA Nørgaardsvej are type 1 and 3 utilized. Type 1 is used for the interior, finishes, closure and MEP activities, whereas type 3 is used for the substructure and superstructure activities.

Part of the cost planning view (only work hours per activity) is illustrated on Figure 68.

Code	Description	Sour..	Formula ..	Consumption	Units	Waste/Factor	Quantity	Unit
A	Foundation	218,9		1,000	m3	1,200	262,6	m3
A001	TIME	262,6		6,397	HR/m3	1,000	1.680,0	HR
B	SOG	211,9		1,000	m3	1,200	254,2	m3
B001	TIME	254,2		9,346	HR/m3	1,000	2.376,0	HR
C	Basement walls	124,8		1,000	m3	1,200	149,8	m3
[0]	TIME	149,8		1,476	HR/m3	1,000	221,2	HR
D	Structural walls (basement)	51,8		1,000	m3	1,200	62,1	m3
[1]	TIME	62,1		1,476	HR/m3	1,000	91,7	HR

Figure 68 – Cost planner view, with information about source quantity, consumption and activity durations.

The source quantities are extracted from the 3D model (TOI) and divided into the desired LBS's with specified WBS's.

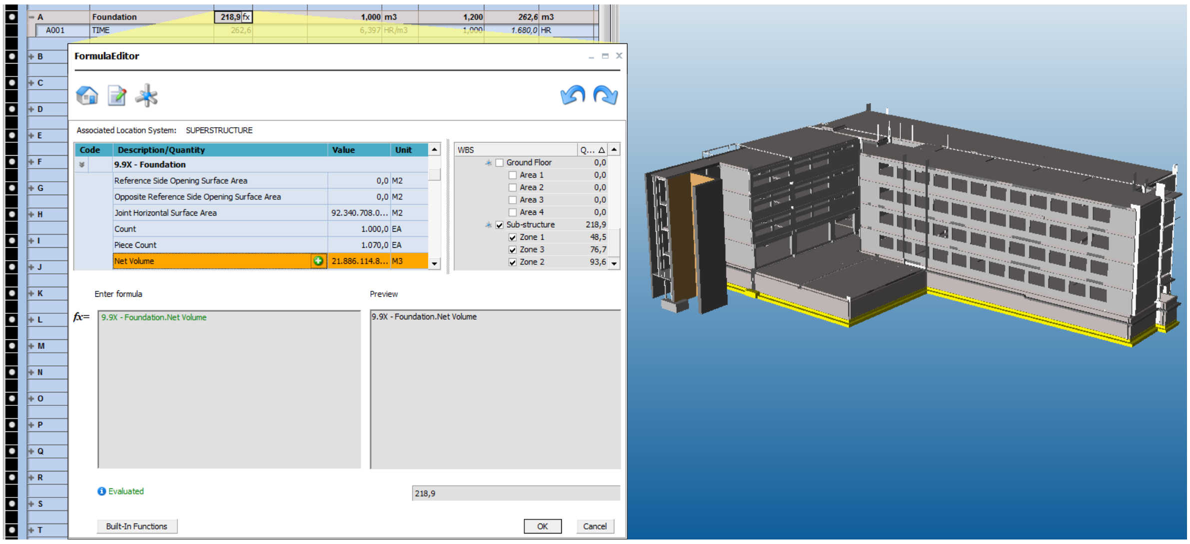


Figure 70 – Foundation QTO with assigned WBS showing the TOI in model viewer

When the components (cost assemblies) and the associated QTO's are configured the task needs to be assigned in the "Task Manager". The "Task Manager", is part of the "Schedule Planner" module. This module is normally used to establish the link between cost and schedule information by mapping cost assemblies and components to defined activities. Cost assemblies and components contain quantities for labor, material and equipment. This function allows utilization of mentioned information's to calculate the amount of work that is associated with a activity by applying a production rate to one or more of the mapped assemblies or components using the following equation;

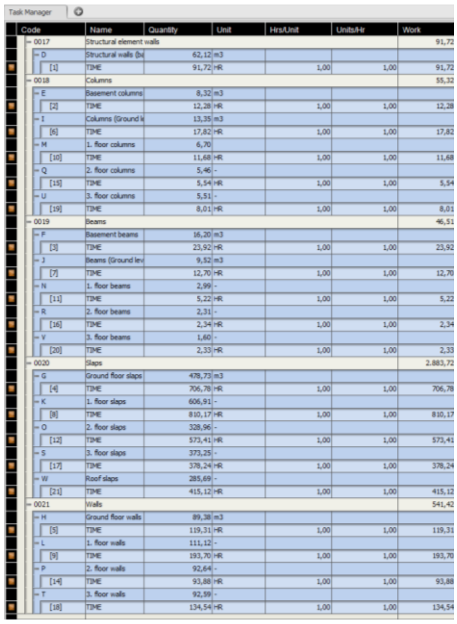


Figure 69 – Task Manager view

Component quantity x production rate = hours of work

This procedure is however not fully utilized in this case, since the hours of work is extracted from the master project schedule of PFA Nørgaardsvej. However it is important to know how the "Task Manager" module works for editing purposes – especially for typing the production rates for each activity.

The production rates per activity are calculated as; estimated duration of activity divided by the model based QTO of a specified activity. The estimated durations of activities are extracted from the master schedule of PFA Nørgaardsvej. The schedule does not contain information about crew size - only duration of each activity in days. These information's are then transformed to work hours, by multiplying assumed 8 working hours per day. Furthermore the actual crew sizes per week are utilized for calculating the total used hours per activity.

When all activities with integrated LBS's are mapped within the "Task Manager" module, the schedule configuration can be initiated; this is executed under the "Schedule Management" module. At first, the LOB schedule looks like a big mess. Primarily due to all activities start at the same date, project locations hierarchies per activity are wrongly distributed and only one crew member is assigned as standard for each activity. Besides that, the schedule project settings are configured with standard settings, making the actual import/initiation date as project start day and loading a standard US calendar as template for the schedule timetable.

The schedule settings are configured under "Edit calendar", where the Danish calendar is loaded. Furthermore the working days of week are selected making Saturday a working day. See Figure 71.

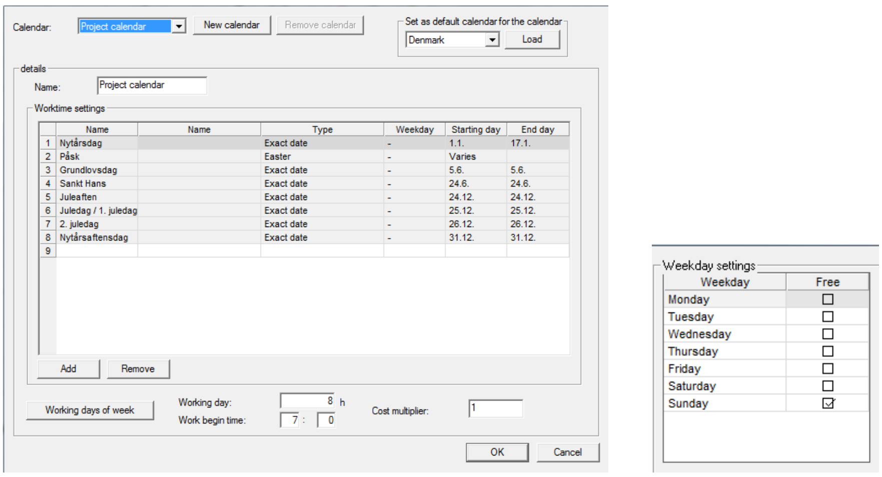


Figure 71 – Project calendar, worktime and weekday settings

Start and end date are configured under "Project settings". Start date is set to 11-7-2011 and deadline to 21-5-2012.

The location complete and display orders are modified making the LBS hierarchy as following;

Hierarchy																						
2	Project MTH PFA Nørgaardsvej																					
3	Sub-structure			Basement			Ground Floor				1. Floor				2. Floor				3. Floor			
4	Z1	Z2	Z3	Z1	Z2	Z3	A1	A2	A3	A4	A1	A2	A3	A4	A1	A2	A3	A4	A1	A2	A3	A4

Table 2 – Location complete and display order

The modifications are applied under "View settings". Each task is set to start at Z1 or A1 and continue to either Z2 or A2, then to Z3 or A3 and so forth.

Task continuing in location hierarchy level 4 are then split, making each activity independent in each location hierarchy level 3. E.g. assembling and installing walls in basement zone 1, 2 and 3 are independent tasks from the rest of the wall assemblies (ground floor to 3rd floor incl. roof in area 1, 2, 3 and 4).

The breakdown of each continuing tasks within several locations make it possible to choose which logical build-up a given task should follow. E.g. slabs in ground level should firstly be installed before installation of slabs in 1st floor. These logical configurations are then saved as dependencies and cannot be overruled in the furtherer scheduling process. These dependencies should be applied for all activities. This can be performed under the "Network View" module. See Figure 72.

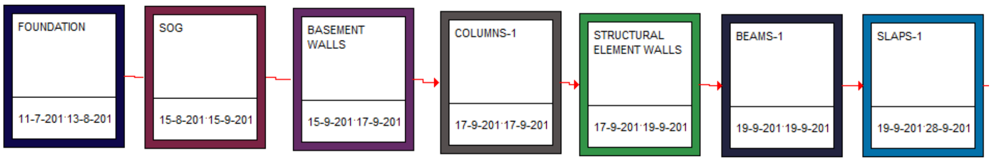


Figure 72 – Part of the network view

The red lines connecting tasks to each other represents the dependency type. For the case of MTH Nøregaardsvej, one dependency format is used in some parts - FS (finish to start). The dependency means that activity A has to be finished, before activity B can begin. This dependency is only applied for activities which also uses the same dependency in the Gant-chart.

When necessary activities contain dependencies, the next step is to define the behavior of each task concerning when it starts and whether stops and restarts are permitted or not. This is performed in the Flowline view, where any task is double-clicked, whereas the "Edit Task" module "General" dialog appears.

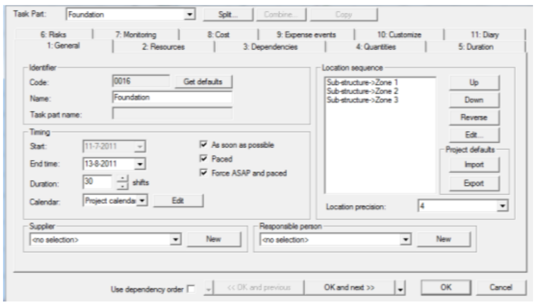


Figure 73 – Setting behavior within Edit task

The ASAP (As soon as possible) option forces activities to start directly after completion of predecessor activities.

The Paced function forces continuous flow of activities. Removal of both functions (ASAP & Paced) will make any activity freely movable to any desired start date and enable stops and restarts. See Figure 73

When the behaviors of all tasks are defined the next step is to assign resources to all tasks. This is performed under "Edit task" module "Resources" dialog. See Figure 74

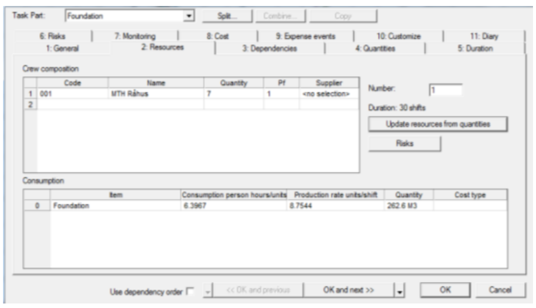


Figure 74 – Assigning resources within Edit task module

When cost for the project is not calculated to the level of labor resources, crews for tasks should be defined manually. The durations of the tasks are defined by their production rate of the crew that works on it, using the following formula: Duration = (Units of work) / (Crew output per hour x number of crews), where crew output per hour is defined as the inverse of production rate of any task.

E.g. the duration of reinforcing, erect forming, casting and stripping foundation is calculated as;

$$\text{Duration} = \frac{262.6\ [m^3]}{(6.397\ [HR/m^3])^{-1} \cdot 7\ [crew]} \approx 240 \text{ HR} = 30 \text{ shifts}$$

When resources and behaviors of each task are defined, the LOB schedule should be completed and subsequently comparable with the actual master schedule (Gant-chart) for the case of MTH PFA Nørgaardsvej.

To perform a 4D simulation of the created LOB schedule the time and location based information can be imported back to Vico Office "4D Manager".

4D simulations are integrated part of the Vico Office workflow and does not require any additional effort to create or maintain. The imported 3D BIM elements are connected to specific tasks through TOI and "Cost Planner" mapped and assigned components. The mapped "Cost Planner" components and assemblies are furthermore linked to tasks within "Schedule Planner" giving the ability to playback, review and communicate the created schedule by running 4D simulations.

The process of creating 4D Simulation within Vico Office requires following mapping;

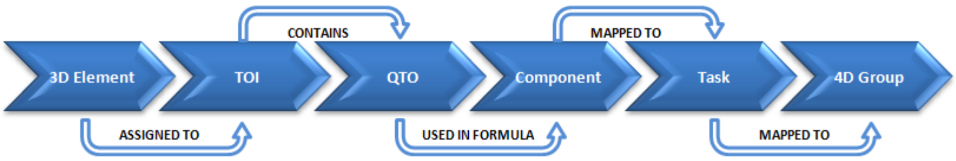


Figure 75 – Process for developing 4D simulation within Vico Office

The "4D Manager" module "Simulation Settings" dialog includes several tools enabling users to design and configure the output of the 4D simulation. Some of the functions are described in the following;

- *Late Start and Running Late Tolerance (applicable only when Production Control is entered for the project) lets you define when elements should be marked as "Started Late" and "Running Late".*
- *Show/Hide provides settings for additional information that is presented on top of the 4D view.*
- *Date Stamp shows the current date in the top left corner of the simulation;*
- *Week Counter shows the current week (counted from the beginning of the simulation/schedule) in the top left corner of the simulation;*
- *Day Stamp shows the current day (counted from the beginning of the simulation/schedule) in the top left corner of the simulation.*
- *Show unassigned 3D Elements provides the option to either hide or show elements that are not associated with any Task in the schedule. When the check box is cleared, only those elements that have been associated with Tasks will be visible throughout the simulation playback.*
- *Element appearance after completion is relevant - as noted in the dialog - only for 4D Groups with "Build" behavior, as these are the only elements that remain visible after finishing of associated Task(s). The option lets you decide what the color of completed elements should be: gray, translucent or the color assigned in the original CAD model.*
- *3D Elements with pending Task Appearance lets you set the color of those elements that are between two Tasks (one Task has been completed, the second one has yet to start).*
- *The Legend options provide two choices for presentation of 4D Group color clarification. The Static legend option shows an overview of all defined 4D Groups and colors, the Dynamic legend updates when Tasks in a 4D Group occur*

These functionality can however only be utilized by defining and mapping tasks to 4D groups, which can then be used to specify the behavior and representation of linked elements when the tasks occur. See Figure 76

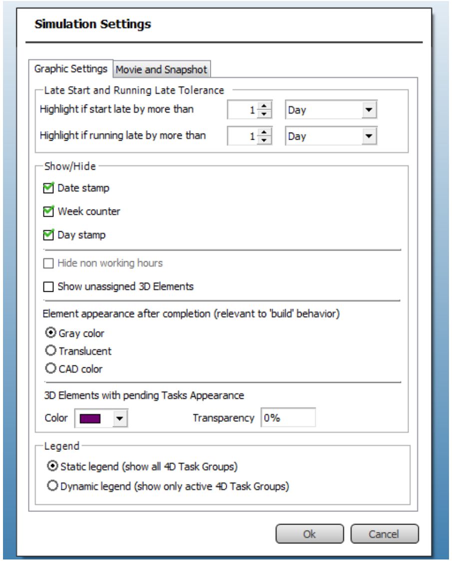


Figure 76 – simulation settings

The mentioned features were investigated for the project case, however the output panel was not available since it was locked. For these reasons simulation settings was not investigated furtherer in this thesis.

Chapter 5

Results

5. Results

The following chapter highlights the obtained results from the tests performed to clarify the overall objectives of this thesis.

Following results are draw attention to;

- Hard clashes, showing amount of clashes which could cause constructability issues for the case of MTH project PFA Nørgaardsvej
- Comparison of clash detective results and actual construction installations photos.
- The advantages and disadvantages of the investigated clash detectives in terms of interoperability, key features, retail price and support
- obstacles and problems with BIM models, in relation to performing clash detection
- 4D sequencing of construction activities for the case of MTH project PFA Nørgaardsvej
- obstacles and problems with BIM models, in relation to performing 4D simulation

5.1 Hard clashes

Table 3, shows the amount of identified hard clashes performed on the Autodesk Revit platform models for the case of MTH project PFA Nørgaardsvej.

Following factors are applied for obtaining the results;

- All hard clashes are based on a tolerance of 10 mm.
- None rules or ignoring parameters are applied for all conflict detections.
- The duration of performing the tests are recorded manually and perform under same hardware.

Application	Clash detection	Model format	Clashes	Total	Duration
Navisworks Manage 2012	Mechanical Ventilation VS Electrical	NWC vs. NWC	69	519	12 sec.
	Mechanical Ventilation VS Superstructure	NWC vs. NWC	369		22 sec.
	Electrical VS Structures	NWC vs. NWC	81		15 sec.
Solibri Model Checker v.7	Mechanical Ventilation VS Electrical	DWG/IFC vs. IFC	300	2302	2 min. 44 sec.
	Mechanical Ventilation VS Structures	DWG/IFC vs. DWG	1306		7 min. 7 sec.
	Electrical VS Structures	IFC vs. DWG	696		4 min. 59 sec.
Tekla BIMsight v.1.4.1	Mechanical Ventilation VS Electrical	DWG/IFC vs. IFC	300	2302	Approx. 50 min.
	Mechanical Ventilation VS Structures	DWG/IFC vs. DWG	1306		Approx. 200 min.
	Electrical VS Structures	IFC vs. DWG	696		Approx. 120 min.

Table 3 – Clashes and run time results from specified clash detectives and model formats

5.2 Clash results vs. actual installations

The following section compares and highlights selected constructability reviews, accomplished by the performance of clash detection and how these issues have been solved in the actual construction site. The assessment is based on clash detection results compared to the actual installations images.

Comparison 1

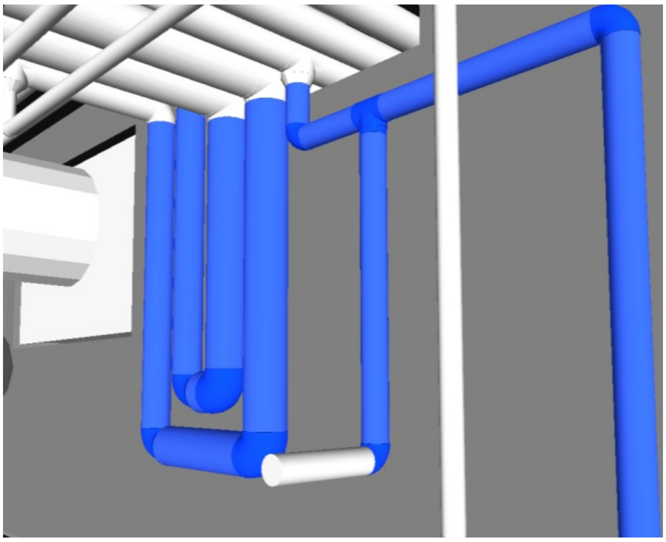


Figure 78 – MEP installations (blue) clash with wall (grey)

Figure 77 – Solved issue of MEP installations

Comparison 1 shows that the MEP installations are greatly upgraded compared to the planned installations. Many constructability issues including pipework routes and MEP related system upgrades including RFI's are assumed to have been discussed and solved during the construction period.

Comparison 2

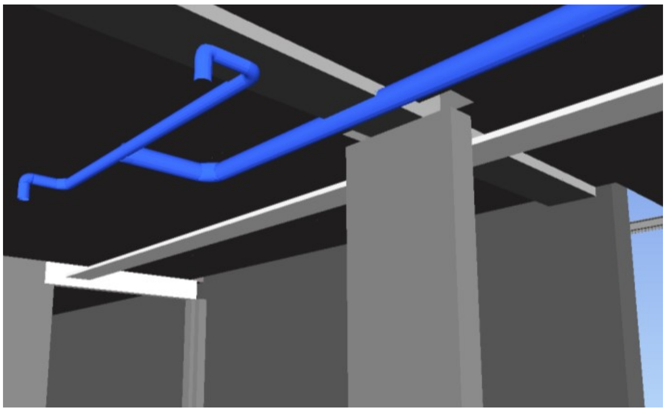


Figure 79 – HVAC (blue) clash with structural beam (grey)

Figure 80 – Actual HVAC installation

Comparison 2 shows that the HVAC ductwork has been solved by lowering the ductwork. It is assumed that this issue has not caused severe time delays or construction related buildability issues. The drawings used for installing the ductwork are moreover assumed to contain wrong informations about elevations/levels. Finally, RFI are presumable not been sent, since the issue can fairly easy and quickly be solved.

Comparison 3

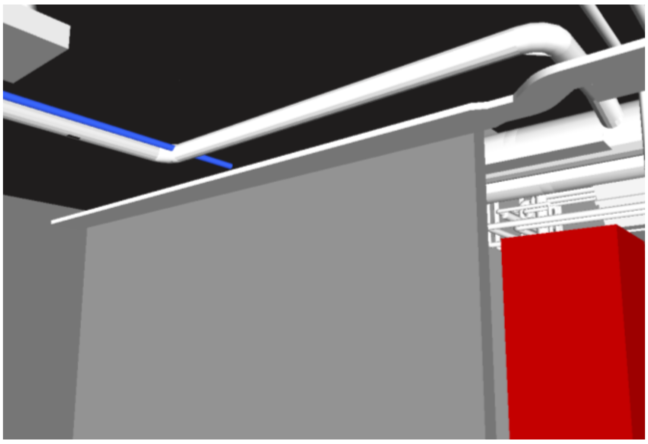


Figure 82 – Plumbing (blue) clash with HVAC duct (white)

Figure 81 – Actual MEP and HVAC installation

Comparison 3 shows that the plumbing pipework remains unchanged, whereas the HVAC ductwork has been modified by inserting bended HVAC components. It is assumed that this issue has not caused severe time delays or construction related buildability issues. According to MMN has RFI not been send.

Comparison 4

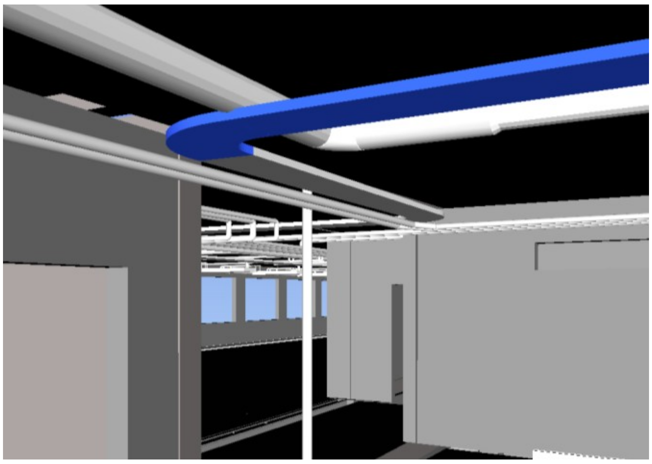


Figure 84 – Cable tray (blue) clash with HVAC duct (white)

Figure 83 – Cable tray installation

Comparison 4 shows that the cable tray remains unchanged in terms of its route and placement. It is clear that the issue have been solved during construction. According to MMN the issue was solved by manually bending the cable tray. RFI has not been sent.

Comparison 5

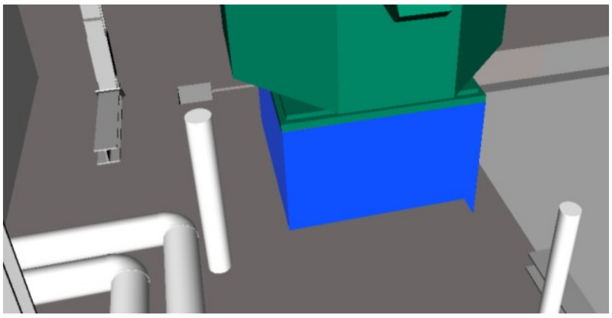


Figure 86 – Part of HVAC vent (blue) clash with roof slab (grey)


Figure 85 – Not finalized and primary solution

Comparison 5 is rather difficult to illustrate. According to MMN was this issue a source of several conflicts and problems during construction. Several RFI's was send and the issue caused noticeably construction delay and additional costs. The issue was solved by cutting the hollow core slabs.

Comparison 6

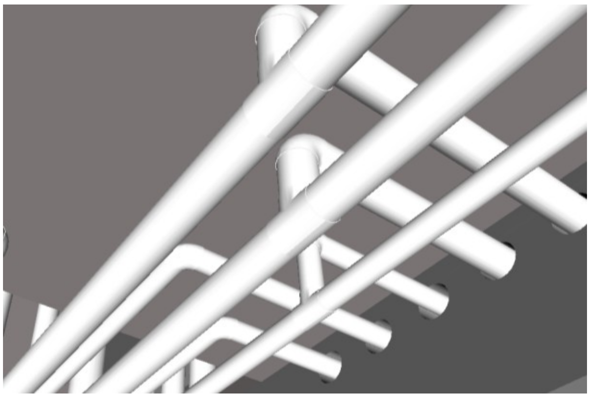


Figure 87 – Planned installation of pipes (white) without clashes


Figure 88 – Actual installation

Comparison 6 shows that the plumbing pipework inside the installation shaft were constructed as intended.

Comparison 7

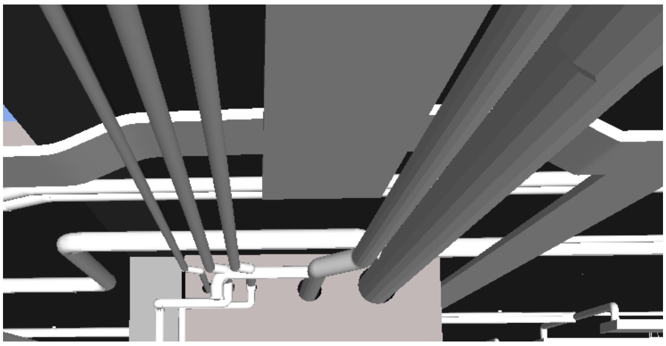


Figure 89 – Cable tray (blue) clash with HVAC duct (white)


Figure 90 – Actual cable tray installation

Comparison 7 shows that MEP and HVAC installations were constructed as intended.

5.3 Software comparaison

Following section highlights the identified features and capabilities of utilized clash detectives. The reviews are used as a basis for determining the advantages and disadvantages of each clash detective in terms of interoperability, key features, retail price and support. The review is inspired by AEC bytes software reviews and Tekla BIMsight comparison sheet [W].

Table 4 shows the similarities and core differences of review softwares.

	Autodesk Navisworks Manage 2012	Solibri Model Checker v.7	Tekla BIMsight v.1.4.1
Main use	Project review tool for design	BIM checker for QA and QC	BIM collaboration tool for construction
Combining projects			
IFC support	✓	✓	✓
DWG support	✓	✓	✓
Viewing multiple models	✓	✓	✓
Clash detection			
3D Navigation	✓	✓	✓
Measuring	✓	✓	✓
Clipping planes/sectioning	✓	✗	✓
Markup	✓	✓	✓
Redline	✓	✓	✓
Save model views	✓	✓	✓
Object coloring and transparency settings	✓	✓	✓
X-ray	✗	✗	✓
Finding and grouping objects from models	✓	✓	✗
Rule settings	✓	✓	✗
Parameters	✗	✓	✗
Direct model vs. model	✓	✗	✓
Tolerance settings	✓	✓	✓
Direct switchback to native design application	✓	★	✗
Rendering	✓	✗	✗
Information takeoff	✗	✓	✗
Clash Management			
Updated model support	✓	✗	✗
Saving clash settings	✓	✓	✗
Back tracking	✓	✗	✗
Status of addressed clashes	✓	✗	✗
Collaboration			
Create notes	✓	✓	✓
Note sharing	✓	✓	✓
BCF support	✗	✓	✓
Document based reports	✓	✓	✗
Other			
On-line support	✓	✓	✓
On-line training material	✓	✓	✓
Download size	1.4 Gb	116 Mb	57 Mb
Retail price (approx.)	45.000 DKK	34.000 DKK	0 DKK
Price source	julysoftware.com single workstation license	AEC bytes review single workstation license	TeklaBIMsight.com

✓ = Possible ✗ = Not possible ★ = Not actual

Table 4 – Comparison sheet of standalone clash detection applications

System requirement are fairly equal, however the test of all applications indicated that the 3D engine behind each application are very different. Solibri MC and Navisworks tests (with large merged IFC files, approx. 100 MB) runs without any problems, however Tekla BIMsight struggles to handle the performed 3D navigations.

5.4 LOB Schedule

Figure 91 shows the resulting BIM based LOB schedule for the case of MTH project PFA Nørgaardsvej.

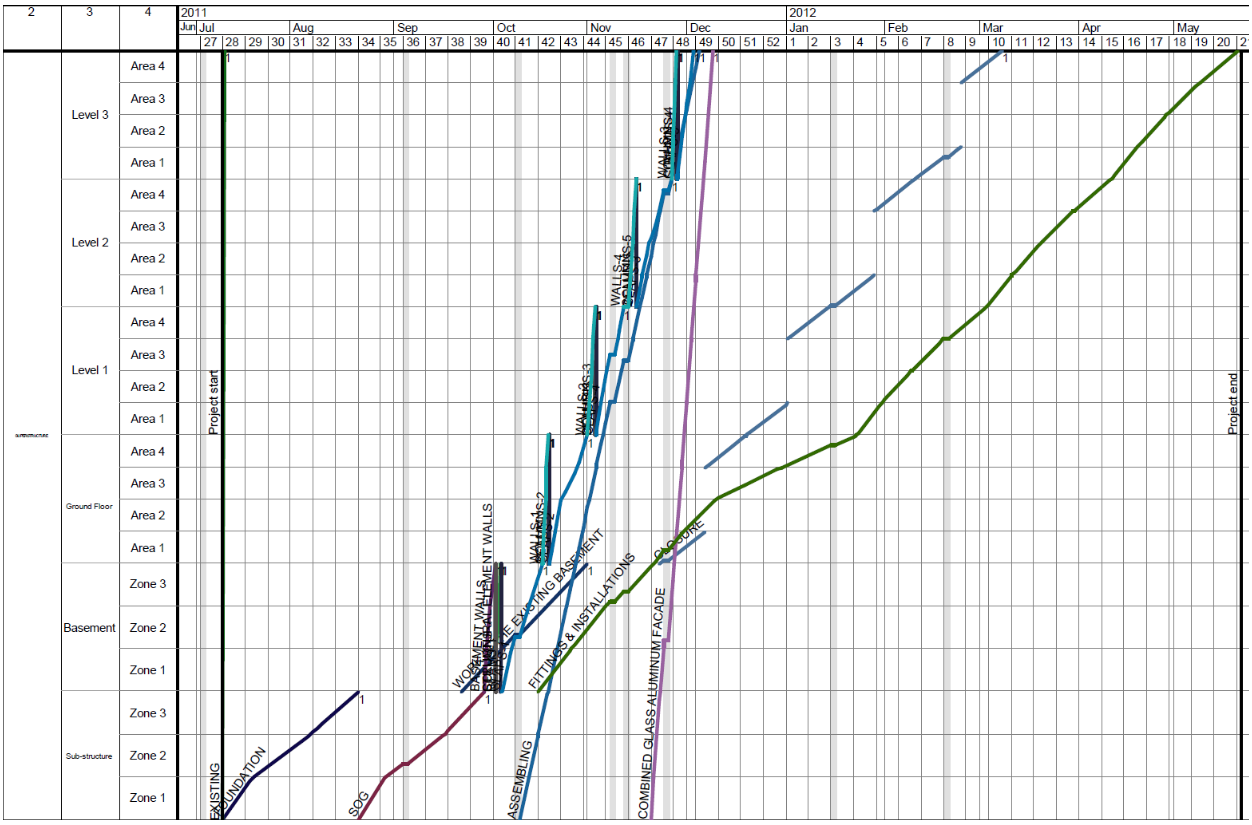


Figure 91 – BIM based LOB schedule for the case of MTH project PFA Nørgaardsvej.

The corresponding resource graph is depicted in Figure 92

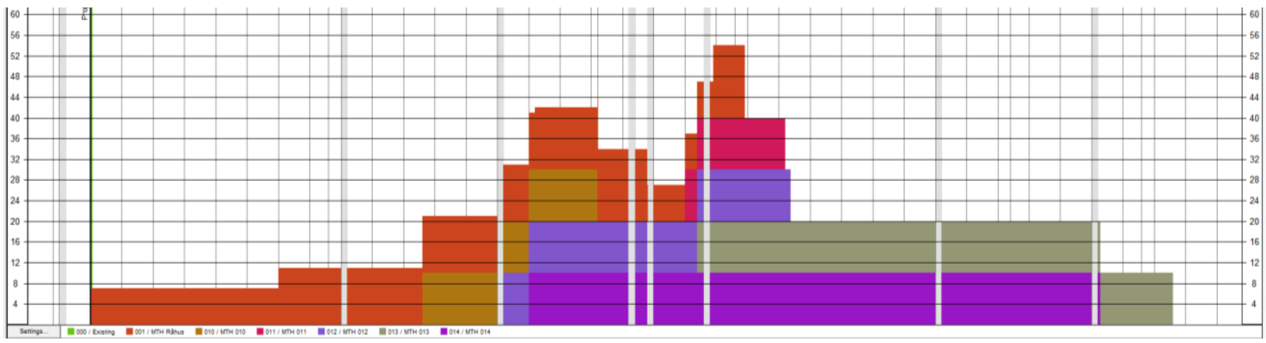


Figure 92 – Scheduled crew plan for the case of MTH project PFA Nørgaardsvej.

Both figures (90 and 91) are found in the Vico Office, under “Flowline view” and “Resource graph”.

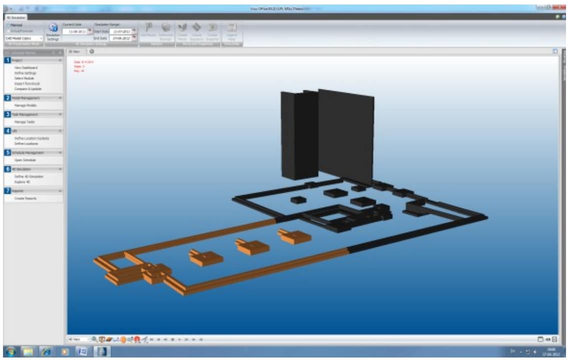
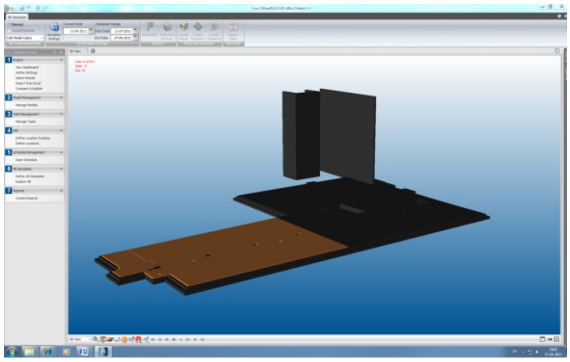
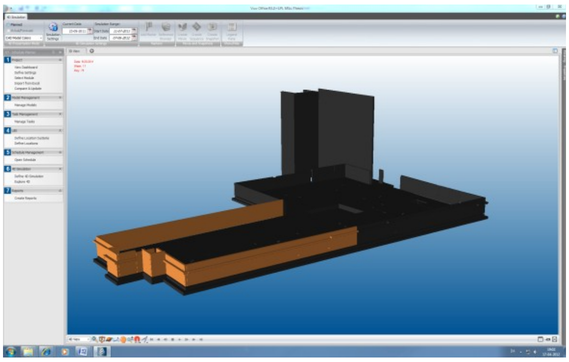
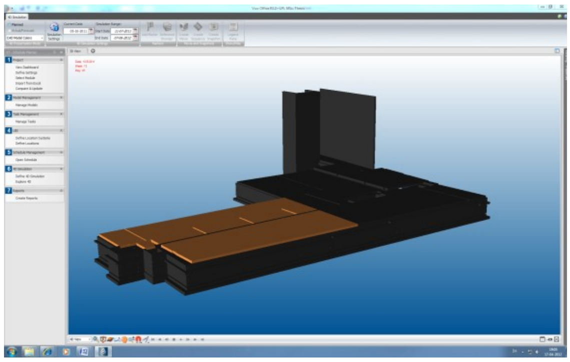
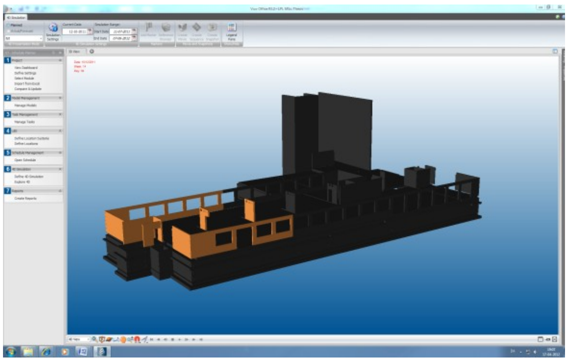
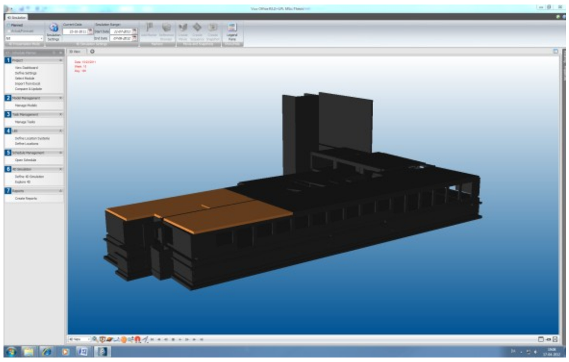
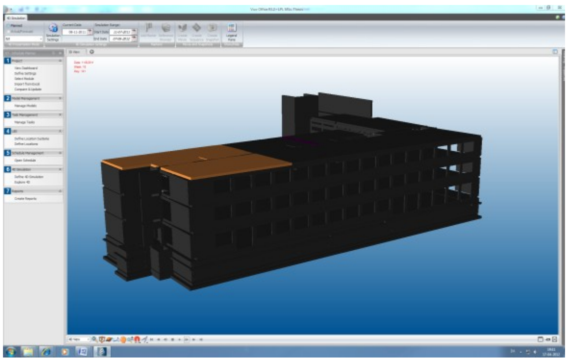
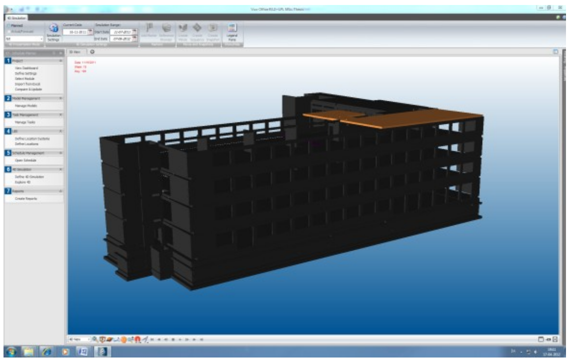
The Vico Office file can be found on the attached CD, under the directory;

//PFA/4D/Vico/LPL MSc. Thesis.vico

5.5 4D Simulation

The following section illustrates eight screenshots of the LOB based 4D simulation of PFA Nørgaardsvej. The screenshots are randomly selected LBS activities, nonetheless they show the construction progress in a chronological way.

The model based virtual 4D simulation is found on the attached CD, in following directory; //PFA/4D/Vico/ LPL MSc. Thesis.vico

5.6 Clash detection model problems

Model problems occurred during the testing of utilized clash detectives are described in this section. They are considered as results, since a solution was needed to be configured in each of the utilized discipline models. The modification was performed in each of the utilized discipline models native design application.

The modification of original models has been essential for the performance of clash detection, because the technique demands that all discipline models share the same coordinate system.

The problem occurs when the Autodesk Revit based models are exported to IFC and DWG. Export to NWC did not cause any problems. This was due to Navisworks and Revit operate on the coordinate system applied in Revit, under "Shared coordinates".

The need for exporting the DWG format occurred after an initial IFC export of the MEP model showed that linked HVAC model in the Revit project was not exported. The HVAC model was modeled by MTH's subcontractor, named Air Team. The native HVAC model was not made available for this thesis, however MTH agreed to make use of what was available in their models for this thesis. The linked HVAC model could in this case only be exported using the DWG format.

Figure 94 and Figure 93 depict the problems with the exported discipline models opened in Solibri MC.

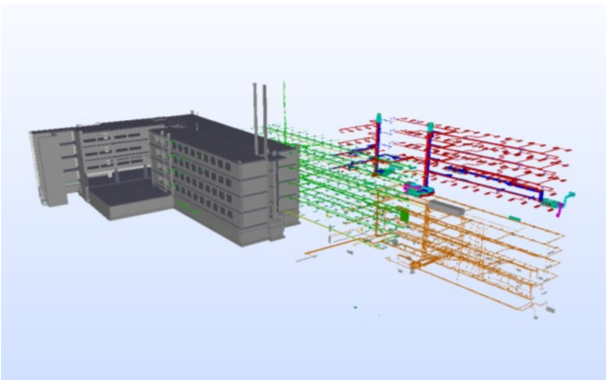


Figure 94 – IFC and DWG models in Solibri MC, perspective 1

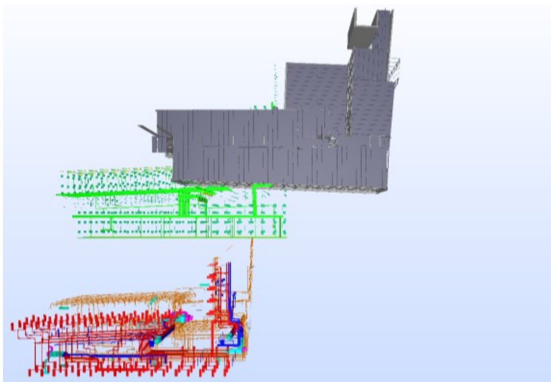


Figure 93 – IFC and DWG models in Solibri MC, perspective 2

Both figures illustrate clearly, that there was an inconsistency regarding the placement of each discipline model. The models did not share coordinates which initially resulted in displaced models. The issue was solved by modeling "dummy" object on each discipline model. These objects (when merged) were then used as references for manually moving entire models one by one. All DWG based models needed in addition a rotation of 2.3 degrees in order to overlap with the IFC models.

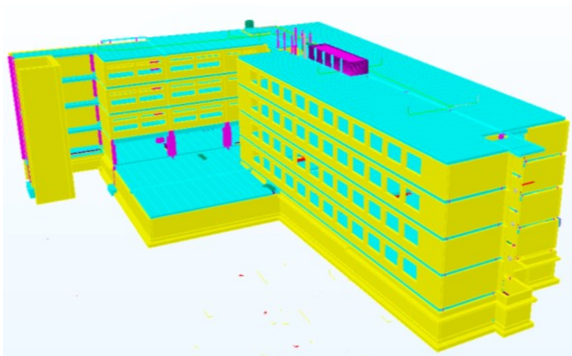


Figure 95 – Merged and color modified IFC and DWG models sharing same coordinate system

The outcome of this procedure is depicted in Figure 95.

5.7 4D modeling problems

All discipline BIM models were exported to Vico Office through Revit Architecture 2012 add-in "Publish to Vico Office". See Figure 96.

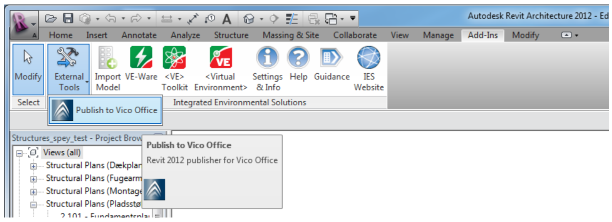


Figure 96 - Export to Vico

When the exported models are activated in Vico Office, it was clear that there were some problems with the coordinate systems of each discipline model. The models did not share coordinates which resulted in displaced models. The issue is illustrated in figure Figure 97.

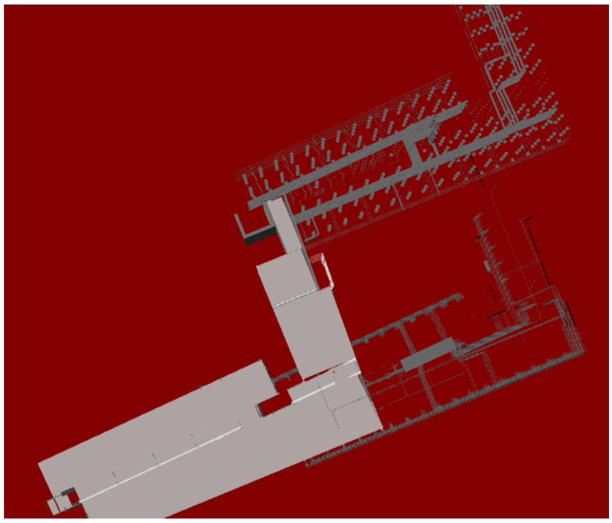


Figure 97 - Displaced discipline models

Since Vico Office is not capable of moving the reference system of each model, it was necessary to adjust and correct the coordination system of each discipline model. The coordinate systems in each of the discipline models were then investigated in Revit. This can be done by activating the "Site" properties; "Project Base Point" and "Survey Point" in "Visibility Graphics" on any floor plan view.

The coordinate system inspection showed inconsistencies of above mentioned settings. These settings where adjusted successfully were a re-export of each model were performed subsequently. However, when activating the modified exported Vico models other coordinate system related problems occur within models were external models are linked to the exported Vico models. See Figure 98.

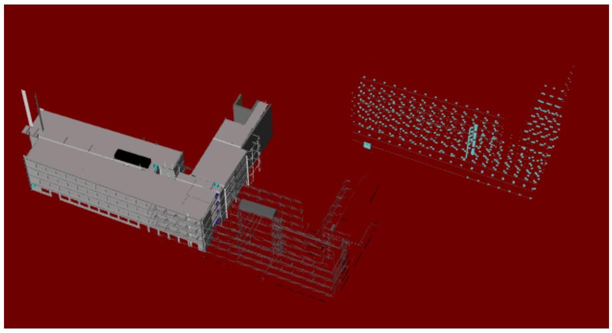


Figure 98 –Linked models did not changed position

This issue could not (in this case) be solved in Revit, since the linked model are attached files within the Revit project file.

The linked model needed to be re-imported to Revit, where the coordinate system of the specific model already is adjusted and corrected. This can only be performed in the native design application where the linked model is modeled. Since this was not possible, an alternative solution was investigated. All linked models were exported to a dwg format with the outcome that all parametric design solution was lost, but it was necessary.

The exported dwg formats were then compared in Navisworks, where all discipline models were imported. This was performed to get the full picture of each models displacement from one another.

In order to analyze the displacement, each model were exported to IFC and DWG and opened in Navisworks. See Figure 99.

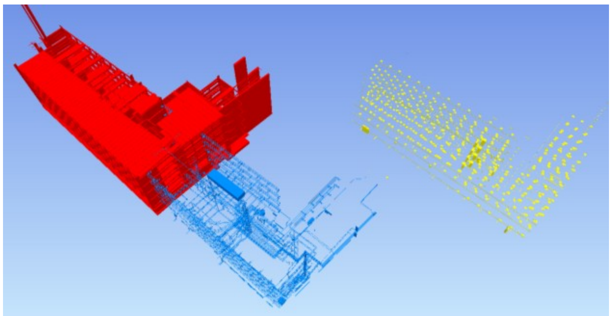


Figure 99 – Displaced models view in Navisworks

The DWG file formats where then manually moved in AutoCAD in accordance with the results obtained in Navisworks. Subsequently all models where opened in Solibri MC to visually verify that all models shared the same coordinate system. The visual examination confirmed that all models shared the same coordinate system. See Figure 100.

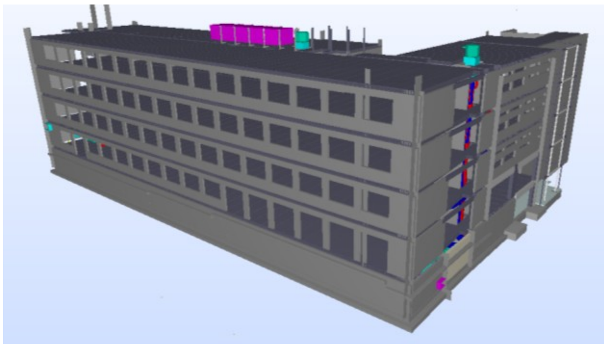


Figure 100 – Models share same coordinate system

However the IFC exported models showed some inconsistencies with the Revit based models. E.g. all slabs geometries were incorrectly exported, along with key element items such as cable-trays were not visible - as they were not exported successfully in the IFC models. See Figure 101.

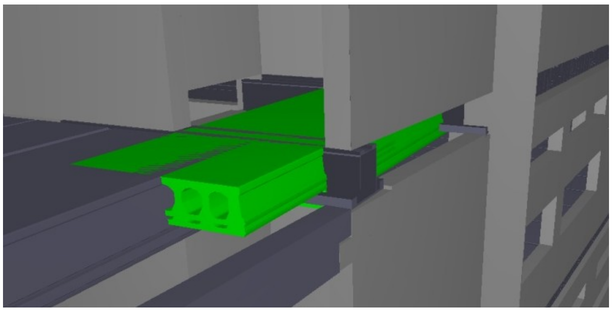


Figure 101 – Incorrectly exported IFC slap

The models check up and inspection resulted in a course of action, with the outcome to separate and split the MEP models into different models by utilizing the IFC and DWG formats.

Items and components which were not exported to the IFC format were manually selected (in Revit) and exported to DWG. As result following models needed to be imported to Vico Office;

- Structural model - export to Vico from Revit
- Electrical model - IFC export excl. cable-trays
- Electrical model - DWG format incl. cable-trays
- Plumping model - IFC export excl. HVAC
- Plumping model - DWG format incl. HVAC

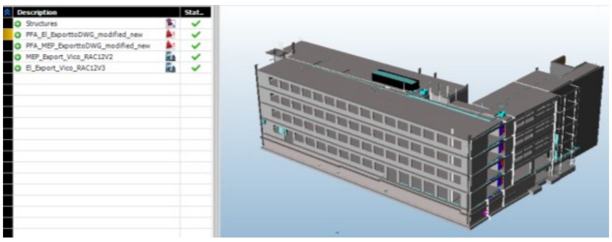


Figure 102 – Manage models view Vico Office

All models where then successfully imported and activated in Vico Office - as separate models. See Figure 102. Subsequently a final visual examination of each model where performed, to verify the corrected coordinate system along with missing items and components. As an additional check-up, the activated DWG models where investigated for their TOI. The investigation showed that this type of model import only contained layers and element type properties. Since both import types lack item and component information the TOI needed to be manually assigned. Assigning TOI for the MEP components were assessed to be too extensive and time consuming, which initially left the MEP models out of the further scheduling and 4D sequence modeling.

5.8 4D results analysis

Converting the existing Gant-chart based master schedule of PFA Nørgaardsvej to a LOB schedule was successfully applied in Vico Office. The creation of the LOB schedule was performed by utilizing discipline BIM models and a customized crew plan developed according to the assumptions made to ease the conversion process. The comparison of both schedules shows that key activities starts and ends as expected, indicating that BIM based QTO's with calculated production rates based the customized crew plan worked as anticipated.

The output and results are however questionable, since the input data were insufficient in terms of information and detailing level. The assumptions should counteract the lack of information's however they proved to be key barriers and obstacles for optimizing the schedule. It was assessed that modification needed to perform an optimized schedule where too extensive, for these reasons, is an optimized LOB schedule for the case not performed.

The problems are caused by the hierarchy dependencies for assigned activities are based on the Gant-chart dependencies. This problem can only be solved by manually reassigning the dependencies of all assigned Gant-chart based dependencies.

Nonetheless the actual LOB schedule shows areas where the schedule could be optimized. All activity lines which are colliding should be avoided, since this means that several (two or more) activities have been planned to be executed during the same time. Another area where the schedule could have been optimized is to move several successor activities when the predecessor activity is finalized in a specific zone or area. E.g. when the construction of the foundation is finalized in zone 1, the successor activity (slab on grade) could in theory start their activities in zone 1.

The idea to convert the Gant-chart to LOB was ambitious in terms of looking at the information provided.

The LOB schedule would ultimately provide a more detailed schedule but when the assumptions and added information's are insufficient the outcome is questionable. However it shows that there are possible areas where the schedule could be optimized in relation to get a more reliable schedule with the outcome to avoiding activities are colliding ect.

For the creation of the 4D simulation was the LOB scheduling satisfactory, but the actual process of planning activities using BIM based LOB method not performed as it should. This is because the individual activities should be divided into several sub-activities which together provide the total time of each activity. For example the installation of the foundation should be divided into several activities including excavation, formwork, reinforcement, casting, concrete hydration (hardening), and formwork. All these sub-activities will eventually be affected by the fact that they are split up in areas where these activities will follow the selected order activity progression. Each of these activities can be analyzed in order to optimize the schedule. If the production rate enables that a activity can start when the predecessor activity is finished in a zone/area or floor. These methods will avoid unnecessary waste of time by assigning dependencies to each of the different activities.

Chapter 6

Discussion

6. Discussion

The investigated and utilized clash detectives are roughly identical in terms of analyzing discipline models for constructability issues. Each application is capable of identifying clashes by adjusting sets of rules, parameters or by comparing entire discipline models against each other. The obtained result comparing predefined sets of discipline models, shows 2 of the 3 investigated applications identified equally amounts of clashes. The reason why the obtained results are not the same for all applications is caused by the 3D model format utilized for the tests. Clash detection performed within NW12 uses the native file formats, whereas clash detection within SMC and TBS uses a combination of DWG and IFC formats. The results showed moreover that identified clashes using the file formats of DWG and IFC are a lot more than those identified using NWC format. The reason why the DWG and IFC based clash detections identified a lot more clashes is assumed to be affected by the use of the DWG format. This is because the format converts all objects into separate surfaces and not 3D elements. E.g. a wall contains 6 surfaces whereas the object based IFC or NWC model is regarded as one unit with 6 merged surfaces. The probability for identifying clashes is for these reasons much higher, because many of the objects are converted to enormous amount of surfaces. This issue could have been analyzed in furtherer details, but since this setback was not the focus of the study, the problem was accepted in order to continue with the research objectives.

The navigation within each clash detective was not part of the analysis for determining the advantages and disadvantages of the investigated applications. This subject needs to be part of the overall judgment, since there was great difference in the smoothness and reaction time when navigating within loaded models. NW12 and SMC where handling the navigation pretty good and fast, whereas TBS where slow and inefficient in terms of moving around, zoom and pan. The run times for performing clash detections was also not part of the focus areas, however this issue is identified as important as the navigational issues since the run times was very dissimilar for all tests. NW12 identified the intersections fastest, whereas SMC was came in 2nd place being a few minutes behind NW12. TBS worked extremely slow and was up to several hours to identify same amount of clashes identified in SMC. This is a huge drawback for TBS because any user utilizing any kind of clash detective needs to perform quick intersection tests in order to get a full picture of what to report, what to sort out, what to ignore and most importantly what to assign critical, moderate ect.

Judging the applications in terms of interoperability, key features, retail price and support, it is interesting to see that TBS is somewhat a preferable solution for any contractor whom wish to perform clash detection. This is primarily due to the application is capable of meeting all criteria's set within the investigation. The interoperability features works with BCF, the key features are similar to its competitors, the system have a web based online support, and best of all its free of charge. However it is important to note that TBS does not support any kind of clash management, which can cause confusion when dealing with different discipline models, especially when several BCF reports have been sent to responsible team members. This issue can however be managed by other systems, which are not covered in this thesis, such as MS Outlook.

NW12 contains a system which supports the idea of managing clashes and this feature helps coordination of clashes quite a lot. What is even better is the applications ability to directly switchback to Revit. This enables quick and intelligent way of fixing or modifying issued clashes. However this ability requires both software installed on same machine, which initially would be a costly solution for any contractor whom which to perform and solve constructability issues quickly.

SMC supports the BIM methodology the best way, since the application is capable of interoperate with any design software vendor capable of utilizing IFC formats. The BCF format is supported, and what is ever better is its ability to create so-called ITO's. This feature must be regarded as a huge help for any BIM coordinator since it gives the opportunity for takeout whatever information is stored within IFC specifications. A great finding within this research was SMC ability to report the BATID information to Revit through ITO. The IFC based BATID information is embedded within Revit as Element ID and is Revit own GUID system. The BATID is however a digital system containing only 7 digits. This gives a limit to report 9.999.999 elements. The necessity of reporting such many BATID reports is however assessed to be unrealistic for any given project. In cases where this issue should become actual any BIM coordinator can arrange, ignore and sort the interference detection by systematizing the search of clashes. E.g. start with first floor, and then move to next level when issued clashes are resolved.

Clash reports should in any case be reported to responsible team members or other collaborative project partners. The content of the issued clashes need to be fixed and modified upon an agreed schedule. Each application is capable of sharing and mapping clashes, which simplifies cooperation and communications processes involved coordinating the issued conflicts. NW12 is capable of reporting clashes in the form of html , whereas SMC is capable of report in PDF, spreadsheets and BCF. TBS supports only sharing of conflicts in BCF. All report types can be attached with pictures which are considered very important since red-linings, markups and notes can be inserted - improving the recipients understanding of each clash. This process requires however manual editing and should be performed every time in order to avoid confusion, misunderstandings and misleading.

The best practice for remodeling or reengineering discipline models in terms of fixing or modifying issued clashes can be achieved by utilizing the NW12 SwitchBack functionality. BCF can also be used, but until now the format is not made useful within native design application project files. E.g. Revit based projects in RVT format. This issue is however under development and the problems faced using this interoperable format is assumed to have been solved in the matter of months. The best practice for solving conflicts is a direct import or automatic switchback to the native design application, where the model conflict tested was born. This feature is essential for performing efficient clash detection, since it is a method where model problems can quickly be solved without having to manually search for the issued object. This saves time and money for any contractor who which to perform intelligent clash detection. This method will eventually improve communication among employees which also will be naturally reflected in the design quality. This method is especially significant and important during the design and pre-construction phase of a construction project.

BIM models can be linked with time and activity based information from any type of Gant-chart based schedule. This feature is however only possible for applications which enable this functionality, e.g NW12, Vico Office, Synchro among others. Vico Office enables this functionality either through importing a Gant-chart directly to its schedule application or by utilizing its 4D and 5D capabilities. However a direct Gant-chart import is not capable of showing the build-up scenario through 4D simulation. This feature is only available when a Gant-chart is converted to a BIM based LOB schedule. This is achieved by utilizing the LBS, QTO and ITO abilities within the application. This process requires production rate of each activity with assigned resources in from of crew size per activity. Converting Gant-chart to LOB schedule gives furthermore a more solid and well thought schedule, since LOB schedules contains more information than Gant-chart based schedules. The higher information level gives as a result a higher quality schedule and ability to verify whether a schedule is planed correctly. Through LOB scheduling any contractor can check whether there are two activities at the same place/area/zone at the same time. This is evaluated by viewing the activity lines represented for each activity. If two activity lines collide with each other the issue would become a reality when the construction begins. Such issues can be avoided by optimizing the schedule in such way, that it is avoiding two activity lines collides. In some cases the issue of activity lines that collides can be accepted by reviewing what kind of activity is planned to progress at the inspected time. If one of the activities is progressing outside and the other is representing works inside the issue would normally be accepted. Such issues can however be difficult to see on a LOB schedule. A combinations of LOB schedule and 4D simulation helps to show the described issue.

The resulting products of performing 4D simulations of construction activities are well-known to help GC's to get greater project overview, transparency and insight knowledge of upcoming activities. This is because 4D simulations bring any construction project into a virtual world, where the planned construction schedule is tested. This planning tool is especially valuable for any contractor in the design and pre-construction phase, because the 4D model builds the construction project virtually before the real construction begins. A 4D simulation is explicitly capable of showing inaccurate, wrong or erroneous build-up scenarios and even constructability issues. These matters can be solved without any additional construction costs, which eventually also gain any contractor avoiding rework and schedule delays. Subcontractors will also benefit from any 4D simulations, since they will be become more aware of which activities are critical for their upcoming works. Moreover they will have an opportunity to see whether the scheduled and agreed task is accomplishable and buildable given the spatial conditions and time duration given to them.

Chapter 7

Conclusion

7. Conclusion

Recognizing constructability issues early in the design and construction phases can help general contractors to avoid problems that hinder construction operations and increase construction costs.

The results and analysis obtained in; Chapter X, Test 1 – 7, Chapter X; Comparison 1 – 5 and Chapter X; BIM based LOB 4D simulation, proves this statement. The results demonstrate that severe and moderate constructability issues where identified utilizing clash detectives and 4D BIM methods. Some of the identified issues where faced during the construction period since such analysis where not performed during the early stages of the construction project.

The investigated and utilized clash detectives are roughly identical in terms of analyzing discipline models for constructability issues. Each application is capable of identifying clashes by adjusting sets of rules, parameters or by comparing entire discipline models against each other. In terms of interoperability, key features, retail price and support, it is interesting to see that TBS is somewhat a preferable solution for any contractor whom wish to perform clash detection. This is primarily due to the application is capable of meeting all criteria's set within the investigation. However it is important to note that TBS does not support any kind of clash management, which can cause confusion when dealing with different discipline models, especially when several BCF reports have been sent to responsible team members. NW12 contains a system which supports the idea of managing clashes and this feature helps coordination of clashes quite a lot. What is even better is the applications ability to directly switchback to Revit. This enables quick and intelligent way of fixing or modifying issued clashes. SMC supports the BIM methodology the best way, since the application is capable of interoperate with any design software vendor capable of utilizing IFC formats. The BCF format is supported, and what is ever better is its ability to create so-called ITO's.

A great finding within this research was SMC ability to report the BATID information to Revit through ITO. The IFC based BATID information is embedded within Revit as Element ID and is Revit own GUID system.

Clash reports should in any case be reported to responsible team members or other collaborative project partners. The content of the issued clashes need to be fixed and modified upon an agreed schedule. Each application is capable of sharing and mapping clashes, which simplifies cooperation and communications processes involved coordinating the issued conflicts. NW12 is capable of reporting clashes in the form of html, whereas SMC is capable of report in PDF, spreadsheets and BCF. TBS supports only sharing of conflicts in BCF.

The best practice for solving conflicts is a direct import or automatic switchback to the native design application, where the model conflict tested was born. This feature is essential for performing efficient clash detection, since it is a method where model problems can quickly be solved without having to manually search for the issued object. This saves time and money for any contractor who which to perform intelligent clash detection.

BIM models can be linked with time and activity based information from any type of Gant-chart based schedule. Vico Office enables this functionality either through importing a Gant-chart directly to its schedule application or by utilizing its 4D and 5D capabilities. A 4D simulation is only available when a Gant-chart is converted to a BIM based LOB schedule. This is achieved by utilizing the LBS, QTO and ITO abilities within the application. This process requires production rate of each activity with assigned resources in from of crew size per activity.

A 4D simulation is explicitly capable of showing inaccurate, wrong or erroneous build-up scenarios and even constructability issues. These matters can be solved without any additional costs, which eventually also gain any contractor avoiding rework and schedule delays.

Subcontractors can also benefit from any 4D simulations, since they will be become more aware of which activities are critical for their upcoming works. Moreover they will have a change to see whether the scheduled and agreed task is accomplishable and buildable given the spatial conditions and time duration given to them.

8. Perspectivation

Implementation of constructability analysis and methods related to perform such review require investment of competencies, software and education. Implementation requires moreover changes in procedures, company culture and awareness of potential constructability issues both at the corporate and project level. The decision of implementing such review should not be performed on project level, however in the firms overall organizational level. This will for sure affect many of the existing working methods. Initial implementation should firstly be tested for pilot project. The Project Manager and the foremen for the given construction project should learn the BIM ways and implement the BIM goals set for the given project. This crew should also work together in the succeeding construction projects to be able to implement the lesson learned in the previous project. The problem of the current working method will not promote the lesson learned because the team behind the management of construction projects varies from project to project. Why should a Project Manager spend huge amount of time learning the BIM benefits implement the objectives to a given project and explain the procedures to a certain crew assigned to the project, if this is going to be a lost investment for the current crew, because the Project Manager cannot be sure that he/she is going to have same crew on next project?

It should also be noted that it takes time and patience implementing BIM methods to any company. The utilized software does not alone grant to achieve BIM goals and objectives. Many problems will be faced by the design team, solved one by another and learned from project to project.

Another huge problem any design team will face when trying to implement BIM is the fact that there are not many guidelines which help the implementation goals. These guidelines are however being developed, but it is going too slow. In order to implement BIM currently any firm must therefore take small step and set specific target project by project. The lesson learned can subsequently be notes and logged whereas these maybe can serve as guidelines for upcoming projects.

A very important observation learned in this thesis is, that the discipline models needs to be modeled correctly in order to achieve the goals and objectives set for utilizing the models. It does not give any meaning if the models are made for constructability analysis if entire MEP systems are modeled as one big unit. Furthermore it is a necessity to figure out which applications to use for the specific project, since the interoperability of some softwares are not up to date.

The use of BIM models has in the Danish construction market, so far, not been fully utilized as an information carrier in the process of ordering constructions and operations. However the prospects are in return significant, especially when the necessary open standards and software solutions are implemented as daily working practices and when the concept becomes more widely used.

Both small and large contractors would benefit from BIM. Intentions with implementation and the use of BIM will however be very different. It depends on the employees, education, economy, etc., but the movement toward BIM is very hard to avoid if companies will remain competitive.

9. Bibliography

10. List of tables

11. Table of figures

12. Appendix