Jacob Wangara

Quality Management in BIM

Use of Solibri Model Checker and CoBIM Guidlines for BIM Quality Validation.

Helsinki Metropolia University of Applied Sciences

Bachelor of Engineering

Civil Engineering

Bachelor’s Thesis

28/05/2018

Author Title Number of Pages Date	Jacob Wangara Quality Management in BIM. 44 pages + 1 appendix 28 May 2018
Degree	Bachelor of Engineering
Degree Programme	Civil Engineering
Specialisation option	Sustainable Building Engineering
Instructors	Sunil Suwal, Senior Lecturer, Jorma Säteri, Head of Department

The aim of this bachelor's thesis was to introduce the importance of having a flawless BIM for a construction project in the design phase. What guidelines have been set in place for designers to help them produce a BIM with a certain level of standard. The thesis also discussed the main design requirements used in Finland, namely common BIM requirements. For a quality BIM, the model quality needs to be verified and one of the main programmes used for BIM validation Solibri model checker (SMC) was discussed. It was important to find out how designers in Finland use the requirements and how they validate their BIM models using SMC.

For the goal to be achieved, a theoretical text review of BIM, was done and how quality management can be implemented on the model produced by designers, and how to do quality and quantity validation of the same was about. The usage of the requirement and validation of BIM, a user survey was conducted to Solibri customers which would provide important information of how the users interact with the software.

The research results showed that having a quality validation software like Solibri Model Checker, makes correction easier in the early stages of design construction. The study also showed the importance of having quality BIM towards achieving sustainability of structures produced. The research also provided the company with a generic view of how their customers are use their software, possible development areas, where to put more effort in marketing their product, and how well their customers are satisfied with their product. With these results, is the company able to channel their resources in the right direction with the aim of meeting their customer's needs.

Keywords	BIM, Quality assurance, Quantity control, CoBIM, Solibri

Acknowledgement:

First and foremost, I would like to thank GOD for this far HE has brought me in life. It is not by chance to wake up every day, go to school or work and carry about my everyday activities. Praises and honour be to HIM. To my school Metropolia University of Applied Sciences, for giving me the chance to take part in these studies, I pass my gratitude for the opportunity. Thank you.

It would not have been a reality without the help of my supervisors and language teacher. A vote of my sincere gratitude to my immediate supervisor Mr, Sunil Suwal for his advice, words of wisdom and constant follow up throughout the project. He has been supportive and encouraging during my writing of this thesis. Also, to my Head of degree program Mr, Jorma Säteri.

To my work supervisor Mr Jouni Piirainen, lots of gratitude for your positive words and constant encouragement. To my colleagues at work I am thankful for all your brilliant ideas that contributed to the success of my thesis. Having no knowledge of Finnish language, it was not easy to translate the interview questions to Finnish. Thanks to my colleague for helping me with that. It was a great experience exposure and a learning opportunity, gathering the data and interpreting it to an understandable research format throught the writing of this thesis.

My fiancé, family and friends, I'm blessed to have you around. Thank you for your support through all the challenges I have come across, be blessed all.

Jacob Wangara
28/05/2018

List of Abbreviations:

2D	Two Dimensional
3D	Three dimensional
BCF	BIM Collaboration Format
BIM	Building Information Modeling/ Model / Management
CAD	Computer Aided Design
CoBIM	Common BIM
GUID	Globally Unique Identifier
IFC	Industry Foundation Class
ISO	International Organisation for Standardization
ITO	Information Take-Off
MEP	Mechanical Electrical Plumbing
PDCA	Plan-Do-Check-Act
QA	Quality Assurance
QC	Quality Control
SMC	Solibri Model Checker

Contents

1 Introduction

Since BIM (Building Information Modelling) came into the construction industry, it has created a paradigm shift in ways to which construction engineering projects and processes are handled. The use of BIM has broadened in the architecture, engineering and construction (AEC) industry. The implementation of BIM in a project improves on the chances to save cost, ensures delivery of quality work, on time. The technology has enabled the creation of accurate digitalised representation of structures. BIM generates a lot of information which engineers and all participating parties in a project should be able to rely on throughout the whole project. For the information produced during BIM design to be acceptable and trustworthy, it is necessary to validate its correctness. BIM has made the process of validation easier by providing 3D models which can be used by software like Solibri, and errors can be corrected already in the design phase, compared to the older method of using 2D drawings. [1.]

It is also important to have guidelines for how designing and modelling of BIM should be done, although the process might vary according to locations and areas around the globe. The guidelines are there to ensure the creation of quality BIM which contributes to the sustainability of the structures and enhance the efficiency of the delivered product. Having in mind that this structure will be used by humans, the guidelines are set for designers to deliver usable and conducive structures which are accessible, comfortable to live in and to use. This thesis highlights the requirements used mostly in Finland during the design phase of a BIM model.

The project also aims at answering the question “why should design quality be payed attention to?” As more data is fed into the BIM, more errors are also added to the BIM model and these errors could have major consequences later in the project or affect the overall outcome of the project. The cost of fixing an error on site is usually high. To ensure that the errors do not alter the project, tools like Solibri are important to incorporate in construction projects. Solibri model checker (SMC) is a widely used software for flagging the errors of a building design. It also makes documentation of possible fixes possible.

This study focuses on finding out how SMC customers use the software in their projects for BIM validation. The aim of the research survey is to provide Solibri as a company with an overview of how their product is used by the target market, and how the research would contribute towards appropriate measures being taken by the company to contribute to the development and growth of the software to benefit the end user and the growth of the company itself.

2 About BIM

Building information Modelling (BIM) is defined as a digital representation of a physical structure or building [2]. BIM is also defined as new concepts which is highly improved with technology and reduces various forms of waste and inefficiencies in the construction industry [3]. In a single construction project, there are various participating organisations whereby accurate coordination is required for enough information interchange between the participants. Building Information Modelling provides the right platform for this kind of project coordination [2]. The term BIM, constructed in the early 2002, can also represent virtual design, construction and maintenance of structures. BIM as a process loops over virtual designed models that facilitate sharing of information and details to actors in a construction project which makes collaboration easier at different phases, and by various disciplines involved in a project [3].

The term BIM is commonly used by most software developers to show the capabilities of their products. This has, unfortunately, caused a wide range of confusion in understanding what BIM really is [1]. BIM is not a human replacement in construction designs. Humans are still needed with their special skills to create the models since BIM cannot be automatically generated. BIM is just a platform that makes construction design handling much easier using more visually advanced and more accurate representations of the actual structure. BIM definition is usually misunderstood to be computer aided design (CAD). To make it clear, any CAD software can be used, yet the results are not BIM at all. BIM is also misinterpreted as 3D. 3D files are usually modelled geometry using 3D software tools and can only be used for visualisation, but they lack the intelligence of BIM to interpret the objects in the 3D files and how they relate to others [3].

BIM is a fast-growing technology in architecture, engineering, and construction (AEC) industry. With BIM, it is possible to generate one or more digital structural models simultaneously. BIM provides a good platform for various analyses and control of the structure in different design phases compared to the old manual way of doing the same. The technology also provides accurate geometry and information required for construction, fabrication, and quantity analysis all through the construction process [1]. BIM offers an opportunity for owners and end users to be actively involved during the construction process, especially during the design phase which makes it easy to adjust changes and new requirements in BIM rather than doing it in later stages of the project [3].

2.1 Benefits of BIM

BIM brings many advantages in the construction sector. Having a visual representation of the building has made it easy to manage the information needed during the design and construction phase, during the usage and maintenance of the building, in short the whole life cycle of the structure [2]. BIM has made it easy to share huge amounts of 3D data, making integration between different disciplines working on the same project easy compared to the older ways of doing the same as illustrated in figure 1 [4]. Having a visual model has also made it easy for architects to involve the owners and end users during the construction process as mentioned above [2].

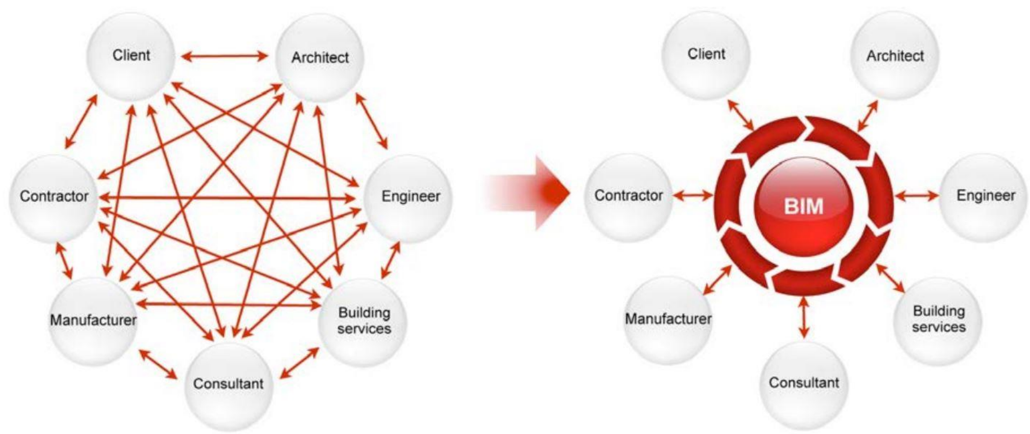


Figure 1. Information sharing change before and after BIM [4].

Architects work have been simplified since the arrival of BIM. This is because they can minimise risks through the visualisation of their design and simulations of the virtual model in later stages of the project. The models can be assessed by a variety of people who have interest in the work being done, which includes government and funding organisations. BIM provides a platform whereby quality assessment, duplication in the model and error detection is possible in early stages before huge losses are incurred during construction. Through quantity analysis BIM, provides clear and accurate cost estimates in early development stages of the project, and contactors can use the BIM for quantity extraction. Improved control over a project is experienced while using BIM, one of the key advantages being proper documentation of decisions made, less time is used while making the project drafts, and finally quality results with less time spent on it. [3.]

For the owners of structures, BIM provides concept, feasibility and design advantages. In early stages of the project, it can be used to determine whether a designed project will be achieved on a given budget or if the design needs to be simplified to be in the budget brackets. Having a pre-designed model gives a better chance for a closer evaluation of the structure to see whether the desired quality and standards are achievable. [1.]

Having a BIM model is more advantageous compared to multiple 2D drawings [3]. BIM ensures the production of accurate 2D floor plans drawings possible throughout the project whenever needed. This ability is handy when there is a need of 2D drawings after changes are made in the design, it takes less time to print the 2D drawings, making the visualisation of the project easy and faster at any stage. Quality BIM gives accurate geometry, and measurements are shown in the file as they would be later in construction. With BIM it is easy to see the relation between building elements, which was not possible during the 2D era of construction designing. Energy efficiency evaluation is easily done by linking a BIM model to an energy analysis tool [1].

To better understand the benefits of BIM, the advantages can be summarised by the principles that set the technology aside from 3D and CAD files. The principles include communication, integration, interoperability, knowledge and certainty. BIM provides communication and collaboration platforms where all project participants can share their work. When it comes to Integration BIM can combine various files for example architectural, structural and mechanical models, in a single BIM file. Having different modelling software's used in a single project, BIM provides interoperability between this software by providing a standard IFC (industrial foundation classes) file that can be opened by most BIM software. BIM as a technology can understand and give information of objects in 3D according to their properties, and quantities during modelling. BIM provides certainty because it includes an actual virtual representation of all components. The above explained principle summarises the capabilities of BIM. [3.]

2.2 Challenges of BIM

A BIM model can consist of a combination of various models from different modelling tools. This means that, when the model is exported from one environment to another and shared between the modelling tools, or when the models are being brought together, a special tool with combining and reading capabilities is needed to ensure that the information in the models remains the same. This may bring about some complexity, errors and waste of time in a project. [2.]

Another issue in the BIM technology is the legality of the model. Who owns the model, fabrication, analysis, accuracy of the model and the data set contained in the model. As more of the construction industry disciplines are getting familiar with BIM, most of them have made BIM a requirement and if possible, BIM should be incorporated in all stages of a structure including construction, maintenance, renovation and life cycle stages.

The use of BIM modelling tools and the manipulation of a BIM model requires some level of knowledge and understanding. This knowledge is essential also to coordinate the various disciplines involved in a project. BIM knowledge requires time and education to get acquainted with the required knowhow on handling and making use of BIM models. If the knowledge is lacking, there might be a break or hitch in communication during the execution of a project. [2.] As illustrated in the figure 2 below, the adoption of BIM as a new way of doing design may be slow at the start but in the long run the technology has even greater gains.

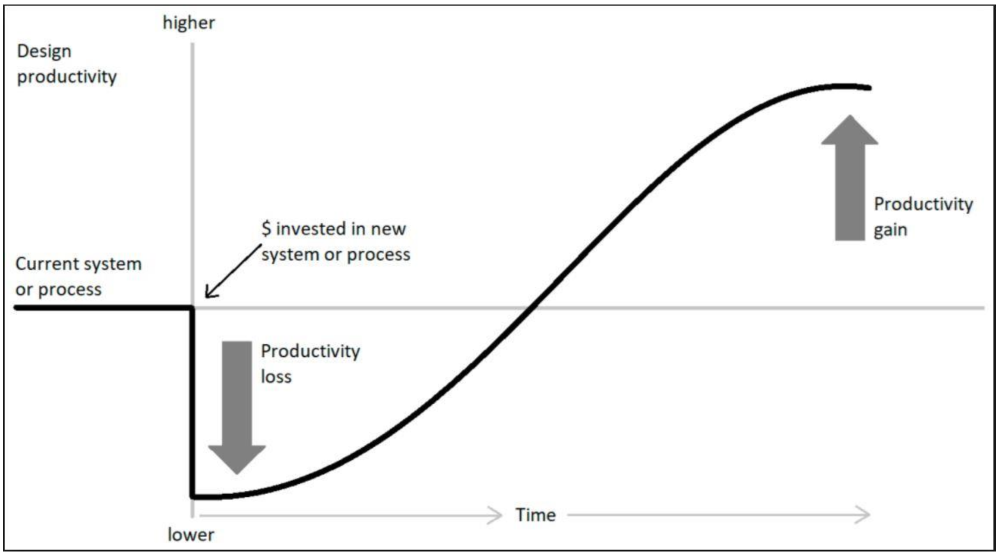


Figure 2. Effect of BIM adoption as a new process [5].

Due to the slow adoption of BIM technology, the spread of the technology has been a challenge. The worldwide use of the technology is important since some companies may have subsidiaries all over the globe and it is important that they are all on the same level of operation. Corporate culture is a leading challenge. People have their comfortable way of doing things. BIM technology may cause them to adapt to new methods of doing things which may raise resistance. Old construction habits, where responsibilities were defined using stakeholders also poses a challenge to BIM technology. Tasks performed by several stakeholders is now being done by architects and designers, but the rules remain unchanged. With BIM, quantities can be acquired automatically from the software's and this instils fear to surveyors on losing their jobs. [6.]

2.3 Quality Analysis and Quality Checking in BIM

There are two principal methods used for assuring quality of BIM that is checking and analysis. Quality assurance (QA) can be defined as a management system used by construction companies to ensure delivery of high quality products to their customers and clients. [7.] The system may contain programs like hiring of qualified professionals, training the employees with the required knowledge, incentives for high performing employees which is usually used as a motivation. Quality control (QC) is different even though in most cases the two terms are often used interchangeably. QC is more of inspecting, checking and confirming that the work or product that is produced meets the set standards or is correct. For correctness determination of information contained in BIM, one must be able to compare the information to some reference or requirements. [7.]

When analysing a BIM model, the quality checking covers the checking of technical integrity of the model, the content of the model as well as the verification of the information contained in the model. The technical integrity of the model is confirmed by checking whether the BIM file from its authoring tool has been produced correctly and whether the model is structurally correct. The verification of the information in the BIM file verifies that in each design phase, the model has corrected design definition contained. Finally, the content of the BIM design and its quality is checked. This can be done by comparing the model components in different stages of design, by clash detection or by checking some specific requirements such as for example fire exits, accessibility etc. There are various applications that can be used to ensure QA and QC for BIM projects. This study primarily focuses on one of such application Solibri Model Checker. [7.]

Quality is one of the main factors when it comes to goods and services delivered. In a construction project, delivering the structure on time, within the budget, guaranteeing the safety of those working on the project, ensuring that the structure works as desired after delivery, are all part of quality. The demand for higher quality structures has been on the rise. It has mainly been influenced by the standards, set internationally by the International Organization for standardisation (ISO). [7.]

Using BIM as in quality management in a construction project provides quality information as it shows the real structure, including quantities like area, height, thickness, material, texture and other properties. Combining various models from different disciplines for viewing provides important details of the building components, quality of the materials used for the elements, and controlled procedures all in a single BIM. Assigning responsibilities can also be done in a clear manner, and they can be included in the 3D model to be viewed by the participating disciplines. This makes communication between the disciplines on issues concerning the project easy, ensuring smooth workflow enabling the achievement of the desired quality. All this communication and interchange of data is aimed at improving the quality of BIM via sharing of files that have been ren through clash checking, correction and documentation. [8.]

Quality management in construction can be achieved by various management methods. One of the possible methods is PDCA (plan-do-check-act). This method is normally used in businesses for the control and continual improvement of processes and products. The PDAC method can support to validate the quality of information in BIM in construction. The first step is to create a plan covering the quality policies, description of products, and standard and regulation has to be analysed. Specific and clear goals must be set for construction specification, where the used materials and methods must fulfil the quality requirements. The second step is the execution of the plan. The third step is where the results of already undertaken activities are assessed for quality achievement. Before the last step, feedback should be gathered from the previous steps so the actions to be taken would be in accordance with the required results. The figure 3 below shows the quality control plan. [8.]

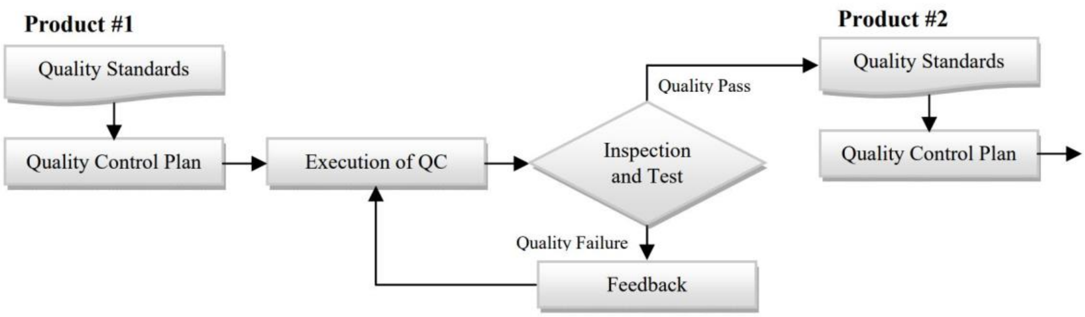


Figure 3. Quality Control Process Flowchart [8].

The process of QA and QC involves checking the following five levels of BIM, the inventory BIM, spatial BIM, building element BIM which includes architectural and structural models, system BIM and finally all the models merged together as merged BIM. Inventory BIM and spatial BIM includes checking that the name and areas of spaces are checked to confirm whether they correspond with the measurements document. Visual inspection of spaces is done, and the most recommended way is to use different colours to represent different categories of spaces. Different colouration makes identification easy. An observation should be made to ensure that spaces do not cross each other. [9.] When checking the building element BIM, the elements should be clearly identifiable. Consistency of information in the BIM, and the naming of building elements is verified. A Check for overlapping elements is also done to avoid inconsistencies when information is taken off. System BIM checks whether there are internal clashes in the MEP system model. The Consistency of naming done during modelling should also be checked. The division of electrical systems according to desired floors is confirmed. Finally, when checking the Merged BIM, all IFC models from various disciplines are brought together to check their compatibility. [9.]

2.4 Importance of Quality Analysis and Quality Checking in BIM

Having a quality model to use in a construction project can save the project participants lots of money and time. This is because it is easier to fix an error of design on a computer rather than bringing the whole wall down or using a hammer on site trying to fix the same issue physically. Quality models help maintaining order in information sharing, increasing the level of safety for those working on site. Having quality models in a project also ensures that the project is delivered on time due to scheduling and that the project is complete within the budget margins. A quality BIM is useful to all parties involved in a construction project. Even during the occupancy of the building, facility managers can use the BIM model to do their routine checks and use it in the life cycle analysis of the building. [10.]

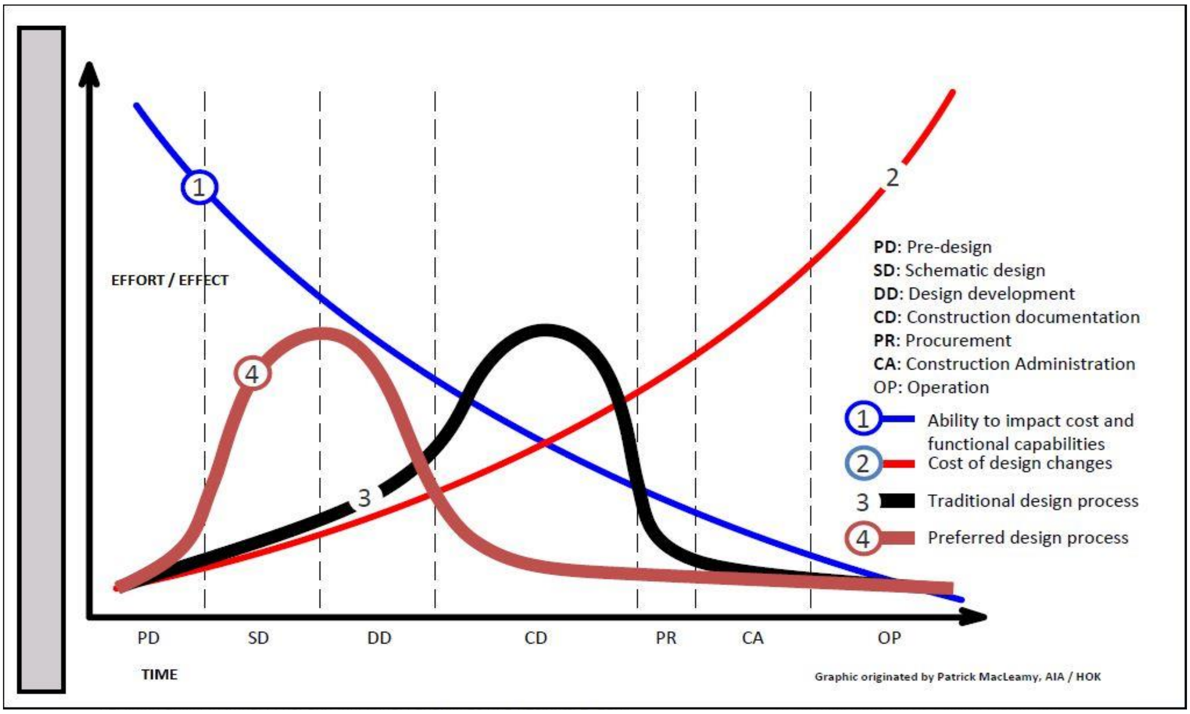


Figure 4: Macleamy Curve [11].

The Macleamy curve shown in figure 4, shows the ability of BIM to impact cost and functional capabilities in a design process. The curve illustrates the fact that there is a greater flexibility of changes during the design phase with minimal cost if implemented in the early stages of design using BIM. If changes are done during construction documentation, it would cost less with little effort when BIM is used compared to the traditional design process. The curve shows a significant difference when comparing the vertical distances between the two curves. With a BIM based process, designers have the chance to invest more time and efforts towards designing better products compares to the traditional processes where it takes more time and effort to prepare construction documents according to the curve. [11.]

There are many advantages with a quality model. A Smooth workflow between different designing teams is one of them. Project designs are delivered on time. It costs less to produce a quality designed model since not so many hours are spent on correcting the model. Apart from a smooth transition within the design team, having a quality model on site ensures that things are put in place and constructed with ease. A quality BIM reduces waste produced during correction of flaws on site compared to correction of the model on a computer.

3 Common BIM Requirements

In Finland, the use of BIM dates back to the 1980’s. It was the efforts of the Funding Agency for Technology and innovation (Tekes) which played a major role driving Finland in the international development and standardisation of BIM integration. The role of BIM was recognised and used to enhance productivity, processes and quality in design and construction of buildings. This led to an increased demand of BIM encouraging both the public and private organisations to develop some BIM guidelines for themselves. As the pressure built up for the industry to update their guidelines, Common National Requirements for Building Information Modelling (CoBIM) were set up. There are 13 documents in English and 14 in Finnish that can be used as guides in BIM based projects. The standards were put together by 10 drafting organisations and 24 funding organisations. The CoBIM guidelines are hosted and monitored by the BuildingSMART Finland. [12.]

After the requirements were set, they were approved by the executive group members of the participating project parties. The requirements are set according to different fields of construction involved and the various phases of design in place. This is to ensure that in all stages of design, there is a synchronised flow of details and information without any hindrance or misunderstanding between the involved parties. With the standards in place and observed, less time is spent on following what has been changed and where. This also provides smooth interchange of the design in a single form of document that can be universally used by most design software. [13.]

CoBIM provides BIM requirements for a construction project, targeting both new construction and renovation, as well as the use and facility management of buildings. The minimum requirements for modelling and the information contents of the model are included in the requirements. The minimum requirements are intended to be observed in all construction projects, whereby the use of the requirements is advantageous. As of 2016, 99% of BIM projects in Finland were estimated to use CoBIM. [12.]

CoBIM provides standards or current qualities to be achieved throughout the design stages of a structure. In different stages of design, the designers of all involved participating parties in the project find it necessary to be more accurate and give more details on what was modelled and how the modelling is done. The CoBIM requirements are based on information collected from different owners and organisations, some of the requirements had been used previously by designers, and other requirements ideas were gathered from user experience. [13.]

3.1 General Requirements

There are general definitions that determines which types of modelling must be pre-modelled in a specific way before the other phases are set. In every construction project, there must be a site where the structure is to be placed. The requirements state that measurements must be taken with adequate accuracy. The requirements state that the site should at least have a 3D surface model. It is also important to include various surroundings like mountains, rivers, drainage systems and nearby cables and nearby structures to provide clear information to the next designer on the actual look of the site and its surroundings. [14.]

Measurements, information gathered on the site, old plan drawings and other documentation, are used as supplemental information when inventories are modelled. This also requires the original documents to be included in the specification of BIM. BIM specification should also include the layer hierarchy system used in the inventory. If the hierarchy system is not used, a calibrated logical way should be done considering building elements when the authoring tool of the model does not have layers. In most modelling applications, each building element has its own intended modelling tool. If for some reason like a difference in geometry, an element is not modelled with its intended tool, the principal used in the modelling of the element should also be documented in the BIM specification. This is critical since the model is likely to be used in different modelling applications during various design phases. The information in the transferred model should always be constant and correct. [14.]

Modelled building elements need to be classified. This helps ensuring that the levels and the inventory models are accurate and in detailed. The methods used when making the classification should also be documented in the BIM classification. It is also important to note that the coordinate system used in the model is project defined to ensure the datum is located near the building origin. If there are negative coordinates involved, it may cause problems during model creation. A relation is made between the coordinate system and the system used in the model by using the X and Y coordinates which have to be stated in the documentation. [14.]

3.2 Architectural Requirements

The architectural design in the BIM model contains the main tasks of the architectural design, such as sketches, and plan drawings. In all BIM based projects, an architectural model is a must in all phases of design. The model forms the basis of all other models and includes various analyses and simulations. It is therefore crucial that the architectural model is technically correct and accurate thought the project. The model should contain specific requirements for the architects, the information should be consistent, but the requirements are independent of software. The specifications might vary according to the companies handling the projects and the owners of the projects. [15.]

There are three levels of accuracy required in an architectural model as shown in table1.

Table 1. Architectural level of Accuracy [15].

Level of Accuracy	Level of modelling
1	correct geometry and position according to requirements, names and description given to building parts
2	In addition to Level 1, the model should have properties to provide the quantities and essential information for cost estimates.
3	Levels 1 and 2, information needed by contractors should be available for example dimensions of parts, type,decibel requirements.

The modelling principal in architectural design is the geometry, and the level of information in the model is enriched as the design progresses. This is because in every different stage there are some specific design tasks to be done. As mentioned above in this document, the modelling of elements with their corresponding tools is encouraged and if that is not done, it should be well documented for consistency of information. [15.]

Architects usually determine the coordinate system to be used. They usually set it so that the model is on the positive side of the X Y axes and near the origin of the drawing area to avoid problems during modelling. The Z axis in the model usually represents the real height of the building. If for some reason the coordinate system in the model is not properly set, whereby the ratio of the distance to origin are too high, this may cause inaccuracies which in turn causes issues during the construction phase. According to the requirements, the architectural model is to have the correct geometry, and the positioning of components should be done correctly. The model should also be detailed with the component properties which can be used during quantity estimations. [15.]

Once the system of coordinates is selected and agreed upon, the reference materials e.g. inventory models must be changed to the chosen coordinate system. After the coordinate system has been selected, it is tested by different design disciplines. A simple model is designed by each discipline and interchanged, all models from various disciplines are combined to see whether they have the same coordinate origin. In addition, it is important to ensure that the XY position and the 2D drawings produced from the models match the building information modelling. If all the required tests are passed according to the sketch, the modelling is done. [15.]

The following parts of a model have been picked as an example of what is to be modelled, what the level of accuracy should be and what the components should contain when the guidelines in the architectural discipline are followed.

Space Modelling

Although not tangible or solid, a space is seen as a three-dimensional object enclosed by the surrounding elements walls, floor and ceiling. In modelling of a space, the zone or space tool of the designing software is used. Spaces usually have a relation to their surrounding elements. If relation changes when an element elevation is increased or reduced, the change has to be documented since it affects the space relation. The spaces must be next to other spaces and should not cross. [15.]

A space is supposed to be measured from the surface of the floor below to the bottom of the slab above and from the surrounding surfaces of walls to those of other walls. If this is not possible and the space measurements cannot be taken from floor to ceiling, at least the volume of the same space should exact. It is often wise to use tools that generate space automatically from the surrounding elements since it makes it easier and more accurate in tasks where model simulation is involved. Slicing of spaces is discouraged to avoid complications when the space is used for other related purposes. [15.]

When a space or zone tool is used modelling spaces, areas and volumes are calculated automatically. It is stated in the building requirements, that the area and volume of the modelled space should include all the components in the space area. As mentioned above, the space geometry defines the volumes and the gross areas of the structure. If it is not possible to take measurements from the top of the floor to the bottom of the ceiling, the method used during modelling should be well documented since this information is needed during quantity and cost estimations. [15.] The Labelling of spaces should also be done. A room is given a space id and use. This information if transferred unaltered to other applications since the space has the same use all the time. The requirements state that the construction spaces are named according to the standards, so that the use of spaces is identifiable. [16.]

Walls

Walls can be bearing walls, exterior walls, interior walls or partition walls. Exterior walls are modelled so that they touch the floor beneath and the bottom of the slab above. In construction projects with special needs, where a wall is being modelled, the wall can be split to include subcomponents in the wall. During design modelling, the architect is required to explicitly differentiate between the interior walls and the exterior walls not to cause problems for other disciplines that run 3D simulations. If the modelling is accurately done without any gaps between the walls, the relation between the walls, spaces and other elements should be automatically set by the designing software. [15.]

For partition walls, correct thickness and height is required. Exterior walls should be modelled according to their respective floors, they should also include the substructures of the structure. The guidelines state that each wall should contain a name and ID for example in walls that need fire ratting to have a unique identifier which separates fire walls from other walls. Facade and glass walls should be modelled first. If the glass surfaces are modelled using a curtain wall tool, it is documented to ensure that the IFC writing function supports the tool used. The guideline checklist ensures that the accuracy of the wall is the required minimum and the wall has its type, maximum gross area, length and width defined. [16.]

Doors and Windows

The type of each door and window must be included in the information sent to sharing software. Apart from modelling the doors and windows, corresponding tools can also be used to model openings in various programmes, but this should be well documented so that the other sharing programmes do not to interpret the opening as a regular door or window. In case a curtain wall is made up of only windows and doors, a host wall should be pre-modelled, and the windows and doors added later. If modelling is done directly using the curtain wall tool, the documentation should be properly done to avoid conflicting information during data transfer to other programmes [14]. The modelling of windows and doors should be done in a way that it gives the right location, size, type information and marks the ID should. Fittings for windows and doors with a list of details and they should be related to their main components. [16.]

Slabs

Slab tool in the modelling software should be used to create the foundation, floor or roof slabs. If for some reason the authoring software cannot model slabs using the slab tool, a general model tool can be used to replace the slab, but the use and the identity of the slab should be well presented by using names or layers. For proper quality and quantity assessment, slabs should be so that they do not collide or overlap with the exterior walls [15]. Slabs should have their name defined e.g., floor or roof, ID, elevation, area and thickness should be given for quantities [16].

Beams and Columns

An appropriate modelling tool should be used to model the beams and columns in a model. If some beams or columns have a complex geometry the modelling tool cannot provide, it is advised that a general model tool can be used, but the purpose and ID of the beams and columns should be well presented, with a name or level. In the architectural design, beams and columns are not a priority, only the measurements and their relation to other elements which would be confirmed in the structural design to avoid design errors is considered important. [15.]

Columns and beams should be modelled with their dimensions and areas. They should be referenced to individual floors from the surface of the slab beneath to the top of the slab above. Wall related columns and beams can cut through the wall in the right positions. This component should be given the type and ID unique to each category of either beams or columns. [16.]

Stairs

Stairs are to be modelled individually according to each floor. In certain kinds of stairs, extra elements may be included like landings and railings. In most modelling software, stairs are quite a challenge since they can cause inaccuracies in the model [15]. Stair ID, name and type should always be given [16].

3.3 Structural Requirements

In this section the article will be covering the content and information expected in a structural BIM model from a structural designer. The use of BIM model targets smooth flow of information to all the parties involved in a construction project. It is set clear that when the structural model is exported, it should only have structural components even if other discipline models were used for reference.

Compared to the architectural model, the structural model has four levels of accuracy as listed in the table 2 below.

Table 2. Structural BIM level of accuracy [17].

Level of Accuracy	Modelling accuracy level
1	Geometry and location should be correctly modelled
2	Additional to level 1, structural elements are created in a way that the model can be used for basic quantities
3	Level 1 and 2, concrete elements and cast in place components. Steel structures modelled as assemblies, similar to concrete elements (containing composite columns and reinforcing.)
4	Level 1-3, All piling specification shall be included in the model and piles are modelled as build

The load bearing and non-bearing structures in models, whose size and location affects other designing disciplines are designed by the structural engineers in the structural model. The structural model should be clear and correct in every detail. [18.]

A task allocation list is used for structural type definition in every project. For the structures to be included in the BIM model, they are also to be included in the 2D print which the architect also uses. These 2D drawings should be available all through the project for various uses like the ones on site and for energy assessments. The storeys and sections of a structural model are done with the compiled coordinates mentioned above. The details defined in the storeys and sections in the structural model, should be clearly defined to provide the involved parties with details when the information is shared between various software. [18.]

In most modelling programmes, components are given unique identification numbers (GUID). The GUID should remain the same if corrections are done on the model, all the way until the installation of the component on site. All components in the model should, however, be named and numbered in a logical way as agreed upon with the owners and other participating parties in the project. The numbering and labelling should be available to all parties in the project in order to provide details of the model. [18.]

Each component in a structural model, must include certain pieces of information. They must have name, profile, information about which floor they belong to, their material, a logo, information about their status, their elevations, coordinates, and measurements such as area length and volume. This information must be included in the exported IFC file since all BIM software understand it. [17.]

3.4 Mechanical, Electrical & Plumbing Requirements

The necessary model requirements for the MEP (Mechanical, Electrical and Plumbing) models is that the model should only contain the MEP components. No other discipline models should be used for reference. The MEP designer provides a ‘void provision’ model to the structural engineer before the structural design is complete. It provides a model showing reserved spaces or areas belonging to service rooms or machinery locations for example. This minimises unnecessary collision errors in the quality check. MEP modelling is divided in schematic design and detailed design. In schematic design, the

MEP components are roughly done to provide important details to other designing disciplines in the same project. In the detailed design, the whole model of the building is designed in full details and functionality. [19.]

The MEP model just like all other models, provide details about how the contents were modelled, and what software and version were used for designing. The not modelled components like ventilation machinery, heat radiators, heat distribution centres, sockets, switches and pump are also to be specified. There are two levels of specific requirements that have to be met by the MEP design, based on the form of documentation provided along with the MEP design. They are document -based MEP and BIM-based MEP. [19.]

The Document-based level provides documentation of properties such as indoor air quality, electrical and technical failure protection, lighting and equipment standards. The designer of the MEP model includes these requirements in the pilot BIM, provided by the architects. This enables all designers, clients and end users of the structure to simulate the design functionality before the real structure is set up. The BIM-based level links the information to room object as part of the IFC export. This linking of object to spaces provides a property set. An IFC property set may contain information like airflow per square metre, relative humidity, ambience of the space or room, just to give few examples. [19.]

During the modelling stages, the MEP engineers must also consider fluid dynamics because some of the models include separate parts which are actually a part of a system. The engineer has to ensure that the whole system is functional as one and all that links in the different stories are well connected for consistent fluid mechanics. [19.]

4 Case Study

The BIM files is extremely complicated, and it is not possible to ensure its correctness without software assistance, one of the widely used BIM validation software is solibri model checker (SMC). An outline of its capabilities and functionalities are illustrated below.

4.1 Solibri Model Checker.

Solibri Model Checker (SMC) is software that assesses BIM models to check their integrity and reliability, quality and physical security. The software makes the process of quality analysis and quality control easy and fast. Running a building through SMC can be compared to taking an X-ray of the building before construction and thereby exposing hidden flaws and weaknesses in the design. SMC picks out the components and checks whether the BIM model complies with the building codes and organisation practices. [20.]

SMC is the leading software in quality assurance and control, as well as quantity analysis of BIM models. According to Solibri’s website, Solibri provides tools for BIM validation, design review and analysis, coordination during design process, and code checking. Solibri checks technical integrity of a BIM model, verifies the information in the BIM file, and runs checking and clash detection. In addition, it can be used for information take-off purposes. Solibri focuses its attention on quality assurance and quantities. Solibri uses a special set of rules to check the BIM models in various ways, uses innovative ways to validate data in the models and creates checking results according to the rules used during checking. [21.]

Solibri can also be used for visualisation or visual checking of a BIM file. Solibri provides a proper visualisation platform where all components of the BIM file can be visualised in their full details as modelled in the authoring software. Solibri is also used for communication between project participants. When problems are detected and collected, a slide show presentation can be made, and shared and various disciplines may inform the BIM coordinator about matters that need correction. [20.]

A general overview of how quality analysis and quality checking is performed using SMC is represented in the figure 5.

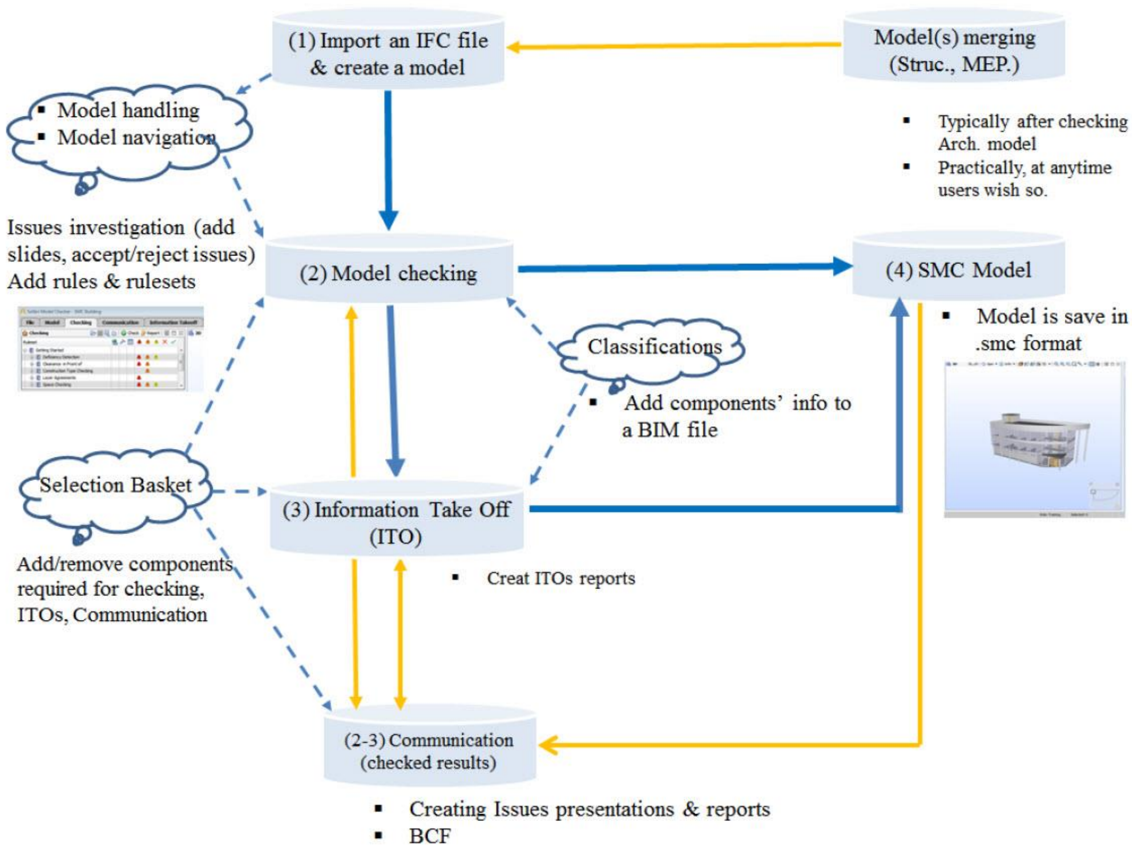


Figure 5. Quality Analysis and Quality Checking using Solibri Model Checker [20].

The user interface of Solibri Model Checker provides several visualisation tools used at any stage of QA and QC of a BIM file. Below are the most common layers used during visual checking of BIM in SMC are introduced.

4.1.1 File Layout

When launching the application, the user logs in with his or her registered credentials. On the software, the file layout is the first to be displayed as shown in figure 6. On this layout, the user can see all the recently opened files, open a model, update and save a model, exit the software, view the roles, go to the Solibri solution centre, which is an online account web page, get help materials, and use the ruleset manager for rules modification.

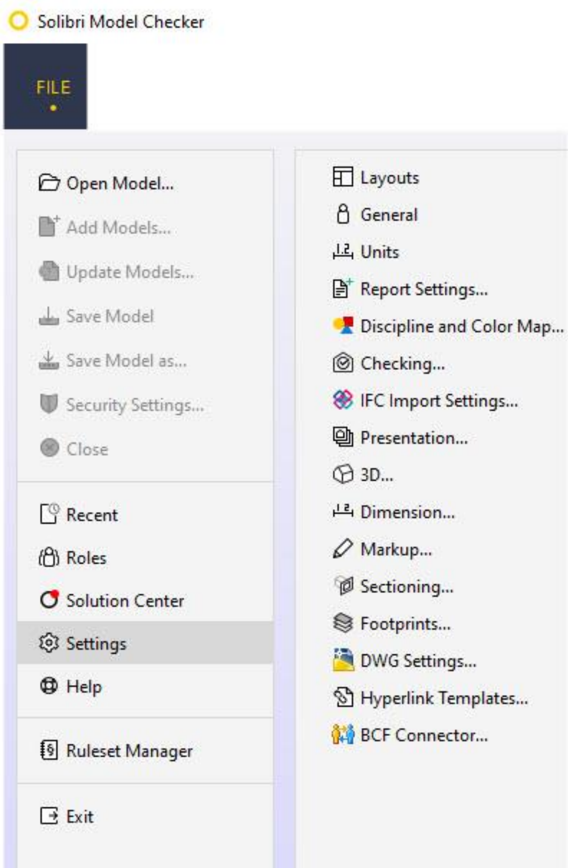


Figure 6. File layout as it is displayed in Solibri Model Checker.

If the user wants to fine tune the settings preference of the software in general, it can be done in the file layout. There are changeable settings for example for Layouts and how the software displays the user interface, to units to be used in the software during measurements, for report settings which are used in communication and take-off reporting, for checking and for what to display in the checking results, for 3D settings and for how BIM models should be displayed in SMC, for mark-up settings, sectioning and so on. [20.]

4.1.2 Model Layout

In model layout, the user can choose the model he or she wants to work on. This layout displays the BIM model on the 3D window in SMC. Here, the model can be visualised according to the user's preferences. Most of visualisation is done on this layout where the user can use tools like pan, zoom, set the 3D layout to walk mode, and use the selection basket to set what to see and not to see in the 3D. Tools that display grid lines, zoom to object, paint, show and hide components that the user would like to work with are provided on this layout. When the user clicks any component on the model, an info dialogue box pops up showing the details included during modelling of the selected component or element from the authoring software, which provides the user with the ability to visualise embedded information in BIM. The tools are illustrated in figure 7 below.

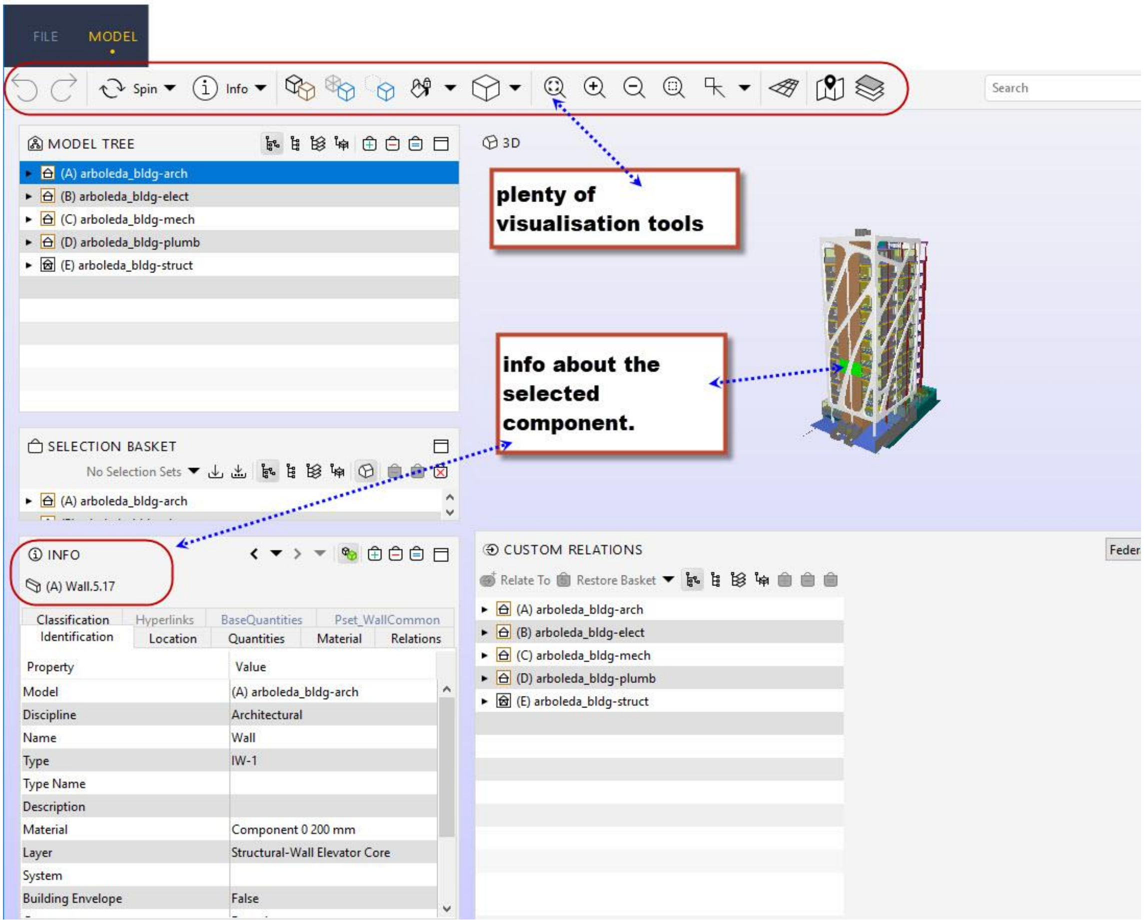


Figure 7. The display in the model layout of SMC.

The checking layout provides the user with the tools and rulesets which can be parameterise and used to run checking and clash detections.

4.1.3 Checking Layout

Contractors show clash detection between models from different disciplines as one of the most important uses of BIM technology. How project participants would bring a high level of accuracy in BIM models and the possibility of using multiple models in one platform in a single file was among the new capabilities brought by BIM to the construction industry. This would set BIM models apart from 2D drawings. BIM technology allows the project actors to run all models against each other to see how much interference there is in the design. The technology allows anything to be tested against specific components, and objects and data are collected. As the testing is conducted, clashes reduced, and the range of components is tested. The results show problems that are to be resolved either before construction begins, or even later during the construction process. SMC provides an easy platform for collection, distribution and viewing of the data made for reporting and communications between disciplines. [22.]

When checking a BIM model with SMC the user can load either one or several IFC files from different designing disciplines. For quality validation, the user must to select a specific role and ruleset to match the chosen form of checking as shown in figure 8. Different users may have different preferences regarding the rules to use depending on what results they expect. A pop-up dialogue box opens in the checking layout where these roles and rulesets are added to SMC.

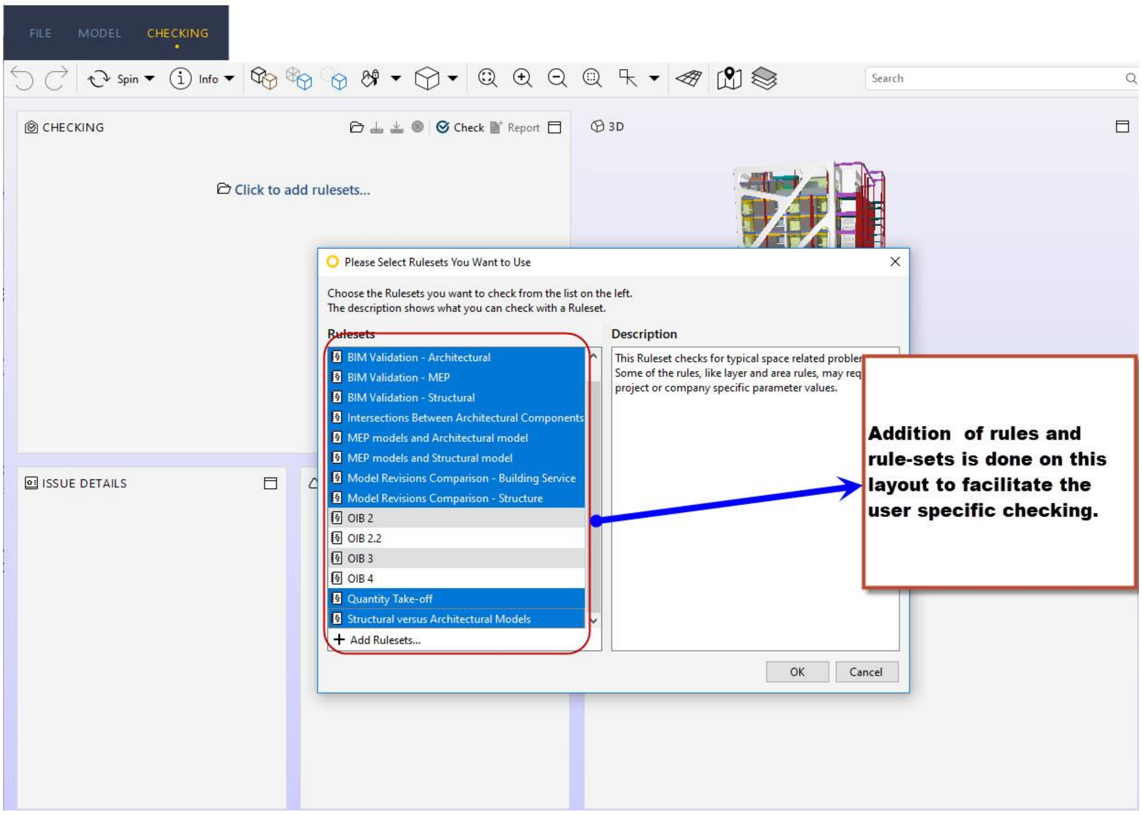


Figure 8. Rule selection for checking in SMC.

Once the rules are selected and parameters set, the checking process is executed in a single click. The software then runs the rules against the BIM file, and if it encounters a flaw of any kind, the software creates a conflict result. The detected conflicts are flagged with differently coloured triangles showing the severity of the issue as critical, moderate or less critical as shown in figure 9. The colour coding helps the user to select which issues to handle first.

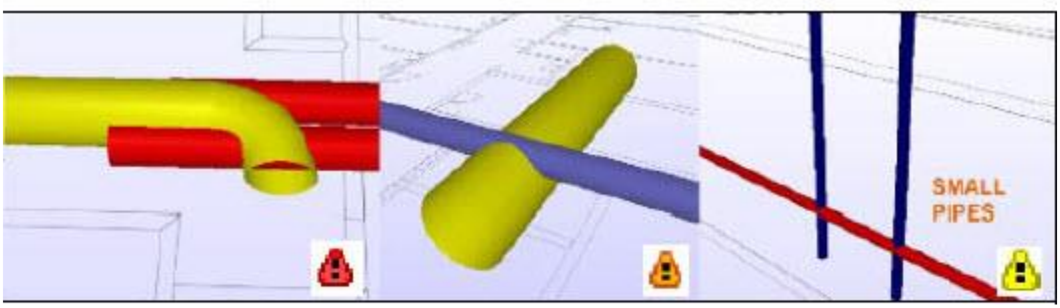


Figure 9. Issue severity as shown in Solibri Model Checker [23].

With the rules as its brain, Solibri Model Checker reasons the difficulty of fixing some of these collisions. As shown in figure 9 above, it is easier to fix problems with small pipes on site hence it is identified as a clash of low severity, compared with the case of big and several pipes colliding at once. After checking has been done on a BIM file, SMC displays the results as shown in figure 10.

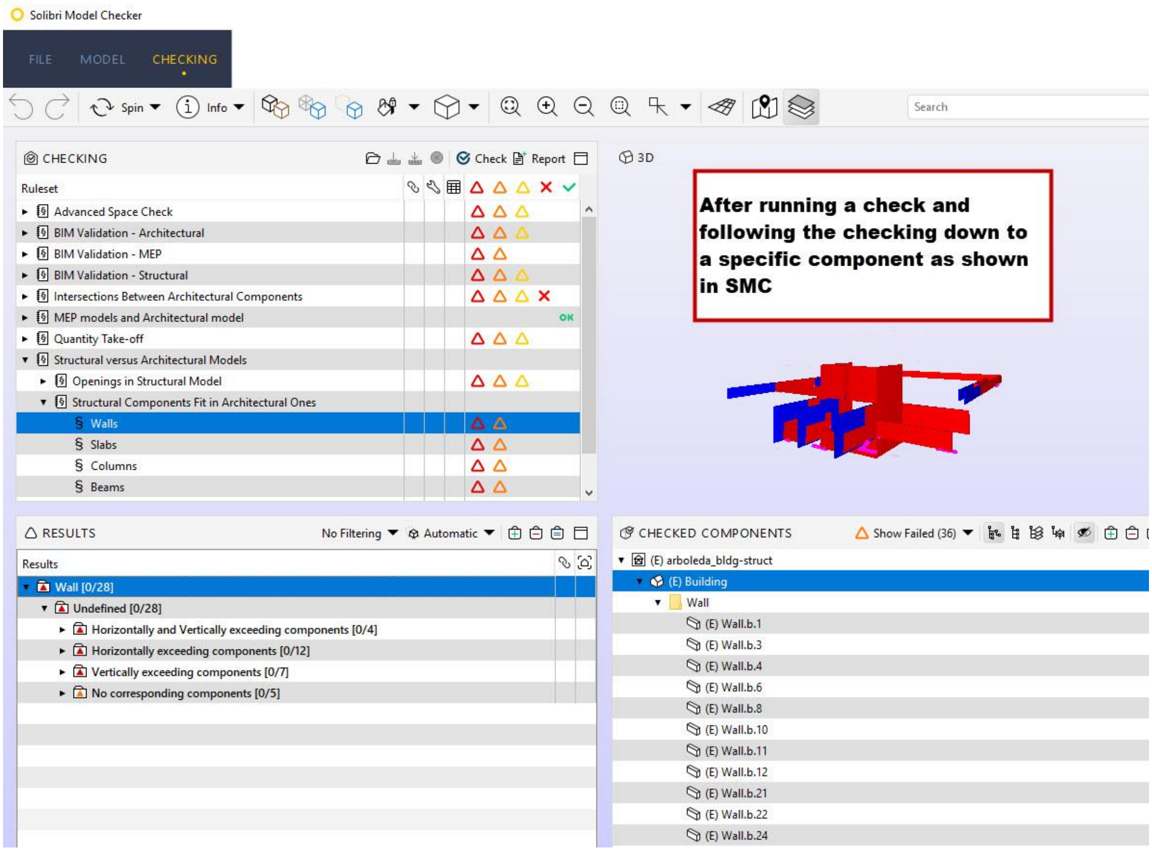


Figure 10. Checking results in SMC.

The checking results are listed against the rule used so it is easy to analyse the source of the problem. The user is then required to go through the flagged issues and document them.

4.1.4 Communication Layout

Various discipline involved in a construction process produce different models which are later combined and assessed in a single model. This is made possible by sharing a single format file IFC unique to BIM models. An IFC file is a neutral platform for object-based file format containing data in models. The IFC platform is registered and certified as an ISO standard for data exchange for BIM information. Most modeling programmes are able to export models as an IFC file which can be shared with other BIM programmes. For design coordination to flow smoothly, project members need a way to communicate which Solibri model checker provides. After the checking has been done, the user can start compiling the issues in a presentation by making slides of individual or a group of issues as shown in figure 11. This is usually done in the checking layout of SMC when assessing the results. By clicking on an issue rule, a drop-down menu opens in SMC showing the involved components in the issue results.

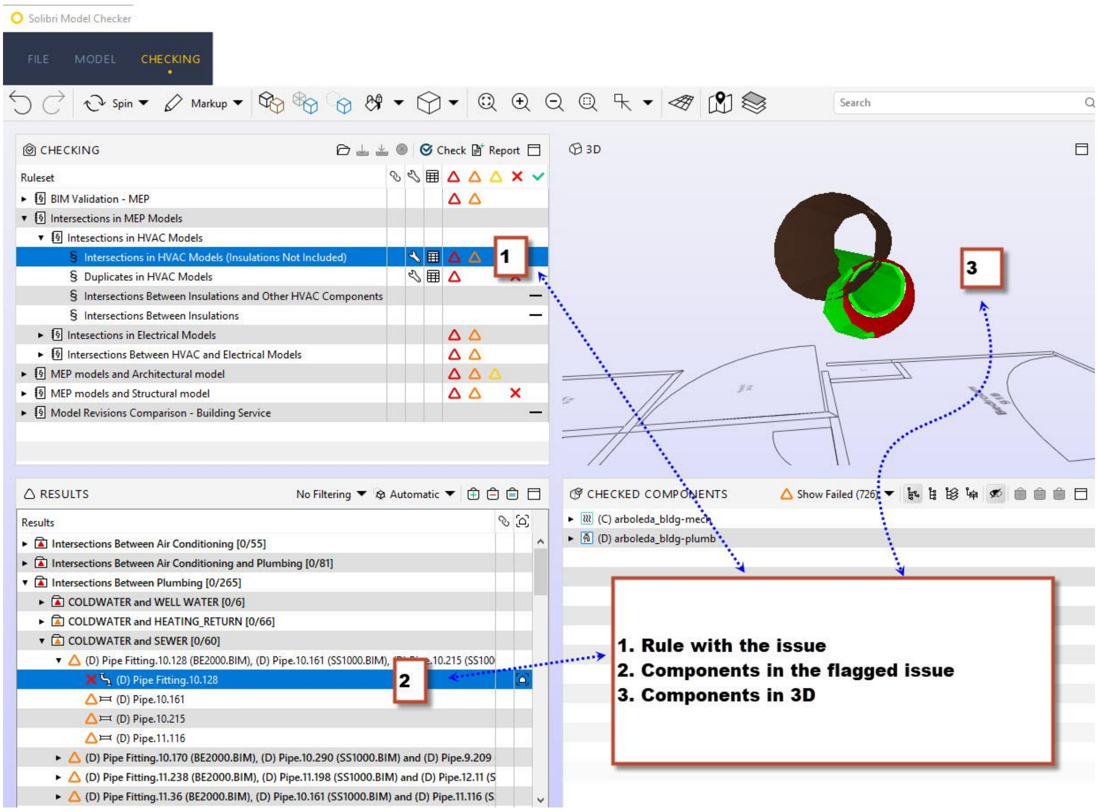


Figure 11. Issue viewing in SMC.

While still assessing the problem, the user can right click on the result and add a slide of the created problem to the presentation as shown in figure 12.

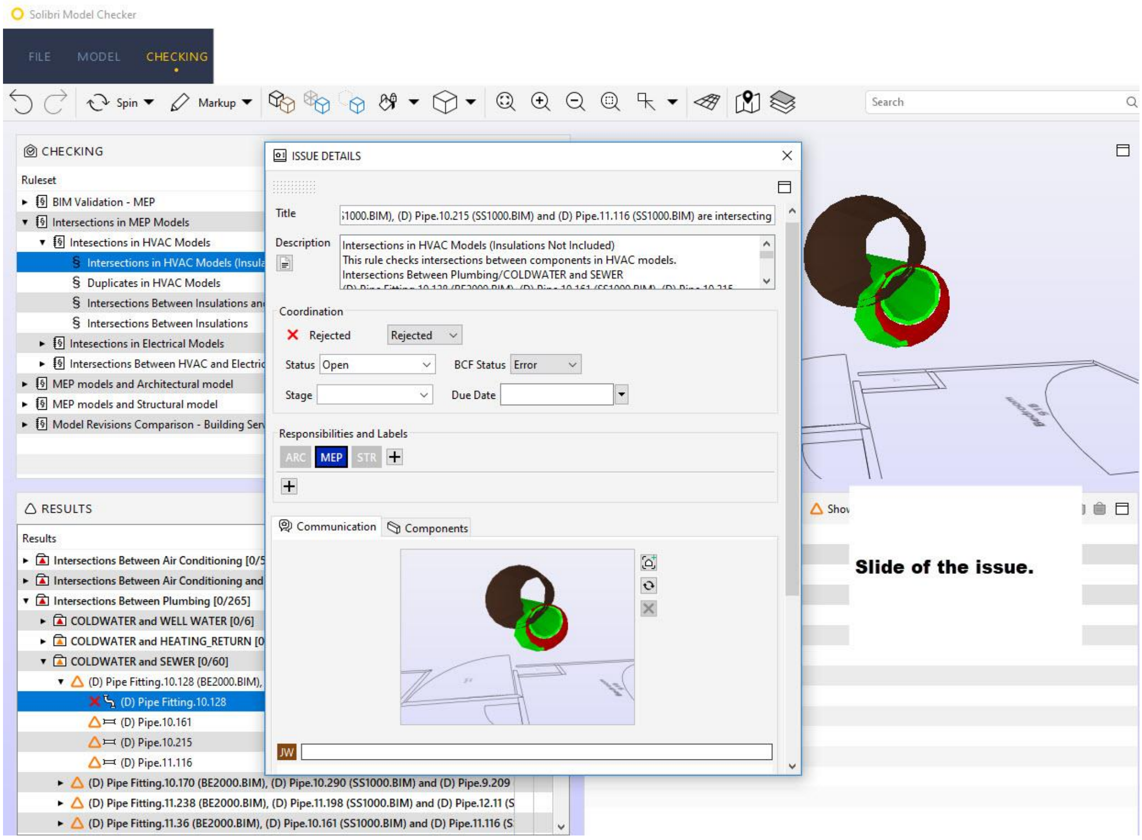


Figure 12. Slides for communication in SMC.

After the slides have been compiled and collected, a presentation is made. The user can switch to the communication tab and add a presentation about the checking results as a new presentation and give it a name. The presentation can be viewed as a slide show using SMC, as shown in figure 13.

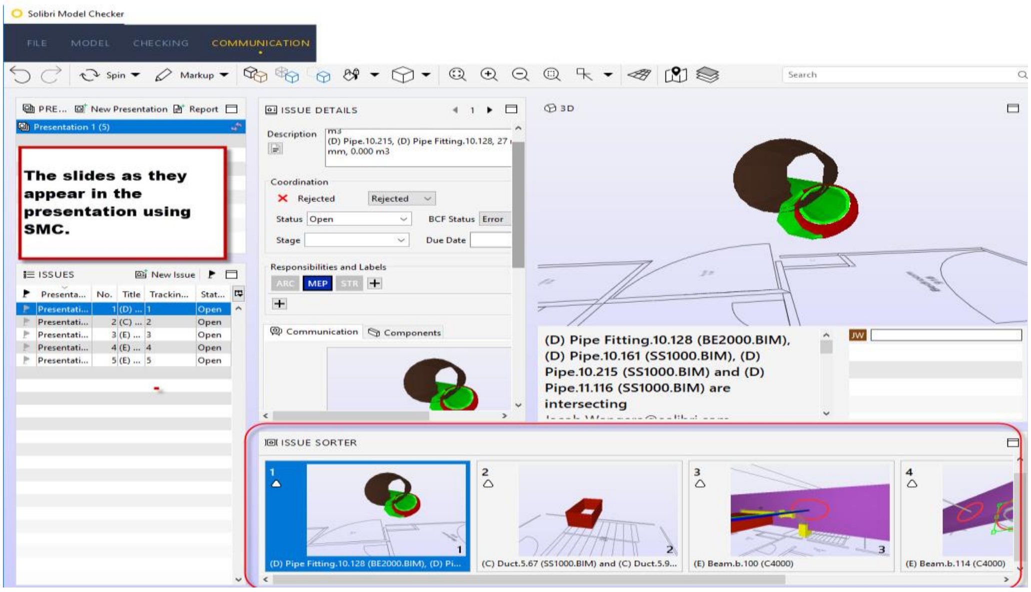


Figure 13. Slides in SMC during a presentation.

The presentation can then be saved as a BIM collaboration Format (BCF) file, exported from SMC. A BCF file is an open file XML format “BCFXML” which enables communication involved in BIM processes. BCF came about because of difficulties in communication between project members where bulk models used to be shared, prior to BCF. To simplify this sharing process, Solibri and Tekla developed an XML schema and proposed it to buildingSMART in 2010. The schema went through scrutiny and development, which lead to buildingSMART adopting it in 2014 after intense public review. Apart from BCF, SMC can also export other sharing files in Excel, PDF or RTF formats as shown in figure 14. The created reports are shared and used for communication. Once a user receives the compiled slides as BCF. The BCF can then be opened using SMC, and comments added on the slides or to fix the faulty or clashing components assigned to them. Fixing detected problems is done with the modelling software from where the original IFC file was obtained.

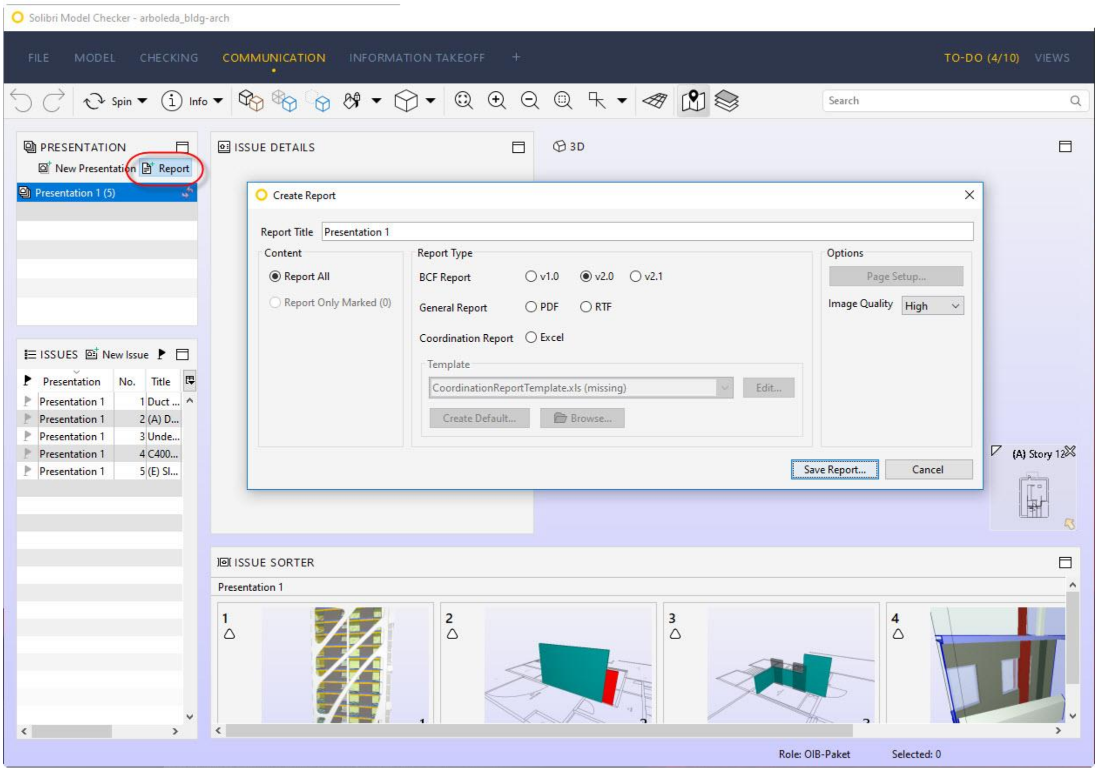


Figure 14. Possible export files in SMC.

In a construction project, there are various players involved. They all need to keep constant communication between them. An example of such communication with a BIM coordinator involved is shown in figure 15.

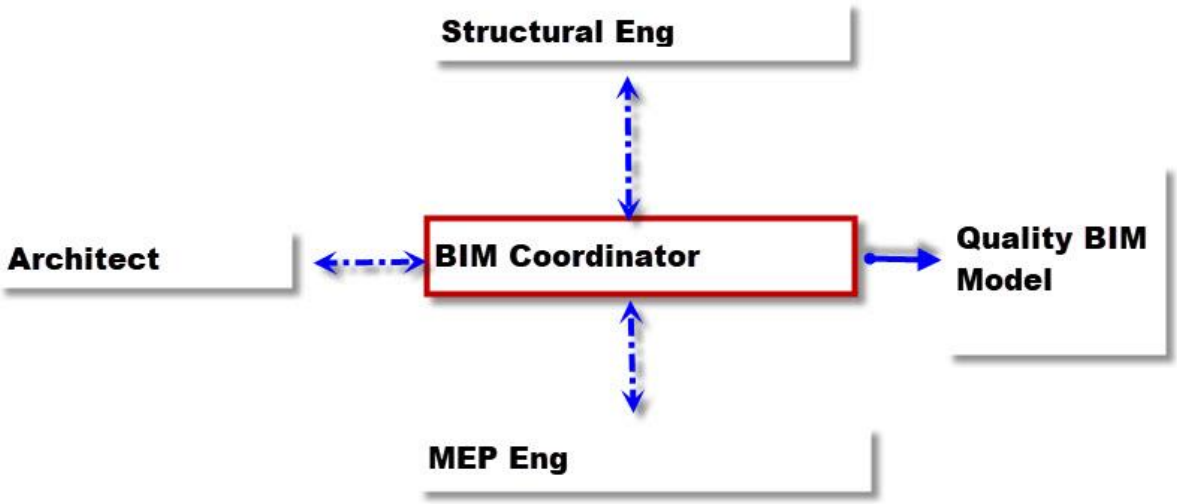


Figure 15. Communication in a design team with a BIM coordinator involved.

4.1.5 Information Take-off and Quantity Take-off.

In general, a BIM model contains hierarchical information of all components down to the objects and parts contained in the model. This means some things are more difficult to see than others when conducting visual checking. Contractors working with the materials to be used on the building, need to know the specific number of components in the model and, therefore, information take-off is essential. SMC provides the user with the ability to compile, organise, visualise and make reports information in an instant. The information may range from area calculations, volumes, number of components and so on depending on the user's requirements. [24.]

When the user navigates to the information take-off tab on SMC, an information take-off (ITO) definition must be set. The setting involves choosing of the discipline of the model they want to work with during information take-off, and what components and information are of interest to the user as illustrated using figure 16.

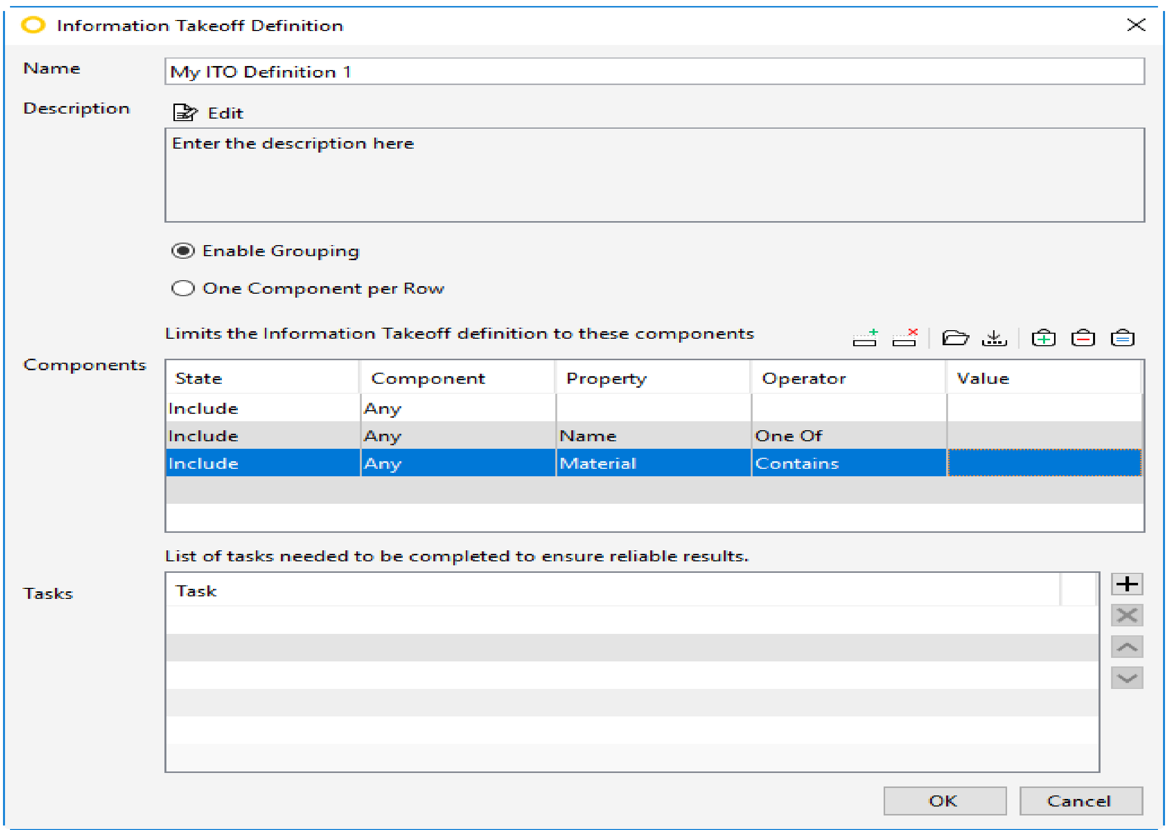
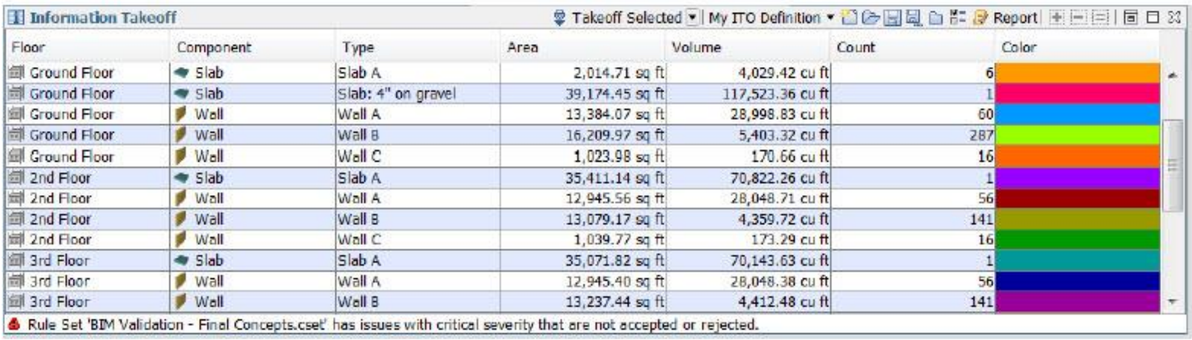


Figure 16. Information Take-off definition dialogue box in SMC.

After the ITO definition is set, the user arranges how the information should be displayed when the ITO is reported (e.g. by floors, by space or by system). Different colours are used to distinguish between components (e.g. different wall types.) as shown in figure 17.


Information Takeoff   Takeoff Selected | My ITO Definition   Report

Floor	Component	Type	Area	Volume	Count	Color
Ground Floor	Slab	Slab A	2,014.71 sq ft	4,029.42 cu ft	6	
Ground Floor	Slab	Slab: 4" on gravel	39,174.45 sq ft	117,523.36 cu ft	1	
Ground Floor	Wall	Wall A	13,384.07 sq ft	28,998.83 cu ft	60	
Ground Floor	Wall	Wall B	16,209.97 sq ft	5,403.32 cu ft	287	
Ground Floor	Wall	Wall C	1,023.98 sq ft	170.66 cu ft	16	
2nd Floor	Slab	Slab A	35,411.14 sq ft	70,822.26 cu ft	1	
2nd Floor	Wall	Wall A	12,945.56 sq ft	28,048.71 cu ft	56	
2nd Floor	Wall	Wall B	13,079.17 sq ft	4,359.72 cu ft	141	
2nd Floor	Wall	Wall C	1,039.77 sq ft	173.29 cu ft	16	
3rd Floor	Slab	Slab A	35,071.82 sq ft	70,143.63 cu ft	1	
3rd Floor	Wall	Wall A	12,945.40 sq ft	28,048.38 cu ft	56	
3rd Floor	Wall	Wall B	13,237.44 sq ft	4,412.48 cu ft	141	

Rule Set 'BIM Validation - Final Concepts.cset' has issues with critical severity that are not accepted or rejected.

Figure 17. Information Take-off as set by the user in SMC [24].

SMC provides a set of classification which can be used during information take-off. The classifications include,

- Building elements classification
- Space group classification
- Space usage classification
- Furniture classification
- MEP components classification
- Vertical access classification [23.]

Users can also create their own classifications or modify the classifications provided by SMC to serve their needs. The use of classification adds to the reasoning of SMC while conducting information take-off from the BIM file. The software provides additional ITO definitions for building elements, spaces and space grouping. After the user acquires the desired ITO, it can be reported with SMC provided templates or plain excel spreadsheets as shown in figure 18. [23.]

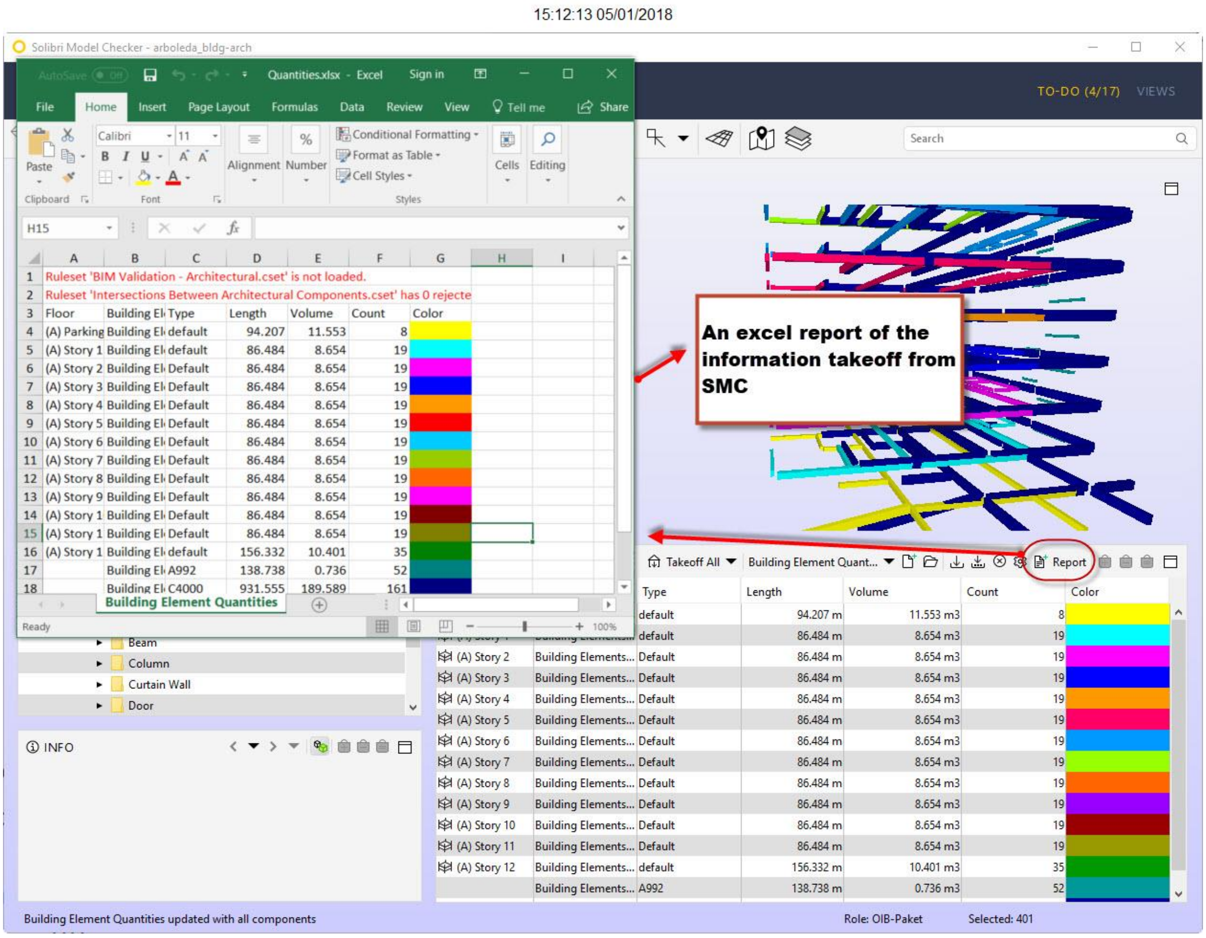


Figure 18. Reporting ITO with SMC on Excel.

Quantity take-offs can be reported as an Excel file. There are templates designed to extract the quantities and give the cost estimates of various components and when they are used in a cost simulation software, the information is used for procurement purposes.

5 Benefits of Solibri Model Checker for CoBIM

SMC relation to CoBIM requirements is given in this chapter, examples of such relations will be highlighted and explained. CoBIM is a set of standards used in Finnish construction industry. These standards do not govern how SMC works but they provide guidelines for various designers, matters to consider in design work. Therefore, when SMC is used during quality analysis and quality checking of a designed BIM model, SMC and CoBIM has somethings in common. Although the rules used by SMC are independent, it seems that “great minds think a like”, SMC seems to work as a verifying tool for the COBIM requirements ensuring a quality model of the required standards.

SMC is well known for its advanced rules developed for quality validation. From the rules, Solibri has compiled an extension with rulesets that are used to verify the CoBIM requirements. The rulesets in the extension are listed below:

- CoBIM 2012 - Checklist for Starting Situation BIM
- CoBIM 2012 - Checklist for Architectural BIM
- CoBIM 2012 - Checklist for Structural BIM Element BIM
- CoBIM 2012 - Checklist for Electrical Element BIM
- CoBIM 2012 - Checklist for HVAC System BIM
- CoBIM 2012 - Checklist for Checklist for Merged BIM

To begin with, the CoBIM 2012 for Architectural BIM, it contains sub-rulesets and rules that verify the requirements set in CoBIM for Architectural models. The ruleset ensures that proper documentation has been provided with the architectural model. Verification of the coordinate system used is done using the ruleset. The ruleset also checks if the components in the architectural model have been modelled with the correct tools. The ruleset is used for checking whether the architectural model contains any duplicates of building elements. It verifies whether the model has gross area for spaces, in the space heights are according to the requirements, and whether names, types and usage of spaces are given. There is no intersection between defined spaces and spaces which touch components around them. The ruleset ensures that good modelling practices of Architectural requirements have been met during modelling by validating components such as external walls, providing the minimum size of door openings is provided, and checking that slab dimensions are of sensible bounds and that there is clearance in front of doors and windows.

SMC provides CoBIM 2012 for structural building element verification. It contains sub-rulesets with one or more rules under them. Apart from checking the common requirements in both architectural and structural requirements, this ruleset also checks that the required building elements are included in the structural model. The ruleset verifies the floor storeys in the model, makes sure that the modelled elements are located on their respective floors, and that the elements have a unique id, name and type, confirmation of openings provided for the architectural model, the ruleset checks whether the structures are supported. Verification of spatial provision for the MEP model is also done to avoid collisions when the IFCs are merged. Each rule provides a note which gives the user an idea of what they need for manual checking and parameterisation. The user has to manually check some of the detailed components.

For the verification of the MEP model, the CoBIM 2012HVAC and Electrical Elements ruleset is used. The ruleset verifies that the components of the model belong to the right system, and that the components are defined according to floors. The ruleset ensures that the system names are defined systematically, there are no duplicates in the model, the model contains air handling units, and there is no collision between systems and components in the same model and MEP models. The rulesets are used to check if the components have balancing information like volume flow and pressure levels.

The CoBIM 2012 for Merged BIM rulesets are used to verify that all models are compatible. The ruleset contains sub-rulesets to verify that the combined model has models from all disciplines (Architectural, structural and MEP), it verifies that there is no conflict between the disciplines involved, ensures that all models use the same coordinate system and have a common origin. With such a wide variety of rulesets to choose from, SMC can be used for more than CoBIM verification.

5.1 Importance of Using SMC

Based on the features of Solibri Model Checker introduced in this thesis, it is easy to say that the use of Solibri model checker in a project will save both the project owner and the contractors lots of time and money, which means that the overall project will be profitable and of good quality. SMC provides a good platform for visualisation to all members involved in the project from the earliest stages of the project. This will provide, for example, the owner an actual representation of the structure for viewing before the delivery of the project. The use of the model in SMC is considered safe in a way that the BIM model cannot be altered when in SMC, only what is modelled can be analysed and visualised. The project players get to see the same model with information they require. The process of error identification and correction has been simplified and made fast in a BIM model. Correction of errors means that possible accidents have been prevented and the safety of those working on site is increased.

The use of SMC makes fixes easier since they are discovered in the modelling stage, rather than later in the project, that it would be costlier and time consuming to manually fix the mistakes in the site may be. Solibri makes the quality analyses and quantity checking process easy and fast. With rules that provide various capabilities serving the taste of each user, checking and verifying the quality of a BIM model is easy and convenient. This in turn makes the whole project comply with the necessary CoBIM requirements in a specific project. Solibri Model Checker supports IFC files which are produced by majority of the designing software.

Solibri Model Checker makes acquiring of quantities from a BIM model easy. This is made possible from the earliest stages of the project therefore procuring of the required materials is easy, which facilitates faster project kick-off. SMC can be used throughout the life cycle of the building which aids facility managers and makes maintenance easier. Solibri can be used in all construction projects which gives Solibri a wide range of use different construction fields.

As mentioned above, SMC provides a good communication platform for various designing discipline, making the correction of design flaws easier. A corrected model can be checked against the older version of the same model to check where the changes have been made and to verify that the correct changes have been made.

6 User Survey Results and Discussion

As mentioned above, a survey was conducted with the customers of Solibri Inc, whose headquarters are situated in Finland. The survey was conducted among Finnish users. The reason for surveying only users in Finland was because the common BIM requirements (CoBIM) are followed mainly in Finland. The participants were selected from the super user list in Solibri database. The reason why super users were selected was to ensure that the feedback received was from users who are familiar with the quality validation software. This list of users included all disciplines in a construction company from architects, to engineers, consultants, contractors and many others.

The survey was conducted to find out how Solibri super users used the software during quality validation process, to determine if the CoBIM rules provided by the software were enough or whether the users wished to get more information about the rules in the software, and how necessary users viewed it to have a quality BIM in a project. The study would help understand the assumption that the quality of BIM is ignored during design phase, but it can have a great impact in the overall project if payed attention to. This kind of survey was the first of this kind to be conducted on the software usage and customer feedback of the same time. It would provide the company with valuable information to know how their software performance and is used by various construction disciplines.

6.1 Methodology

From the user list, 200 email addresses of users only in Finland were selected. The survey was done with an online form, the link was attached to the emails. The survey used two languages English and Finnish, to maximise the amount of feedback and to ensure that the respondents would give answers to the survey in the language they most felt comfortable using or fully understood the meaning of the questions. Out of the 200 users selected, a feedback of 28 responses was received. This was 14% which could be called a success, considering the feedback rates in. There was no incentive to motivate the users to give feedback, an incentive would have been a great booster to increase response rate. This inclusion of an incentive was suggested to the company for future surveys to get better response rates.

The survey had a range of questions twenty in total. There were three main groups of the question; the users background, the usage of the software, and the use of CoBIM requirements with the software. The user background question provides important information about the size of the company where the respondents worked. This would provide the research with the knowledge of what kind of impact or response the result would cause in the long run to the software providing company. Getting to know how the customer utilise the software was important because it would provide information on how they do quality checking and what part of the software is used most and what purpose it is used for in most cases. It was relevant to know if the customers use CoBIM rulesets provided by the software and how important they find quality validation in BIM.

6.2 Results Analysis

During the analysis of the results, about the field or department the user worked with, the results showed that a majority of the respondents were from construction companies involved in most construction related tasks from design to site management. A big number of respondents also had a contractor background, followed by BIM -coordinators and design team members. Knowing about the tasks the respondents handled at their respective workplaces was important to get to know the users' daily activities. The results showed that more than half of the respondents did contracting related tasks as shown in the chart. This result interprets the results of other questions about the tools that were most utilised in the software.

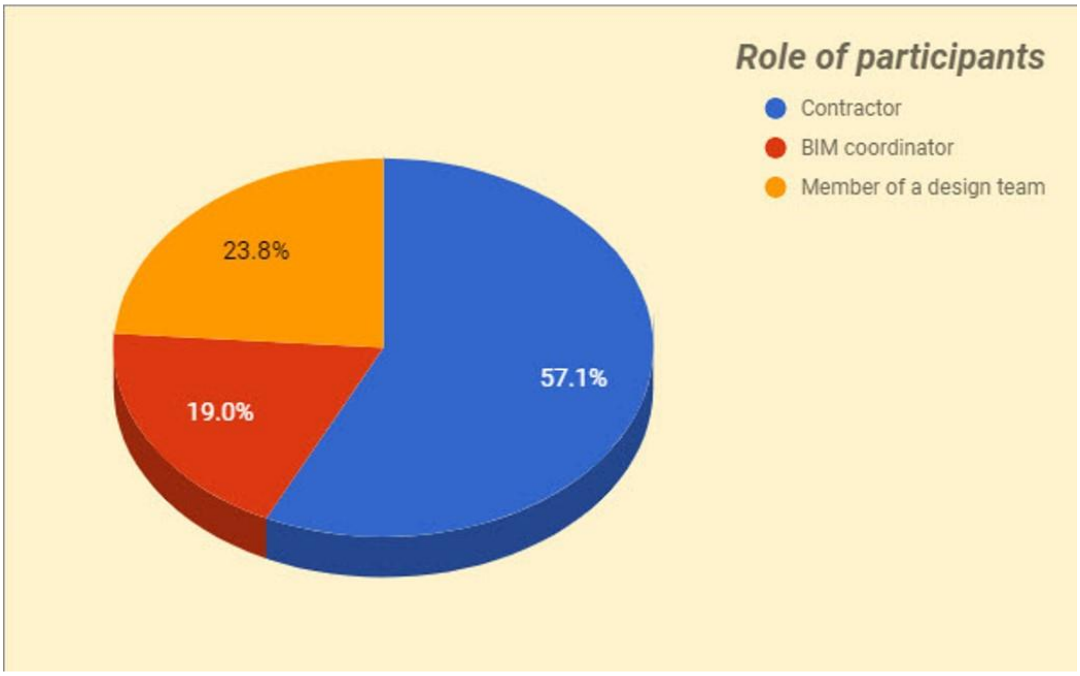


Figure 19. User roles.

The survey also shows that more than 60% of the users use the software on site. These results can be related to figure 19, suggesting that the contractors need the software to get the quantities of a project on site.

The software can be used in various ways. One of the aims of the survey was to establish which functionalities of the software were mostly used. Some interesting results were acquired about the purpose the users were using the software for as shown in figure 20. Even though the software has lots of rules to check the quality of the models, most users used the software for visual checking, and quantity take-offs. The difference is not much when a closer look is taken at the values, but the difference is still tangible. Such results would raise questions like why are the rules not so much utilized? With such questions in mind, more research would be triggered to get to the bottom of the issue and to provide a suitable solution. The company would be interested in finding out why: are the rules difficult to configure, are they well-advertised, or do the users need training. Coming up with the solution for this, the company would ensure that the customers use the software to achieve their goal!

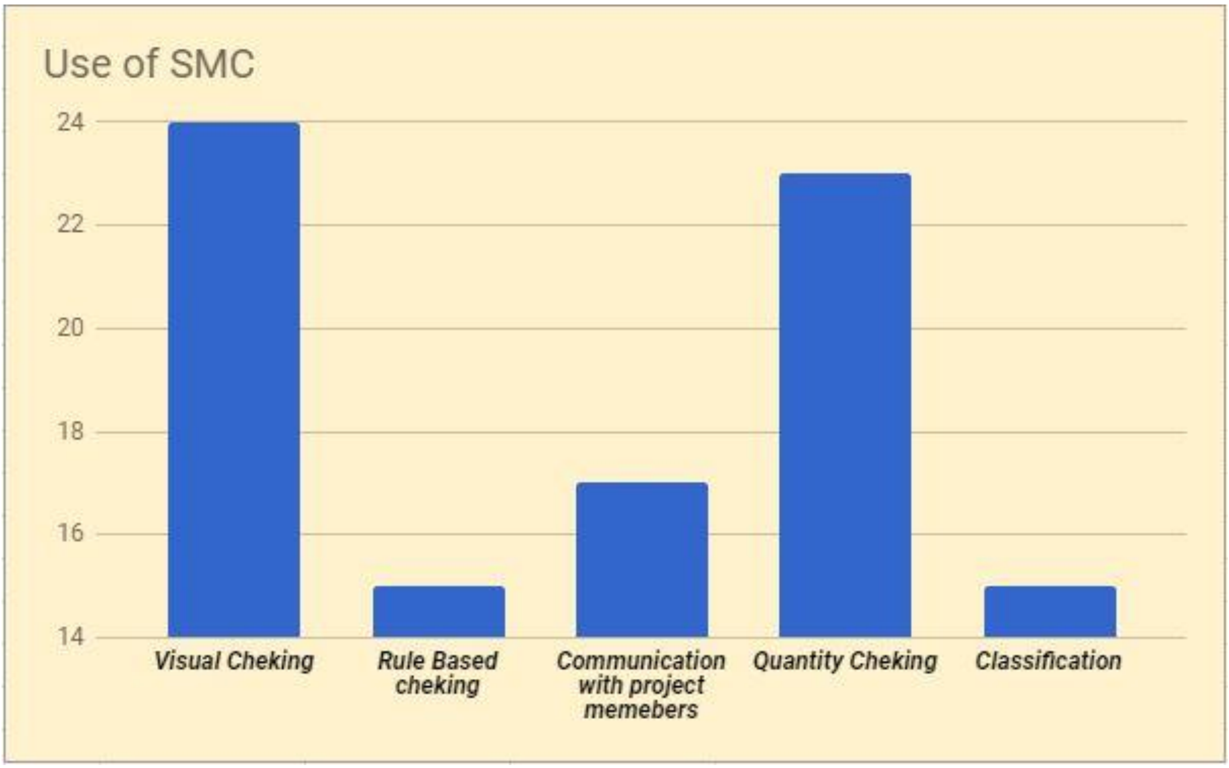


Figure 20. Most used Functionality of SMC.

For the research, it was important to know how the participants commonly communicate with the other project members. The results showed that PDFs and Excel sheets were most commonly used, followed by the BCF files and the cloud-based BIM-Collab API (Application Programming Interface). These results were not as expected. The use of

BCF was more encouraged as mentioned above. The BCF was specifically created to ease communication between project members. The results would raise concerns as to why the BCF and other forms of communication are not so used? Could it be that the platforms are not well known, and users of the software need to be trained on how to use them? the platforms malfunction? This sort of questions raised by the company when answered, they would provide solutions as to why this kind of usage is happening.

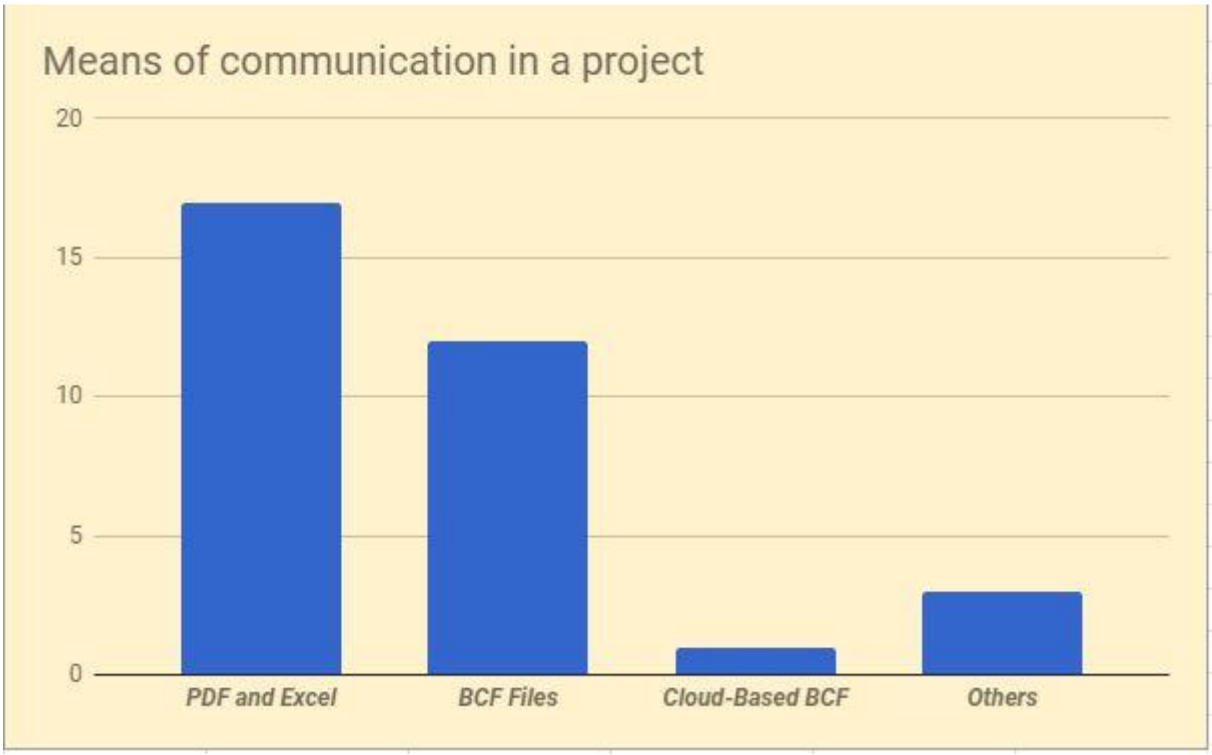


Figure 21. User means of communication in SMC.

SMC offers various ways of checking quality and it was important to find out how the super users did their quality validation. Did they use rules, did they do quality validation visually or how did they execute their BIM validation process? Surprisingly, the rule based checking and visual checking were closely matched. The results showed that 51% of the users who responded did visual checking while the other 49% did also rule based checking. This result could be interpreted with the help of figure 21. Since most of the respondents in this survey turned out to be contractors, the results in this section are explained. Contractors would do visual checking for quantity take-off purposes, followed closely by BIM-coordinators who presumably do most of their checking with the rules. The same results are also seen in the most used parts of the software, where ITO is significantly used. There was also interest in knowing whether the user did their quantity take-off before or after quality verification. The question was importance since it is important to have a quality BIM before quantity take-off to avoid misleading quantities. This was the case where most respondents said they had to verify the quality of BIM first before the quantity take-off. It shows that quality is payed attention to nowadays compared to when the BIM technology was introduced.

Since SMC uses a lot of rules to verify how the modelling of a BIM model has been done, it was important to see whether the users have used the software to verify compliance with the building requirements. The results were no surprise since the CoBIM requirements are the most used building standards in Finland as shown in figure 22.

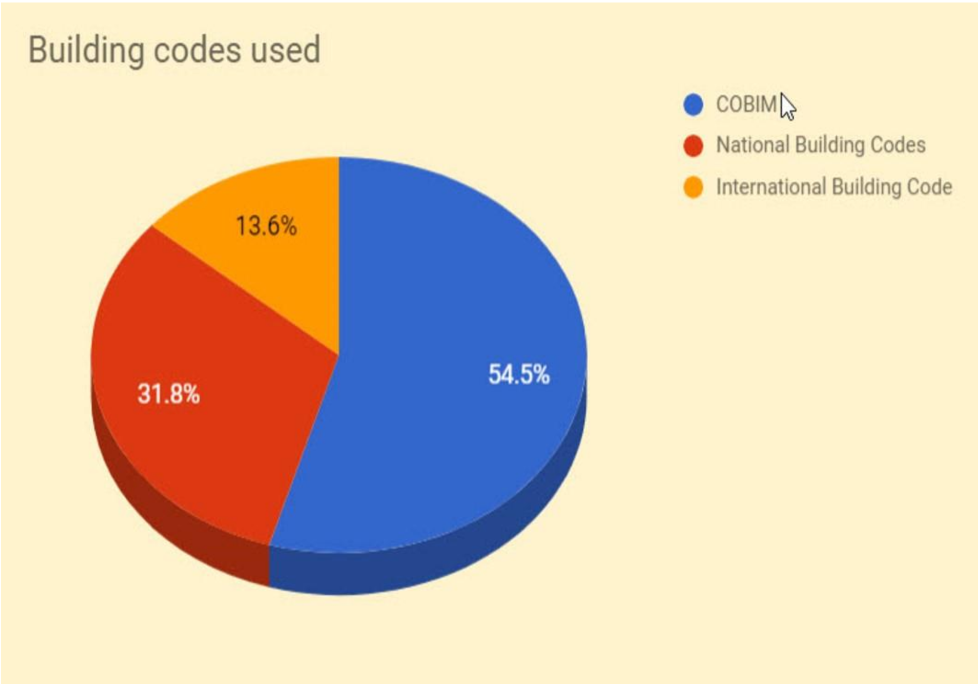


Figure 22. Requirements and Standards used.

Apart from CoBIM, there are other standards used for BIM design, therefore it was important to find out how the CoBIM standards fair against other standards. This would shed light on the execution of CoBIM within Finland. Knowing what rules were used for BIM verification would help the writer understand if the ruleset extension provided by the software for CoBIM verification was utilised. Surprisingly, the majority of the users preferred to use the whole list of rulesets rather than the compiled CoBIM extension. This raises the questions, why the CoBIM rulesets are not used, are they not well known, do they do a thorough job in BIM verification or are they not so detailed when used. These questions need to be included in future research to find out the answers. It would also provide the company with an opportunity to understand what the users need during requirements verification. At the same time, with the rising level of accuracy while doing BIM designs, it could be the software is used for detailed checking and not just requirements verification.

The respondents were also asked how important they think quality analysis of BIM is. The results obtained showed that about 80% of the respondent see the practice of quality checking as very important and the rest, 20% find it important. It shows that the culture of model checking is growing in a positive way. This would in turn improve the execution construction projects since errors and faults are minimised in the design phase of the project.

The respondents were also asked about the main challenges they faced when working with the software. The answers could be used to develop the product further to better fulfil the user’s needs. Most of the answers received from the respondents showed that the use of rules is a main challenge, as is creating classification and how setting parameters for certain requirements. The results showed that in depth knowledge of rules was probably not well understood. The company is considering training and online discussion forums for example to facilitate proper understanding of what the rules are capable of and how to use them to suite the users best.

It was also important to know how the software functioned or how happy the customers were with the software. When the software is used for quality checking the users were asked what percentage of flaws are detected and 70% of the respondents said that the software is capable of detecting up to 75% of flaws in a BIM file, 20% of the respondents said that the software could detect 50% of the flaws and the 10% of the users said the software only picked 25% of flaws in a BIM file. The users were asked if they could recommend the software as a quality and quantity tool to others. The response was encouraging: 96% of the users say that would recommend the software to others. The company was pleased with the positive feedback, but the company wanted to know why some users gave low accuracy rating for the software. The company should ensure that the users use it as it is supposed to and find out if more training is needed. Are there bugs? Such discussions arose during company presentation. Working to improve the accuracy of the software was among the suggestions given during discussion. The overall positive feedback shows that the respondents are happy with the tool and the results they get which is what every company would want to achieve when it comes to customer satisfaction.

7 Conclusion

This thesis has been carried out at Solibri Inc. The goal of the study was to find out the importance of having a flawless BIM model in a project, and what bennefits it brings. Another aim was to find out how users are using Solibri as a quality and quantity analysis tool. Having the CoBIM requirements provided by the Finnish building industry, do designers fulfil the requirements during BIM design? All this information is important to see where BIM quality is heading compared to the older ways of doing the same. Building information technology has brought a significant positive change in the construction industry. The ability to detect errors in a designed BIM model well before construction is among the major breakthroughs. When project members have a single platform to use for communication and information sharing, the project execution is simplified compared to the older ways of communication which caused delays and slowed down the project. Contractors have it easy with the usage of BIM, acquiring quantities from quality models, ensuring smooth transitions in delivery of materials.

CoBIM requirements are beneficial in making design work easy, which consequently leads to the production of quality BIM. The survey clearly shows that CoBIM requirements are used and are considered important, not only for BIM models, but also for the sake of the produced structures. Safety is ensured during project delivery, sustainability is demonstrated when a quality BIM is used, waste of materials, which also influences costs, is decreased. With an existing quality BIM, the users of a facility can pre-plan repair works ahead of time. The BIM would provide necessary information through the occupancy of the structure, making facility management easier. The BIM would also be continually updated making life cycle analysis of structures easy to follow.

Solibri as a quality assuring tool has lived up to its standard as shown in the survey. The wide variety of uses the software offers serves a wide range of discipline requirements and needs in the construction industry. The software can be used by architects, engineers, contractors and BIM-coordinators. The ability of the tool to provide numerous functionalities ensures that every party in a project can use it for quality verification, quantity checking and visual checking of a BIM file.

For the company, the survey answered some questions while raising others. Thus, the company needs to spring in action to conduct further research to see whether the questions raised in this thesis could be answered. The company would get an insight into how their customers use their product on an international level, and whether the customers are satisfied with the product. In such a wide industry like construction, where competition is high, achieving a positive rate of customer satisfaction is one of the many achievements a company would want to attain. The feedback would also air opinions of users, showing possible development areas and in return, bring profit to the company. As mentioned above, training could also be arranged. Features that the users are not familiar with, or do not know well, could be marketed and advertised to pass information and knowledge to the users.

Because of the survey, the company considered doing more surveys since this was the first of this kind. The company would be interested in knowing at an international level how the software is doing in the market and how they could serve better even regions that use for example different standards, since they would also need different rules to check their models. This final year project was the first step to show the results before the surveys would start to be conducted in the international level. The survey brought about an interesting finding that the company did not know about the interaction of end users with their software. During the presentation of the results, discussion on various points sparked interest in finding out more about what the users actually do with the software.

References

1 Eastman Chuck, Teicholz Paul, Sacks Rafael, Liston Kathleen. BIM Handbook 2nd ed. A Guide to Building Information Modeling for Owners, Managers, Designers, and Contractors. Hoboken, New Jersey: John Wiley & Sons Inc; 2011.

2 Maunula Antti. The Implementation Of Building Information Modeling (BIM). Helsinki University of Technology SimLab: SimLab Report series; 2008.

3 Finith E. Jernigan. BIG BIM little bim, The practical approach to building information modeling, Integrated practice done the right way! 4Site Press: Salisbury, Maryland USA; 2007.

4 Salih Sen. The Impact of BIM /VDC on ROI [online]. Stockholm: KTH, Architecture and Building Environment.;2012. URL:https://www.kth.se/polopoly_fs/1.340468!/Menu/general/column-content/attachment/Thesis_Salih_SEN_final.PDF. Accessed 10 December 2017.

5 Reizgevičius Marius, Ustinovičius Leonas, Cibulskienė Diana Kutut Vladislavas Nazarko Lukasz.Promoting Sustainability through Investment in Building Information Modeling (BIM) Technologies: A Design Company Perspective. [online].URL;http: //www.mdpi.com/2071-1050/10/3/600/htm. Accessed 14 April 2018.

6 Kannala Matti. Escape Route Analysis Based on Building Information Models: Design and Implementation.2005.

7 Knutson Kraig, j. Schexnayder J. Clifford, Fiori Christine, Mayo E Richard. Construction Management Fundamentals 2nd ed. 1221 Avenue of the Americas, New York: McGraw-Hill; 2009.

8 Lee Namhun, Salama Talat, Wang George. Computing Information Modeling for Quality Management in Infrastructure Construction Projects [online]. URL:http://itc.scix.net/data/works/att/w78-2014-paper-009.PDF . Accessed 12 December 2017.

9 Kulusjärvi H. Solibri Inc. Common BIM requirement series 6 [online]. 2012. URL;https://buildingsmart.fi/wp-content/uploads/2016/11/cobim_6_quality_assurance_v1.PDF Accessed 13 April 2018.

10 Stephen Mike, Houston Martin. Quality Management in the Design and Construction of Enclosure systems [online]. April 2012. URL:https://c.ymcdn.com/sites/www.nibs.org/resource/resmgr/BEST/Best3_steffen.2.6.PDF. Accessed 19 December 2017.

11 The Division 4 Triclinium. [online]. URL;http://division4triclinium.blogspot.fi/2013/06/of-macleamy-curve-efficient-design-and.html. Accessed 13 April 2018.

12 European Construction Sector Observatory. Policy measure fact sheet Finland, CoBIM Requirements. Thematic Objective 3. November 2016
URL; https://webcache.googleusercontent.com/search?q=cache:UlXLabASp5UJ:https://ec.europa.eu/docsroom/documents/23530/attachments/2/translations/en/renditions/native+&cd=2&hl=en&ct=clnk&gl=fi.Accessed 13 April 2017.

13 Henttinen T. Gravicon Oy. Common BIM Requirements Series 1 [online]. 03/2012.
URL:https://asiakas.kotisivukone.com/files/en.buildingsmart.kotisivukone.com/COBIM2012/cobim_1_general_requirements_v1.PDF.
Accessed 01 October 2017.

14 Rajala M. Tietoa Finland Oy. Common BIM Requirements Series 2 [online]. 03/2012 URL:https://asiakas.kotisivukone.com/files/en.buildingsmart.kotisivukone.com/
COBIM2012/cobim_2_inventory_bim_v1.PDF. Accessed 01 October 2017.

15 Henttinen T. Gravicon Oy. Common BIM Requirements Series 3 [online]. 03/2012.
URL:https://asiakas.kotisivukone.com/files/en.buildingsmart.kotisivukone.com/COBIM2012/cobim_3_architectural_design_v1.PDF. Accessed 03 October 2017.

16 BuildingSMART Finland. CoBIM 2012. Täydentävä liite osa 3. Arkkitehtisuunninttelu Mallinnustarkkuus Tilaan ohje [online].URL;https://buildingsmart.fi/wp-content/uploads/2016/11/YTV2012_Taydentava_liite_ARK_Tilaajan_ohje.PDF. Accessed 14 April 2018.

17 BuildingSMART Finland. CoBIM 2012. Täydentävä liite osa 5. Rakennesuunnittelu Mallinnustarkkuus Tilaajan ohje [online].
URL;https://buildingsmart.fi/wp-content/uploads/2016/11/YTV2012_Taydentava_liite_RAK_Tilaajan_ohje.PDF . Accessed 14 April 2018.

18 Kautto T. Finnmap Consulting Oy. Common Bim Requirements Series 5 [online]. 03/2012.
URL:https://asiakas.kotisivukone.com/files/en.buildingsmart.kotisivukone.com/COBIM2012/cobim_5_structural_design_v1.PDF. Accessed 05 October 2017.

19 Järvinen T, Tuomas L, Kaleva K, Heljomaa K. Olof Granlund Oy. Common BIM Requirements Series 4 [online]. 03/2012.
URL:https://asiakas.kotisivukone.com/files/en.buildingsmart.kotisivukone.com/COBIM2012/cobim_4_mep_design_v1.PDF. Accessed 11 October 2017.

20 Getting Started with Solibri Model Checker V9. Solibri Inc, PDF; 2017.

21 Kulusjärvi H, Widney J. Solibri Inc, PDF. Introduction to Deficiency Detection.2010.

22 Brad Hardin. BIM and Construction Management. Indianapolis, Indiana: Wiley Publishing,Inc; 2009.

23 Kulusjärvi H, Widney J. Solibri In, PDF. Spatial Coordination White Paper. 2009.

24 Kulusjärvi H, Widney J, Jauhainen J. Solibri Inc. Introduction to Information Take-off, PDF. 2010.

Appendix.

Solibri Model Checker User Survey

1. In which fields does your company operate?
    a. Architecture
    b. Structural engineering

c. Mechanical, electrical and plumbing engineering
d. Consulting
e. Other, which?

2. What is your role in the company or a construction project?
    a. Contractor
    b. Design team member (architect, engineer)
    c. BIM coordinator
    d. Consultant
    e. Owner

3. Do you use Solibri products on site?
    a. Yes
    b. No

4. Which Solibri products do you use in your projects?
    a. Solibri Model Checker (SMC)
    b. Solibri Model Viewer
    c. Solibri IFC Optimizer
    d. None of the above
    e. Others

5. Which functions of Solibri Model Checker do you use?
    a. Visual checking
    b. Rule-based checking
    c. Communication with project members via
    d. Quantity checking (information take-off)
    e. Classifications
6. How do you use the functionality/ functionalities above?
    i. Visualisation
        1. Mark-up tools
        2. Dimensioning tools
        3. Sectioning tools
    ii. Rule-based checking
        1. SMC default rules
        2. Rules you have created yourself
        3. Rules from extensions
        4. Others
    ii. Communication with project members via
        1. PDF and Excel reports
        2. BCF files
        3. Cloud-based BCF server (BIMcollab)
        4. Others

7. Do you do visual or rule-based checking before quantity take-off for model verification?
    a. Yes

   b. No.

8. Do you use Solibri's default resources or your own resources?
   a. We use the default resources
   b. We use our own resources for

9. If you answered b) to the previous question, what do you use the resources for?
   a. Rules
   b. Classification
   c. ITO templates
   d. Roles

10. Which building codes do you use to check your projects?
    a. International building code
    b. COBIM
    c. National building code
    d. Other

11. Which rules or rulesets do you the most in quality assurance against COBIM requirements?

12. Are there any rules you would wish to be added to the list of COBIM rules in SMC?

13. Which classification system do you use?
    a. General
    b. Uniclass
    c. OmniClass
    d. National standard
    e. The company's own classification

14. What are your main challenges when using Solibri's products?
    a. Using and creating rules
    b. Rule-based checking
    c. BIM coordination
    d. Classifications
    e. Information take-off
    f. Visual checking by using 3D tools
    g. Other

15. In your opinion, what is the percentage of errors picked by SMC during quality checking?
    a. 25% of all errors
    b. 50% of all errors
    c. 75% of all errors
    d. 100% of all errors

16. In your opinion, what is the importance of checking quality in the design phase?
    a. Very important

   b. Important
   c. Less important
   d. Not important

17. Would you recommend Solibri Model Checker as a quality assessment tool?
    a. Yes
    b. No

18. Why would you recommend/not recommend Solibri Model Checker?

19. What is the number of employees in your company?
    a. 10 or less
    b. 11 to 50
    c. 51 to 100
    d. 101 to 250
    e. More than 250

20. Further comments about your use of Solibri products:

FINNISH :

1. Millä aloilla yrityksesi toimii?
    a. Arkkitehtuuri
    b. Rakennesuunnittelu
    c. Sähkö- ja automaatiotekniikka
    d. Konsultointi
    e. Muu

2. Mikä on roolisi yrityksessä/rakennusprojektissa?
    a. Urakoitsija
    b. Suunnittelutiimin jäsen (arkkitehti, insinööri)
    c. BIM-koordinaattori
    d. Konsultti
    e. Omistaja

3. Käytätkö Solibrin ohjelmia työmaalla?
    a. Kyllä
    b. Ei

4. Mitä Solibrin ohjelmia käytät projekteissa?
    a. Solibri Model Checker
    b. Solibri Model Viewer
    c. Solibri IFC Optimizer
    d. Ei mitään näistä
    e. Muita ohjelmia

5. Mitä näistä Solibri Model Checkerin toiminnoista käytät?
    a. Visuaalinen tarkastus
    b. Sääntöihin perustuva tarkastus
    c. Kommunikointi muiden projektin jäsenten kanssa
    d. Määrien tarkistus (informaation talteenotto)
    e. Luokittelu

6. Miten käytät edellä valitsemaasi toimintoa/valitsemiasi toimintoja
    a. Visuaalinen tarkastus
        i. Merkintätyökalut
        ii. Mitoitustyökalut
        iii. Leikkaustyökalut
    b. Sääntöihin perustuva tarkastus
        i. SMC:n oletussäännöstöt
        ii. Omat säännöstöt
        iii. Laajennusten säännöstöt
        iv. Muu
    c. Kommunikointi muiden projektin jäsenten kanssa

i. PFD- ja Excel-raportit
ii. BCF-tiedostot
iii. Pilveen perustuva BCF-palvelin BIMcollab)

7. Teetkö visuallista tai säännöstöihin perustuvaa tarkastusta ennen mallin varmistusta ja määrien laskentaa? Jos et, miksi?
   a. Kyllä
   b. Ei

8. Käytätkö Solibrin oletusresursseja vai omia resursseja?
   a. Käytän oletusresursseja
   b. Käytän omia resursseja

9. Miten käytät edellä valitsemaasi toimintoa/valitsemiasi toimintoja?
   a. Säännöt
   b. Luokittelu
   c. ITO-pohja
   d. Roolit

10. Mitä rakennusmääräyksiä käytät projektien tarkastamiseen?
    a. Kansainvälisiä rakennusmääräyksiä
    b. Yleisiä tietomallivaatimuksia (YTMV)
    c. Kansallisia rakennusmääräyksiä

11. Mitä sääntöjä/säännöstöjä käytät eniten tehdessäsi laadunvarmistusta Yleisten tietomallivaatimusten mukaisesti?

12. Onko jotain sääntöjä, joita toivoisit lisättävän SMC:n Yleisten tietomallivaatimusten säännöstöön?

13. Mitä näistä luokittelujärjestelmistä käytät?
    a. Yleinen
    b. Uniclass
    c. OmniClass
    d. Kansalliset standardit
    e. Oma luokittelu

14. Mitkä ovat suurimmat haasteesi Solibrin ohjelmien käytössä?
    a. Sääntöjen käyttö ja luominen
    b. Sääntöihin perustuva tarkastus
    c. BIM-koordinointi
    d. Luokittelut
    e. Informaation talteenotto
    f. Visuaalinen tarkastus 3D-työkaluilla
    g. Muu

15. Kuinka suuren osan virheiden kokonaismäärästä Solibri Model Checker mielestäsi havaitsee?
    a. 25% kaikista virheistä
    b. 50% kaikista virheistä
    c. 75% kaikista virheistä
    d. 100% kaikista virheistä

16. Mikä on mielestäsi laaduntarkastuksen tärkeys suunnitteluvaiheessa?
    a. Erittäin tärkeä
    b. Tärkeä
    c. Vähemmän tärkeä
    d. Ei tärkeä

17. Suosittelisitko Solibri Model Checker -ohjelmaa laaduntarkastustyökaluna?
    a. Kyllä
    b. Ei

18. Miksi suosittelisit/et suosittelisi Solibri Model Checker -ohjelmaa laaduntarkastustyökaluna?

19. Kuinka paljon yrityksessäsi on työntekijöitä?
    a. 10 tai alle
    b. 11−50
    c. 51−100
    d. 101−250
    e. Yli 250

20. Muita kommentteja Solibri Model Checker -ohjelman käytöstä: