Technical University of Denmark

Quality Assurance Process
in BIM-based integrated design

REPORT

Special Course: Quality Assurance in BIM-based integrated design
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Reflective Report 1
Integrated design workflow based on current practice and literature

Introduction:

Developing an integrated design environment from a comprehensive perspective including ‘function’, ‘information,’ and ‘process’ is necessary to avoid data losses and enable quality assurance. Hence, an integrated design system requires BIM data generation and documentation, **quality evaluation of BIM data** and BIM data storage and management. [1]

Generation of BIM data is traditionally made with Revit in the AEC industry. The generated data is then stored and managed either decentralized on local server or centralized in a cloud. The proposed topic for the special course, however, aims to further explore the quality evaluation part of the integrated design process (QA-process) of the BIM data. Hereby, the focus is set on the functional integration of the design evaluation through the Model Checking as well as on an integrated process support creating a comprehensive environment around the collaborative design evaluation.

Current research shows that an interoperable IFC and BCF-based design process allows the project team to develop a BIM-based semi-automatic validation of design choices and to improve interoperability in the field of process information exchange as well as coordination between design disciplines.[2] This process is supported by two categories of rulesets, project specific (BIM Validation & Clash Detection) and regulation specific (Code Checking) rulesets.

Adjusting the rulesets according to the current project phase as well as the model’s LOD (level of development) and the computational complexity, enables the creation of an iterative and continuously evolving model checking process[3]. Model checking as an iterative process allows to detect design issues and share the information with all relevant stakeholders in order to increase common understanding and task management to optimize the design according to the client needs. Furthermore, disciplines work collaboratively early in the project and costly design changes are avoided due to the model checking. Model checking should also foster collaboration and client engagement to receive a consistent and functioning design. [4]

Yet, Mehrbod et al. (2018) revealed that project participants do not exploit BIM tools to their full capacity by still preferring 2D drawings or analog documentation in design coordination meetings and design audits. As the paper reveals, this state is only altered with the help and supervision of a BIM Coordinator.[5]

[1] M. Oh, J. Lee, S. W. Hong, Y. Jeong (2015)

[2] N. Treldal, H. Parsianfar, & J. Karlshøj (2016)n

[3] W. Solihin, & C. Eastman (2015)2

[4] A.L.C. Ciribini, S. Mastrolembo Ventura, M. Paneroni (2016)

[5] S. Mehrbod, S. Staub-French, N. Mahyar, M. Tory (2018)

1. Integrated Design System

The building industry is characterized by its fragmented project environment and poor collaboration between all project participants.[6] In a construction project, a lot of different experts work on the same project in order to design a holistic and functional building.[7] However, their responsibilities and services overlap little resulting in an inefficient process where all parties are properly doing their work but barely communicate or collaborate in order to increase efficiency. A study revealed that in an average construction project, the architects and engineers, responsible for designing the building and planning the project, use over half of their time only for managing already existing information, which has not been shared within the project team.[8] This general issue in the industry calls for a collaborative process in the designing a building, where experts work together and use their expert knowledge more efficiently.

In this case, all relevant stakeholder involved in a building project should be able to integrate their expert knowledge early in the design phase, where changes have the highest impact and lowest costs.[9] Especially the opinion and requirements of the user or facility manager should be implemented to enhance design quality. This lack of early integration of all relevant stakeholder results in an increasing number of collisions between different disciplines. Furthermore, costly design changes are needed during the execution phase to correct the errors.[10]

In order manage this change towards a more collaborative and integrated design, the building industry is supported by the global trend of digitalization. Building Information modeling has been adopted well in different markets and its importance will increase further due to the great potential in information management and interdisciplinary collaboration. Yet, to achieve the full potential of BIM, a framework is needed, merging people, processes and technologies.

Oh, Lee et. al. (2015) propose an integrated system for BIM based collaborative design, based on the 3 integration concepts *functional integration*, *integrated information management* and *integrated process support*. To achieve functional integration, software is required, which is able to support a collaborative design process with functions as modeling of a building model, quality assurance, communication with other participants and interoperable information sharing and storing. Interoperability is the key technical factor for a collaborative design enabling collaboration between the disciplines throughout the entire design process through communication and information exchange. This interoperability, however, has to be managed properly as it is prone to be misused by the creation and supply of unnecessary information and time-consuming conversion and sharing of files. Therefore, an integrated information management enables the proper use of all information produced during the design. This is supported by implementing an integrated process support, which forms a framework coordinating and organizing the steps and tasks for the entire design process and linking the different functions. It also enables to provide the information that each participant needs at every design stage.

For the implementation of the proposed system, three interconnected modules have been developed which are applied in an iterative process from the initial design idea until the submittal of the construction documents.

[6] Farmer (2016), p. 33
[7] Sommer (2016), p. 125
[8] Flager, Haymaker (2009), p. 4
[9] Sommer (2016), p. 66 f., p. 132
[10] Sommer (2016), p.144

a. BIM Modeler

Modeling the building is the initial work in the system. In here, building objects are defined with their appropriate properties according to the level of detail in the current design phase. As described above, a building is a complex subject, which is designed by different disciplines. Disciplines as Architecture, Structure and MEP all model their own building model and then link their models to a central model.

b. BIM Checker

Due to the splitting into several discipline models, the evaluation of the design quality is a crucial and continuous task in a collaborative design. This evaluation is divided into design review and regulation review. Design review reveals design errors of the model and makes corrections. The design review includes three factors for spatial analysis:

1) Classification of space (referring to a type of space defined by the user e.g., classification by room purpose, by floor, etc.),

2) Property information of space including area, location, volume and object

3) 3D visualization representing the visualization of review results

The regulation review identifies target building issues regarding legal regulations and makes design modifications based on this review. This review requires a separate ruleset for model checking which is based on legal regulations extracted from the building code and other relevant guidelines. The ruleset is provided by the rule set manager and organized by each design phase. In the **pre-design** phase for example, the ruleset reviews the building scale whereas the rules in the **schematic design** phase focus the building type and on constructability in the **design development and construction documents** phases

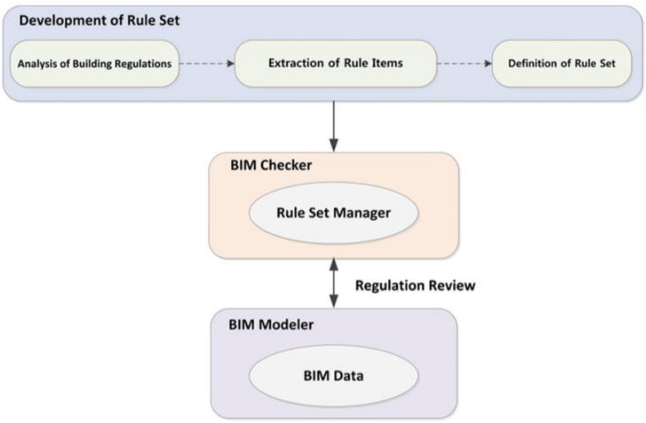


Figure 1: Rule set for regulation review

c. BIM Server

Besides creating and evaluating data and information, an integrated server is necessary to directly manage the information produced by the BIM Checker and BIM Modeler. The server is based on a database system with multiple access for the project participants and an access control, managing the different accessibility rights of each user. These accessibility rights are classified for the entire project, a library or an object by defining whether the user can create, modify, delete and/or read information.

The proposed integrated design system is then established by linking the modules BIM Modeler, Checker and Server within the BIM-based collaborative design process. The following visualization shows how this can be organized including all integration concepts.

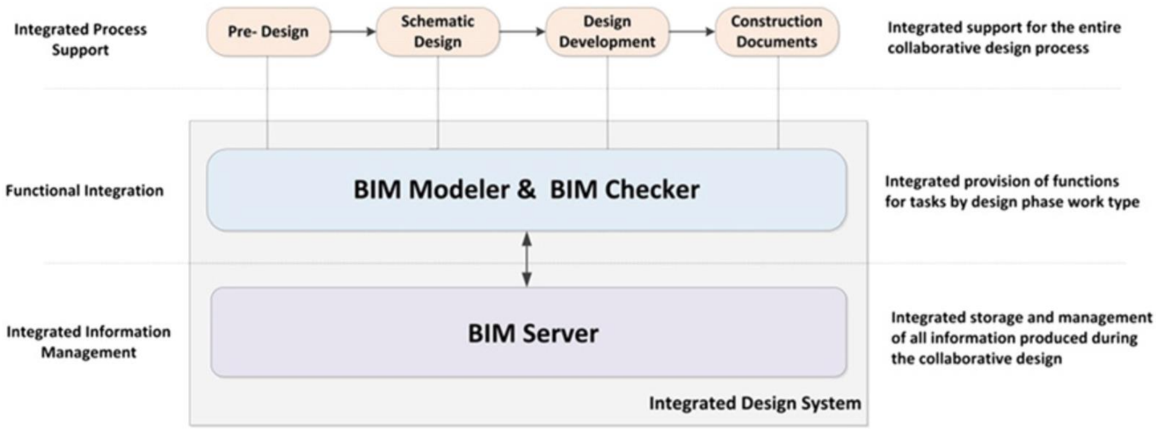


Figure 2: Integrated Design System

In conclusion, the proposed system is a holistic attempt to solve the problems of collaborative design in an organized and integrated manner. This solution can be seen as an overall approach how to use existing BIM technology and knowledge of all project participants in design in a more efficient and controlled way.[11]

In this study, the focus lies on the integrated function of BIM Checking. Especially the collaboration part in model checking will be analyzed and explored in detail in order to answer the following research questions:

How can BIM collaboration tools such as BIMCollab and Revizto foster collaboration between the project participants within the design process, where model quality and clashes are evaluated with Solibri Model Checker and Nawisworks?

What process is needed to manage BIM collaboration in the design phase and how can IPD-principles help to improve the process?

What other positive outcomes such as quality, decision making, transparency and client engagement can be generated by using collaboration tools in practice?

This introduction to the integrated design system is followed by a detailed description of the state of art approaches in BIM model checking and collaboration. First, the terminology of model checking is analyzed in order to understand the full capacity. Afterwards, the current software environment for both model checking and the subsequent collaboration and task management will be explored. As a mediator for the software application, IFC and BCF file formats are analyzed. Especially the Building Collaboration Format (BCF) is of interest as it enables to improve interoperability in the field of process information exchange and to communicate BIM related tasks, derived from the model checking. Furthermore, two best practice approaches for the iterative process of design evaluation are reviewed, showing the current approach of an integrated and BIM-based design in practice.

[11] Oh, Lee, et al. (2015), p. 1 ff.

After this literature and best practice review, this study is thriving to further explore the future implications and limitations of BIM-based integrated design. Therefore, several interviews with experts in the construction industry in Denmark and Switzerland will be conducted. The interview questions will be developed in a reflective manner based on the literature review and are supposed to form the bases for exploring the software application of both quality assurance and collaboration in integrated design. To sum it up, the study will include an overall reflection on the current approaches of integrated design in the construction industry and tries to implement an additional perspective by using Integrated Project Delivery principles. Here, it is analyzed how these principles can foster collaboration and integration of all stakeholder in the design process.

Based on all gathered information the study proposes an integrated process how to manage quality assurance in a BIM-based collaborative design. The following visualization shows a summarized overview of the content in this study:

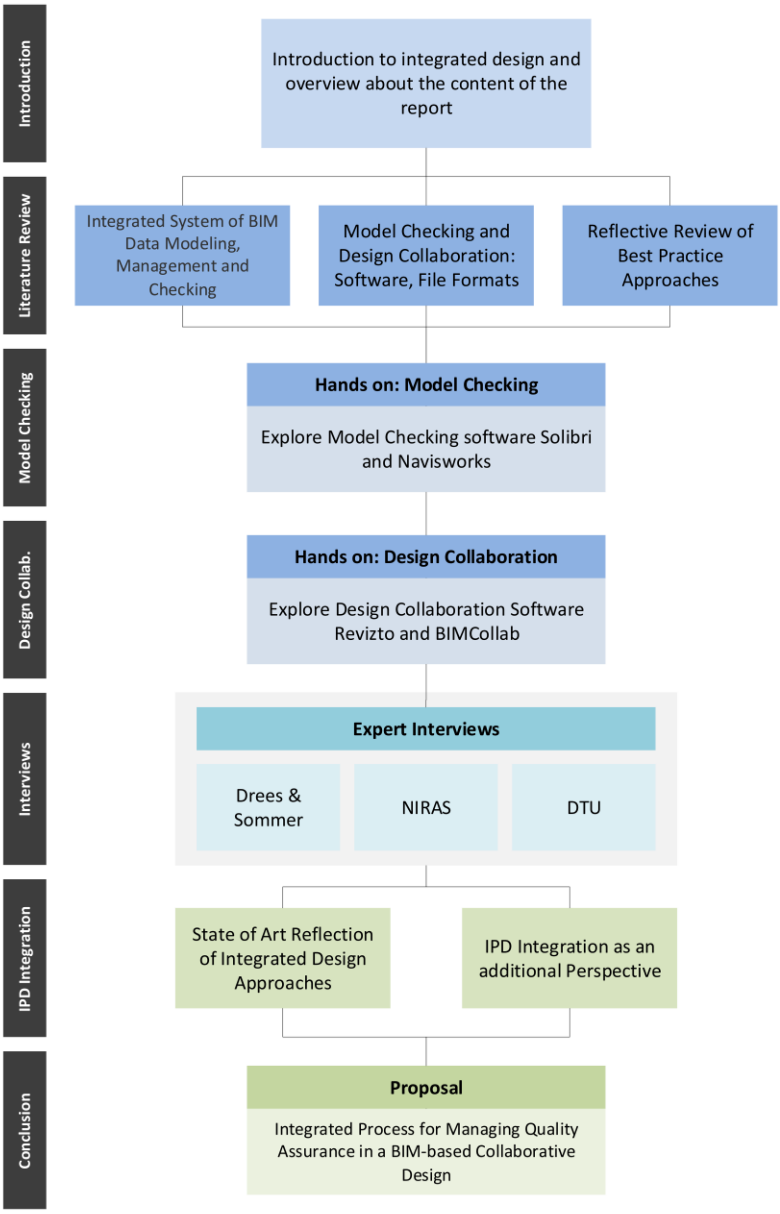


Figure 3: Content Overview of the Report

2. BIM Model Checking:

Now, as the general system of integrated design has been introduced in one perspective, the next step will be to have a closer look on BIM model checking, as this is the focus area of this study.

The reviewed paper investigated a case study in Italy, where BIM-based validation and construction optimization has been implemented for the first time. Therefore, an IFC-based interoperable process developed for advanced model and code checking. BIM-based model checking is the process of validating the design according to various design requirements. In general, model checking is the main term which splits up into the three aspects BIM Validation, Clash Detection and Code Checking. In all aspects, a control system is established, enabling the user to perform a check on design. The checking results are either evaluated as “pass”, “fail” or “warning”, where a further attention is needed. With this system of model checking, a continuous and holistic QA-process can be established throughout all design phases with consideration on stakeholder integration. In digital design, the aim is to develop at least a semi-automatic model checking process, meaning that a rule-based checking system is established according to the project specific design requirements, automatically validating the building model. In contrast, standard validation processes tend to be error-prone, time consuming and only consider a subjective perspective. In this regard, the reviewed paper stated that these traditional validation processes are only able to validate 5-10% of the informative content of the design – instead of 60% of BIM-based model checking – resulting in constructability issues, a big amount of costly changes during the construction phase as well as to little transparency throughout the design and construction phase.[12]

Rule-based model checking is enabled by BIM tools as Solibri Model Checker (SMC), which allow to customize rule parameters according to the projects-imposed requirements. Next to enabling this customization, these tools support the development of a digital and collaborative QA-process with better checking capabilities, as long as an interoperable IFC and BCF-based data exchange environment is established within the project. During the process, it is also recommended to implement several validation checkpoints to continuously detect potential design issues, leading to an iterative process of model validation, analyzation of the results and coordinating derived remediation tasks. As described earlier, model checking is a 3-step process, starting with BIM Validation. The purpose of this step is to receive building models from various disciplines, which are all of a high quality and reliable for further data analyses. This process is also known as internal model checking, as the focus is on checking the quality, internal consistency, parametric attributed and modeling procedures and progress (LOD) of a single discipline model.

Clash Detection, the next step in the model checking process, both takes the individual discipline and collaborate model into account. Here, mainly geometrical interferences between objects are detected and investigated. SMC is also able to validate alphanumerical data as well as geometrical data, allowing to analyze the detected clashes and group the according to their severity. The main purpose of clash detection, however, is the interdisciplinary validation of design quality as all discipline models are merged into one federated IFC-model, containing all relevant information of each model. Therefore, Clash Detection, also known as collaborative model checking, is also suitable to check coordination and collaboration between the different design teams and improve decision making and task management while integrating all relevant stakeholder as the main contractor.

[12] H. Kulusjärvi (2012)

The most common application for clash detection is between structural elements and MEP systems. Due to its suitability for this study, clash detection is chosen for the hands-on experience in model checking software. Especially the coordination between the structural and MEP design offers a potential base to first detect clashes in existing IFC-models and then use the generated information to explore collaboration and coordination between those two disciplines until the issues are resolved.

The Code Checking domain is the last step of the model checking process and intends to check the compliance of the proposed design solution to local building codes and regulations. Rules are customized and derived from legal requirements at local, national and/or international level, client requirements as well as standard solutions based on best practices in BIM-based design. Examples for this code checking, based on the conformity of design parameters are window-to-floor ratio, minimum width, maximum number of steps or minimum size of landings of a staircase, or accessibility and fire prevention rules.

Concluding the impressions model checking as an iterative process, it allows to detect design issues regarding the aspects internal model validation, collaborative clash detection as well as project specific code checking. These steps are then followed by sharing the generated information with all relevant stakeholder in order to increase common understanding and coordinate task management to optimize design quality. Furthermore, BIM-based model checking enables the different disciplines to work collaboratively early in the project and avoid costly design changes in the construction phase due to early model validation. Model checking should also foster collaboration and client engagement, by using collaboration tools, to receive a consistent and functioning design based on the three consequential checking phases BIM Validation, Clash Detection, and Code Checking as early as possible.[13]

[13] A.L.C. Ciribini, S. Mastrolembo, Ventura & M. Paneroni (2016)

3. Software used for model checking:

This chapter will provide an overview for the software environment in the area of BIM modeling, checking and collaboration. The software is described with a short introduction in this chapter, while it will be explored later in the project.

Modeling	REVIT[14]

Autodesk Revit is the standard modeling software for BIM applications in the construction sector. Revit's main feature is the 3D-based model design for different discipline models as Architecture, MEP or structural, enabling a collaborative design process where multiple project contributors can access a centrally shared model. This enhances the coordination in the project, reducing the number of clashes and necessary rework. Revit is also highly committed to ensure interoperability in a building project. Therefore, different file formats as DWG, DGN, and IFC are used in addition to the Revit file format rvt. Furthermore, Revit includes a lot of different software add-ins, making it a very powerful tool to conform to interoperability standards and meet owner delivery requirement.

Checking	SOLIBRI MODEL CHECKER (SMC)[15]

Solibri Model Checker is a Finnish software application for BIM quality assurance and control, based on the open standard format IFC. Besides the overall term of quality assurance, SMC offers a broad set of features as BIM Validation, design review, multi-disciplinary coordination, model checking & clash detection, code checking, and issue management.

A building model can be imported into SMC by saving it as an IFC-file. A great advantage of SMC is the function to open multiple discipline models at the same time to create a combined coordination model for interdisciplinary model checking.

Model Checking with SMC is based on pre-defined rulesets. Rulesets consists of several rules for checking different aspects of the design. Both for each discipline model as well as the entire project. SMC provides a standard collection of rulesets for checking models. These rulesets can be reviewed and modified in the Ruleset Manager according to the project needs. Rules come with different parameters as the minimum and maximum dimensions of components, the ratio of the window area to the floor area of spaces, the maximum allowable distance of any space to the nearest exit when checking for valid escape routes, the allowable overlaps when checking for intersections between any two types of components, checking if there are enough parking spots for disabled people in a parking lot. An individual selection of rulesets can then be applied to the specific project to customize the model checking for the specific project needs. The results of the check can be reviewed individually and marked as "accepted" or "rejected" according to the project specification regarding project issues or clashes. Each clash can be recorded as an issue and communicated via the communication feature of SMC.

[14] http://www.imaginit.com/revit (17.02.2019), Autodesk Revit Overview
[15] https://www.solibri.com/about (11.02.2019),

Therefore, the detected issues can be combined in a single presentation and used to coordinate issue management. This presentation can then be exported as a BCF file. With this BCF-operability of SMC, issues can be synchronized to issue management platforms such as BIMcollab for exchanging IFC models annotated with comments, markups, etc., for collaboration. The authoring software is then used to modify the checked models according to the identified issues. Afterwards, the modified model can be updated in SMC, still keeping all unsolved issues in order to not lose track of the issue management. Furthermore, it is possible to color-code the changes to see them more clearly using a dedicated Model Revisions Comparison ruleset.

These features of SMC were also confirmed in a webinar from Autodesk, where a BIM-Manager is giving insight of his experience with Solibri. He highlights the well-functioning default rule-based model checking in Solibri, but also mentions that collaboration only with Solibri is very limited as the report structure does not allow for a good task management in order to resolve the clashes. Therefore, an additional software for this step is always needed. Furthermore, the webinar compares both SMC and Navisworks within their model checking and collaboration abilities. This is reviewed in the following paragraph.[16]

Checking	**NAVISWORKS[17]**

Navisworks is an autodesk based software with the purpose of holistically reviewing and coordinating and simulating already existing model data. Reviewing models can be performed as a collaborative process with stakeholders during the design phase in order to improve control of the project. The features of Navisworks are divided into both software Manage and Simulation. Navisworks Manage is able to aggregate different data into a single model as well as perform clash detection and model coordination. Navisworks Simulations is then able to take the model data and create a simulation of the project schedule including interaction with different objects.

The clash detection tool is able to identify and inspect clashes in the model and create a report in order to manage the identified interferences. It is recommended to either do a clash detection to complete design work or to use it as a continuous model evaluation. A benefit of Navisworks in this subject is the ability to identify clashes for both static objects in the model and moving objects in a schedule-based animation as a crane rotating through the top of a building. The workflow of clash detection in Navisworks is described as follows:

1. Start a new test in the clash detective window of the software
2. Set the rules for the test
3. Select the required items to be included in the test, and set the test type options
4. Review the results and assign issues to responsible parties
5. Produce a report of the identified issues and circulate for review and resolution

[16] https://www.autodesk.com/autodesk-university/class/Solibri-or-Navisworks-2017-0#video
[17] https://www.autodesk.com/autodesk-university/class/Navisworks-Manage-Empowering-Clash-Detection-2015

A big difference between Solibri and Navisworks is that Navisworks is able to support more than 50 file types and has a strong connection to Revit. This means, when importing a model directly from Revit into Navisworks, the imported information is way richer than if an IFC-exchange is used as it really received the same information as modeled in Revit. Furthermore, due to its Autodesk-internal approach, it is a bi-directional workflow, so if a clash is resolved in Revit, the BIM Manager only has to update the Navisworks file in order to keep track of the clash remediation. This means, that no error-prone file-format exchange and regular down- and uploads are needed.

Solibri, on the other hand only supports IFC-based models and although IFC is the standard format for the industry, a lot of data is lost during the file export as IFC is supposed to be a slim and light file type. In the hands-on experience with both software application, the suitability for the QA-process and collaboration workflow is analyzed thoroughly.

Collaboration	REVIZTO[18]

"Revizto is a real-time issue tracking software for Architecture, Engineering and Construction with a focus on collaboration and BIM project coordination"

The purpose of the software is to identify, track, and report on model-based design and construction issues in order to foster collaboration and the project efficiency in the design process. The great advantage of Revizto is its game engine implementation enabling the project members to identify and manage design clashed in 3D. The software can be used in addition to model checking software as Navisworks and Solibri for a better understanding of each issue. Furthermore, Revizto offers a task management feature, allowing the users to follow the progress of model improvement and resolve challenges in real time. In general, Revizto is a multifunctional and interoperable software application which enables the user to share, present, collaborate and edit BIM model data from various BIM software sources. This study, however, only investigates the collaboration feature (issue tracker) of Revizto. Interoperability is an important requirement when using a collaboration tool for model evaluation and therefore, Revizto works with almost every common BIM software. Besides interoperability, an intuitive interface enabling a collaborative identification and management of design issues, is similar important. By using a cloud-based and integrated platform ensures real time collaboration while being always up-to-date about the model data.

[18] https://revizto.com/en/

Issue Tracker:

Revizto issue tracker is mainly a collaboration platform, enabling the project team to efficiently organize issues, assign tasks and work responsibilities. The project will be uploaded to the cloud-based platform, where team members receive different access levels and tasks according to their responsibilities.

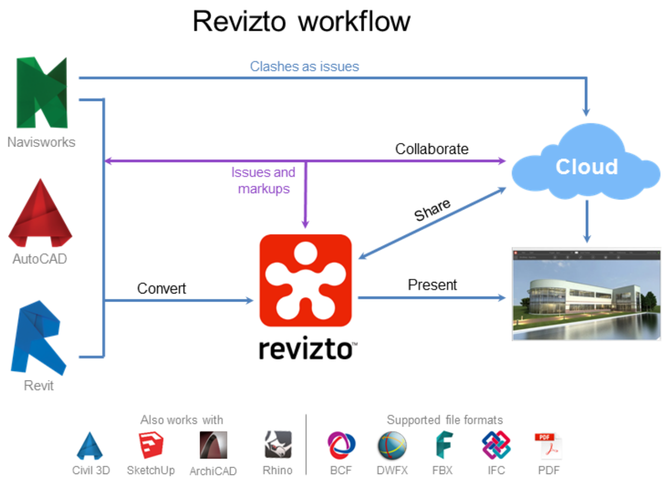


Figure 4: Revizto workflow

Issues can either be imported from Naviswork or created directly in Revizto or an add-in for Revit, Navisworks or AutoCAD. It is noted that Revizto is fully integrated in those software applications which allows to switch between the software and easily find a problem in the software, the project was created to modify it subsequently. An issue always consists of a screenshot, a description of the problem an assignee responsible for solving the issue and other parameters. When importing or exporting issues from other programs from or to Revizto, it is recommended to use the BCF-format as a mediator. This file format will be explained in the next chapter.

Collaboration	**BIMCOLLAB**[19]

BIMcollab, similar to Revizto, is a BCF-based issue management tool for Open BIM projects which is able to import detected issues and clashes from other software via the BCF-file format enabling a coordinated and collaborative issue management. This software is also cloud-based enabling collaboration and linking issues directly to specific positions and object in the model. This can be accessed again through another BIM software of the user's choice. Issues can be edited or even added in BIMcollab and assigned to a specific issue management workflow, meaning assign responsible people, deadlines and other information regarding the issue. BIMcollab issue management offers a structured way of storing, sharing and managing issues. Furthermore, BIMcollab is able to track the issue management progress by translating it into illustrative graphs and always showing the latest project activities.

Example BIMcollab workflow:

Disciplines Model is created in a BIM modeling application such as Revit and import discipline models into a model checking software as Solibri or Navisworks where the models can be combined in a coordination model and checked according to specific project specifications. The issues are then identified and translated into slides of a presentation including information data about the issue, a snapshot as well as the location of the issue.

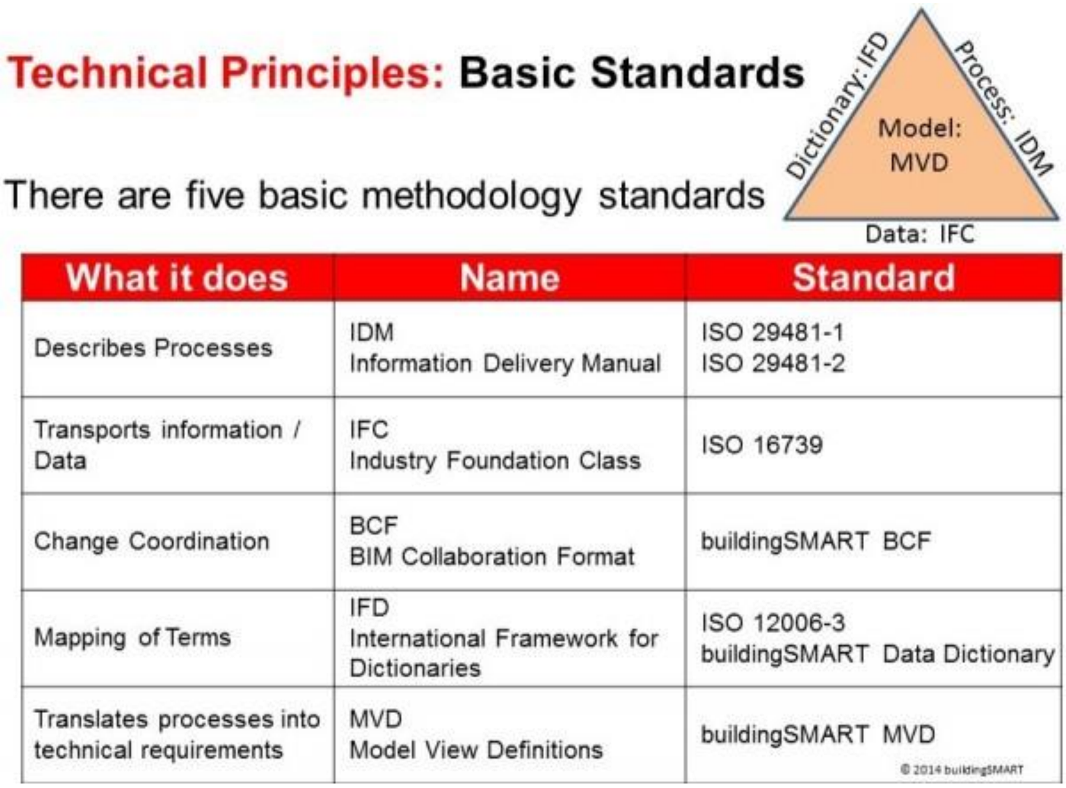
[19] Info based on: BIMcollab webinar *Master Your BIMcollab Workflow* (12.02.2019), www.bimcollab.com

For sharing the issue data, the data can be shared as an entire Solibri/ IFC model or exported via the BCF file format. The best solution for an integrated and collaborative workflow is to use the BCF connector of Solibri and upload the issues to a server linked to BIMcollab. After adjusting and mapping parameters from Solibri to BIMcollab standard (user etc.), the data can be reviewed in the web applications of BIMcollab.

BIMcollab Zoom is able to visualize the BIM model and create new issues based on the 3D-identification. In the BIMcollab interface, an activity log of all imported issues is displayed in the issue tap. The list consists of all issues identified in the history of the model from Navisworks, Solibri or other model checking software. BIMcollab is able to integrate all this data in a single software as a single source of truth. After having all issues set in the software, editing the issues and generate a task management workflow is the next step of the collaboration process. BIMcollab offers a more coordinated and collaborated way than only using the model checking software reporting function. Similar and linked issues can also be filtered and edited all in the same time, creating a lean process which reduces the effort of editing each single issue on its own. Especially assigning the issues to a responsible person. The assigned persons are then supposed to solve the issue, upload the information again via the cloud, where it can be reviewed by other team members, approving the resolution. This workflow structure enables a lean process by removing the issue of uncoordinated collaboration and blaming other parties of the project. BIMcollab summarizes the data with an issue management chart to visualize issue progress and issue coordination in the project. After the issue is assigned to the specific designer, a Revit integration of BIMcollab enables to access the issue data directly in the authoring software, here Revit. This means that all information and comments about the assigned issues for the discipline designer are present and can be reviewed and resolved immediately without a big process of issue coordination. The objects behind the issue can be directly reviewed in Revit and modified or fixed in the authored software. Reviewing the affected objects can also include a section box to see direct surroundings. In general, BIMcollab offers an interoperable solution for a holistic issue management from the identification over the coordination towards resolving issues and approving the solution.

4. File Formats:

buildingSMART is an international organization which is dedicated to allow sharing of information throughout the lifecycle of any built environment asset, between all the participants, regardless of which software application they are using. Data should be available throughout design, procurement, construction, maintenance and operation by minimizing data losses and maximizing interoperability between different applications. In total, buildingSMART generated 5 types if open standard with different functions but all with the same goal to maximize the efficiency and collaboration in building projects. All their standards are non-proprietary and neutral, meaning that no particular software vendor is favored. The following picture shows an overview of all standards and their according ISO translation, if applicable.



What it does	Name	Standard
Describes Processes	IDM Information Delivery Manual	ISO 29481-1 ISO 29481-2
Transports information / Data	IFC Industry Foundation Class	ISO 16739
Change Coordination	BCF BIM Collaboration Format	buildingSMART BCF
Mapping of Terms	IFD International Framework for Dictionaries	ISO 12006-3 buildingSMART Data Dictionary
Translates processes into technical requirements	MVD Model View Definitions	buildingSMART MVD

Figure 5: buildingSMART standards

The most important standards of buildingSMART are described below:

IFC (Industry Foundation Class)

BuildingSMART invented the file format IFC (Industry foundation class), an internationally recognized standard in the AEC industry, enabling to share data between different software applications. According to NBS, IFC is supported by around 150 software applications. This means that AEC professionals can use their favorite software application for their specific task and still be able to participate in the global trend of collaboration in the construction industry. IFC can be seen as the mediator to achieve BIM's full potential by exchanging digital data regardless of the BIM software. In general, IFC sets specific guidelines about which information is exchanges between application. Besides geometry, IFC is able to link alphanumeric information as properties, quantities and classification to building objects in order to maintain the meaning of the data.[20]

[20] https://www.buildingsmart.org/about/what-is-openbim/ifc-introduction/ (17.02.2019), IFC Introduction

BCF (BIM Collaboration Format)

The BIM Collaboration Format is a simple open standard XML format for change coordination in BIM-based design and construction processes. The format encodes messages in order to exchange workflow information and enable communication between different BIM applications. The standard was first introduced by Tekla Corperation and Solibri Inc and was then adopted by buildingSMART as an open standard.[21]

Simplified workflow communication is the main purpose of BCF, as it able to enhance the efficiency of change coordination. Before BCF was invented, exchanging issues and change requests required to exchange the whole BIM-model while the receiver had to compare multiple versions of BIM-models to filter the specific request. BCF is simplifying this process by only exchanging the data needed for workflow communication. This fosters the degree of collaboration in BIM-workflows because only the lean data and not the entire building model is exchanged between software applications. In addition to the issue information, new versions of the BCF file format are able to contain small components of a BIM model and multiple viewpoints of a specific issue. Recently, BCF also introduced the webservice bcfAPI, enabling an automated and seamlessly exchange of BCF-data information instead of the manual approach via the XML format.[22]

Treldal et al. (2016), explored this format as a mediator for task management in building design and propose an information system including both IFC and BCF. Task management is identified as crucial in order to coordinate and collaborate in BIM process featuring lean construction and other management approaches to minimize complexity in a building project. All these approaches require collaboration and thus, require open standards enabling interoperability in order to freely exchange building information. As described above, IFC is mainly used to exchange product data as geometrical and parametric information. In addition, BCF introduces process information, while still be able to contain specific parts of the product information (BIM snippets). The information of BCF is task related and includes information regarding status, type and assignee, any comments related to the task and references to related objects in an IFC model. A direct connection between BCF and IFC models is therefore possible. Especially the development of the web service bcfAPI greatly simplifies the management of BCF files in a project, as hundreds of these files are necessary for communicating tasks in a real project. With bcfAPI, a BCF server can automatically synchronize BCF tasks with others and therefore enables real-time collaboration and updates if a task is solved by a specific project participant. This reduces the need for inefficient information update requests as well as double work, as all project participants can always rely on an automated and up-to-date information flow.[23]

In case of the software BIMcollab, which is based on BCF data exchange, enables the management of workflow data in a structured way by combining all information in a single database on the cloud. This ensures up-to-date information and a continuous flow of BCF files across all project participants, resulting in an organized and collaborative process of issue management in a building project. Using BCF, information can be extracted from Solibri or Navisworks.

[21] https://www.buildingsmart.org/standards/technical-vision/open-standards/ (17.02.2019), Open standards
[22] http://www.buildingsmart-tech.org/specifications/bcf-releases (17.02.2019)
[23] Treldal, N.; Parsianfar, H.; Karlshøj, J. (2016)

5. Task management in an integrated design project via BCF:

Based on the findings of Treldal et al. (2016), this chapter explores task management in an integrated design project, its requirements and how it can be organized within the project team. Furthermore, this chapter tries to apply the finding about collaborative task management to the integrated design system of chapter 1. After the review of two model checking workflows in the following chapter, the researched information should be sufficient to have an overview about the state of art practice within this area and to derive specific challenges where further development is needed.

One area of improvement are the standard formats itself. In the construction industry, there are many types of process related tasks such as cost, risk and contract management or the management of client/user requirements. Others are site registration or responsibility interfaces. BCF for example is a standard format which addresses a specific task, include creator and responsible person, manage the status and the development of the task. However, BCF only focuses on the communication of clash detection findings or other issues but cannot not be expanded to other AEC-related tasks. Therefore, numerous other standards as the IDM Part 2 (define and manage contractual agreements) has been developed to cover all processes. In order to improve interoperability, all developed standards for task management should be harmonized into a single format, including all process information. The paper also identified several issues of different collaboration tools, including Revizto and BIMcollab, when exporting BCF XML files. In some cases, the information got lost although the software should be able to include the information, or because the software does not support the specific attribute. Therefore, interoperability is not given for all information when using an integrated approach with different software applications, as they interpret BCF files differently.

In general, the analyzed collaboration tools support general needs for task management, like information about issues, decisions and comments as well as the link to the BIM model. Task related information as assignment to a person, categorization, linking to deadlines or schedules, location and workflow management (roles, responsibilities) is currently only partially or not supported. Therefore, a closer look on the information exchange will be included when exploring the model checking workflow with Solibri/ Navisworks and Revizto/ BIMcollab. It is also interesting to investigate whether new versions of the software applications have improved by solving the claimed issues in the paper, based in 2016.

Based on the current challenges of the BCF format the paper introduces an information system for building design with the main focus on task management.

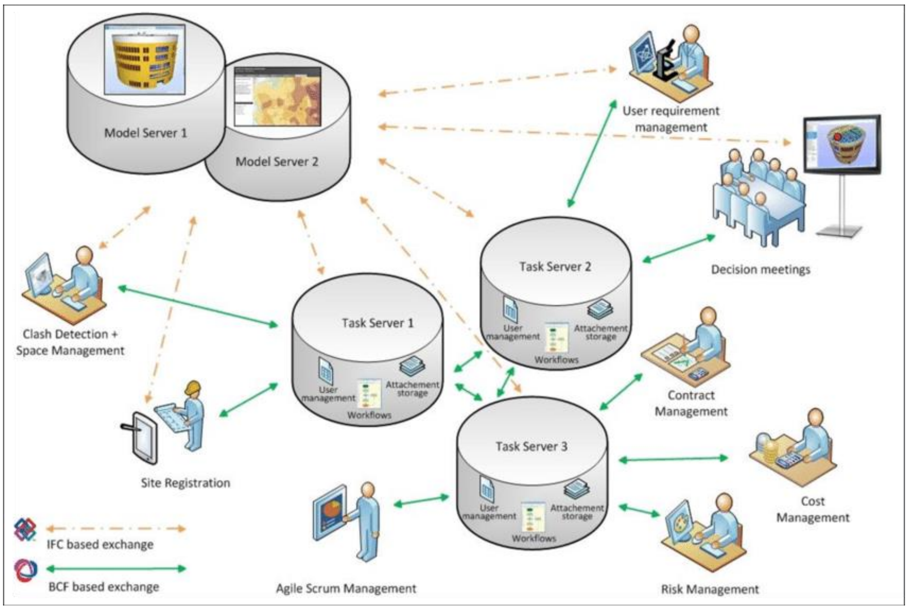


Figure 6: Information system in building design

Centralized task management server are usually the best option to be implemented in order to provide an up-to-date status of the project, enable real-time information exchange and continuous commenting as well as minimizing information losses. A central BIM server is also proposed in Oh, Lee et. al. (2015), where both product and process information (BIM Modeling & Task Management) are handled in a single source. However, this centralized server bears a challenge to manage confidential information from different project participants. Therefore, the paper rather proposes a decentralized system with one ore more model server and multiple task servers containing information about user management and workflows. Within the server, there is no need for data exchange, but as soon as information has to be exchanged from one server to another, a mediator as IFC (product information) or BCF (process information) is needed to ensure interoperability. Especially the task servers need to be accessed from different participants and therefore require user rights and workflows. However, the need for a full interoperability is required as long as information is available for reference. The web-based bcfAPI, can be used to exchange information to enable automated synchronization between the different servers and tools.

The proposed information system with decentralized servers requires a tool, which is able to query all task servers to collect specific task information. Such a tool would require the ability to identify the task as well as its location. This means that BCF should preferably use URIs instead of GUIDs as a specification of a task in order to enable that any system knows exactly where the original task is located. Along with the further development of BCF, to support a broader range of process activities in the AEC industry, these requirements need to be established in order to make a decentralized information system work efficiently. [24]

In this study, the question whether a centralized or decentralized information system is more beneficial, will be further investigated. However, there are different and project specific aspects as the contractual constellation, which influence the outcome of this question. New project delivery methods as IPD and project alliances might be a solution to overcome confidentially challenges within a project team and open up the project for a centralized solution, an open BIM.

6. BIM quality assurance workflows:

As described in the previous chapters, establishing a functioning and coordinated QA-process (Quality Assurance process) for evaluating the model quality throughout the different design phases, is a crucial requirement for every BIM-based design. It coordinates the different disciplines, gives them frequent and specific tasks or deadlines in order to always keep the model on a high quality level. An organized process including all relevant stakeholder and different inputs and outputs in a specific sequence also allows to manage the big amount of clashes, identified in an large building projects. Furthermore, the process should be developed both in a standard version as well as a project specific version. This means that the general sequence and environment for a QA-process in the integrated design should be developed in advance being flexible enough to be adapted to the specific project case with its stakeholders. As a result of the quality assurance process, the issue communication and collaboration should be organized as easy as possible to facilitate and automate the issue remediation process of each discipline.

In this chapter, two workflows from different companies are investigated and analyzed. Both companies are specialized in BIM coordination and developed a general QA-process, which is applied to their project in order to manage and coordinate issues in the building models.

[24] Treldal, N.; Parsianfar, H.; Karlshøj, J. (2016)

a. NIRAS

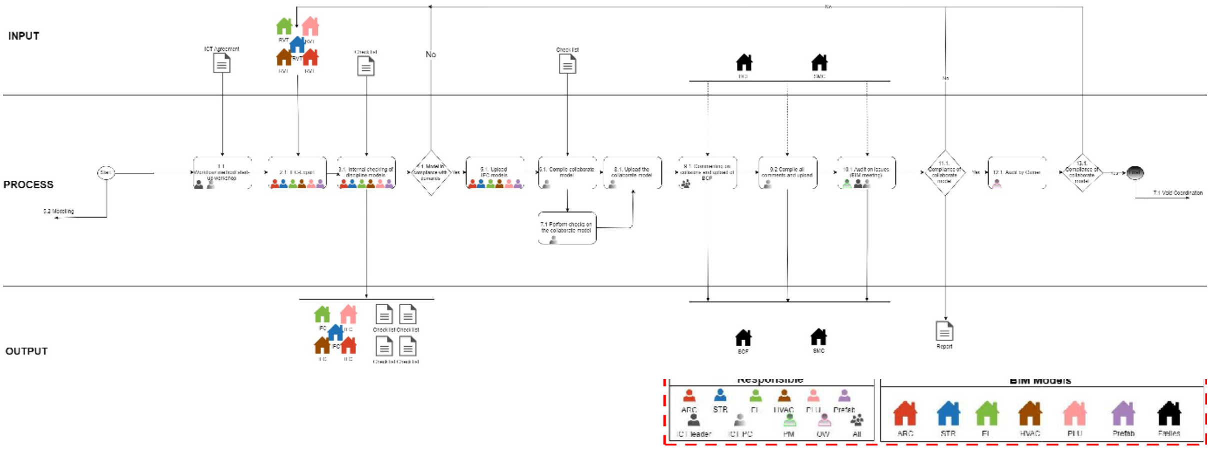


Figure 7: QA-process of NIRAS (Appendix 1)

The QA-process of NIRAS comprises three different levels, the process of model checking and issue coordination itself as well as inputs and outputs of the process. Furthermore, the process includes all tools and especially people involved in the project. Including all relevant stakeholders in the process allows to assign responsibilities and coordinates different tasks during the process. The QA-process or consistency control process includes all required steps to be able to approve the quality of the building models. The generic workflow is then translated into an iterative QA-loop plan when applied to a project. At first, the workflow will be analyzed, followed by the explanation of the QA-loop plan.

Before the workflow can start, the ICT leader and project coordinator (ICT PC) have a workshop in which the QA-process is reviewed, a method is defined and adapted to the project specifications. This workshop is based on the ICT-Agreement of the project. This agreement is signed by all participants and defines all requirements regarding information and communication technology, especially digital collaboration in the project. When the start-up workshop is held and the method of model quality assurance for the project is selected, the process starts straight after a specific design stage has been achieved. All disciplines (architecture, structural, electrical, HVAC, plumbing and prefabrication) will export their Revit models into the IFC-format which allows them to internally check the discipline models with software like Solibri, or Navisworks. In order to quantify the quality of the models, NIRAS developed a checklist for the model checks, where the disciplines are supposed to document the quality of the model according to general and project specific requirements. The checklists (see **Appendix 2**) for the discipline models contain information about an initial revision (model name, shared coordinates and grids), continuous revision (classification or level of) as well as information about discipline model clash assessment. As a result of this internal discipline model checking, the IFC models as well as the checklist for each discipline are provided. After this step, the first gate in the process follows. If the models are in compliance with the set requirements of the checklist, the IFC models are uploaded to the project server. If the model does not meet the requirements, it has to be modified until all discipline requirements are met. These requirements mainly concern whether the disciplines used the proper Revit-template, the proper naming convention or element definitions as well as internal clash assessment. After the upload to the project server, the ICT project coordinator creates a collaborate model out of all disciplines (e.g. with Solibri). Based on this collaborate model, model checks are performed, identifying all interdisciplinary issues. Therefore, it is crucial that all the models meet the basic requirements before they are uploaded for the coordination checks. Note that all discipline models should be equipped with a location parameter to enable location-based collision control. This breaks the process of collision control in enhanced and eatable chunks instead of getting overwhelmed by the bulk of issues.

Then, all parties involved in the process have the chance to comment on the identified collisions. The generated and commented issues of the collaborate model are then exported either as a SMC-file, consisting of the entire model or a BCF-file containing all issues with basic information. Using BCF, the issue management can be managed without the need of big data transfer, as it only contains the information needed to start the task management process of issue remediation. Compiling all comments and uploading them on the project server is again the responsibility of the ICT PC.

With the created information about all issues including the expert comments, a BIM meeting is held with the Project Manager, the ICT leader as well as the ICT PC. The purpose of this meeting is to establish an audit on the identified issues where issues can be categorized according to heir relevance or priority and again evaluated according to the project compliance. After this assessment of the collaborate model, a report is generated in order to inform about the findings. Again, if the collaborate model is in compliance with the requirements, the process proceeds with the next step. If the model, however, does not meet the requirements, the disciplines have to solve the identified issues. The next step in the process is an audit by the owner, where he is able to review the building model and evaluate the compliance from his perspective. After the owner gives his approval, the QA-process of NIRAS is determined and proceeds with a void coordination.

If the model does not meet the requirements in the collaborate model checking, the model goes back to the disciplines as the whole workflow is based on a iterative issue management and remediation process. In this case, the file format BCF is used to manage the process because it enables to assign specific tasks to responsible disciplines based on the identified issues. It also allows to track the progress and automates the issue remediation via the cloud-based application. Furthermore, all comments regarding a specific issue are included and can be traced back within the process, providing a reliable information flow within the issue management. Another advantage is the ability to review the issues in an audit via a 3D-walkthrough or even VR-environment to facilitate the collaboration. Software applications enabling this issue management are Revitzto, Solibri or BCF-manager.

This consistency control process enables to understand the workflow from receiving a unreviewed model towards a model which is in compliance with all project specifications. In order to apply this process to a specific project and ensure high quality models throughout the design phase, the consistency control needs to be translated into an iterative process on a weekly or semiweekly basis. Depending on the specific project, the actual layout of the loop plan can be adapted but in general, the following sequence should be followed in order to apply the consistency control process. On the first day of the loop, all discipline models should be uploaded to the project server. Then, the ICT leader compiles or updates the collaborate model, performs collision checks and uploads the Solibri Model Checker (SMC) file including the information about all collisions. After this has been done, the disciplines are able to comment on the collisions, specify the time of collision remediation and re-submit the upload. Based on this, the ICT Leader generates a report with all pending collisions which will be discussed in the BIM meeting. In the BIM meeting, all open collisions are reviewed and the decisions are sent out to the responsible disciplines to correct the collisions. After the BIM meeting, the discipline should have some days to correct the identified collisions before they prepare the models for re-exporting on the project server, so the process loop can go on.

NIRAS mainly divides between the responsibilities of the individual disciplines and the ICT PC/ BIM Manager. Here, each discipline is responsible to ensure the quality of their model through the consistency check. The BIM Manager is responsible for identifying and communicating the interdisciplinary collisions. He also defines and adjusts the rulesets enables to incorporate locations for the clashes and exports a summary report for the collision control.

b. Drees & Sommer (D&S)

Drees & Sommer also established a BIM collaboration process for a building project with ROCHE in Switzerland. This process is also reviewed in order to compare both processes in the end and derive challenges and opportunities of a QA-process within an integrated design approach.

The workflow of Drees & Sommer focuses on the application of the collaboration tools Revizto and gives a detailed overview what requirements have to be met from each discipline at what time in order to have an efficient model checking process. The tools, suggested in this process are Revit for design, Solibri or Navisworks for the collision checks, revizto for the management of issues and tasks as well as the navigation through the model (see figure 8). As in NIRAS, the discipline models are compiled in a collaborate model. The collaborate model is updated after each iteration and synchronized via Revizto. In general, the workflow of D&S is comparable to the process loop from NIRAS as it resembles an iterative process with the goal to identify and coordinate collisions in a continuous and collaborative manner between the project participants.

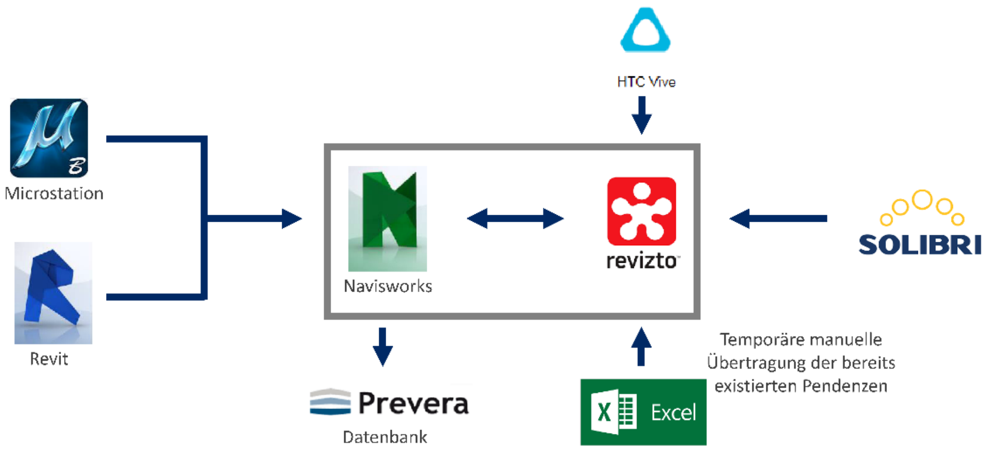


Figure 8: Software integration in the QA-process of D&S

After the collaborate model is synchronized to Revizto, the model is checked for collisions and analyzed via the Revizto cloud. Clash detection and identification of clashes can be made with Solibri, Navisworks or directly with Revit by all stakeholders. However, the identified issues are only reviewed in Revizto, meaning that only one cloud-based software application is used without the need to error prone data transfer after the clash detection. Furthermore, a continuous issue tracking and adjustment can be performed directly in Revizto, making it a lean and simple coordination process. The ability to see all issues in a 3D-model view or even VR also facilitates to understand issues and allows the project participants to decide upon the relevance and priority of the issues in order to identify urgent collisions to be resolved immediately. If the participants identify a new issue during their 3D or VR-review, Revizto enables a direct issue creating in the software. After the model is analyzed, a digital issue coordination enables to assign the issues to the relevant stakeholders and starts the collaborative task management for problem solving. Additionally, this process generates a report which contains all comments regarding the identified issues in Revizto.

D&S also assigns general responsibilities and tasks to the project participants to clarify crucial tasks and enable an efficient BIM collaboration process.

Disciplines (Architect/ Engineers):

- In time upload of their discipline models
- Active support in the BIM collaboration and clash detection
- Active collaboration in the issue management and remediation

BIM-Coordination:

- Providing the of the up-to-date collaborate model
- Synchronize collaborate model with Revizto-model
- Collision checking in several software applications
- Review of the collisions only in Revizto
- Follow up on pending issues in Revizto/Navisworks
- Identification of most relevant and urgent issues in order to be resolved
- Document all findings and information by generating a regular report after each iteration

An interesting fact derived from a short interview with an expert from Drees & Sommer is that the intention of using this quality assurance process for Drees & Sommer is mainly to increase transparency and client engagement in the design. This means, that collaboration in model checking does not necessarily require an integrated design approach, although BIM-based quality assurance and collaboration in the project are also strongly correlated.

Reflection:

The QA-process of NIRAS resembles a holistic workflow including most relevant stakeholder involved in the integrated design. Especially the fact, that also prefabrication is an individual discipline in the process shows the innovative and lean approach of the process. Furthermore, having several gates, the model had to pass before the quality is approved, allows to include several iterative processes and ensured that the models meet the required quality level. It also provides a clear method, understandable by all involved parties and coordinates them through the consistency control process. However, a few issues have been identified, which will be described below and further elaborated in a later stage of this study.

- The process does not mention specific software applications for model checking and issue coordination. File formats are included, but as described in the previous chapter, different software applications handle file formats differently. It could be beneficial to mention example software for each step of the process, e.g. Solibri for model checking and Revizto for issue coordination.
- Also not included is any information about the development of project specific or code specific rulesets in order to check the models. NIRAS developed the checklists, but it is unclear whether they are representations of the model checking rulesets. The definition of the rulesets could also be part of the ICT agreement, but the rulesets should be at least reviewed and updated in a regular basis. Basically, the rulesets are derived from the project requirements of the owner and legal aspects and a process would be beneficial which is able to define/ modify the rulesets and trace them back to their origin, providing a consistent and understandable information flow.

- NIRAS specifies that the purpose of the process is to check the digital quality of the model, not the technical buildability of the model. It could be interesting, however, to include a contractor or building expert into the design phase as well to integrate the buildability aspect as early as possible.
- In general, the process could include more stakeholders in specific steps than the owner and disciplines. Early integration of the future user, facility management and contractors can be crucial to develop a holistic design with little digital and future physical collisions.
- The BIM meeting is also only held internally with the Project Manager, the ICT leader and the BIM Manager. It might be better to have a collaborative meeting (co-location) with all parties involved. All project participants should be able to include their opinion and expertise how to solve the issues and decide upon the relevance of each issue.
- Detailed workflows should be established for specific tasks in order to understand what is happening in the critical steps of the QA-process (as the BIM meeting or correction of the issues if the model does not comply to the project specifications).

The process of D&S comprises not the same level of detail as the QA-process of NIRAS, however it includes some interesting aspects, which are relevant for an integrated design project. First of all, the workflow clearly demands the use of Revizto as the central model for BIM Collaboration. Other software might be used for model checking, but all information is reviewed and coordinated through the cloud-based application. Generally, the process also contains the three main steps of compiling or synchronizing the collaborate model, issue identification and issue coordination/ remediation in an iterative process. It also includes different milestones or gates for the process and clearly defines the different responsibilities of the parties, although there it does not distinguish between the designer/engineers. Especially the overview about possible software applications (with focus on Revizto), adds value to the process in a way that every discipline better understands the process. On the other hand, the process only shows a superficial and little holistic overview of the entire QA-process. It is for example unclear where the discipline model checks are performed and by whom. Then it is not mentioned who is participating in the coordination meeting and how the task management is organized after the issue identification.

Therefore, a combined workflow with suitable input of both processes as well as findings from own experience, expert interviews and the literature review is a chance to improve an existing process or define a new holistic workflow for an integrated design approach.

7. ICT Agreement and Danish building norm (bips C402 Konsistentkontrol)

The ICT agreement is a sort of contract that is defined and signed in the early stages of the design by the different participants of the building process, especially between client and designers. This document regulates everything that concerns the information about the design, the communication between the participants (deliverables, information transfer, coordination, etc.) and the technology used during the design (software, communication and sharing platforms, etc.). The ICT agreement is divided into 8 chapters in which the project participants document all relevant aspects regarding information and communication technologies in the project:

- General information about the building, the project and the responsibilities
- Chosen classification system and its purpose
- **Digital communication**
- Establishment of communication platform
- **Digital design and building model management**
- Digital tendering and procurement
- Bill of quantities and its description
- Digital delivery

With this layout, the ICT agreement allows to establish a common sense on how the construction project is managed digitally. Both highlighted chapters are suitable to integrate requirements and information for the collaborative QA-process and therefore, the ICT agreement provides a legal-binding contract which acts as a framework for the digital construction. Especially the legal aspect is very important, as it establishes a standard which has to be followed by all parties involved in a project.[25]

In addition to the ICT agreement, the Danish trade organization bips developed the standard C402 – Consistency Checking in Building Models including best practices of the industry. This standard provides guidance in the application of BIM based quality assurance and supports all necessary steps with examples of working methods.[26]

Having both the ICT agreement as well as the C402 standard, the Danish construction industry removed a lot of barriers in the conservative construction industry for the change towards digitalization. Hence, the industry has set up all needed requirements to enable digital and collaborative approaches as the QA-process. What is still missing is a framework or workflow which integrates all relevant aspects as people, processes and technology into one system for quality assurance in BIM-based design. Hence, this study tries to develop such a holistic workflow providing a simple overview about the integrated system that all parties in a construction project understand and are able to follow.

[25] https://www.bygst.dk/english/knowledge/digital-construction/the-ict-regulation/

[26] C402 Consistency Checking of Building Models (in Danish: C402 Konsistenskontrol af bygningsmodeller), bips, September 2016

Reflective Report 2
Hands on experience on model checking software

In this section of the study, model checking will be explored by applying clash detection tests with SMC, Navisworks. In the process perspective, this means going through step 2 to step 8. First, two discipline models (Structural and MEP) are exported and checked individually for internal clashes. The application of model checking is reduced to clash detection as the focus is set on the collaboration aspect and clash detection offers a simple and good way to explore the identification and management of issues in a BIM-based design process. After the internal check, both discipline models will be combined in a collaborate model, where the model is checked for clashes between both disciplines. In the end of this process, the identified issues will be documented and exported as a BCF file in order to start the collaboration process and task management. **Appendix 2** shows the respective software integration for this and the next chapter.

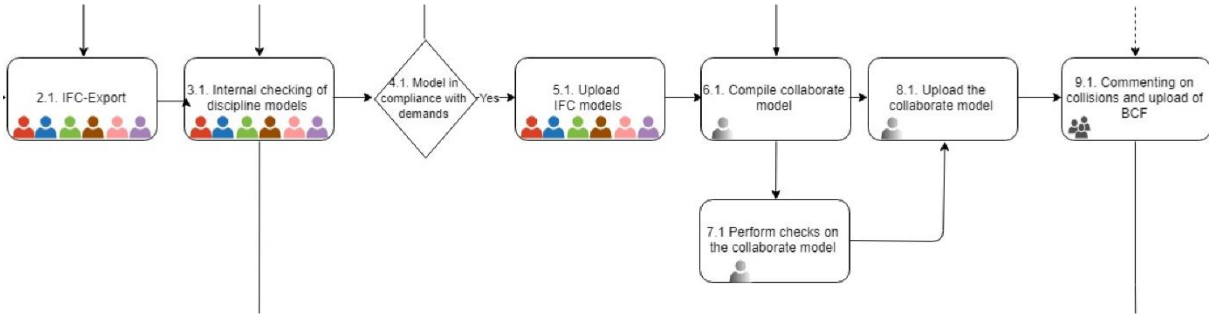


Figure 9: Model Checking in the QA-process

The model, which is used in this study is a medical clinic model, published by the national institute of building sciences (NIBS) and is described as a common BIM-model which can be used for educational purposes.

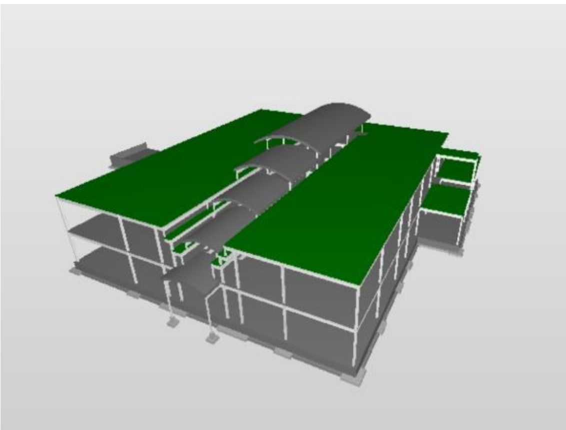


Figure 11: Structural Model (Solibri)

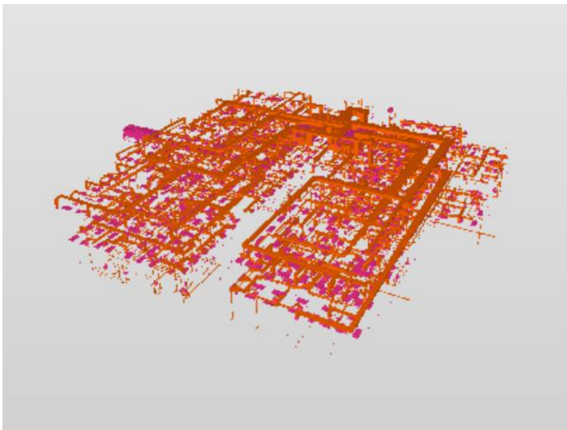


Figure 10: MEP Model (Solibri)

These models will be used to go through the process shown above. In order to reflect on the given QA-process in an early stage, the process has been reviewed and first implications were developed. Based on the literature review as well as regular meetings with Salman Pey from NIRAS, the following three-level QA-workflow for model checking has been derived, which adds an initial step to the given QA-process.

1. **Discipline Modeling**: A continuous reflection upon compliance with other discipline models need to be set up in the early modeling stages of all discipline designer in order foster interdisciplinary thinking and establish collaboration as early as possible. The disciplines are highly influenced by each other and in order to reduce the amount of produced clashes in the first place, every discipline needs to be aware of the overall project and each discipline. Therefore, clear communication of the project goals as well as workflows for each project participant with interdisciplinary relations is a crucial step in the project setup. In this case, a checklist (**Checklist 1**) will be developed to ensure quality assurance during the early modeling phase. It is the responsibility of each discipline to regularly submit the checklist to the BIM Coordinator. Regular compliance reflection can either be done directly with Revit by underlaying other discipline models as linked files using Revits on clash detection features or add-ins as MagiCAD, allowing for live clash detection. A suggested frequency (if live clash detection is not chosen) would be after modeling a specific section or floor in the model. Here, only the actual model checking is reviewed as the used model is already designed and only allows for post-detection and no live detection. The principles how discipline modeling should be performed with a QA-perspective in mind, however, will be reviewed later.

2. **Internal Model Checking**: The first level is supposed to reduce the number of modelled clashes in each discipline model, while the purpose of the second level in the QA-process is dealing with already existing clashes which need to be resolved. After a defined period of modeling, when entering a new design phase or finishing a part of the model, the model is checked internally with a more elaborate model checking software as Solibri or Navisworks. As this step requires an export from the modeling file to IFC (at least with Solibri), it is reduced to only the necessary frequency for the QA-process but due to each discipline's awareness for each other's work, this should be sufficient. After each period, the disciplines have to fill out a checklist (**Checklist 2**) again validating the internal quality of each model.

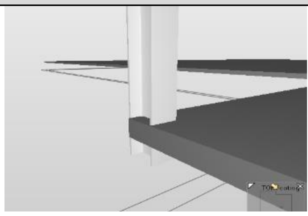
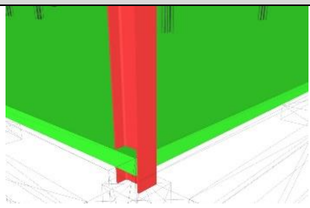
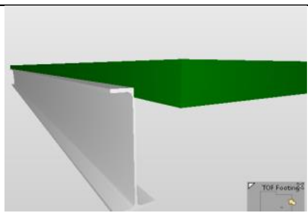
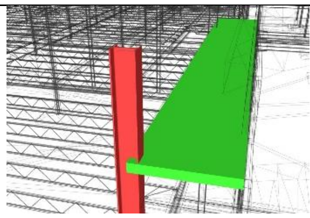
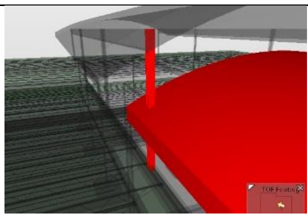
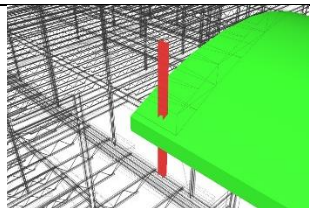
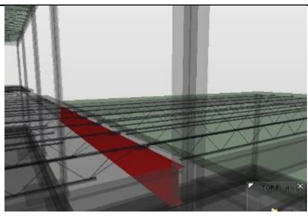
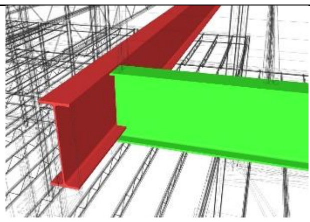
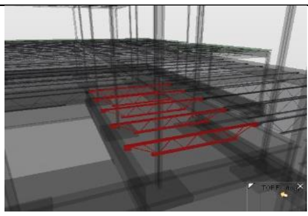
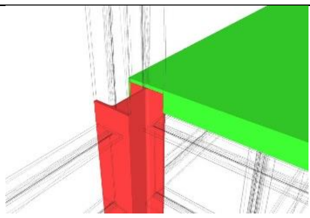
3. **Collaborate Model Checking**: Similar to level two, collaborate model checking also requires an export of the model data into a checking software. This time however, it is the responsibility of the BIM Coordinator to compile all validated discipline models into one collaborate model and check it for interference between the disciplines. This is coordinated with **Checklist 3**. As the number of clashes both internally and interdisciplinary is significantly reduced through the first two level of the QA-workflow, the BIM Coordinator can focus on applying specific rulesets and identifies a more manageable number of clashes compared to current approaches where clash detection can easily result in more than 1.000 clashes.

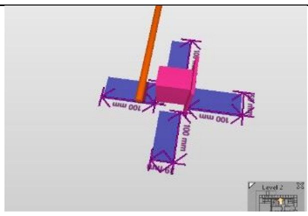
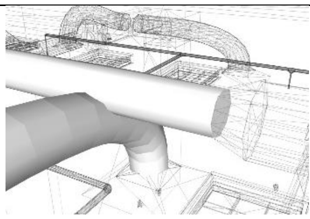
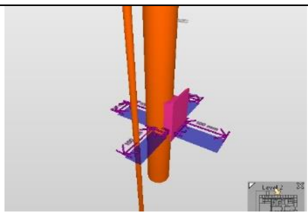
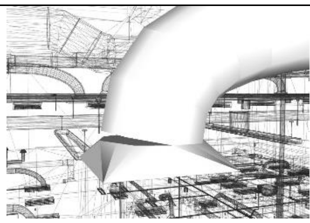
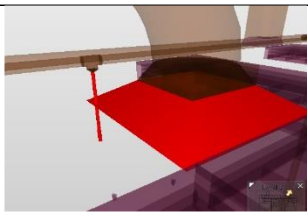
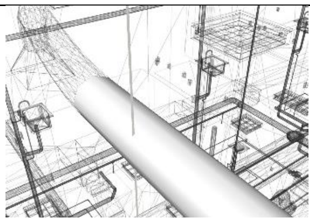
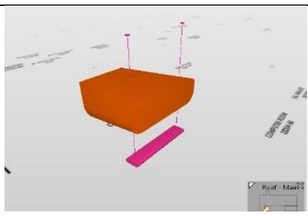
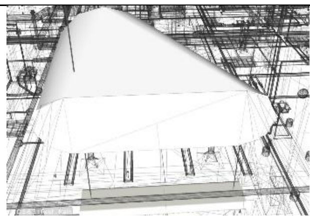
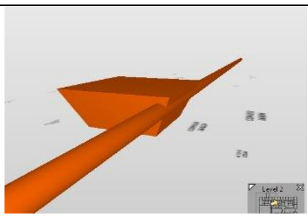
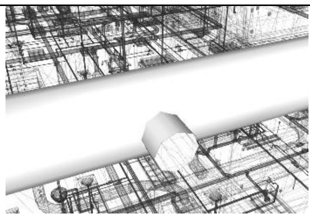
The following review is now including the internal model checking as well as the collaborate model checking, resulting in the identification of numerous clashes for each discipline and each step. To keep the number of clashes manageable, only the most critical issues are selected and taken into consideration when it comes to collaborative task management in the next reflective report. Therefore, 5 issues are selected for each discipline and the collaborate check (in total 15 issues).

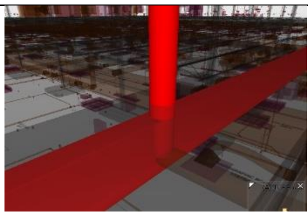
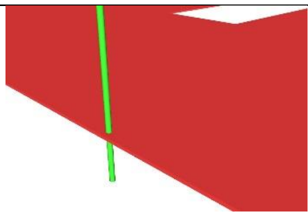
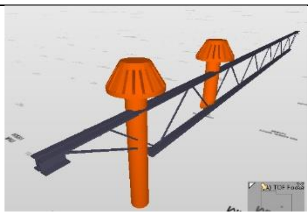
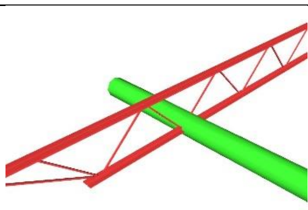
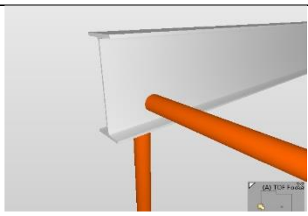
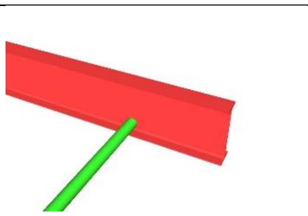
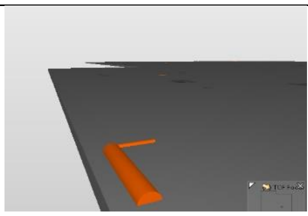
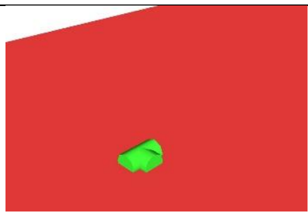
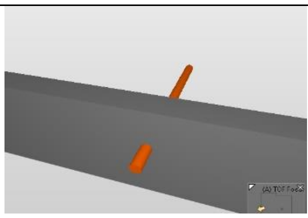
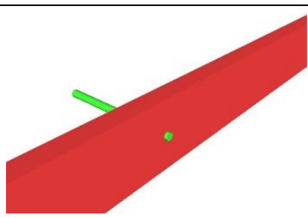
First of all, the model is checked internally. Internal issues in the model might be intersections between predefined objects, like air shafts or water pipes and beams and columns. Other issues might be based on geometrical properties or location, e.g. if the height-thickness-ratio of a wall is not acceptable or if the wall requires a defined "opening in wall" for other components. Furthermore, the internal check will identify doublets of components due to errors of under-drawing, e.g. two identical windows in the same location.

After this check is done with both models, they will be compiled in a collaborate model in order to check the models for interdisciplinary compliance. Here, the focus is clearly set on clashes between the disciplines regarding object intersections or clearance around specific objects.

All results of the model checking exercise are documented in **Appendix 1**, while a short reflection on each application is given below.

Type of Check	No. of Clashes Solibri	No. of Clashes Navisworks	Comment
Internal Structural	**340**	**308**	
Clash 1			Steel columns penetrating the floor slab. Connection to be specified.
Clash 2			Structural component (beam/ columns) interfering a roof element. Connection to be specified.
Clash 3			Supporting column of the upper roof is penetrating the lower roof. An opening has to be created by the structural engineer.
Clash 4			Two beams are interfering (right) or a doublet has been identified (left). To be modified by the structural engineer.
Clash 5			Property value oft he beams (left) to be modified and connection to be specified on the clash to the right.
Internal MEP	**132**	**821**	

Type of Check	No. of Clashes Solibri	No. of Clashes Navisworks	Comment
Clash 1			Too little distance from ventilation outlet (left) and interfering ventilation pipes (right). To be modified by MEP engineer.
Clash 2			Too little distance from ventilation outlet (left) and wrong connection between pipe and outlet (right). To be modified by MEP engineer.
Clash 3			Vertical pipe interfering with horizontal HVAC object. Small pipe to be moved around the bigger object.
Clash 4			Light fixture suspension is going through ventilation pipes. Fixture to be modified to the pipe locations by the MEP engineer.
Clash 5			Interfering pipes. To be specified whether the pipes are connected and need an opening or pipes need to be moved apart.
Collaborate	**1.193**	**940**	

Type of Check	No. of Clashes Solibri	No. of Clashes Navisworks	Comment
Clash 1			Vertical pipe is penetrating a beam (left) or the floor slab (right). Either an opening need to be created or the pipe location needs to be adapted.
Clash 2			Ventilation/ water pipe is going through a braced beam. Pipes to be moved through the openings of the beam or objects to be separated.
Clash 3			Pipe is penetrating a steel beam. If possible, an opening can be created, or the pipe needs to be moved down or up.
Clash 4			Pipes are embedded in floor slab and need to be lifted to lie on top if the floor slab. To be modified by the MEP engineer.
Clash 5			Pipe is penetrating a wall horizontally. Either an opening in the wall needs to be created or better the pipe is moved to not interfere with structural objects.
Total	**1.665**	**2.069**	

Solibri

In order to use Solibri as a model checking application, the models need to be exported as an IFC-file and imported to Solibri. Although the IFC-file format is characterized by its interoperability features, there is still a risk of information loss during the export. Furthermore, a real time clash detection with Solibri as an add-in for Revit translating data in the background would be more efficient than importing and exporting the file manually. Considering the state of art in the construction industry, the IFC-approach is still a good solution for using the modeling data.

In general, Solibri has a great advantage of having default rule-sets already established as a standard in the software. These rule-sets can be modified and adjusted to the project specifications and design stage, as the concept design does not require as detailed and precise rules as the detailed design. The default catalogue of rules is well structured and the user can select different options depending which models are checked. The results are then organized in a breakdown structure, which makes it quite structures but also reduces the ability to quickly look through the clashes. When it comes to reporting, Solibri offers options to export a report as a BCF file, HTML or and Excel table, containing all information about the identified issues. Especially the BCF-option enables the user to use the information of each issue to facilitate the process of resolving the issues.

Reflection on suitability for collaboration:

- BCF-file export enables the responsible discipline to directly use the information of each issue in their modelling software as Revit. Via the add-in BCF manager, the BCF-file is imported into Revit which allows the user to simply click on the issue to be navigated to the location in the Revit file.
- Furthermore, a direct link to BIMcollab is possible, reducing the risk of data loss through BCF-file exports.
- Manually reviewing a created clash detection report and modifying the model according to this hard copy is error prone and time consuming. By integrating a BCF-file export, Solibri offers a powerful issue management workflow from the clash detection to the clash remediation.
- The interoperability of each software application is a great facilitator in integrating different disciplines into the issue management process as is enables a continuous information flow without the need of time consuming reviews.

Navisworks

After using Solibri and the IFC-workflow, the aim was to keep the IFC-based workflow and import the IFC files in Navisworks as well. Although, Navisworks is supposed to support IFC-file formats, the program always stopped working when I tried to import both discipline models. Then I found out that Navisworks is able to directly use the modeled data as a Revit file. Using a rvt. file, Navisworks worked out quite well and did show all information modeled in Revit avoiding any risk of losing data. This is a big advantage as it enables to evaluate and validate all data of the model and not only a slim IFC-version. On the other hand, Navisworks does not include rule-based model checking and only allows to do clash detection between predefined search worksets. It is still a good way of identifying clashes but cannot compete with the model checking capacity offered by Solibri. In the previously mentioned webinar, the user applied a add-in software called collaborate in order to also include rule-based checking as well as collaborative issue management with Navisworks. When using Navisworks for geometrical clash detection, it is crucial to select the sets to be checked properly as otherwise, Navisworks identifies a not manageable number of clashes. The reason for that is, that Navisworks clash detection is only based on geometrical interferences and does not take into consideration different object specific parameters as type, characteristics and requirements. The report option in Navisworks only allows to export a HTML report which can be considered as a hard copy. Only if BIM360 is enabled in a project, a direct link between Navisworks and Revit can be created via the cloud system. As there is no student license available for using BIM360, this option is not subject of this review. In conclusion, Navisworks offers a simple clash detection option but the strengths of Navisworks definitely lie in aggregating different information as models, costs and time schedules and creating building simulations. Clash detection is only a minor feature which is sufficient for identifying geometrical clashes. It is also possible improve the model checking capacity by defining own rule-sets or using an interoperable issue management workflow but it requires new software supplements (Collaborate or BIM 360) and therefore, Navisworks does not offer a all-in-one solution as Solibri does.

Reflection on suitability for collaboration

- Navisworks itself does not allow much collaboration after the clash detection has been performed as the report can only be exported in limited file formats.
- The collaboration capacity of Navisworks can be improved significantly if using an additional application as BIM360 or Collaborate. Furthermore, Revizto should enable a cloud-based link to Navisworks and enable a collaborative task management of the identified issues. This will be reviewed in the following report.

Internal issue remediation using BCF-Manager:

When the disciplines check their models for internal clashes, it is obviously also their responsibility to remedy the identified clashes on their own. Although only the same disciplines are involved some organizational structures still require handing the issues to another person, who will then modify the model. Therefore, it is important to also have a consistent information flow within one company. Solibri provides this flow by generating a BCF-report including the clashes, which can be easily transferred to Revit using the BCF-Manager.

Navisworks on the other hand, does not allow to create a BCF file. Hence, its capacity to create a consistent information flow is quite limited. As mentioned before, Autodesk has its internal BIM360 cloud service, which enables to transfer clash information to Revit. The other option is to manually extract the information from Navisworks with a hard copy of a report and try to find the clash in Revit afterwards. This approach, however, is very time consuming and error prone when dealing with high complex buildings.

Early Integration of Quality Assurance:

While reviewing the given quality assurance process from NIRAS, a lack of early awareness of other disciplines and quality assurance consideration has been identified when the design is started, and different disciplines are integrated subsequently. In order to implement this early integration of quality assurance, two different approaches are introduced which allow the project participants to reduce the number of clashes and issues in their models as well as provide a consistent and continuous information flow from the early establishment of client requirements. The first approach is using linked data to create a location where all project stakeholder can put in their requirements, e.g. client requirements are included as basic rules to follow and are then translated into functional requirements for building systems followed by deriving solutions for specific building units based on the functional requirements. In this case, each discipline can, depending on the project phase, define their requirements and the effect of these requirements to other disciplines. This does not only allow for a continuous information flow in one central location but also allows the disciplines to easily receive limitations and interdependencies of their model regarding the other disciplines.

The second approach has already been introduced earlier as the first step of the model checking and will be investigated more in detail in the following paragraphs.

1. Linked Data Approach

Linking data and improving interoperability between different data sets from linked data communities highly increases the capabilities of building information modeling. By making all relevant data available to the project participants, the project benefits from a more profound and integrated decision making throughout the life cycle of the building, especially including the design phase. Data cannot only be integrated from the discipline designers in the project, but might also include building code regulations for different systems based on local regulations, localized data on new cheaper building materials, energy efficient building devices and systems, as well as real time data on weather patterns, energy prices and geodata.[1]

Törmä (2013), however argues that the main benefit of the Linked Data application in the construction industry is still the integration of discipline model information, enabling interdisciplinary information access from an early design stage, status monitoring and change management. As discipline models are basically different perspectives on the building, the models are all interrelated. Thus, the goal of linked data is to map out this interrelation, define requirements from the disciplines in relation to each other and manage the interdisciplinary workflow to develop a complete and functional building. Sorting out these overlapping areas between the disciplines as early as possible will significantly reduce potential problems and redesign in later project phases. Therefore, decisions can be made as early as possible with expertise data of all disciplines. The goal is to make decisions when they have the most impact and least cost. This is much more likely to be achieved an integrated approach supported by Linked Data, as logical relations between data information are created. The relationship between the ability to change and the costs of changes is graphically illustrated in Figure 1 with the MacLeamy curve, based on the Integrated Project Delivery (IPD) approach. The degressive curve (1) represents the possibility of influencing costs and functional capabilities. The ascending curve

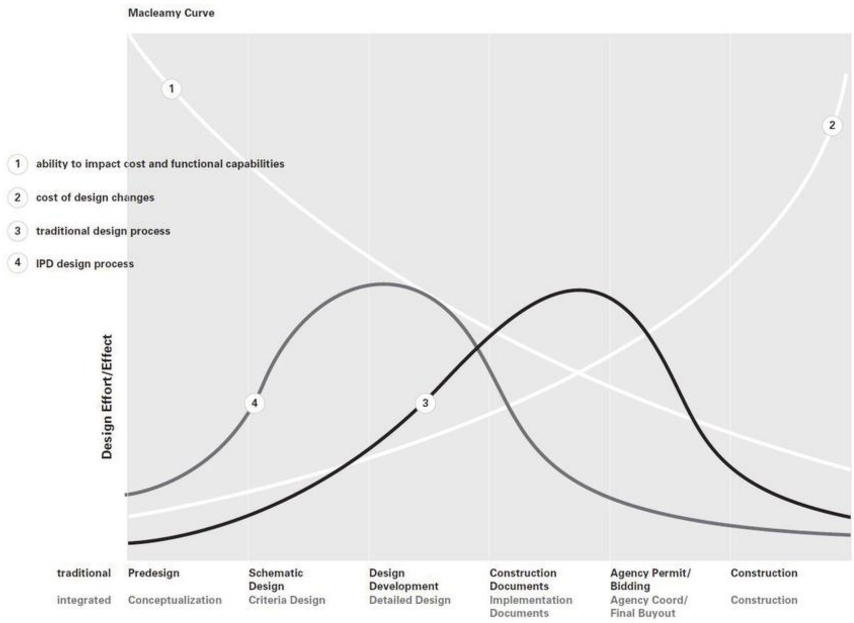


Figure 12: MacLeamy Curve

(2) shows the costs incurred by design changes in each phase of the project. Early planning according to the IPD model including an interdisciplinary information management (4) allows a better use of the course of both curves compared to traditional models (3).[2]

[1] https://www.w3.org/community/lbd/

[2] AIA (2007)

Linking data between disciplines in a project can be established in different levels. Model links can be created to create reference models which can be displayed in the background when modeling another discipline model, e.g. using the architectural model as a reference model, when modeling the MEP design. The relationship can be defined as *sequential*, meaning that one model receives information from another to complete its design, or *parallel*, meaning that conflicting decisions are made on a case to case situation. Furthermore, as these relationships are predefined in a project, they set the rules for instance level links and cross-model information access between specific objects in the models. An example for such an object-based link is e.g. the location of a radiator. The MEP object contains requirements as to be located within a space and preferably below a window. This information can be extracted from the architectural model, defining where a space between walls is created as well as identifying the location and geometry of a window. By establishing centrally stored linksets in a BIM-based design, a network of interdisciplinary relations on different levels is created and serves as a single point of truth (see Figure 13), where all information and requirements for each design can be reviewed and continuously updated according to the project (design) phase.[1]

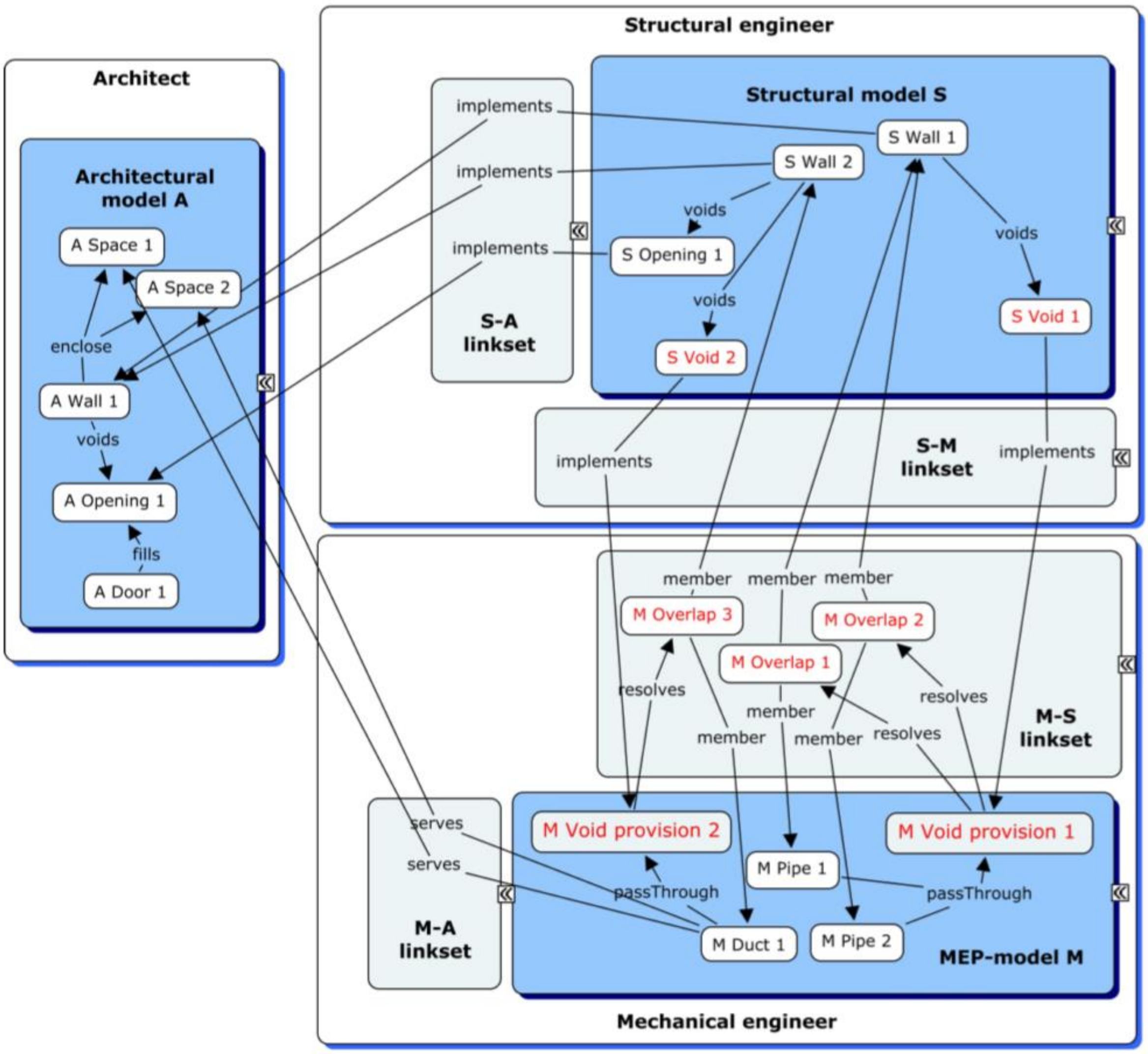


Figure 13: Linked Data relationships between discipline models

[1] S. Törmä (2013), p. 1 ff.

As figure 13 shows, all objects, spaces and other information of a building model can be linked to an interrelated model. For linking data in BIM, the construction industry developed two approaches with the IFC file format of buildingSMART and the Linked Data approach. The main difference between both approaches is that Linked Data is able to also apply a query language to define relationships in addition to a predefined system consisting of a schema, datasets and identifiers. This means that objects cannot only contain specific properties but also relationships to other instances.

Using linked data in BIM-based projects enables to create a centralized linksets where all disciplines and project stakeholder can include their requirements. Client requirements can be set as basic rules to follow and are then translated into functional requirements for building systems followed by deriving solutions for specific building units. In this case, each discipline can, depending on the project phase, define their requirements and the interrelation of these requirements to other disciplines. This leads to a continuous information flow in one central location as well as allows the disciplines to easily link their datasets and understand their relationship with other disciplines. Therefore, Linked Data is a tool to set up a quality assurance system in BIM-based design in early stages of the design but also allows to continuously use the system to update the data throughout the building life cycle.

An example of how this linked information can be beneficial in the early design stages in order to set up a quality assurance environment is provided by a PhD student from DTU, explained with the different perspectives on three rooms.

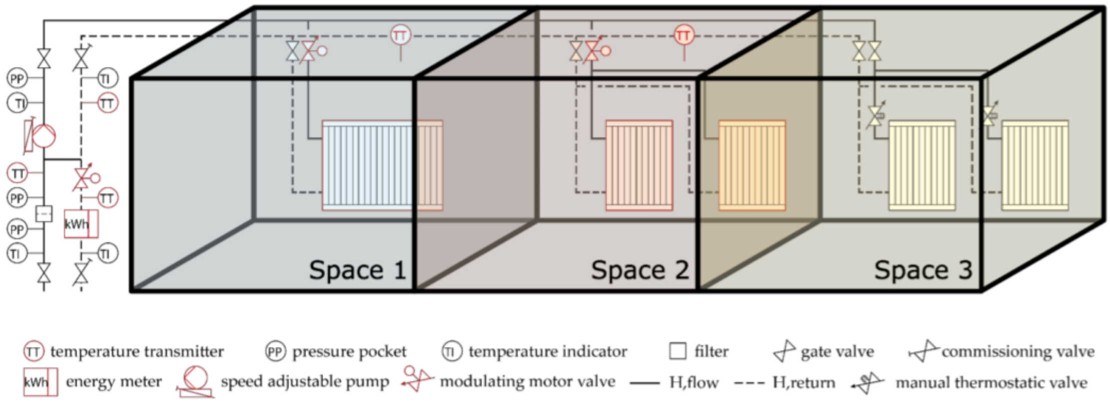


Figure 14: Different perspectives on the same rooms

The first perspective would be the architect's perspective focusing on the spaces which are defined as a specific room type with a specific number of occupants. The ICE engineer, reviewing the same three rooms, will see three thermal zones with different properties and requirements as thermal loads and losses. The automation engineer on the other hand is looking at the sensor system to check the thermal situation in the rooms and the HVAC engineer sees the different radiators and the entire heating/ cooling system for maintaining thermal comfort in the rooms. This little example already includes four specialists which should collaborate for the design of a heating system in the presented rooms. The list of stakeholders even for this little example can be then further continues with the facility manager, client, end-user, fire engineer, etc. Due to this high number of stakeholders relevant for each decision, a centralized dataset of all relations from a meta level to a detailed instance level should be established early in the design phase in order to continuously keep track of all interrelations.[1]

[1] M. H. Rasmussen (2018)

In the end, the dataset of the HVAC engineer contains all information from the predecessors which allows him to design the heating system in compliance with the project without creating any clashes or other issues. How this dataset can look like, is shown in Figure 15.

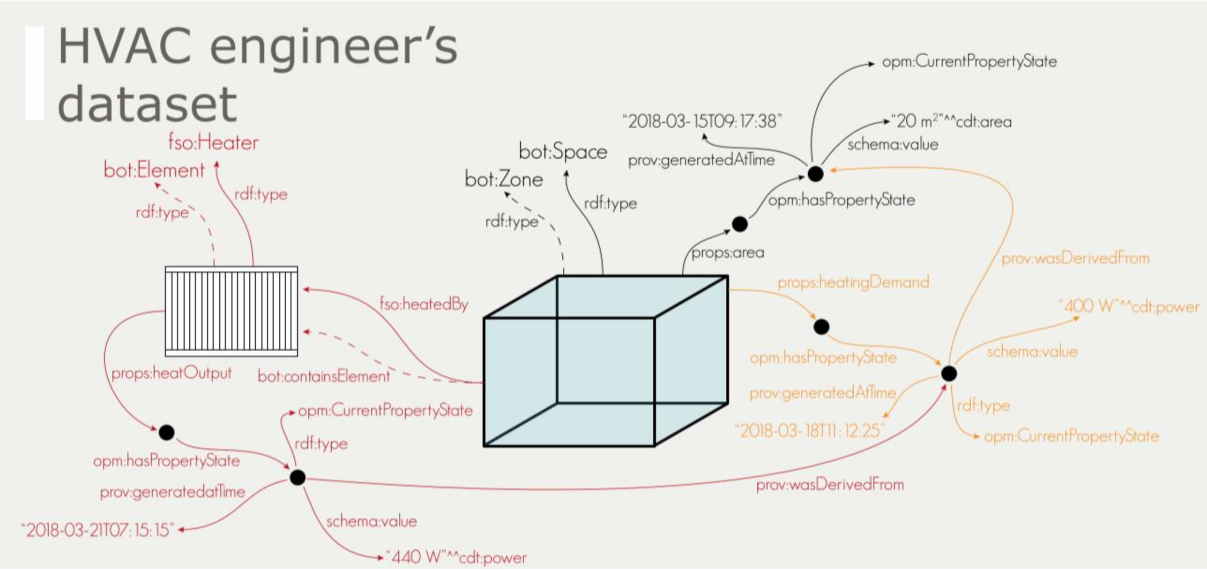


Figure 15: Dataset of the HVAC engineer

Later in this study, the linked data approach for BIM-based QA will be further developed in the expert interviews and then applied in the development of the QA-workflow. Furthermore, a link between this approach and the principles of Integrated Project Delivery will be investigated, as a framework to support the collaborative approach.

2. Live Clash detection in Revit

As described in the beginning of this reflective report, the second approach of an early QA integration focuses on live clash detection tools for the different discipline models. Due to the live detection, clashes are identified directly as the model is created and therefore, each discipline model has a lower risk of containing avoidable and simple errors and clashes. Especially in regard of the following model checking process, it is highly beneficial to avoid as much simple geometric clashes as possible to focus on the more complex clashes later on. This live clash detection can be either applied for an internal clash detection for the discipline model or in combination with a linked reference model to be able to also avoid interdisciplinary clashes right from the start. If using Revit for modeling purposes, there are several tools and add-ins which enable live clash detection. MagiCAD or Clash MEP for example, are MEP tools for Revit which include a feature directly informing the designer when two objects physically collide or interfere in their clearance zones.

This initial step of QA is able to raise the awareness of each discipline to take interdisciplinary collaboration into account to achieve a common goal and in the same time, significantly reduces the number of avoidable clashes. In combination with a subsequent and collaborative model checking workflow, quality of the BIM-based design can be assured by making every party responsible and part of the QA-process.

Reflective Report 3
Hands on experience on design collaboration

This report will deal with the design collaboration in a BIM-based integrated quality assurance process. Identified issues from the model checking activities will be used to explore the software applications BIMcollab and Revizto which are supposed to facilitate the collaborative issue management process. This should allow a holistic and iterative process of resolving clashes and keeping track of the remediation process. In the following paragraphs, the results of the hands-on experience with both combinations **Solibri & BIMcollab** as well as **Navisworks & Revizto** are provided for the purpose of documentation and reflection of the collaboration capability. As the internal issues have been resolved earlier, the models are ready for the collaborate model check through the BIM coordinator. As this task is outsourced to a central party, it is important to establish a continuous and lean information flow within the issue management process. In this study, 5 collaborate clashes between the structural and MEP model have been selected to be assigned to a responsible person, resolved and communicated to the project members (see figure below).

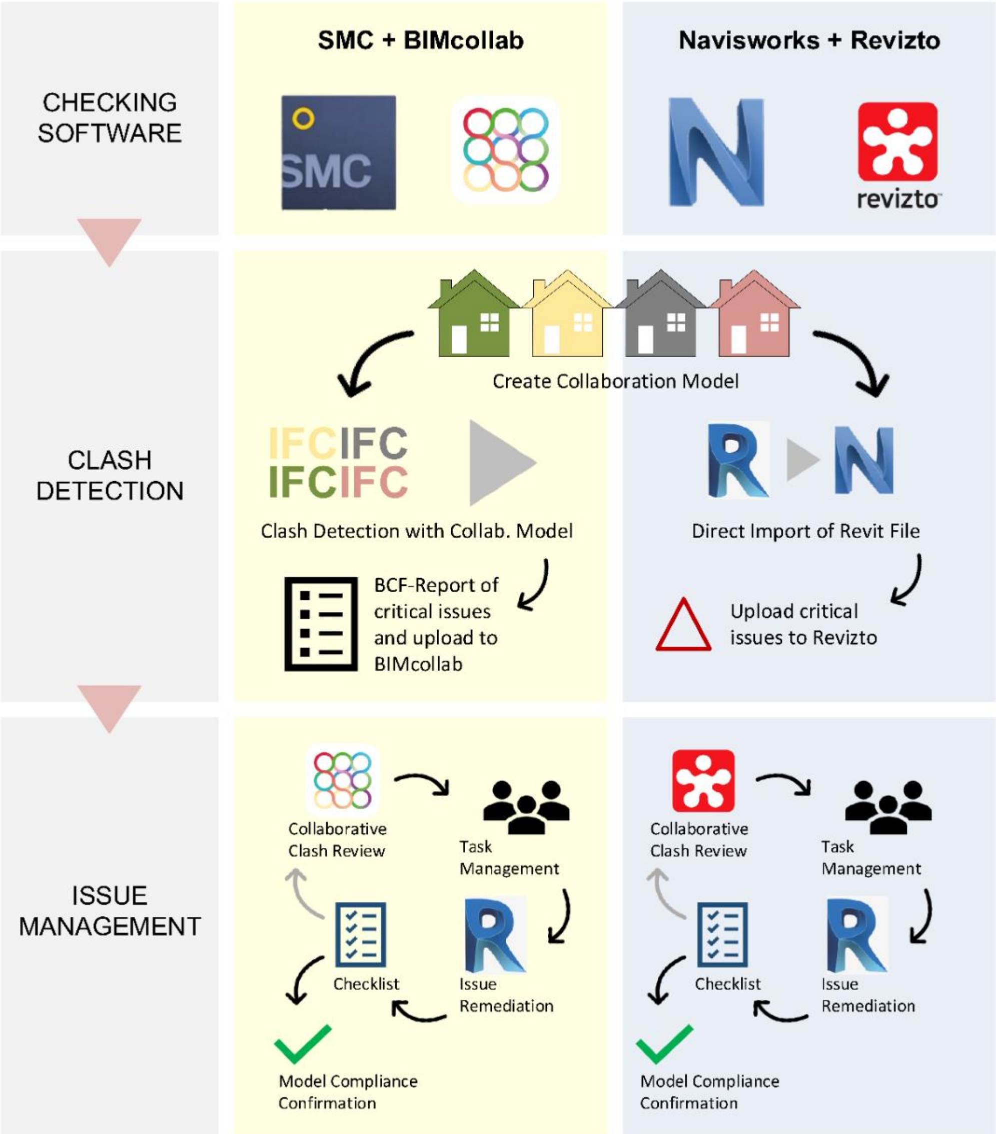


Figure 16: Collab. Model Checking & Issue Management

1. Solibri & BIMcollab

The first combination is the interaction between Solibri Model Checker and BIMcollab. The standard process for this combination is using IFC-files to check the model through Solibri and then translates the identified issues into a BCF-file, which can be used to launch the issue management process with BIMcollab. The interoperability between Solibri and BIMcollab is usually granted by the plug-in in Solibri “BCF Connector”. This plug-in creates a direct link between Solibri and the cloud-based BIMcollab project to use the identified issues for the collaborative issue management process. Unfortunately, BCF Connector was not available for this study but an alternative manual approach with the BCF-file format was chosen to import the clashes into BIMcollab. This basically leads to the same result but requires a little bit more effort. However, it is recommended to get the BCF Connector for Solibri in order to facilitate the information flow and reduce the risk of losing data. After the issue import, the same approach is applied as if using BCF Connector. The following figure shows a simplified process of this software combination.

Figure 17: Solibri-BIMcollab Combination

This combination enables the project members to implement an open BIM workflow as the issue management is again linked to the authoring/ modeling software applications. Because BIMcollab allows to transfer issues and directly inform the different design people responsible for resolving the respective issues. A comprehensive step-by-step protocol for the collaborative issue management is provided as Appendix 3 in this report, while a short reflection on is given below.

The project setup with BIMcollab, as the initial task, is structured in a simple way and includes all necessary parameters in order to manage the issues in an efficient and proper way. First of all, the general project specifications as Name, Owner, Duration and Accessibility or User Rights need can be defined. In addition to that, a range of setting can be adjusted or added such as Team Members, Milestones, Areas, Labels, Types, Priorities and Groups which all aim to facilitate the collaborative issue management process. After importing the issues via BCF file format or BCF Connector, they are ready to be modified and assigned. Especially the feature to assign an issue directly to the responsible person is really beneficial in this process. When assigning an issue to a person an email with the link is sent to this person automatically. With this link, the responsible person can go directly into the modeling software, connect to BIMcollab via the BCF-manager plug-in (log-in required), navigate to the respective issue in the model and resolve the issues directly.

According to BIMcollab users 7 out of 10 issues get resolved straight after the issue has been assigned to the responsible person. This means, that issues are resolved even before the next BIM meeting, allowing to focus on the more complex issues in these meetings.

Figure 18: BIMcollab loop

Due to the email notification of the assigned person, some issues can be solved immediately and the ones who could not be resolved will be discussed in the next BIM meeting and taken into the next iterative loop. This loop starts with the clash review, which is shown above. Through the issue assignment to the responsible person, the task management follows the clash review and enable the assigned person to use all existing information about the issue. Therefore, the issue can be located easily in Revit and remedied by the assigned engineer. Afterwards an approval of various persons, especially of the BIM coordinator is needed in BIMcollab. The approval of the BIM coordinator again includes a checklist for the third step of the QA-process which evaluates the quality of the collaborate model and gives access to the next design phase, if the model passes the checklist and therefore is in compliance with the current project specifications. If the model or more detailed the single issue is not approved, the loop starts over again by one person commenting the issue in BIMcollab, specifying what has to be resolved in order to make the issue approvable.

When resolving the issues, it was identified that Solibri only identifies each clash on its own. Sometimes, several clashes of connected objects are concerning the same issue, which could be combined and then sent to the responsible person. This would facilitate the remediation process as a batch of issues can be resolved at the same time. For more information about this case, please refer to Appendix 3.

In this hands-on experience, all five issues were modified and assigned to different persons for remediation and two of the issues were resolved in Revit using the task management workflow with the BCF-manager. The following figure presents the results as a dashboard after the first issue management loop.

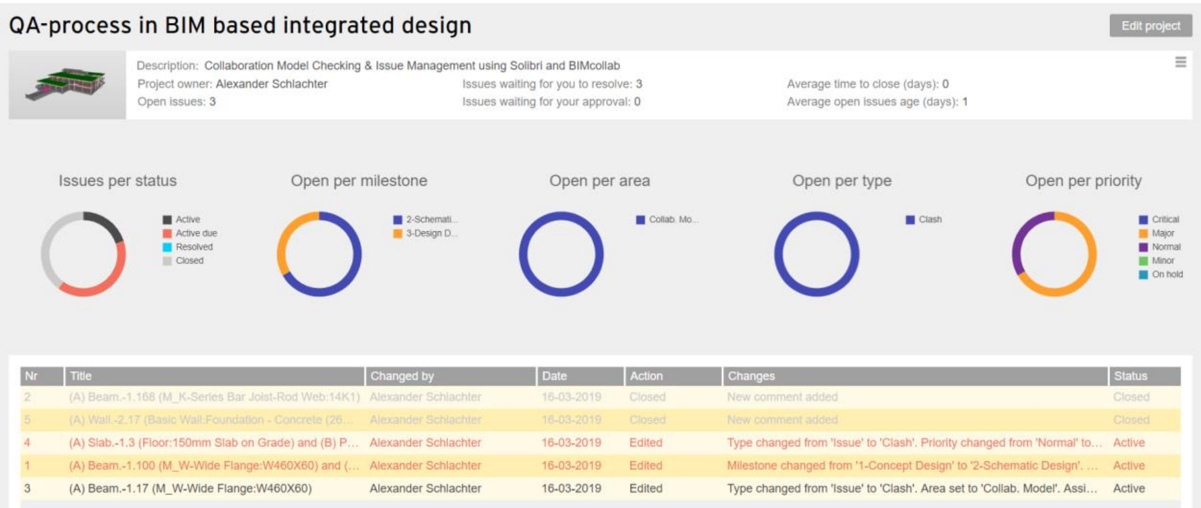
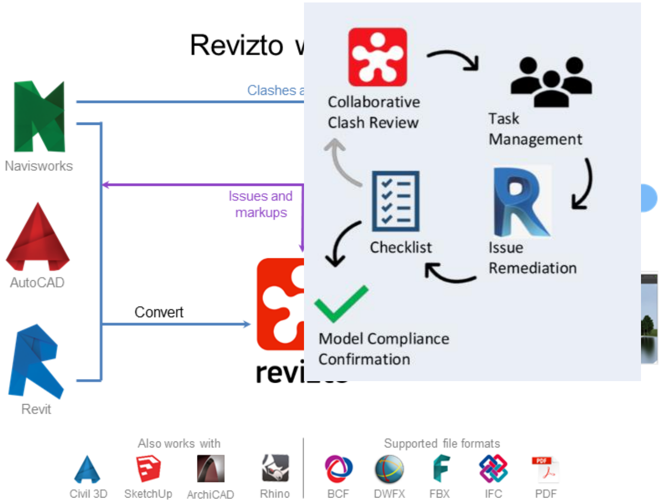


Figure 19: Issue Management Dashboard

Reflection on collaboration and workflow efficiency:

- The project setup with BIMcollab is very profound and allows to add all information (especially all relevant people) which is later needed to perform a collaborative issue management.
- Cloud-based application is accessible everywhere, for everyone with a user account and on different devices.
- Assigning issues to different people responsible to remedy the issue or approve the suggested solution, is really simple and starts an automatic communication process in the background. In this way, smaller issues can be resolved without the need that every party involved needs to discuss those minor issues in the BIM meetings. More complex issues can be then reviewed in BIM meetings to commonly agree on the best solution.
- BIMcollab also provides an automatic email notification for each issue which is assigned either for remediation of approval. The email allows to directly review the issue and resolve it in the authoring software as Revit.
- As BIMcollab only functions as a cloud-based communication tool and no geometrical data is imported, the review options of the clashes are quite limited and always require another software to get a bigger picture of the issue. If an issue is connected to several similar issues within a system, it would be more efficient to group them into one issue in order to resolve the system and not every single part on its own. However, BIMcollab is not able to process this information and only shows a pre-selected section of each clash as a picture in the BCF file.
- In this regards, BIMcollab is also not able to offer a one-stop solution for BIM meetings as a review of all clashes can only be made either with the dashboards and pictures of the issues or in combination with another software (e.g. Revit or Solibri) for visualization purposes. Especially for clients, who are not very familiar with buildings, a visual walkthrough to identify and review clashes highly improve the understanding.
- In general BIMcollab is a powerful tool for the collaboration and communication aspect in the issue management and offers automatic process solutions, allowing the project to have an integrated open BIM workflow. On the other hand, BIMcollab does not offer additional services facilitating an collaborative review of complex issues in BIM meetings, as it does not include model data.

1. Navisworks & Revizto



The workflow between Navisworks and Revizto has been introduced in the first reflective report with the scheme on the right. A benefit of Revizto is its cloud service and interoperable plug-ins for all common BIM applications as Revit or Navisworks. Because the integration of Navisworks as the model checker and Revizto as the issue manager is the most common application of Revizto, this workflow will be applied here as well.

In the workflow, the 3D geometric data is exported from either Navisworks, AutoCAD or Revit to Revizto and then shared with the project members as the project is synchronized with the cloud. The main difference of Revizto is that it uses the model data as a game engine to not only manage issue management but also reviewing the clashes in a high-quality interface. It is recommended to export the model directly from Revit to Revizto and then use Navisworks only for pushing the identified clashes into Revizto, where they can be managed properly. It is really important to use the same coordinate system when working with Revizto and merging information from many different models and origins. Otherwise the collaborative capabilities cannot be performed as planned, although the workflow is followed correctly.

Furthermore, it has been identified during the research on how the Revizto-Navisworks integration works, that the issues should not be grouped in Navisworks unless the issues can be combined into one overall issue, because Revizto will combine these issue groups into a single issue when exporting the data. Therefore, some modifications have to be made before the issues from the collaborate model check can be imported to Revizto. In reflection to Solibri, the feature of Navisworks to group identified issues can also be beneficial and may facilitate the remediation process, but the BIM coordinator should pay attention to the proper application of this feature.

In my opinion, the highlight of Revizto is the issue tracking feature. The interface is set up as a communication platform between the involved project participants. The reporter can coordinate the resolving process of each issue with the assigned person and trace back the information to the creation of the issue. This does not only create transparency between the different disciplines but also highly reduces the required time to communicate issues by having all information in a centralized system. Furthermore, it removes the traditional and conservative collaboration barriers by integrating all disciplines into one platform. This means that Revizto also acts as an issue management log, where information about issues is stored and managed centrally. Especially for long-term and complex project this feature can be of great benefit as all solved, in progress and open issues including the evolution of each issue can be accessed through the Revizto cloud. Similar to BIMcollab, the assigned issues can be resolved directly in Revit via a link between both applications.

The issue management workflow in Revizto is a completely interconnected system between Navisworks, Revizto and Revit. The issues are first identified with Navisworks and then exported to Revizto for clash review and issue management. After the issues are assigned to the responsible person to resolve them, these persons can open the issue tracker in Revit which allows them to have all the assigned issues directly available in the authoring software. The only problem in this process is in Revit, as its viewpoints don't really support an easy remediation process.

Another big advantage of Revizto is its game engine which enables a simple issue review with walkthrough and virtual reality functions. Especially for some less experienced clients but also for all disciplines involved in a project, this can be applied in every BIM coordination meeting to easily navigate through the model, review pending issues and discuss their remediation process in collaboration with all parties.

In this hands-on experience, all five issues from Navisworks were modified and assigned to different persons for remediation in Revizto and two of the issues were resolved in Revit using the task management workflow with the Revizto-Revit link. The following figures presents the results in the issue tracking interface.

Figure 20: Revizto loop

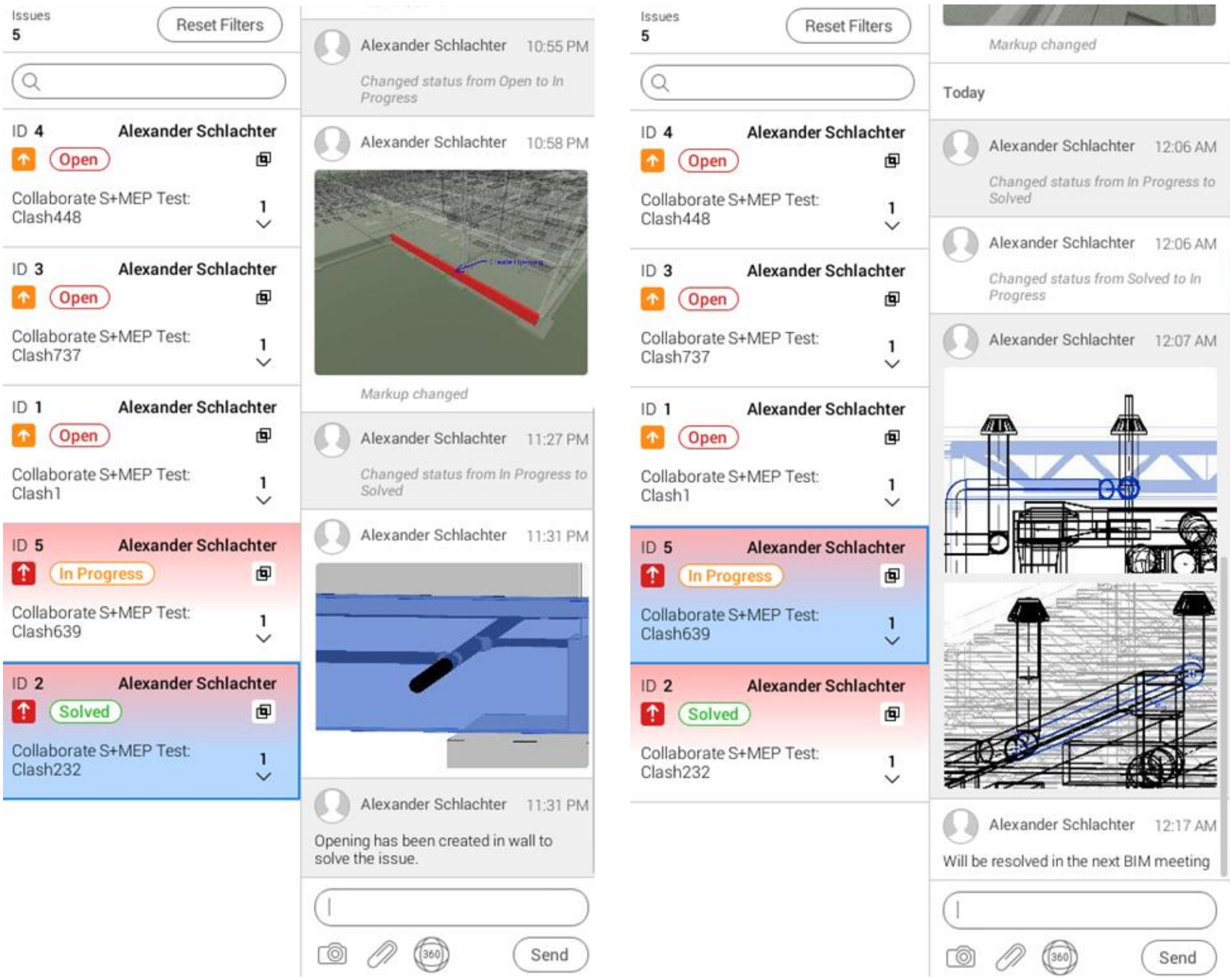


Figure 21: Issue Management results in the issue tracking interface

Reflection on collaboration and workflow efficiency:

- The project setup with Revizto is enables to to add most relevant information (especially about the involved persons) which allows to create a collaborative issue management platform for everyone who has an account and is invited to the project.

- Revizto requires a software application but also includes a cloud-based interface where dashboards and reports of the current project state can be created and shared.
- As Revizto is an independent software application, 3D model data can be processed as well and used for a better review of the identified clashes. In combination with the grouping feature of Navisworks, issues can be handled really efficiently, allowing every person involved to understand both the greater impact as well as direct cause of each clash.
- The issue tracker of Revizto creates transparency between the different disciplines by allowing to trace back every step in the issue remediation process and also highly reduces the required time to communicate issues by having all information in a centralized system. Furthermore, a direct link to the Revit enables a real time remediation and communication as the issue is assigned.
- Revizto does not allow to change the status of the issue directly through the plug-in in the authoring software. Therefore, an additional updating is needed to let the system know that the issue has been resolved. This is made again in the issue tracker.
- In conclusion, Revizto is a very elaborated tool with a many different features. It does not only cover the entire open BIM workflow but also enables the entire project team to collaboratively review the issues with its game engine and virtual reality function. The combination with Navisworks works well for simple clash detection but does not offer such a diverse catalogue for model checking as Solibri does.

Summarizing the application for the quality assurance purpose in BIM-based integrated design, both combinations are able to support a holistic and collaborative issue management workflow and are therefore suitable for the application. Depending on the individual project specification, one combination might be more beneficial as both have their advantages and disadvantages in different areas. However, if both combinations are set up the proper way and used throughout the design phase by all relevant parties - which all understand the QA-workflow, its purpose and are able to use the different tools – the quality of the design can be assured with either Revizto or BIMcollab as the collaboration tool.

Based on this experience, the following chapter aims to formulate several requirements but also challenges and identified issues regarding a standardized QA-workflow in BIM-based design. In order to so, several expert interviews will be conducted with experts in BIM-based integrated design. Therefore, a questionnaire is developed which should help to gain further insights and knowledge about the QA-process. In the end, this is supposed to set a profound base from which a redefined and complete QA-workflow will be created.

Reflective Report 4
Interview methodology and findings

The method is to conduct several expert interviews with different people. The interviews should support the results of the literature research and provide new insights, especially for the development of the QA-process workflow. An increased focus will be placed on the collaborative model checking and issue management, but also other approaches as IPD and Linked Data are explored with the interviews. To accomplish this, informative interviews will be conducted with BIM Managers and experts in the field of collaborative BIM Management and Linked Data both from theory and practice (see figure 22).[1]

- The interviewees will be provided with an information brochure beforehand, including an overview about the literature review and the intentions of the interview in this study. In this brochure a clear research question is formulated, which is the research goal of the paper and is derived from the existing literature.
- Before the interview, QA-activities are formed from the literature research, on the basis of which a questionnaire is created. Based on the answers from this questionnaire, important measures for the development of a holistic QA-process workflow can be derived. This is referred to as deductive categorization.
- The questions were divided into categories in order to provide the interviewees with a red thread for a better orientation. These are successively listed, the introduction (0), Project Setup (1), Discipline Modeling (2), Internal Model Checking (3), Collaborative Model Checking (4), Issue/ Task Management (5) and IPD Integration (6). In order to integrate the Linked Data approach, the additional category Linked Data (7) is developed exclusively for the questionnaire of the Linked Data expert.
- In the interview, the questionnaire is conducted with open questions and the answers are written down. The aim is to obtain as much information as possible.
- The interviews are also recorded so that the results can then be summarized in Chapter 4. The interviews are not transcribed word-for-word, as a simplified method is chosen for the evaluation of the interviews. Only the contents of the interviews that are relevant for the development of the workflow are taken into account for the analysis. After the interview, the goal is to develop a holistic summary of all findings, organized in a structured way based on the categories 1-7.

Expert interviews are chosen because only a small group of people with the necessary knowledge is available for this research topic. With the expert interviews the exclusive information of selected persons is made accessible for this study, which is required for the development of the QA-process.[2] Together they combine expert knowledge about the construction industry of Denmark and Switzerland, about BIM-based design, in particular quality assurance and collaboration, as well as expertise on Linked Data. The interviews will be evaluated here based on the summarizing content analysis according to Mayring. First, the categories (QA-activities), which classify the collected data according to their content, are formed deductively as well as inductively. The categories are developed deductively by deriving them from the existing literature from chapter 1. These categories provide a framework for the interview and are used to develop an interview guide.

The following table will briefly introduce the five expert interviewees and explain what value each interviewee is supposed to offer for the development of the workflow.

[1] Mayring (2014), p. 98 f., 80
[2] Gläser (2010), p. 11

Introduction of the interviewees		
A	**BIM Manager**	
1	**Mike Coombe**	**NIRAS A/S**
	Job Title	BIM Manager in the structural department
	Experience	8 years in NIRAS and responsible upon others for the development of standardized processes in BIM-based design as the QA-process
	Other	User of Revit, Solibri and Revizto
	Value Added	Knowledge about collaboration processes in BIM based design
2	**Reza Nili**	**Drees & Sommer Switzerland**
	Job Title	BIM Manager
	Experience	BIM Implementation in Infrastructure and Building projects since 2013, BIM Manager at D&S since 2018
	Other	User of Revit, Solibri, Navisworks and Revizto
	Value Added	User experience how to manage issues in BIM-based design
3	**Søren Falk Thomsen**	**Drees & Sommer Switzerland**
	Job Title	BIM & Project Manager
	Experience	Worked for exigo in Aarhus and at D&S since 2016
	Other	User of Revit, Solibri, Navisworks and Revizto
	Value Added	Overall process overview of BIM-based design and user experience with issue management
B	**Linked Data Expert**	
4	**Mads Holte Rasmussen**	**NIRAS A/S (PhD at DTU)**
	Job Title	Engineer, responsible for the implementation of Linked Data
	Experience	Engineer at NIRAS since 2013, just finished his PhD at DTU
	Other	Knowledge and interest in automation in the construction industry
	Value Added	Expert knowledge about Linked Data and the benefits for the design as well as construction and operation process
C	**BCF-Expert**	
5	**Andrei-Cornel Danet**	**DTU**
	Job Title	Master Student
	Experience	Just finished his master thesis about the application of BCF in BIM-based design
	Other	User of Revit, Solibri, Revizto and BIMCollab
	Value Added	Expert about the capacity of BCF file format for Issue Management

During the evaluation of the results, the QA-activities are inductively checked for their validity and supplemented if necessary.[1] The following figure shows the deductive categories derived from chapter 1. The complete interview questionnaire developed as a result can be found in the appendix.

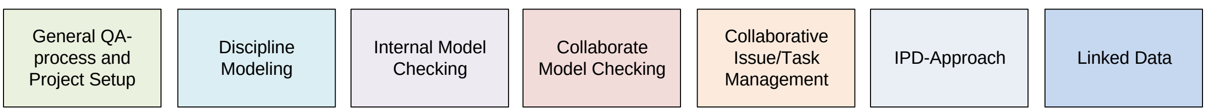


Figure 22: Deductive Categories for the Interview Questionnaire

[1] Mayring (2014), p. 96

Findings:

1. **General QA-process and Project Setup**
   - **Project Setup and QA-Activities**
     - QA for BIM based design should be a clear client strategy from the beginning in order to develop a functioning and collaborative quality assurance. From a consultant perspective, having the QA-process is the way to do the design as it significantly reduces the costly changes during construction, when no QA is implemented. However, for the client it is important to know when (project type, size or constellation) it makes sense to implement a QA process in the design.
     - Consultants should introduce the benefits of QA to the client who needs to develop an intrinsic motivation for implementing QA in his BIM project.
     - The project setup in the beginning of the project should result in an agreement between all planners and other relevant stakeholder and should include the general QA-process workflow, deliverables, roles and responsibilities of the participants as well as define the software and file format environment, the digital model management method, the project server organization and finally the platform for communication and information exchange.
     - The agreement (ICT/BEP) is based on the client requirements, legal standards and the project specifications and will be managed by the leading planner.
     - The project setup shall also include the setup for all QA-related activities (discipline modeling, internal and collaborative model checking and issue management) by developing general workflows and checklists stating what has to be checked and how to deliver it as well as defining responsibilities and relationships between the disciplines.
     - The QA-activities can then be categorized in one-time and continuous activities as well as activities that have to be done before a specific delivery is made.
     - Quality Assurance in BIM-based design can be supported by the two innovative approaches Integrated Project Delivery (IPD) and Linked Data. Both approaches are discussed in chapter 6 and 7 where their benefit to the QA-process is reflected on.
   - **QA-Process**
     - The general QA-process shall be visualized as a simple milestone plan including a brief description for each milestone, the iterative QA-loop plan and if required, the input and output of a milestone. The process needs to be flexible regarding the project (type, size, complexity) and the project teams involved.
     - The general process will be linked to the project time schedule based on the design phases and refers to the developed QA-activities as the input for the different steps. The link to the time schedule allows to adjust the general QA-process subsequently for each design phase as the QA-focus and requirements change significantly with the design development.
     - In conceptual design, where the design is very dynamic, the focus of QA should be in the proper setup of the building models, raising the awareness of collaborative quality assurance, enabling worksharing and live clash detection. After the models reach a specific Level of Development (LOD), internal model checks can be performed by focusing on coordination of spaces, general building requirements and buildability. Subsequently the focus will shift to an iterative process of internal model checking by the individual disciplines and collaborative model checking by the BIM Manager, resulting in a collaborative issue management/ remediation process in order to resolve the identified issues properly.

- A coordination cycle should be implemented throughout the development of the design with regular meetings where the planner sit together and review the design with different perspectives, depending on the design phase.
- The general goal is to reduce the number of clashes in the models from the very start of the modeling task and to shift as much responsibility as possible towards early modeling phases as the effort of modeling correctly is much less than going through the entire issue management process. Furthermore, this approach ideally results in less clashes the BIM Manager has to manage, which allows him to focus on the critical issues with high time, cost and quality impact.
- Collaborative issue management is enabled by a collaboration tools as Revizto and BIMCollab which enable the BIM Manager to translate issue into tasks, assign the tasks to the responsible disciplines and keep track of the remediation process.
- The QA-process as a new implementation shouldn't change the way people in the building industry are working. It should rather support their work with additional and valuable information to increase efficiency in their workflow. Therefore, all involved parties need to sign the ICT/BEP-agreement and understand the process and their responsibilities.

- **File Formats and Software Applications**
  - During the project tender, no restrictions for software applications should be defined to ensure competition and an open process based on a free market. After tender, the software landscape (data synchronization scheme) of the project is defined in the ICT/BEP-Agreement in collaboration with all planners, but also other stakeholder who will use the model later on (contractor, FM). File formats as IFC and BCF might be predefined for collaboration purposes.
  - Leading Planner will coordinate collaboration between companies and software to ensure information flow through the project
  - IFC and BCF based manual workflows work but are not fluent, take a lot of effort and are still error-prone. A direct link between the software applications with the IFC/BCF translation in the background would be the ideal, similar to the BCFConnector, developed for BIMCollab.
  - BCF can be used not only for clash management but can also support the whole spectrum of issues as building regulations, client requirements or interdependencies between different disciplines (communication, collaboration and coordination). BCF, similar to IFC, is an open standard file format that can be used interoperable within the BIM world.
  - As collaboration platforms, both Revizto and BIMCollab can be used. BIMCollab is better for simple issue management through BCF-workflows. Revizto is a more advanced application enabling next to collaborative issue management also to review the model in 3D/ VR and identify or modify issues directly in the model. This provides a better overview and understanding of the model.
  - Linked Data: It doesn't matter from which format the information comes from, the goal is to build something that can turn the information into Linked Data to make it usable by putting it in a categorized and classified structure.

- **Coaching for the QA-workflow participants**
  - Disciplines should be aware of the QA-principles and actively reduce clash creation during the modeling phase
  - When introducing a new process or platform, the need/ benefits should be obvious for all stakeholders involved and the intended workflow should be already developed in general before implementation. Then, an initial workshop should be held as an introduction, followed by more detailed workshops and continuous support by a consultant to ensure the process quality and understanding of roles and responsibilities of the users
- **Information System and server organization**
  - As described before, all interviewees stated that the main purpose of digitalization is to facilitate the project workflow in a simple way with as little impact in the way the people work as possible. Therefore, the information system should support all requirements in the collaborative QA-process but run in the background with a simple access for all stakeholder.
  - Information system can either be set up on local servers, divided in different activities, where the relevant project teams have access to or on a cloud server containing all data in one single source with access control to share the data. A mix of both is also possible, resulting in one cloud only for task management (as BIMCollab or Revizto) and one cloud for all other activities as modeling, documentation, communication and model checking.
  - It has to be a standardized and structured information system enabling all parties to collaborate and do their job. Furthermore, the information system must be defined in the ICT/BEP-Agreement in the beginning of the project and must be in alignment with process workflow and specifications about software, file formats and project participants.
- **ICT/BEP-Agreement**
  - See point “Project Setup and QA-Activities” for general information
  - The ICT/BEP-Agreement enables a structured project setup of BIM based design projects which ensures that all parties involved in the BIM design can perform their task properly, collaborate and achieve the project goal in the most efficient way.
  - Although the agreement should cover and define a lot of aspects, especially regarding quality requirements, it still requires a certain flexibility to be adjusted in accordance to the project development. This means that also the QA process should be generally defined in the beginning, but later, the iterative loop and continuous process needs to be adjusted to the development of the design.
  - The agreement must include design deliverables based on the time schedule with clear requirements about the LOD of the models for each phase.
  - The agreement should provide answers to the questions, where the focus of the QA should be, what to be checked when and how to approve the deliveries/ documents (output of the QA-process).
  - As the agreement is mainly developed by the planner, engineers and if already integrated, the main contractor, a better consideration and integration of all stakeholder is needed to ensure, all stakeholder agree on and understand its content.

- **Checklists for the QA-Activities**
  - Checklists should provide information for the QA-participants, what needs to be checked and how to deliver the result. These checklists can be filled out after a QA-activity has been performed providing a guideline for the performing stakeholder as well as documentation for the checking stakeholder.
  - The checklist helps the BIM Manager to make sure the provided discipline models have the required quality without going through the entire check.
  - Individual checklists should be established for each the QA-activity and depending on the project phase, where the activity is applied, the checklist needs to be adjusted accordingly.

2. **Discipline Modeling**

- **QA-process startup workshop**
  - In the beginning of the project, when all planners are integrated, a startup workshop is needed for the proper implementation of the QA-process. This workshop intends to teach the QA-process and provide information about the workflows as well as the roles and responsibilities of each participant. Secondly, the workshop should include an open discussion resulting in specific adjustments of the process to the project specific time schedule, design requirements and detailing. Sometimes, it is also necessary to integrate certain flexibilities in the process when something cannot be defined in the beginning.
  - The educational aspect of the workshop can be organized in several introduction workshops in the beginning plus continuous support during the project plus user manuals and workflow guidelines.
  - As these adjustments have to be updated continuously, a regular sequence of QA-workshops is needed in order to manage the adjustments to the design development.
  - It is beneficial to include the construction expertise in these workshops to define the criticality categories of issues. This can be done by having contractor as external consultants. This results in a Win-Win-Situation, as the contractor increases the chances to get the job later on and the client receives a valuable and probably quite cheap consultancy.
  - Disciplines should be aware of the QA-principles and actively reduce clash creation during the modeling phase
- **Early collaboration of the design disciplines**
  - Linking models as early as possible and require turning on linked models at least once a day to check for interferences and raising the awareness and the understanding what the other disciplines are doing.
  - Develop a modeling catalogue (will become part of the agreement) with all critical possible interferences between the disciplines (e.g. HVAC - architecture) to define who is modeling the connections of overlapping parts between to two disciplines.
  - Co-Location in a shared project office has been experienced very beneficial to increase collaboration.

- **Reducing the number of created clashes in BIM-based design**
  - Model in 3D as this significantly increases the understanding of the design.
  - Interdisciplinary worksharing and linking all relevant discipline models to your model in order to check their alignment. This enables live clash detection while modeling the discipline model and thus, results in a significant decrease of created clashes. In this way, the responsibility of QA is shifted more towards the modeling side, allowing the BIM manager to focus only on the most critical and complex issues.
  - The quality assurance process requires a high quality of the discipline models at all time in order to run smoothly and without big effort. This can be achieved by educating the planner about how to do QA in their role, raising the awareness about the other disciplines, enabling collaboration and performing continuous model checks with different checking perspectives.
  - Develop QA-activities/ methods for early design phases focusing on the proper model setup, space requirements, general building requirements, interdisciplinary dependencies and relations, etc. Activities could be Linking Models, Live Clash detection during discipline modeling, space models, simple excel checks based on Revit schedules and room books or the development of a modeling catalogue for interfaces in design.
  - Include construction experts (either experienced designer or contractor as external consultant) for buildability reasons as well as to receive their needs for the future construction phase. By doing this, necessary changes in design can be initiated when the costs for the change are still low (during design phase) reducing the amount of expensive and time-consuming changes during construction. Construction experts can perform a regular screening of the design, similar to value engineering.
  - Using more automated workflows with less error-prone acitivites.
  - Use Linked Data to increase transparency in design development and improve management of interdisciplinary dependencies through linked relationships. Design requirements as client requirements, requirements from each discipline or the building code can be scripted and integrated into the knowledge graph, where the data can be used and updated throughout the entire project.

3. Internal Model Checking

- **Content and frequency of the Internal Model Check**
  - Depends totally on the project specification and therefore needs to be flexible.
  - Main job of the planner is to model, and QA should be a minor additional task on a regular basis to improve the design. Therefore, the check needs a simple setup and sufficient time should be planned for the internal model checking.
  - Certain geometrical LOD has to be achieved before it makes sense to start the model checking process.
- **Proof of performance for the BIM Manager**
  - In order to make sure that the discipline models fulfill the requirements, the BIM Manager has two options. First, internal model checking will be defined as the responsibility of the discipline modeler. Here, the BIM Manager can either trust the discipline modeler blindly or establish checklist which are filled out by the discipline, proving that the check has been performed correctly. Secondly, if the trust level between the BIM Manager and the disciplines is week, the BIM Manager might consider performing random model checks on his own to validate the documentation of the disciplines. Based on experience, these checks can focus on the most critical areas of the building.

  - Rulesets shall be developed by the individual disciplines for their specific requirements but are derived from the QA-checklists provided by the BIM Manager. Moreover, the rules should adapt to the project specification & model progression.
  - Each discipline is required to have a BIM expert who is able to perform the internal model checks properly as defined in the ICT/BEP-Agreement. Workshops can support but a certain experience in necessary to ensure the quality.
  - In order to avoid that the disciplines exploit the BIM process by not taking care of the quality as it will be checked anyway, a clear and structures project setup as described above is needed.

4. Collaborate Model Checking

- **Steps for collaborate model checking**
  - Includes and overall check of BIM Validation, Code checking (client + legal) and a more detailed Clash Detection of the collaborate coordination model.
  - Set up customized rulesets which are able to check the fulfillment of the code requirements in the design process. The requirements need to be established at the start to be sure that the necessary parameters come in the model, so you are able to check them later.
  - Certain geometrical LOD has to be achieved before it makes sense to start the model checking process.
  - In detailed design, frequency of the iterative loop in model checking could be 2 weeks, organized by the BIM Manager.
- **Optimization in the information flow from clash detection to issue management**
  - The crucial part is to define the relevance/ criticality of the issues by focusing on the issues that take time, cost money and involve more than one discipline. The Level of relevance then define whether the issue can be resolved by the discipline alone, needs further discussion in the BIM meeting or can be neglected as it does not have any cost/time-impact on the building.
  - Automated filtering/ grouping option based on the issues' criticality directly in the checking software. The automated clash detection is enabled by setting up clear rulesets for each phase and allowing automated grouping of the issues e.g. with semi-automated model checking with Navisworks (A plug-in allows to link Navisworks to Revizto directly and if an issue is resolved and does not appear in the model check anymore, it is automatically closed in Revizto). By doing this, time in QA can be reduced significantly.
  - Establish a central communication and issue management platform where all parties collaborate together with their specific access control.
  - Direct link between the software applications with file formatting in the background (e.g. Revit → Solibri → Revizto).
  - With issue management, BCF can be used for more issue types to improve the process of assigning, tracking and resolving all kinds of issues.

5. Collaborative Issue/Task Management

- **Steps in the issue management activity**
  - Establish an issue management platform where the project stakeholder can collaborate and solve identified issues in an efficient and automated process. In this study, Revizto and BIMCollab were explored and identified as powerful tools for the collaborative issue management purpose.
  - BIM Manager is performing the collaborative model check, transforms the identified issues into specific tasks, uploads the tasks to the platform where they get assigned to the responsible disciplines which then resolve the issues and communicate the issue remediation to the project participants. In order to make sure, the issues are resolved correctly, the BIM Manager can either assign another person (most likely himself) to double-check and approve the proposed solution in order to finally close the issue or just waits until the next iteration of model checking, in which the resolved issue should disappear. The first option increases the transparency and engagement in the process and ensures the quality as only 10-15% of issues in building models are resolved properly, but also requires more effort. The second option is based on trust and a well-functioning model checking. Semi-automated model checking is facilitating this second option.
  - Set up project specific status information for issues (open, pending, resolved, closed) and define who is able to change the status.
  - Within this task management process, a period should be implemented where all relevant stakeholder area able to comment on the identified clashes. These comments should then be considered in the issue remediation. With critical and complex issues, this might be organized in a BIM meeting for a better collaboration.
  - Having a direct link between the authoring software, checking software and issue management software would facilitate this entire process a lot and decreases the risk of data loss due to manual file format exchange.

- **Assigning issues to the responsible disciplines**
  - The issues are assigned to the disciplines by best assessment of the BIM Manager but if it is unclear who is responsible because the issue involves more than one discipline or the issue is just too critical or complex to assign it to a discipline without a collaborative discussion, the issue is taken to the BIM meeting where the involved parties decide together how to resolve the issue.
- **Purpose of the BIM Meeting**
  - Only reviewing critical and complex issues in plenum with the discipline engineers and relevant stakeholder as the BIM meeting is limited in time and resources and cannot include all issues. The BIM Meeting requires a collaboration platform (here: Revizto) for a more efficient collaboration during the meeting by allowing walkthrough interaction and live management of the issues.
  - Discipline leads are participating in the meeting, because they can then assign the issues to the responsible team members. To not waste time in such meetings (discipline leads are expensive) a clear agenda and meeting structure how to review the critical issues is crucial.

6. **IPD-Approach**
   - **Integrating other stakeholder (contractors, users, FM) to the design process**
     - All relevant stakeholder expertise should be included in the project setup to define the project requirements.
     - Contractors can be integrated as external consultants to add their perspective about buildability and construction management to the design development.
     - Physical involvement of FM or Users in the QA-process would cause too much effort and complexity, but their ideas and needs should be included in the requirements and then it is continuously reviewed if the design meets the requirements, by establishing specific rulesets.
     - With Linked Data, online datasets from manufacturers can be used to directly link them to the model. This allows an early and continuous use of real information about building elements from potential manufacturers who provide their information online. During the design phase, the disciplines can search for type information and then find matching elements from different manufacturers. This might result in a global platform as Skyscanner for products.
   - **Multi-Party-Agreement for a better collaboration**
     - In IPD projects, a multi-party agreement is developed between the main stakeholder of the project to facilitate collaboration, data exchange and transparency. In general, the principles of IPD, especially the collaboration aspect should be implemented and used in every project. However, to enable collaboration an early mutual agreement as in the ICT/BEP-Agreement is sufficient as long as a functioning project team can be established which is motivated to achieve the commonly agreed goals for the project. A contractual bonding, however, enables to integrate more stakeholder into the project.
     - The goal is the successful execution of the multi-disciplinary project. Contractually it is defined that in the end, no clashes remain in the coordination model. How this is achieved, is discussed project-specifically and then subsequently documented as the content or appendices for the ICT/BEP-Agreement.
   - **Co-location**
     - Enabling co-location means that the different disciplines in a project are clustered in project offices for a better and interdisciplinary collaboration.
     - The experience shows, that people communicate much more, and this enables an increased information and data exchange but also mutual support and collaboration in general.
     - However, this might only be adequate for big projects as it requires a place where all disciplines physically work together. For small projects it is sufficient if a clear communication structure is established by having consistent and understandable workflows and regular physical meetings.

Linked Data Approach

"*We started in the fields and we did repetitive tasks. We started in the factory and we did repetitive tasks. And now we moved into companies with computers and doing repetitive tasks as spreadsheet monkeys*"

"*Linked Data allows us to build an Abstract Model of whatever in the world we need to look at*"

As seen in both quotes above, Linked Data aims to be a disruptive new method for information management in all kinds of processes. In the building industry, this enables to develop a platform for a structured way of extracting information from Revit models about spaces and other parameters and develop a knowledge graph based on relationships between objects, their parameters and design requirements. This basically means to script the information of the model and add additional information as building codes or client requirements on top.

Linked Data in general goes along with the IPD approach as it aims to develop as much information as possible in the beginning of the project. Furthermore, it enables to gather all information in one source and continuously use the developed data for design & controlling purposes by extracting filtered information. The data can also be updated easily by just adding another relation to an object or adding an updated status for any information in order to keep track of all changes.

Especially in the early design phases, a knowledge graph with Linked Data is very powerful as the models change a lot (spaces and other properties) and the graph would provide a full and transparent overview of how every property has changed during the design.

- **Advantages**
  - Managing interdependencies between building elements and disciplines
  - Space models can be created by extracting simple information from the architectural model. This also enables to develop space categories (e.g. meeting room type 2.1) with preassigned and specific properties (indoor climate class, heat supply, m² per person, etc.). These properties are defined collaboratively in the project and are provided to all planner for their consideration in the discipline models.
  - Parameters and relations of building elements are interlinked and will change subsequently if one parameter is modified in the model.
  - Linked Data allows to automate design processes and more automated workflows are decreasing the risk of errors and increase quality.
  - Different Anthologies (also BCF as XML format) can be included in the Linked Data knowledge graph
  - Linked Data is a convenient tool that can happen in the background and the engineer does not have to take care of
  - Schemas and Anthologies can be developed by the disciplines (decrease dependency on software developers)
  - Data can be extracted from all kinds of sources and it doesn't matter from which format the information comes from as the goal is to build an application that can turn the information into Linked Data to make it usable by putting it in a categorized and classified structure (script).
  - Link building program/ norms and standards from client and legal requirements as scripted information to the knowledge graph of the building project.

  - With Linked Data, online datasets from manufacturers can be used to directly link them to the model. This means that real information from potential manufacturers is used early in the design development enabling the client to get products that fulfills their needs, can be delivered in time and do comply with the cost and quality requirements.

- **Challenges**
  - Crucial to define what should happen automatically and what manually. If the knowledge graph or developed space model should be updated after a specific time or amount of changes in the actual model. Therefore, milestones in the time schedule or requirements (percentage based or if critical parts have been changed) need to be defined, when to take action.
  - Interoperability with Revit is a problem as an open information access from the authoring software is required to allow Linked data to work simultaneously with the used software applications as a supporting and controlling tool.
  - Software developers need to open up, using an open API for data extraction.
  - User communities need to realize the need for an open and transparent information management with Linked Data and increase the pressure on the software developers (e.g. Get Hub)
  - Information from legal building standards or local building codes should be available for everybody in a language that can be used. This information can then be either translated by engineers or directly provided as scripted information, suitable for the Linked Data approach.

Reflective Report 5
Implementing the findings to the QA-process workflow

As described in the Findings, the initially developed 3-level workflow with Discipline Modelling, Internal Model Checking and Collaborate Model Checking will be converted into specific QA-activities, which can be applied into a QA-process workflow that is linked to the time schedule of the project. This enables the user of the QA-process to pick QA-activities depending on the project type and specifications. The activities will be supplemented by the Project Setup which has been identified as one of the most crucial steps for the proper implementation of the quality assurance in BIM-based design. As the process was introduced for integrated BIM based design, collaboration is an omnipresent requirement throughout the entire process and therefore needs a framework and proper setup in order to allow the all project participants to work collaboratively within the BIM environment. The setup will be guaranteed by defining all information and communication requirements, roles, responsibilities and workflows in a mutual agreement as the ICT-Agreement or the BEP in the beginning of the project. This setup, including the QA-process workflow and the QA-activities will be supported by a framework of IPD-principles and aspects of the Linked Data approach, as described in the before. As a result of this, an overall information sheet consisting of the QA-activities and the supportive framework is developed, visualizing the content and the steps for each activity/ framework part (See Appendix 5).

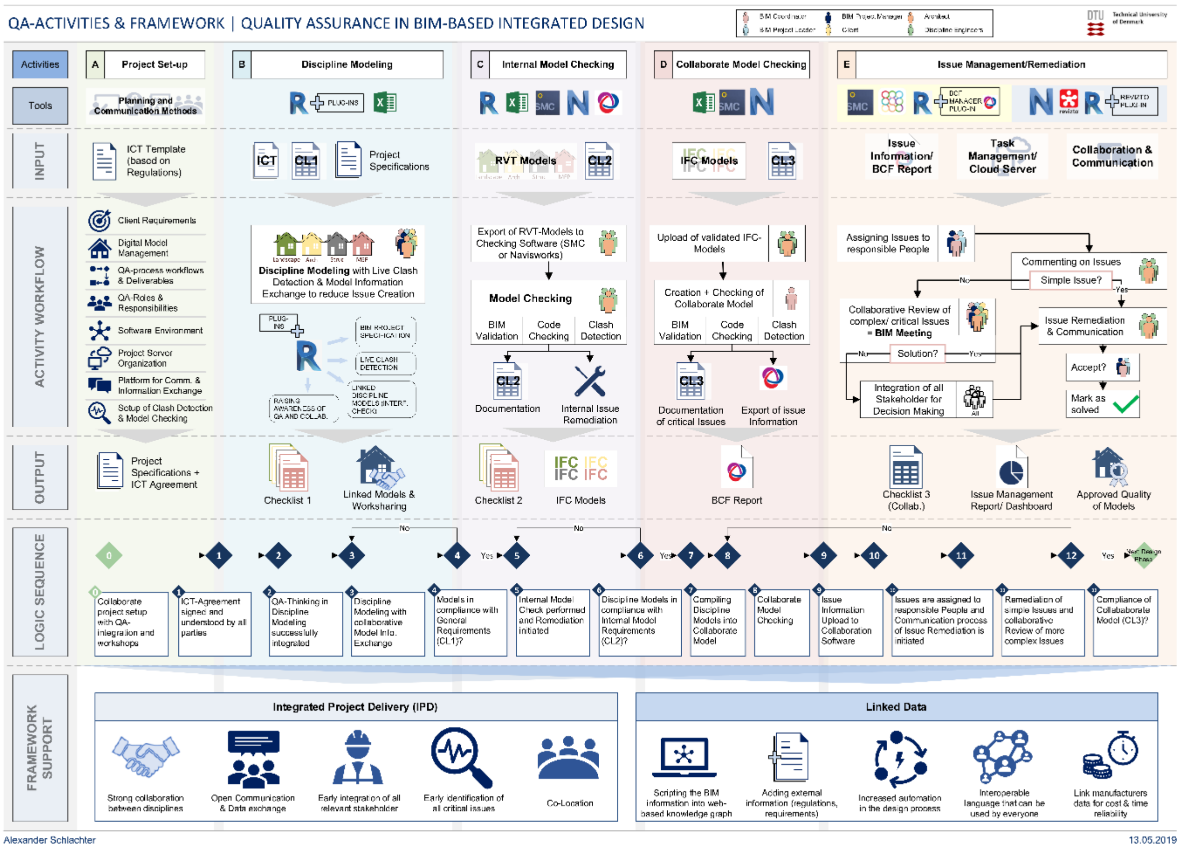


Figure 23: QA-activities and supportive framework

The QA-process with the extra time integration will then be a separate outcome of this study, referring to the QA-activities and framework, but focusing on the link between quality assurance and the design phases of a general project time schedule. The activities can be run as parallel processes where they can be linked to each other throughout the entire design phase to enable a visual relation and add loop processes. This extra dimension of time helps to understand the relationship between the activities and creates flexibility for the user of the QA-process to apply the QA-activities in the design phases and the sequence making the most sense for the specific project. The information sheet, in this case, serves as a library of tools that can be used to implement quality assurance in a BIM based design.[1]

Developing a standardized QA-process and linking it to a time schedule requires to have a standardized source defining the different phases in a BIM-based project. As this study is based on the Danish market, but still aims to give a general recommendation for quality assurance, a ISO-standard will provide an overall time framework of the BIM process where specific design phases from local regulations are applied as supplementary additions. DS/EN ISO 19650, 1 & 2 was developed for Denmark and formulates the BIM process based on the official EN ISO 19650-series for information management with BIM. This standard is reviewed in order to derive the time dimension for the QA-process. As the ISO-Standard (part 2) mostly covers the overall information management during the entire design delivery phase, this information is extended by the official recommendation of the Danish association of consulting engineers (FRI), defining different design phases. This additional information based on both standards is then introduced and put into context of this study in the following paragraphs. As a last step of this report, the QA-process workflow is developed including its supplementary documents as the information sheet about the QA-activities and the recommended framework (IPD/ Linked Data) as well as the checklists, developed for each QA-activity.

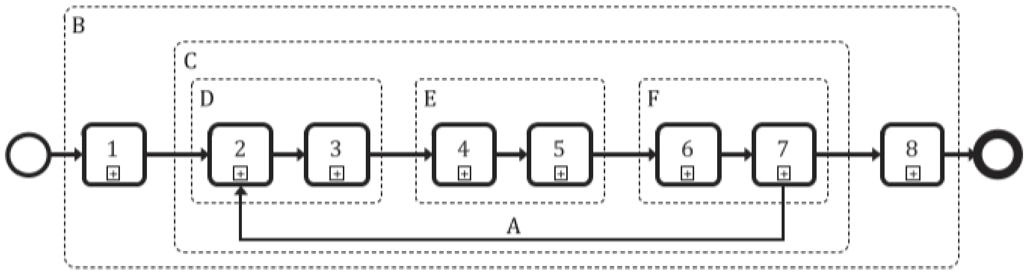
[1] N. Treldal (2017), p. 109 ff.

Design Delivery Phases from DS/EN ISO 19650, 2:

This standard describes the information management using building information modelling for buildings and civil engineering works. It's common data environment (CDE) and other principles of BIM-based design, subject of the first part of the standard are generally aligned with the quality assurance proposal in this study. Especially the CDE uses two gates to develop an information model from the "work in progress"-state over the "shared"-state to the "published"-state. Similar to the internal model checking, the first gate is to check/review and approve the information against the information delivery plan, the agreed standards, methods and workflows. After the information model is then shared, the next step is to collaboratively review all information models for relevant information requirements for coordination, completeness and accuracy.[1]

Furthermore, the standard recommends to define different "level of information need" describing the appropriate quality, quantity and granularity of information needed in different design stages. This should define the minimum amount of information needed to answer each relevant requirement. In this study, this mainly refers to the information needed to reach the next design phase and therefore means the required information in the building models as well as their level of detail (LOD) which describes the quality part of the information.[2] Reflecting on the QA-process, the LOD could be a central measure among other parameters defining when to use which QA-activity and how to reach a next design phase.

The second part of the standard generally describes information management during the delivery phase and gives recommendations about information management from the early assessment of the project to the delivery of the final design (See figure 22).



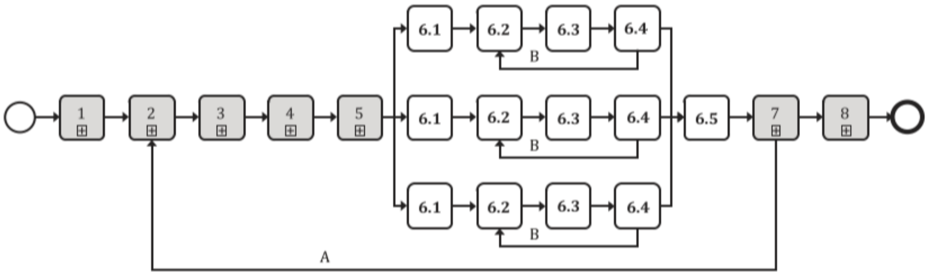
Activities

1	assessment and need	A	information model progressed by subsequent delivery team(s) for each appointment
2	invitation to tender		
3	tender response	B	activities undertaken per project
4	appointment	C	activities undertaken per appointment
5	mobilization	D	activities undertaken during the procurement stage (of each appointment)
6	collaborative production of information		
7	information model delivery	E	activities undertaken during the information planning stage (of each appointment)
8	project close-out (end of delivery phase)		
		F	activities undertaken during the information production stage (of each appointment)

Figure 24: BIM-model delivery process (ISO 19650)

[1] DS/EN ISO 19650-1:2018, p. 25 f.
[2] DS/EN ISO 19650-1:2018, p. 23

Although the ISO standard provides project phases as well, the detailing is too superficial to make a difference between the application of the QA-activities as most of this activity will happen in the phase 6 (collaborative production of information) and 7 (information model delivery). Taking a closer look on phase 6, a quite obvious similarity to the QA-activities and other findings from the interviews can be recognized (figure 23).



Key

6.1 check availability of reference information and shared resources

6.2 generate information

6.3 complete quality assurance check

6.4 review information and approve for sharing

6.5 information model review

A information model progressed by subsequent delivery team(s) for each appointment

B new information container revision

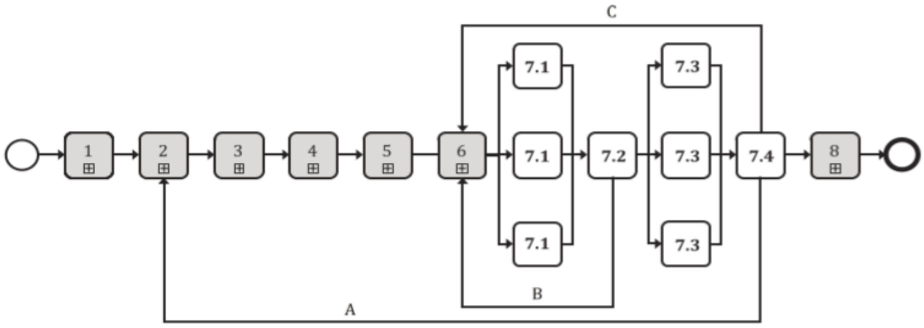
NOTE 1 — Activities shown in parallel highlight the production of information by each task team prior to the information model review.

NOTE 2 — The information model review undertaken in 6.5 can be repeated until such time as the information model is ready to be submitted for lead appointed party authorization.

Figure 25: Collaborative production of information (ISO 19650)

The activities for this phase start with checking the availability of reference information and shared resources. This refers to checklist 1, where the disciplines setup each discipline model in order to fulfill the required information that has been developed in the ICT/ BEP-Agreement. After the proper setup, the models are developed in accordance to the workflows and methods defined in the project setup. A focus on collaborative QA should be already implemented in this stage by linking models and coordinate cross-references in a common data environment. After generating information, a quality assurance check and information review, before the model is approved to be shared for an interdisciplinary review. Again, the reviews and checks are all based on the specifications of the ICT/BEP-Agreement, e.g. the information requirement, the LOD of the models and defined process workflows.

In the next phase, the activities differ slightly to the ones, discussed in this study (see figure 24). After sharing the models, they are reviewed more in detail by the lead appointed party (here: BIM Manager) before the models are submitted to the appointing party (here: Client). The appointing party then performs another information review before accepting the models. In this study, the BIM Manager will do a collaborative model check and coordinate the remediation process and when the models comply with the phase-specific requirements, they are shared with the client for approval (or BIM Manager approves them as a client consultant). This means that the standard only describes one real model check, performed by each discipline, whereas this study proposes at least two different model checks with the internal and collaborative model checking. Although a few differences are identified in the ISO standard and this study, the setup is still similar and both sources are supplementing each other's information.



Key

7.1 submit information model for lead appointed party authorization
7.2 review and authorize the information model
7.3 submit information model for appointing party acceptance
7.4 review and accept the information model
A information model progressed by subsequent delivery team(s) for each appointment
B information model rejected by lead appointed party
C information model rejected by appointing party

Figure 26: Information model delivery (ISO 19650)

The suggested standard process for information management in BIM projects, therefore, enhances and validates the quality of the interview findings and will be considered in the further QA-process workflow development. However, the suggested process also lacks a proper time dimension as it is only a sequence of activities but doesn't include time information from the design development. The activity "generating information" for example is only an abstract definition of an activity but in this case, it would make more sense to link this activity directly to a specific generation of information as in the different design phases. Each design phase then incorporates specific requirements on the model information, the collaboration, the workflows, etc., which have to be fulfilled in order to start the next design phase. Therefore, the next paragraph will focus on defining the standard design phases in Denmark, aiming to develop a consistent and flexible QA-process throughout the design of the project. As described earlier, the design phases are extracted from the publication "Description of services for buildings and landscape, 2018", issues by the Danish association of consulting engineers (FRI).[1] For consistency reasons, their international standardized equivalent from ISO 29481 are mentioned in brackets, where applicable.[2]

Design Phases from FRI

1. Initial consultancy (Project Setup)

The initial consultancy includes the project setup and among others, all activities and deliverables mentioned in the first part of the interview findings. The main activity of this phase is the conversion of the client requirements into project specifications. In regards of a digital project, this means defining any requirements, the client may have for a digital design, the delivery of a digital project and for a digital communication platform. Furthermore, a proper decision-making plan and QA-process are developed and the involvement of external parties (user, FM, contractor) are coordinated.

[1] FRI (2018), Description of services for Building and Landscape 2018, p. 1
[2] ISO 29481-1:2016

Design Management as the next chapter in the FRI publication is not seen as a separate design phase rather a role description and is therefore not reviewed here. In digital design, the BIM/ICT-Manager would handle the scope of this role.

2. Outline proposal (ISO: Outline feasibility)

The outline proposal is a preliminary design phase, developing a proposal for the completion of the project on the basis of the design specification Besides the architectural concept, functions and sustainability as well as proposals for the general choice of materials, design and installation principles are subject of this design phase. This phase will subsequently follow the project setup and may already include QA-activities. In an overall review, it is checked if the requirements of the design specifications (architecture, function, construction method + ICT specifications) are met. The initial concepts of each discipline are also reviewed interdisciplinary by the lead consultant in regards of the client/ legal requirements or interdependencies. As soon as the digital models are created, they will also from part of the quality assurance process. Furthermore, the ICT-specifications are continuously updated and adjusted to the current project phase.

3. Project proposal (ISO: Outline conceptual design)

The project proposal is a revision of the outline proposal including all decisive decisions for the project. The project proposal is the basis upon which the client decides about the aesthetic, functional, technical and financial solution of the project. Through the QA-process, the project proposal should be qualified enough to form the basis for a tender design. After this phase, the design should meet the requirements of the design specification for the overall quality of the building project and is consistent with the updated ICT-specifications. As the digital design evolves a digital quality assurance activity in the form of collision and consistency control of building models as part of the interdisciplinary project review will be established. As LOD of the models is still preliminary, the level of detail of the model check will also be on a high level without much detailing focusing on the BIM Validation.

4. Regulatory project (ISO: Full conceptual design)

The preliminary project (regulatory project) is again a revision of the previous phase in order to apply for the building permit by the authorities. The preliminary project (regulatory project) contains a statement describing the final design of the project in relation to regulatory requirements, including a description of the project’s architecture, choice of design, choice of materials and MEP systems. As the design is reviewed for the application for the building permit, an internal as well as collaborate model check is recommended in order to assure the design is in compliance with all requirements, needed in this stage of the project.

5. Tender Design (ISO: Coordinated Design)

The tender design is supposed to describe the project precisely and with such a level of detail that it can from the basis for tendering, contracting and construction. The tender design must include a list of documents, a description of the building project, work specifications, drawings, a programme and schedules. It also has to be defined what level of detail (LOD) the different models have and who is responsible for further detailing the models where it is needed in order to construct the real building.

Model Checks are done systematically based on the defined LOD after the phase. A detailed interdisciplinary project review is applied for the purpose of collision and consistency control of building models.

6. Construction Project

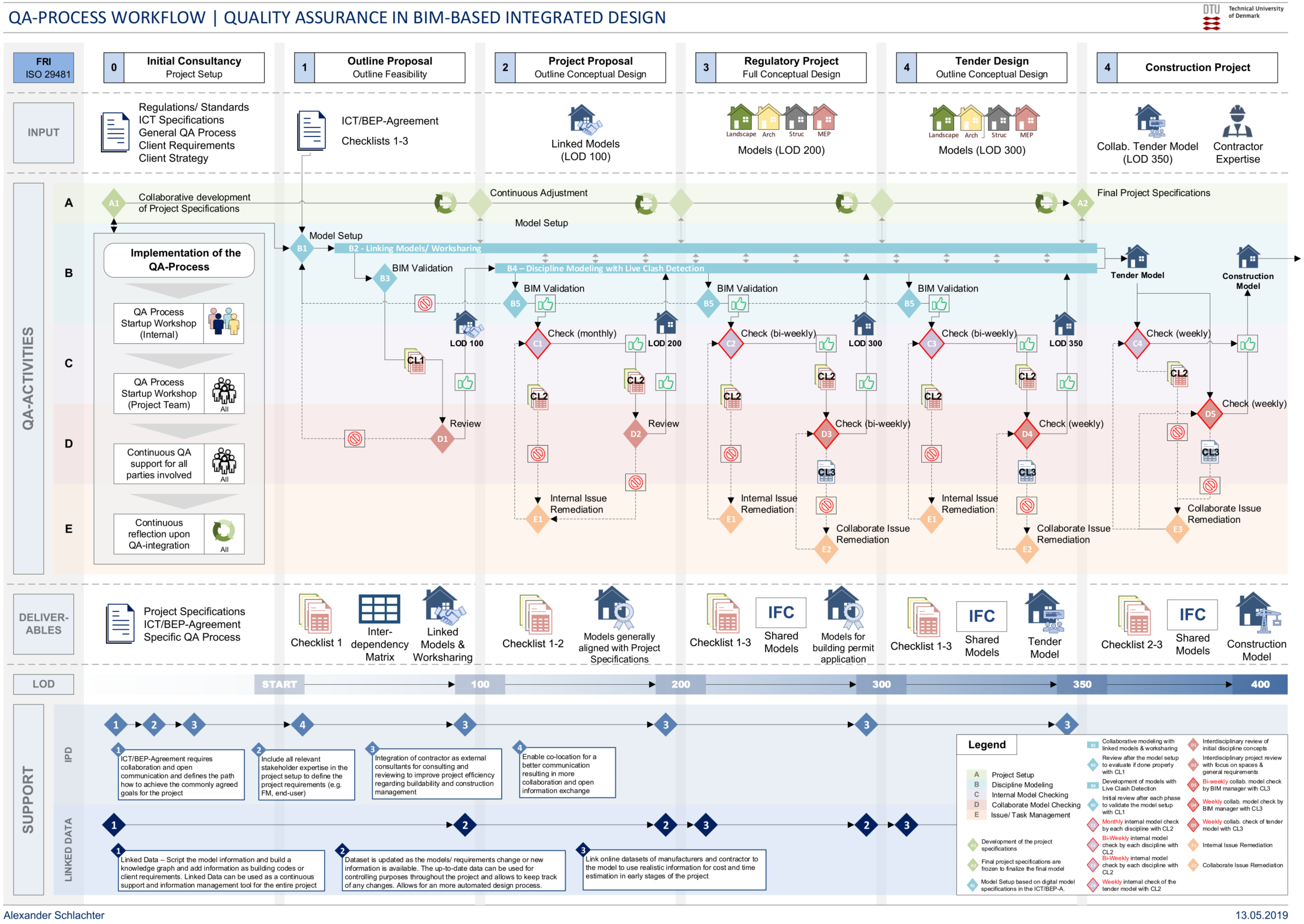
The construction project is a phase after the tenders of the contractors are received and accepted upon which the tender design is further developed to form the basis of the construction project design. This phase is partially managed by the consultant and the contractors and therefore requires a good collaboration in regular meetings and intensive communication. The consultants will perform internal review of the discipline models and take part in the interdisciplinary project review with consultants and contractors. It is the first time, that the contractor who is actually constructing the project, is integrated into the QA-process. This requires an intensive and collaborative issue management process where all critical issues regarding construction and reviewed in plenum and resolved by the responsible party. After this phase, the digital design is finalized and contains sufficient information in the right quality and LOD allowing the contractor to start constructing the building.

Final QA-Process:

By integrating both the QA-activities and the introduced project phases, a comprehensive QA-process workflow is established. The process should provide an overview about the integration of quality assurance during the design phase and recommends as QA-setup for each design phase. Therefore, the QA-activities and the project phases form a matrix structure, where the different activities are aligned to the project development in the corresponding project phase. Furthermore, the project setup, a continuous implementation process as well as the design development are considered in the process. However, the proposed workflow should not provide a process-solution for all kinds of project. Moreover, it should serve as a basic and logic sequence of the different activities over time and can be adjusted to the specific project type and specifications. The BIM Manager together with relevant stakeholder should define the specific QA-process layout in the ICT-agreement in order to make everybody aware and responsible for the digital quality assurance. This needs to be addressed during the project setup.

The process also integrated the supportive framework of IPD and Linked Data which were discussed in the interviews as two approaches that can foster collaboration and information management in construction projects. If the principles of both approaches are implemented early in the project setup, they provide a great potential by continuously supporting the QA-process. However, QA is not the only scope of application for those methods. Therefore, their implementation should be managed in a more overall project perspective where one aspect would be quality assurance in BIM based design.

The QA-process is the final result of this study and can be found in the following page and Appendix 6


QA-PROCESS WORKFLOW | QUALITY ASSURANCE IN BIM-BASED INTEGRATED DESIGN
DTU Technical University of Denmark
FRI ISO 29481
0 Initial Consultancy Project Setup
1 Outline Proposal Outline Feasibility
2 Project Proposal Outline Conceptual Design
3 Regulatory Project Full Conceptual Design
4 Tender Design Outline Conceptual Design
4 Construction Project
INPUT
Regulations/ Standards
ICT Specifications
General QA Process
Client Requirements
Client Strategy
ICT/BEP-Agreement
Checklists 1-3
Linked Models (LOD 100)
Landscape Arch Struc MEP
Models (LOD 200)
Models (LOD 300)
Collab. Tender Model (LOD 350)
Contractor Expertise
QA-ACTIVITIES
A
B
C
D
E
Collaborative development of Project Specifications
Continuous Adjustment
Final Project Specifications
Model Setup
Implementation of the QA-Process
QA Process Startup Workshop (Internal)
QA Process Startup Workshop (Project Team)
Continuous QA support for all parties involved
Continuous reflection upon QA-integration
All
B2 - Linking Models/ Worksharing
B4 – Discipline Modeling with Live Clash Detection
BIM Validation
Tender Model
Construction Model
LOD 100
LOD 200
LOD 300
LOD 350
Check (monthly)
Check (bi-weekly)
Check (weekly)
Review
Internal Issue Remediation
Collaborate Issue Remediation
CL1
CL2
CL3
DELIVER-ABLES
Project Specifications
ICT/BEP-Agreement
Specific QA Process
Checklist 1
Inter-dependency Matrix
Linked Models & Worksharing
Checklist 1-2
Models generally aligned with Project Specifications
Checklist 1-3
IFC
Shared Models
Models for building permit application
Tender Model
Checklist 2-3
Construction Model
LOD
START
100
200
300
350
400
SUPPORT
IPD
LINKED DATA
1 ICT/BEP-Agreement requires collaboration and open communication and defines the path how to achieve the commonly agreed goals for the project
2 Include all relevant stakeholder expertise in the project setup to define the project requirements (e.g. FM, end-user)
3 Integration of contractor as external consultants for consulting and reviewing to improve project efficiency regarding buildability and construction management
4 Enable co-location for a better communication resulting in more collaboration and open information exchange
1 Linked Data – Script the model information and build a knowledge graph and add information as building codes or client requirements. Linked Data can be used as a continuous support and information management tool for the entire project
2 Dataset is updated as the models/ requirements change or new information is available. The up-to-date data can be used for controlling purposes throughout the project and allows to keep track of any changes. Allows for an more automated design process.
3 Link online datasets of manufacturers and contractor to the model to use realistic information for cost and time estimation in early stages of the project
Legend
A Project Setup
B Discipline Modeling
C Internal Model Checking
D Collaborate Model Checking
E Issue/ Task Management
A1 Development of the project specifications
A2 Final project specifications are frozen to finalize the final model
B1 Model Setup based on digital model specifications in the ICT/BEP-A.
B2 Collaborative modeling with linked models & worksharing
B3 Review after the model setup to evaluate if done properly with CL1
B4 Development of models with Live Clash Detection
B5 Initial review after each phase to validate the model setup with CL1
C1 Monthly internal model check by each discipline with CL2
C2 Bi-Weekly internal model check by each discipline with CL2
C3 Bi-Weekly internal model check by each discipline with CL2
C4 Weekly internal check of the tender model with CL2
D1 Interdisciplinary review of initial discipline concepts
D2 Interdisciplinary project review with focus on spaces & general requirements
D3 Bi-weekly collab. model check by BIM manager with CL3
D4 Weekly collab. model check by BIM manager with CL3
D5 Weekly collab. check of tender model with CL3
E1 Internal Issue Remediation
E2 Collaborate Issue Remediation
Alexander Schlachter
13.05.2019

References

A.L.C. Ciribini, S. Mastrolembo, Ventura,M. Paneroni (2016), Implementation of an interoperable process to optimise design and construction phases of a residential building: A BIM Pilot Project, Automation in Construction 71 (2016) p. 62 – 73

BIPS (2016), C402 Consistency Checking of Building Models (in Danish: C402 Konsistenskontrol af bygningsmodeller)

EN ISO. (2018). "*Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) - Information management using building information modelling*", Part 1: Concepts and principles (ISO 19650-1:2018) & Part 2: Delivery phase of the assets (ISO 19650-2:2018)

Farmer, M; Branson, P. (2016): The Farmer Review - The UK Construction Labour model. Modernise or die!, in: *Electronics Education* 2016 (2)

Flager, F; Haymaker, J (2009): A Comparison of Multidisciplinary Design, Analysis and Optimization Processes in the Building Construction and Aerospace, in: *Stanford University CIFE Technical Report* (#TR188)

Gläser, J; Laudel, G (2010): Experteninterviews und qualitative Inhaltsanalyse als Instrumente rekonstruierender Untersuchungen, 4. Auflage, Wiesbaden: VS Verlag (German educational book)

H. Kulusjärvi (2012), Common BIM Requirements 2012 – Series 6 Quality Assurance, buildingSMART Finland, http://files.kotisivukone.com/en.buildingsmart.kotisivukone.com/COBIM2012/cobim_6_quality_assurance_v1.pdf2012)

ISO. (2016). "Building information models - Information delivery manual - Part 1: Methodology and format." ISO 29481-1, Geneva, Switzerland, 28.

M. Oh, J. Lee, S. W. Hong, Y. Jeong (2015). Integrated system for BIM-based collaborative design, Automation in Construction 58, p. 196–206

Mayring, P. (2014): Qualitative Content Analysis. theoretical foundation, basic procedures and software solutio

N. Treldal, H. Parsianfar, & J. Karlshøj (2016). Using BCF as a mediator for task management in building design. In Proceedings of the International RILEM Conference Materials, Systems and Structures in Civil Engineering 2016: BIM in Civil Engineering – Open Data Standards in Civil Engineering (pp. 48-59). Rilem publication

Rasmussen, M. H. (2018) Lecture in course 11034 (DTU)

S. Mehrbod, S. Staub-French, N. Mahyar, M. Tory (2018). Characterizing interactions with BIM tools and artifacts in building design coordination meetings, Automation in Construction 98, February 2019, p. 195-213

Sommer, Hans (2016): Projektmanagement im Hochbau. Mit BIM und Lean Management, 4. Auflage, Berlin, Heidelberg: Springer Vieweg

The American Institute of Architects (AIA) (2007): Integrated Project Delivery: A Guide (Version 1)

The Danish Association of Consulting Engineers, FRI (2018), Description of services for Building And Landscape 2018, Version 1.0

Törmä, S. (2013). Semantic Linking of Building Information Models. Seventh IEEE International Conference on Semantic Computing (ICSC 2013), Irvine, CA

Treldal, N. (2017). Digitalization as Driver for Standardized Specification and Design of Buildings: In Search of an Efficient Building Design Management Methodology. Technical University of Denmark, Department of Civil Engineering. B Y G D T U. Rapport, No. R-367

W. Solihin, & C. Eastman (2015). Classification of rules for automated BIM rule checking development. Automation in Construction, 53(0), pp. 69-82

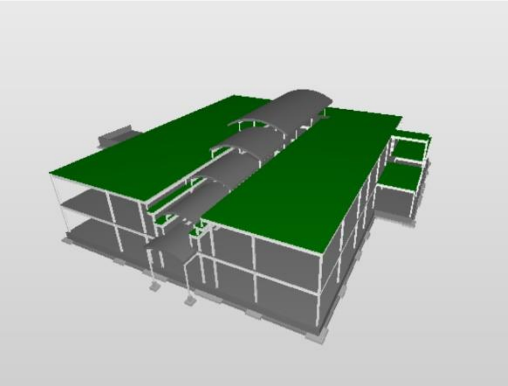
Appendix

Appendix 1

Protocol - Model Checking

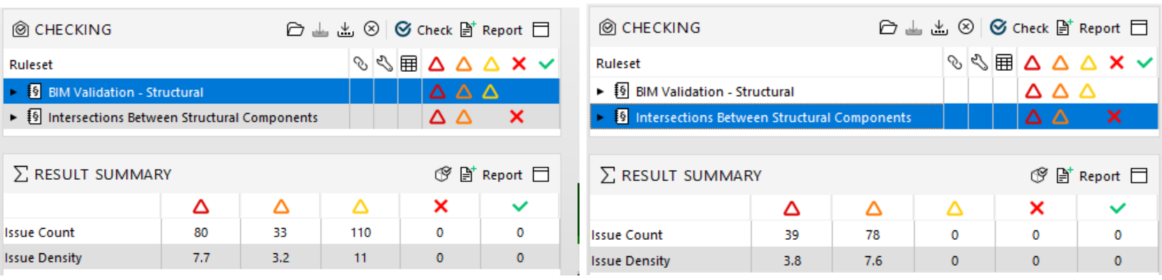
Solibri Model Checker:

1. Structural Discipline Model:



- The structural model is based on the steel construction with columns and beams as well as floor slabs supported by the steel structure. In the center, it has a big open hallway with a rounded roof structure, declining towards the main entrance.

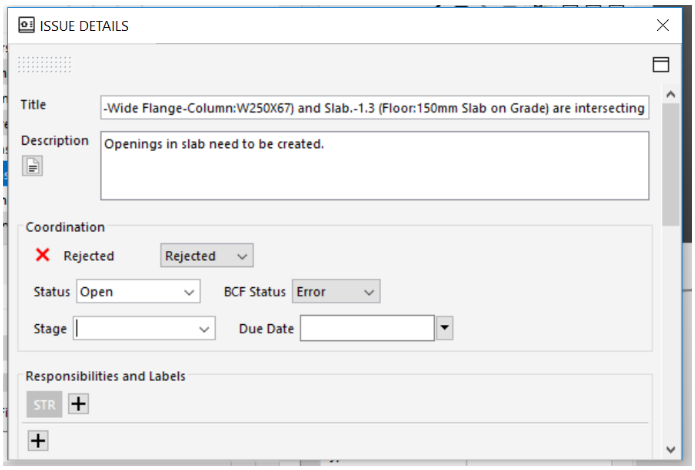
- Rulesets:
    - BIM Validation – Structural (Default)
    - Intersections between structural components (Default)



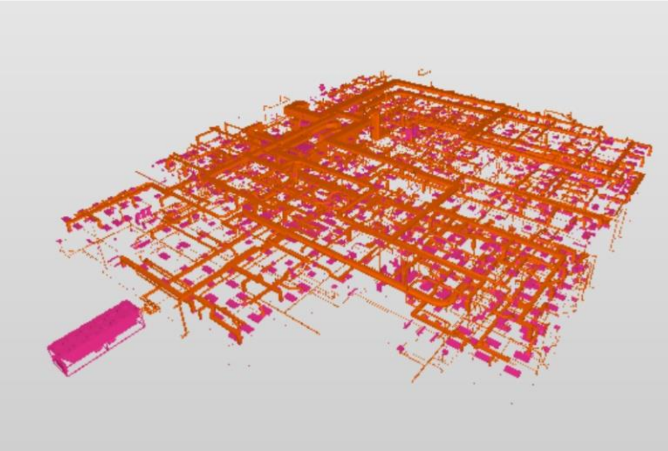
As shown above, the internal check of the structural discipline model resulted in a total of 340 issues (223 in the first ruleset and 117 in the second) with different levels of severity. Solibri now asks the user to review the issues and either reject or accept them. Rejecting issues means that they will go back to the designer/ engineer who is in charge of the correction. In this case, 5 critical issues will be selected and combined in a model checking report for further steps in the quality assurance process. The rest of the issues, which are considered minor, will be marked as accepted.

If an issue is rejected, a slide can be added to the issue presentation. In this slide, the user can identify different properties of the issue as shown in the picture on the right. The presentation can then be exported as a BCF-file in order to start the collaborative task management.

By doing that simultaneously during the issue review, all critical issues are documented properly and can be used for task management.



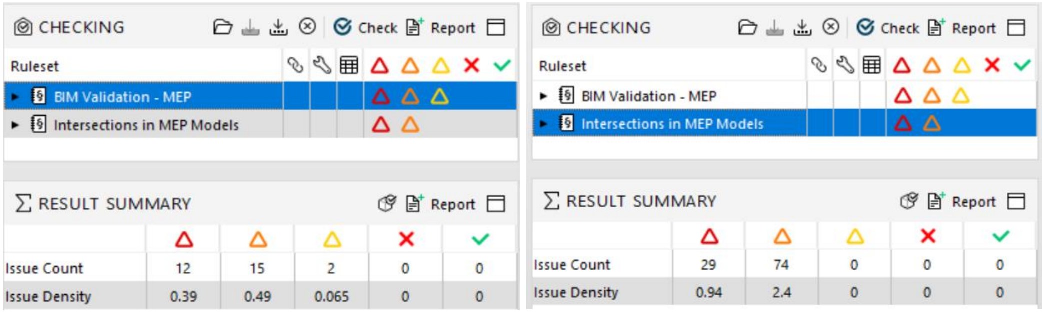
2. MEP Discipline Model:



- The MEP model includes electrical as well as mechanical installations like ventilation, plumbing or piping. It is a complex model where many disciplines interact with each other and have to be coordinated by a central model.

Clashes are limited to HVAC and Electrical in order to reduce the amount of clashes.

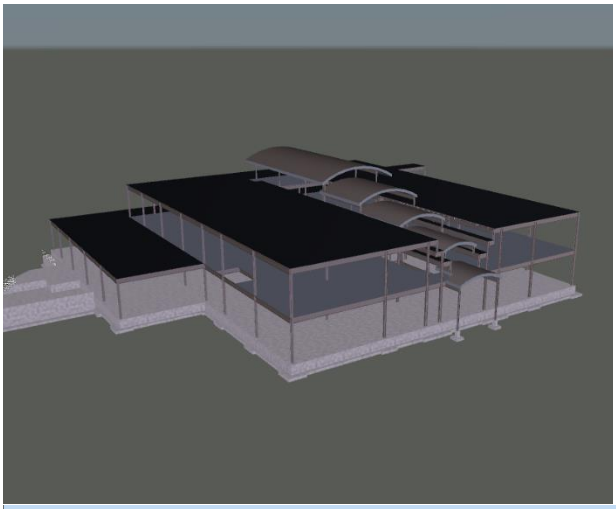
- Rulesets:
  - BIM Validation – MEP (Default)
  - Intersections between MEP Models – HVAC and Electrical (Default)



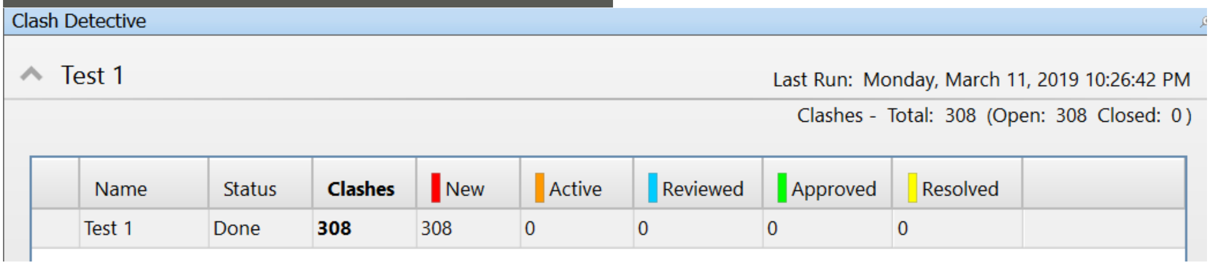
The MEP model check resulted in a total of 132 issues (29 in the first ruleset and 103 in the second). It was recognized that the ruleset 'intersections in MEP models' could not find components from the electrical discipline, as they are not classified as such. This shows how important it is to do a BIM validation of each model, before doing the clash detection, in order to analyze the model's compliance to the set requirements. Normally, the MEP engineer would have to specify all undefined components in a classification component list in Solibri. In this case however, the number of identified issues is sufficient for the purpose of this course.

Navisworks:

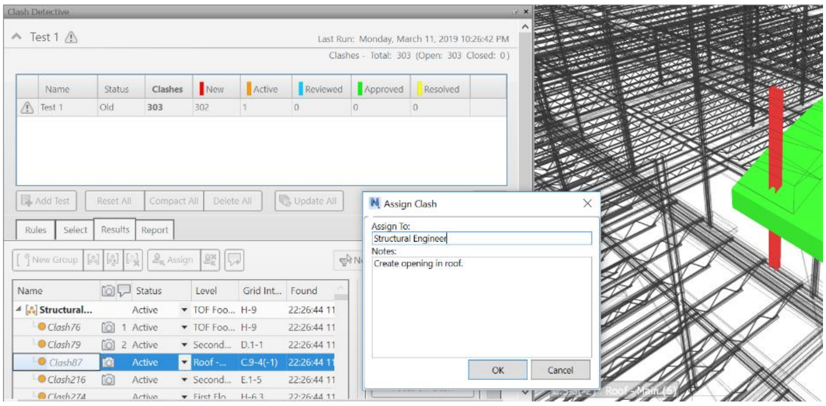
1. Structural Discipline Model:



- Clash Detection between Structural Model and Structural Model, in order to identify all internal classes. It is noted that clash detection with Navisworks mainly allows to identify geometrical interferences between two sets of objects. In this case, the structural model is checked against his own model data.



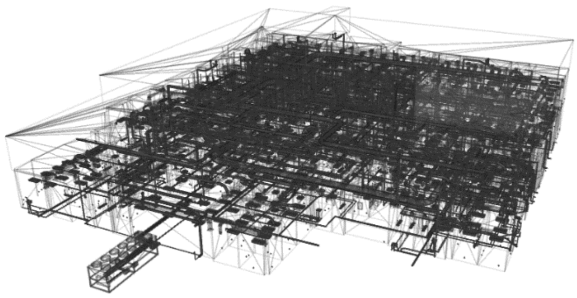
As shown above, the internal check of the structural discipline model resulted in a total of 308 issues compared to 340 issues in Solibri. Similar to Solibri, Navisworks now asks the user to review the issues and either reject or accept them. When rejecting an issue, the user should assign a responsible person (designer/ engineer) who is in charge of the correction and mark all irrelevant clashes. In the beginning, the same clashes as in the clash detection with Solibri were tried to find in order to validate the check and make it comparable. Here, Navisworks creates a list of all clashes to review and evaluate them. This list does not have any breakdown structure and only lists the identified clashes, organized by its column values. It was difficult to find the same clashes as double-objects or other clash options are not supported by Navisworks.



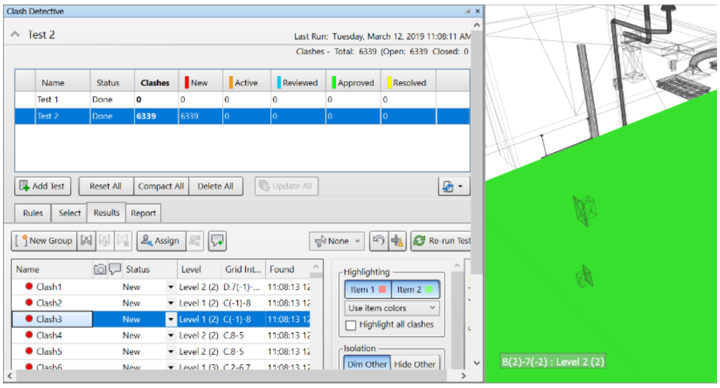
Again, 5 critical issues are selected and combined in a model checking report for further steps in the quality assurance process. The rest of the issues will be marked as accepted, so the workflow only focusses on the chosen 5.

Navisworks is then only able to safe the Report as an HTML file, showing a list of the identified clashes. The only possibility to use the information directly for modifying the clashes is by using Autodesk BIM 360. This, however, is not reviewed as a license was not available for this study.

2. MEP Discipline Model



- Clash Detection between MEP Model and MEP Model, in order to identify all internal clashes. It is noted that clash detection with Navisworks mainly allows to identify geometrical interferences between two sets of objects. In this case, the MEP model is checked against his own model data

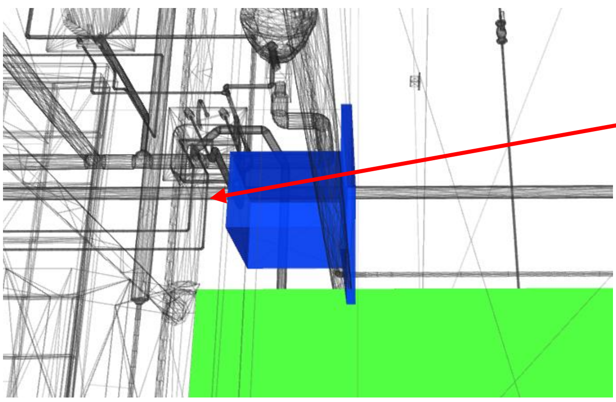


Name	Status	Clashes	New
Test 1	Done	**0**	0
Test 2	Done	**6339**	6339
Test 3	Done	**821**	821

When performing a clash detection with the entire MEP model, a total of 6339 clashes has been identified with Navisworks. Therefore, sets for HVAC installations including the Air terminal and several ducts as well as for electrical installations have been created to reduce the number of clashes to 821. As done automatically with the ruleset in Solibri, I was now able to only perform the clash detection with between the HVAC and Electrical discipline.

Also note, that Navisworks allows to perform either a normal clash detection (Hard) or a duplicate identification which should identify duplicates of object. However, this did not work out with neither the Structural or MEP model, although Solibri identified duplicates before.

Due to the limited clash detection features with Navisworks as well as the huge amount of identified clashes, it was impossible to find the same clashes as with Solibri. The first clash from Solibri for example, was based on a too s short distance between a ventilation outlet and a pipe. As Navisworks does not include rules which tell the software that a specific distance has to be applied for specific objects, it only checks for the set clearance parameter for all objects in the model. Therefore, the same approach as in the structural model was applied here, identifying 5 clashes similar to the ones from Solibri.



Short distance between pipe and ventilation outlet, identified with Solibri, but not with Navisworks.

After these individual discipline checking, the model should be modified by the responsible designer/ engineer who is in charge of solving the identified issues, as described in the QA-process. This can either be done by reviewing the created issue report of Solibri or Navisworks. This approach is quite inconvenient as the designer has to understand the information in the report and manually search for the clash in the model. For a better orientation, the Solibri/ Navisworks model can be used simultaneously to navigate through the model. A more advanced approach might be to use the Revit add-in BCF-manager which allows to use the information of the BCF-file exported from Solibri. When clicking on the identified issue, it automatically navigates to the respective issue where it can be modified directly. With Navisworks, Autodesk offers an internal cloud service BIM 360 which allows to make the clash detection information available in the Revit model, where it again, can be modified quite easily.

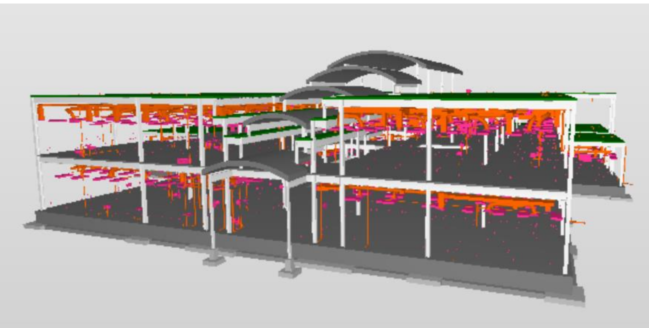
Protocol of Collaborate Model Checking - Clash detection

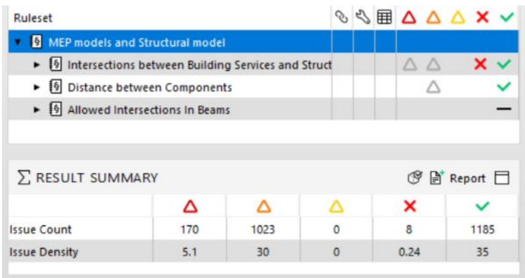
Collaborate Model (Structural and MEP Model)

After both models have been checked individually, they are merged in both software applications in order to check for interdisciplinary clashes. In this case, only the clashes between both models are checked, so it does not interfere with the other model checking

Solibri Model Checker:

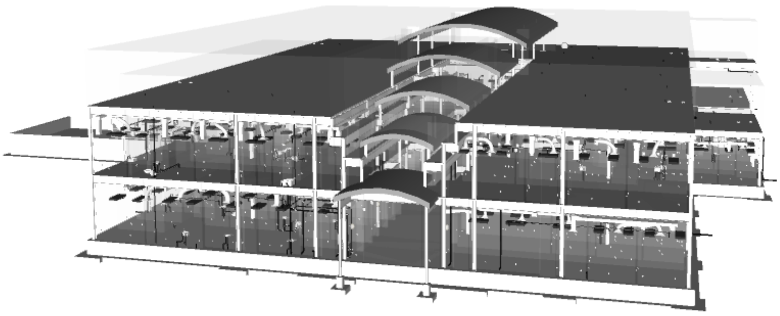
- Rulesets:
  - BIM Coordination (Default)
  - MEP models and Structural model (Default)

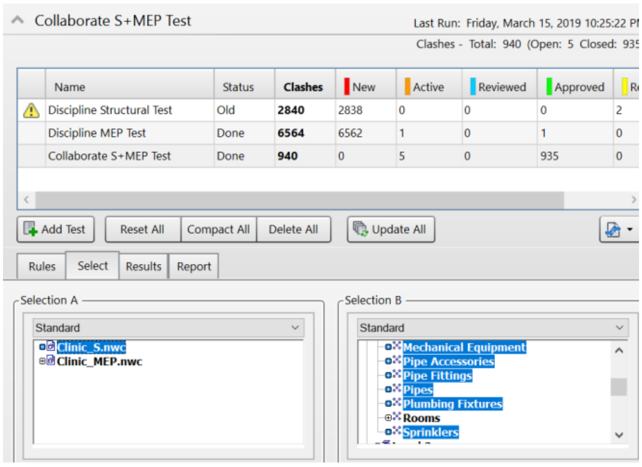




As shown in the summary on the right, the collaborate check with Solibri resulted in a total of 1.193 issues with different levels of severity. This is a huge number of clashes, which again calls for an initial QA-step in order to prevent the creation of clashes in the first place. 5 of the most critical issues are selected again and combined in a model checking report for further steps in the quality assurance process. The rest of the issues, which are considered minor, will be marked as accepted. These minor clashes are for example short distances between pipes and structural components or interferences where an opening can be made easily (e.g. when the thickness of the penetrated object is small).

Navisworks:

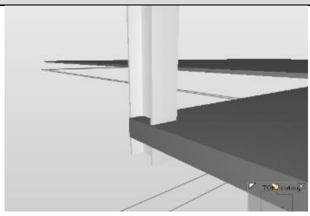
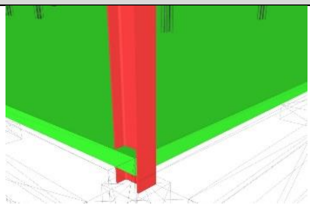
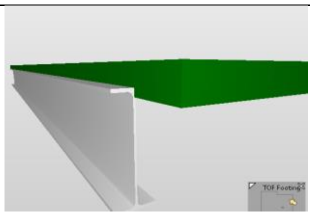
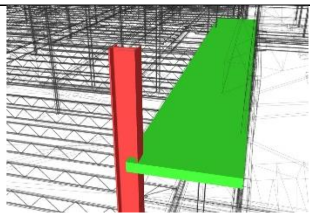


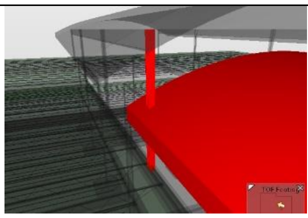
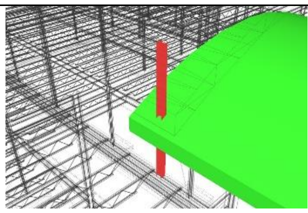
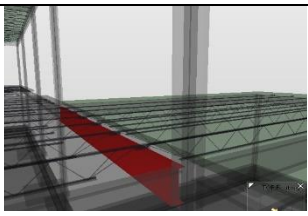
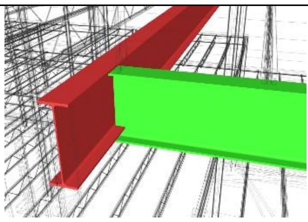
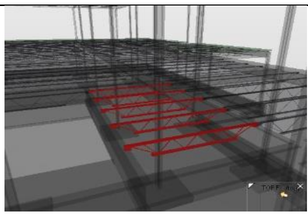
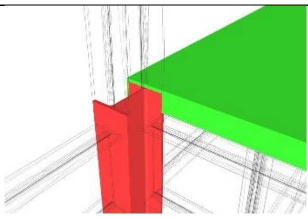
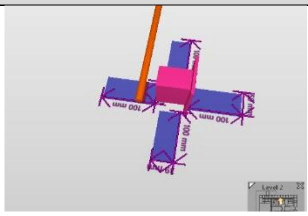
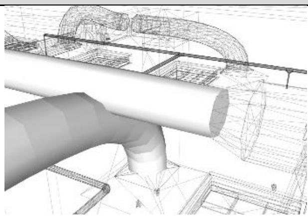
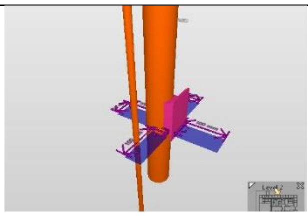
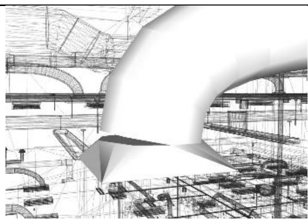
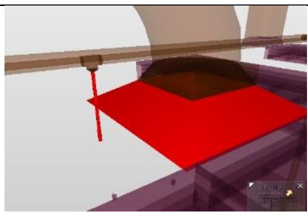
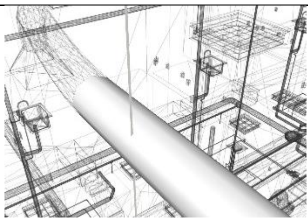
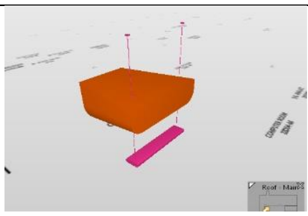
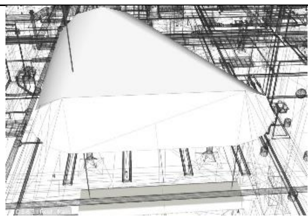


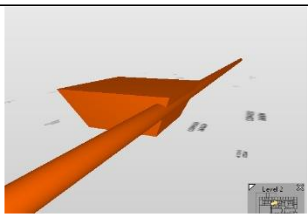
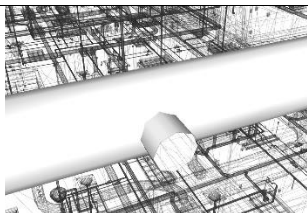
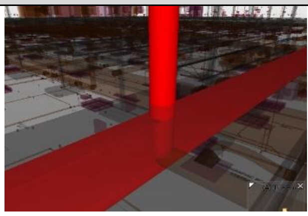
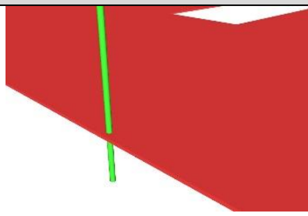
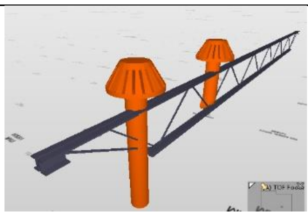
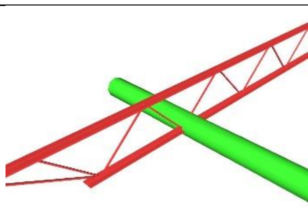
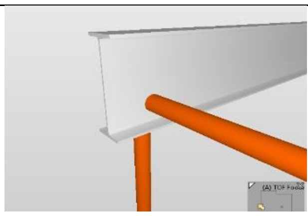
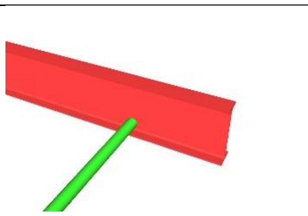
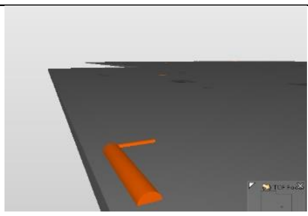
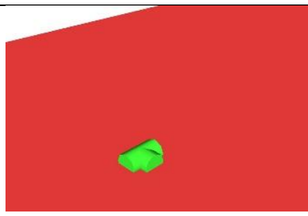
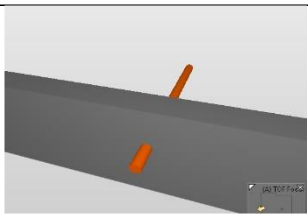
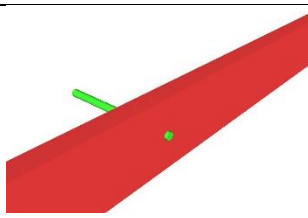
The collaborate model check with Navisworks turned out to be a little tricky, as all spaces, identified as rooms in the MEP model are also checked against the structural model when selecting the entire MEP model as subject to be checked. Therefore, an individual selection of all MEP-related objects was created and checked against the structural model. By doing that, the number of clashes was reduced from initially 6.564 clashes to 940.

In general, the identified clashes for the collaborate model with Navisworks were quite similar to the ones from Solibri, whereby the selected clashes also resemble the selection in Solibri.

To sum the clash detection up, the following table gives an overview about all clashes which will be in used for the collaborate task management with BIMcollab and Revizto.

Type of Check	No. of Clashes Solibri	No. of Clashes Navisworks	Comment
Internal Structural	**340**	**308**	
Clash 1			Steel columns penetrating the floor slab. Connection to be specified.
Clash 2			Structural component (beam/ columns) interfering a roof element. Connection to be specified.

Type of Check	No. of Clashes Solibri	No. of Clashes Navisworks	Comment
Clash 3			Supporting column of the upper roof is penetrating the lower roof. An opening has to be created by the structural engineer.
Clash 4			Two beams are interfering (right) or a doublet has been identified (left). To be modified by the structural engineer.
Clash 5			Property value oft he beams (left) to be modified and connection to be specified on the clash to the right.
Internal MEP	**132**	**821**	
Clash 1			Too little distance from ventilation outlet (left) and interfering ventilation pipes (right). To be modified by MEP engineer.
Clash 2			Too little distance from ventilation outlet (left) and wrong connection between pipe and outlet (right). To be modified by MEP engineer.
Clash 3			Vertical pipe interfering with horizontal HVAC object. Small pipe to be moved around the bigger object.
Clash 4			Light fixture suspension is going through ventilation pipes. Fixture to be modified to the pipe locations by the MEP engineer.

Type of Check	No. of Clashes Solibri	No. of Clashes Navisworks	Comment
Clash 5			Interfering pipes. Tob e specified whether the pipes are connected and need an opening or pipes need to be moved apart.
Collaborate	**1.193**	**940**	
Clash 1			Vertical pipe is penetrating a beam (left) or the floor slab (right). Either an opening need to be created or the pipe location needs to be adapted.
Clash 2			Ventilation/ water pipe is going through a braced beam. Pipes to be moved through the openings of the beam or objects to be separated.
Clash 3			Pipe is penetrating a steel beam. If possible, an opening can be created, or the pipe needs to be moved down or up.
Clash 4			Pipes are embedded in floor slab and need to be lifted to lie on top if the floor slab. To be modified by the MEP engineer.
Clash 5			Pipe is penetrating a wall horizontally. Either an opening in the wall needs to be created or better the pipe is moved to not interfere with structural objects.
Total	**1.665**	**2.069**	

Appendix 2

Software application in Quality Assurance Workflow


Project Setup
ICT-Agreement
- Software Applications
- Workflow Definition
- Communication
- Model Responsibilities
1 DISCIPLINE MODELING
Landscape Model
Architectural Model
Structural Model
MEP Model
AUTODESK REVIT
Discipline Modeling Checklists
Quality Assurance in Discipline Modeling
PLUG-INS
BIM RROJECT SPECIFICATION
LIVE CLASH DETECTION
LINKED DISCIPLINE MODELS (INTERF. CHECK)
RAISING AWARENESS OF QA AND COLLAB.
2 INTERNAL MODEL CHECKING
CHECKING SOFTWARE
CLASH DETECTION
ISSUE REMEDIATION
COMPLIANCE CHECK
Solibri Model Checker
SMC
IFC IFC
Run IFC-based Discipline Check
List of critical issues in each model (e.g. BCF)
BCF Manager
OR
Manual Report
Issue Remediation with Revit
Internal Model Checklist
Navisworks
AUTODESK NAVISWORKS
Direct Import of Revit File
Clash detection between to sets of objects
BIM 360
OR
Manual Report
Issue Remediation with Revit
Internal Model Checklist
3 COLLAB. MODEL CHECKING
CHECKING SOFTWARE
CLASH DETECTION
ISSUE MANAGEMENT
SMC + BIMcollab
Navisworks + Revizto
revizto
Create Collaboration Model
Clash Detection with Collab. Model
BCF-Report of critical issues and upload to BIMcollab
Direct Import of Revit File
Upload critical issues to Revizto
Collaborative Clash Review
Task Management
Checklist
Issue Remediation
Model Compliance Confirmation
Collaborative Clash Review
Task Management
Checklist
Issue Remediation
Model Compliance Confirmation

Appendix 3

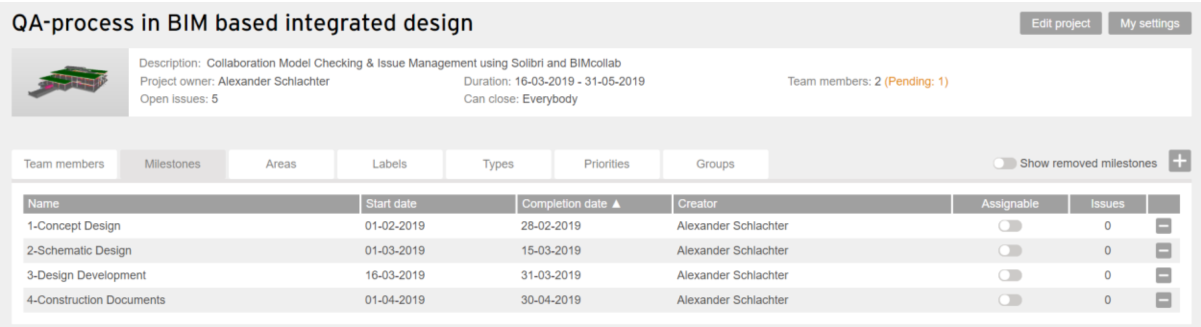
Protocol - Collaborative Issue Management

Protocol of Collaborative Issue Management

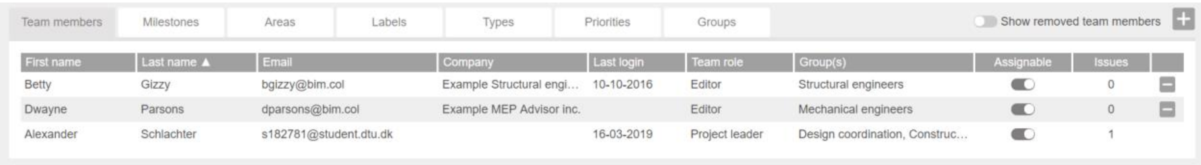
Solibri & BIMcollab:

1. Project Setup:

Before importing the issue data into BIMcollab, a project has to be set up. This project should include all necessary settings to properly organize and assign the issues later. In this case BIMcollab offers several options. First of all, the general project specifications as Name, Owner, Duration and Accessibility or User Rights need to be defined. Afterwards, a range of setting can be adjusted or added such as Team Members, Milestones, Areas, Labels, Types, Priorities and Groups which all aim to facilitate the collaborative issue management process. As an example, the following Milestones and Team members (Structural engineer, MEP engineer and BIM Coordinator) have been created in the project.



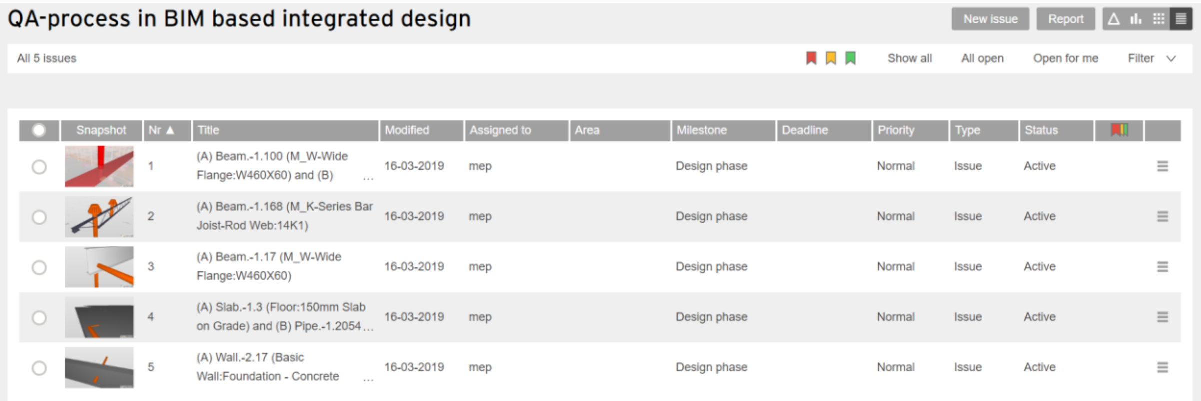
Name	Start date	Completion date ▲	Creator	Assignable	Issues
1-Concept Design	01-02-2019	28-02-2019	Alexander Schlachter		0
2-Schematic Design	01-03-2019	15-03-2019	Alexander Schlachter		0
3-Design Development	16-03-2019	31-03-2019	Alexander Schlachter		0
4-Construction Documents	01-04-2019	30-04-2019	Alexander Schlachter		0



First name	Last name ▲	Email	Company	Last login	Team role	Group(s)	Assignable	Issues
Betty	Gizzy	bgizzy@bim.col	Example Structural engi…	10-10-2016	Editor	Structural engineers		0
Dwayne	Parsons	dparsons@bim.col	Example MEP Advisor inc.		Editor	Mechanical engineers		0
Alexander	Schlachter	s182781@student.dtu.dk		16-03-2019	Project leader	Design coordination, Construc…		1

2. BCF-Import

Afterwards, the issue data is ready to be imported into the project. As the BIM Connector was not available, the information about the issues created with Solibri are imported into BIMcollab via a manual BCF-import. This worked out well and all issues were added into the BIMcollab project, as seen below:

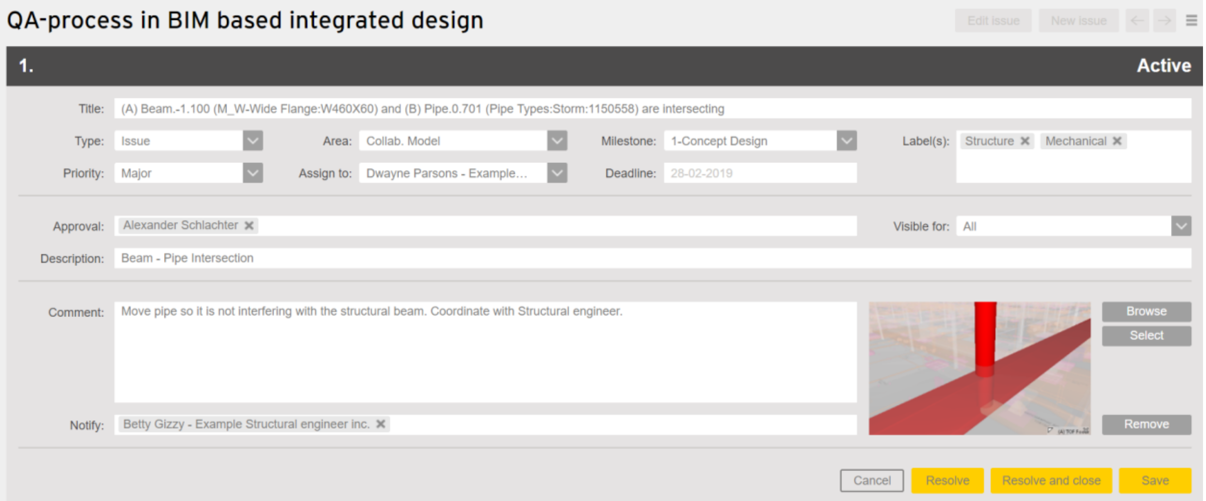


Snapshot	Nr ▲	Title	Modified	Assigned to	Area	Milestone	Deadline	Priority	Type	Status
	1	(A) Beam.-1.100 (M_W-Wide Flange:W460X60) and (B) …	16-03-2019	mep		Design phase		Normal	Issue	Active
	2	(A) Beam.-1.168 (M_K-Series Bar Joist-Rod Web:14K1)	16-03-2019	mep		Design phase		Normal	Issue	Active
	3	(A) Beam.-1.17 (M_W-Wide Flange:W460X60)	16-03-2019	mep		Design phase		Normal	Issue	Active
	4	(A) Slab.-1.3 (Floor:150mm Slab on Grade) and (B) Pipe.-1.2054…	16-03-2019	mep		Design phase		Normal	Issue	Active
	5	(A) Wall.-2.17 (Basic Wall:Foundation - Concrete …	16-03-2019	mep		Design phase		Normal	Issue	Active

3. Modify issues and start issue management process

The next step is to assign information to each issue such as due date, responsible project participant comments and other information. In this case, the collaborate issues affect both the structural and the MEP engineer, however, BIMcollab only allows to assign the issue to one person. Therefore, the issue is assigned to the engineer who is going to resolve the issue. This also requires an interdisciplinary coordination with the other engineering discipline. Therefore one engineer is assigned to resolve the issue and the other is notified to support the issue management process.

In the example below, the issue is assigned to the MEP engineer. However, the issue is labeled as structural and mechanical and the structural engineer is notified after the issue has been saved.



According to BIMcollab users 7 out of 10 issues get resolved straight after the issue has been assigned to the responsible person. This means, that issues are resolved even before the next BIM meeting, allowing to focus on the more complex issues in these meetings.

The same approach has been applied to all issues in the project to get the task management process started. The following picture shows an overview of the assigned issues.

Snapshot	Nr ▲	Title	Modified	Assigned to	Area	Milestone	Deadline	Priority	Type	Status
	1	(A) Beam.-1.100 (M_W-Wide Flange:W460X60) and (B) ...	16-03-2019	Alexander Schlachter	Collab. Model	2-Schematic Design	15-03-2019	Major	Clash	Active
	2	(A) Beam.-1.168 (M_K-Series Bar Joist-Rod Web:14K1)	16-03-2019	Alexander Schlachter	Collab. Model	3-Design Development	31-03-2019	Major	Clash	Active
	3	(A) Beam.-1.17 (M_W-Wide Flange:W460X60)	16-03-2019	Alexander Schlachter	Collab. Model	3-Design Development	31-03-2019	Normal	Clash	Active
	4	(A) Slab.-1.3 (Floor:150mm Slab on Grade) and (B) Pipe.-1.2054 ...	16-03-2019	Alexander Schlachter	Collab. Model	2-Schematic Design	15-03-2019	Major	Clash	Active
	5	(A) Wall.-2.17 (Basic Wall:Foundation - Concrete ...	16-03-2019	Alexander Schlachter	Collab. Model	2-Schematic Design	15-03-2019	Critical	Clash	Active

The issues in red identify that the deadline is already expired and that the engineers are urged to resolve these issues immediately. A suggested solution to resolve the issue is also included as well as the information that the assigned engineer has to coordinate his task with the other (meaning structural and mechanical engineer in this case).

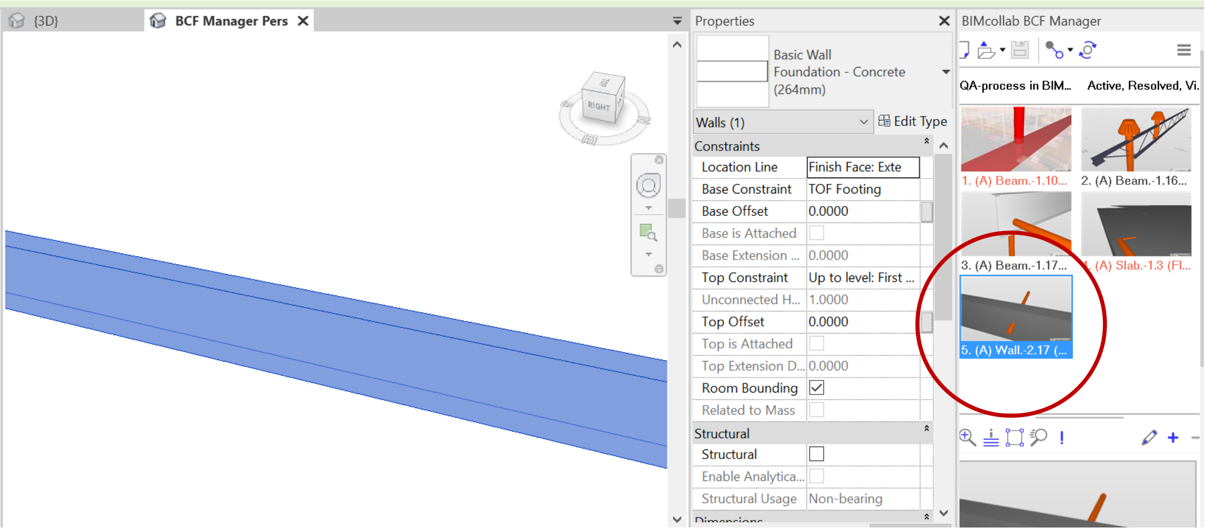
4. Issue management loop

Due to the email notification of the assigned person, some issues can be solved immediately and the ones who could not be resolved will be discussed in the next BIM meeting and taken into the next iterative loop. This loop starts with the clash review, which is shown above. Through the issue assignment to the responsible person, the task management follows the clash review and enable the assigned person to use all existing information about the issue. Therefore, the issue can be located easily in Revit and remedied by the assigned engineer. Afterwards an approval of various persons, especially of the BIM coordinator is needed in BIMcollab. The approval of the BIM coordinator again includes a checklist for the third step of the QA-process which evaluates the quality of the collaborate model and gives access to the next design phase, if the model passes the checklist and therefore is in compliance with the current project specifications. If the model or more detailed the single issue is not approved, the loop starts over again by one person commenting the issue in BIMcollab, specifying what has to be resolved in order to make the issue approvable.

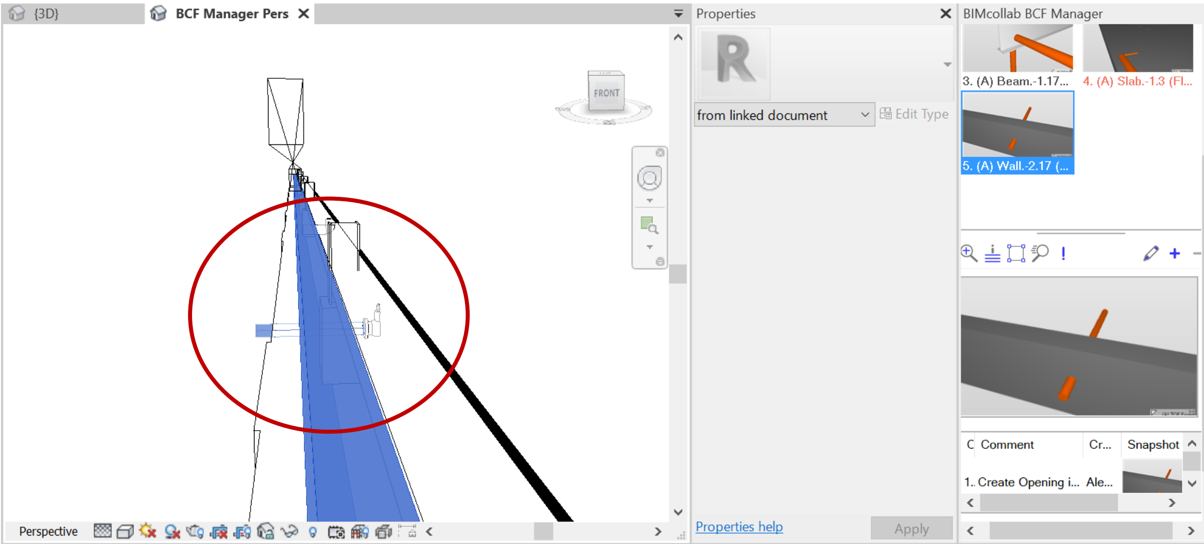
a. Issue remediation in Revit

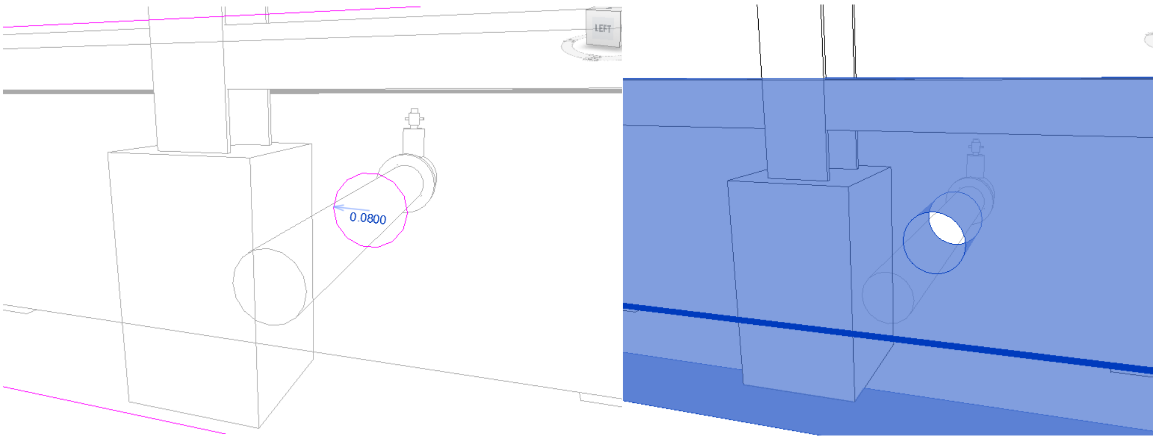
How the identified issues are now easily resolved in Revit will be reviewed below. Therefore, I will use the role for both the structural and mechanical engineer to resolve the assigned issues in their perspective after receiving an email notification. In this case, BIMcollab provides an add-in for Revit which is called BCF-Manager (has been used to resolve internal discipline clashes before), to import the BCF information into Revit and start resolving the assigned issues.

As I am playing the role for all engineers, all issues have also been assigned to my BIMcollab account. This is shown below on the right. The BCF-Manager is presenting all issues that have been assigned in BIMcollab and also contains the location of the issue. In this case, the issue number 5 was double-clicked and is therefore shown now in the Revit view. Here, the structural model was selected to resolve clash number 5. Therefore, the view only shows the structural component affected by the clash, and not the MEP component. In order to solve this, the MEP model is linked into this model, so the opening can be created in the right spot.

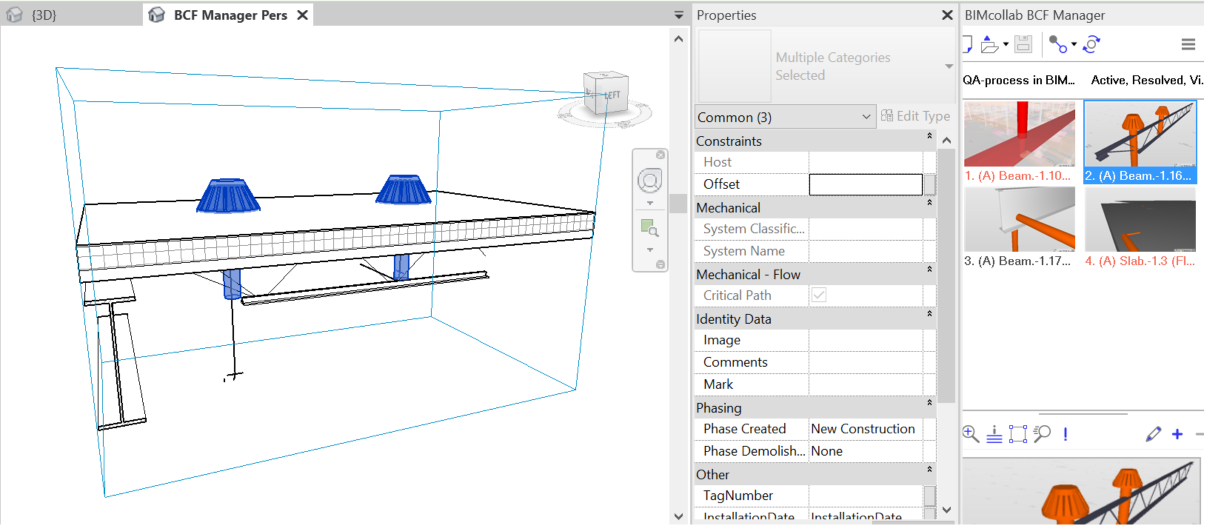


Using a section box and the MEP model as a underlay, both components could be identified in Revit. However, this example provides some difficulties when is comes to executing the proposed solution of creating an opening in the foundation wall. In the end, I managed to create an opening and set the issue as resolved. Of course, this operation has to be validated by a structural analysis before submitting the changes to the other project participants.

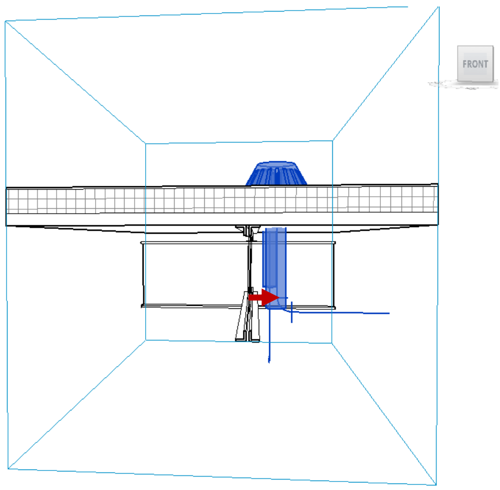




To give another issue remediation example, a clash between pipes and structural components will be resolved in the MEP model, having the structural model as a linked file.

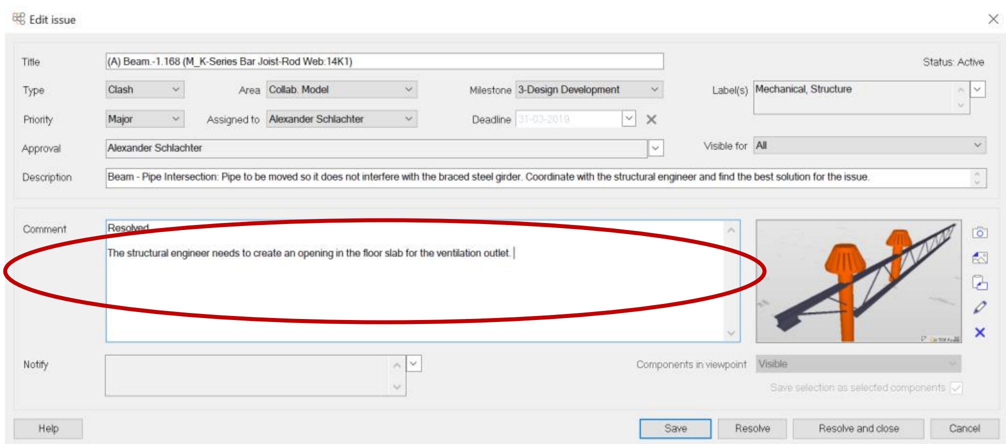


In this example, the assigned issue concerns only the clash between the pipe and the steel girder. However, the view above clearly identifies another clash between the floor slab and the ventilation pipes. As this example is presented in the perspective of the MEP engineer, the ventilation pipes will be moved in order to resolve the assigned issue, but a comment will be added that the structural engineer needs to resolve the floor slab issue. By doing that, the all participants in the project benefit from the collaborative issue management and can easily resolve issues on their own. As a result of this, the BIM meetings can be used to only review the most critical and complex issues.



Back to resolving the issue, the MEP components (ventilation outlet and pipe) are moved to the right, so they do not interfere with the structural beam. Furthermore, the connecting pipes are also modified, so they fit to the new location of the ventilation outlet.

After the issue is resolved, the same process of marking the issue as resolved, synchronizing the information to BIMcollab and creating a new IFC-file for the MEP model is applied similar to the previous issue.

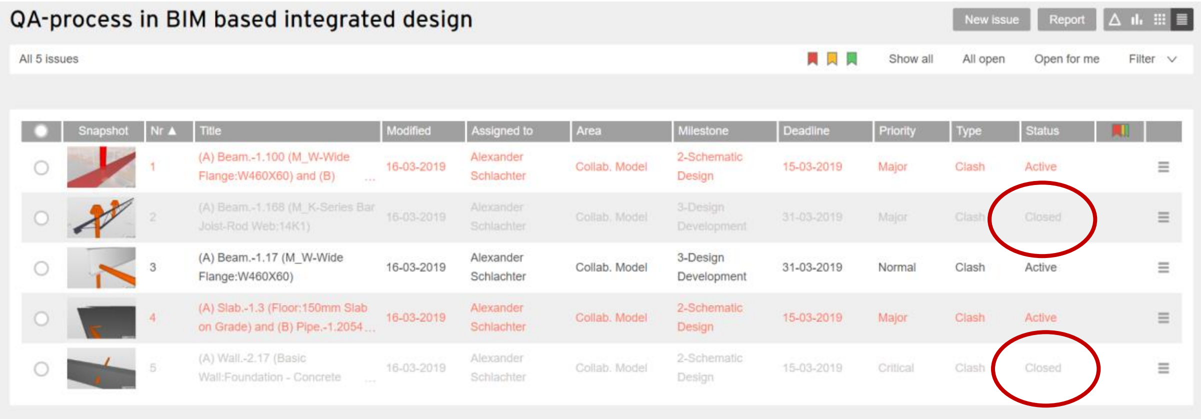


b. Issue Approval:

Each issue needs to be resolved by the assigned person. After resolving the issue in Revit, the BCF-Manager directly allows to mark the issue as resolved and synchronize the information to the BIMcollab project in the cloud.

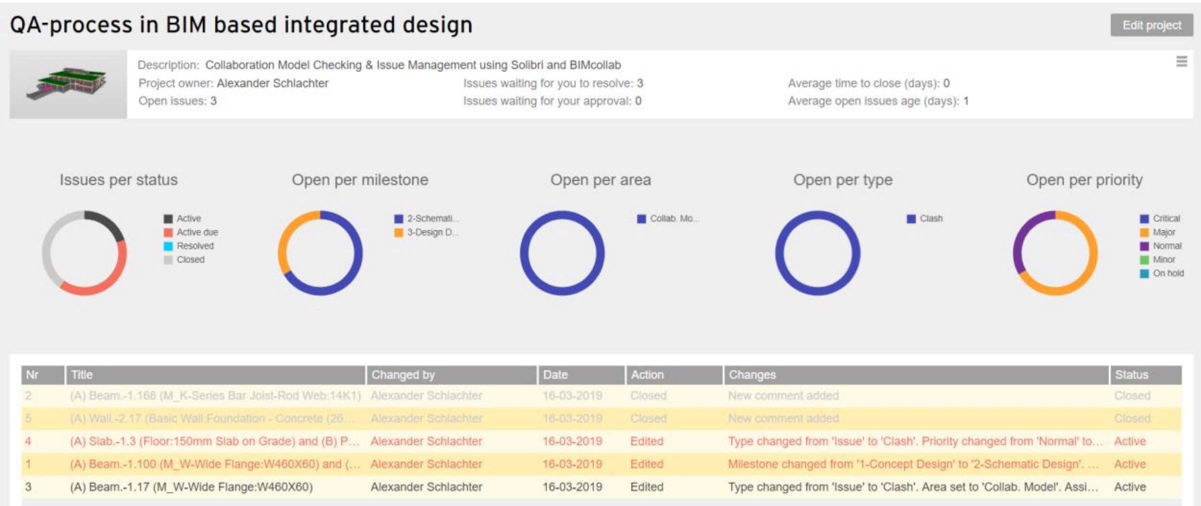
In addition to that, BIMcollab allows to add persons who need to approve the changes once the issue is marked as resolved by the assigned person. By doing that, this removes the problem of finger pointing in a project and nobody can afterwards claim, that they did not know about this change. An issue, in the common sense, is either approved or it is not.

After synchronizing the issue (approval is not needed here as I am the person assigned to resolve and approve the issue), the BIMcollab web-applications shows that the issue is closed.



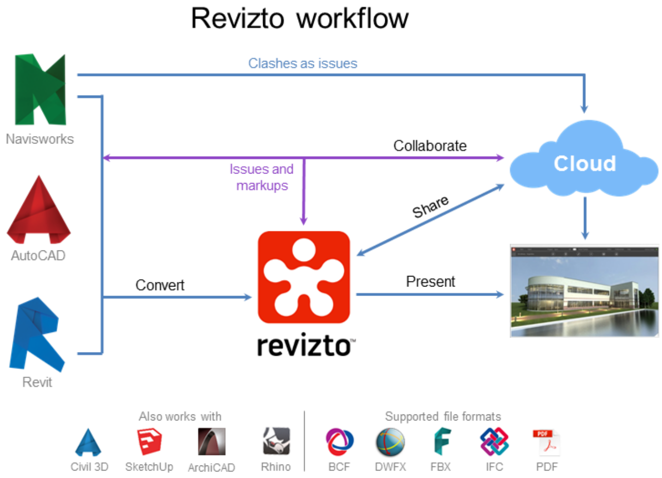
After the issue is resolved and within the approval stage, the BIM coordinator needs to receive an updated IFC-model from the discipline engineer in order to check the model again with Solibri. The model in Solibri can simply be updated and the same clash detection test can be applied. After checking the model again, the BIM coordinator will fill out the checklist and approve the model for the next design phase.

Final result of this iteration loop:



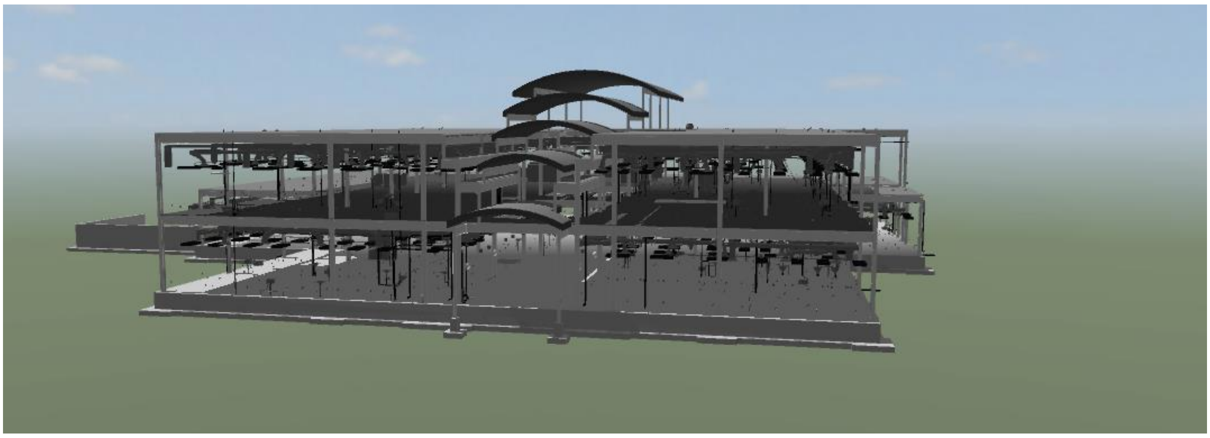
Navisworks & Revizto:

The workflow between Navisworks and Revizto has been introduced in the first reflective report with the scheme on the right. A benefit of Revizto is its cloud service and interoperable plug-ins for all common BIM applications as Revit or Navisworks. Because the integration of Navisworks as the model checker and Revizto as the issue manager is the most common application of Revizto, this workflow will be applied here as well.



1. Project Setup:

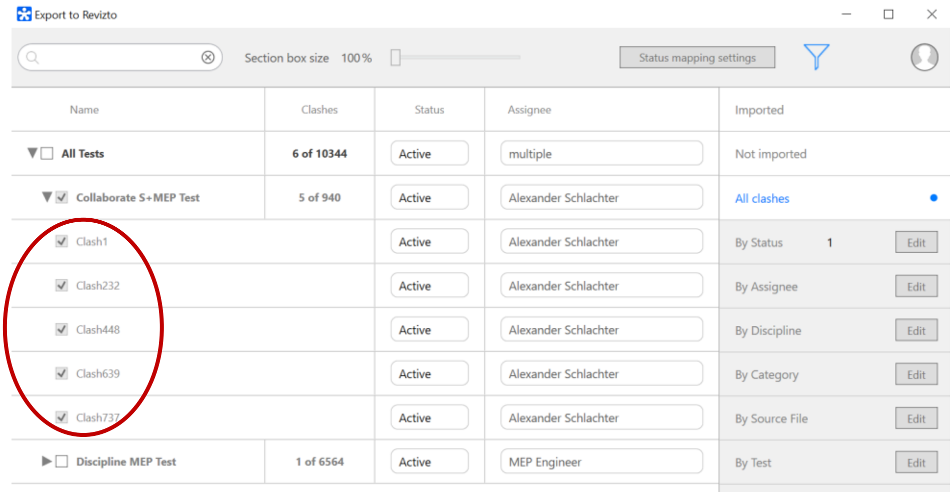
The project setup in Revizto is similar to the one from BIMcollab as the first thing to do is create a project and assign project participants and their function. The main difference of Revizto is that it uses the model data as a game engine to not only manage issue management but also reviewing the clashes in a high-quality interface. Therefore, Revizto requires an export of the geometrical model information from one of the above mentioned software. It is recommended to export the model directly from Revit to Revizto and then use Navisworks only for pushing the identified clashes into Revizto, where they can be managed properly. Here, both the structural and MEP model are exported into Revizto as a Revit file for the 3D geometry. Then both models are also linked to the Revizto project which allows the user to modify the model in Revit and synchronize the changes directly to the Revizto project.



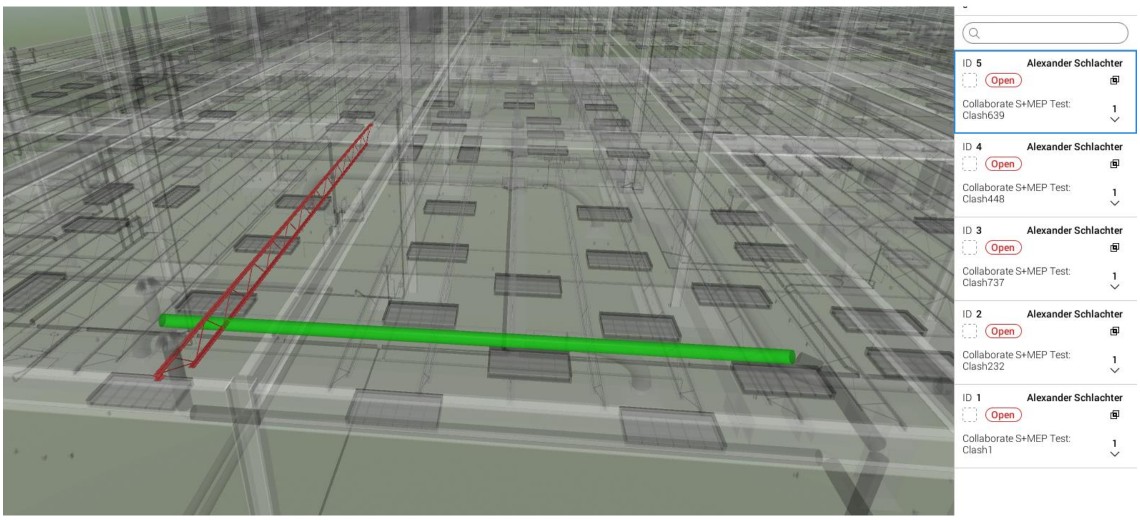
Furthermore, it has been identified during the research on how the Revizto-Navisworks integration works, that the issues should not be grouped in Navisworks unless the issues can be combined into one overall issue, because Revizto will combine these issue groups into a single issue when exporting the data. Therefore, some modifications have to be made before the issues from the collaborate model check can be imported to Revizto.

2. Importing issues to Revizto

When exporting the issues from Navisworks via the Revizto plugin, several tests can be selected, and individual issues can be chosen from each test to be exported to Revizto. This enables an easy workflow to get rid of all issues that are either considered minor or do not concern the project at this stage.



Then the selected issues are synchronized to the Revizto project in the cloud and can be reviewed and managed through the issue tracker in Revizto. As shown below, all 5 clashes are listed in the issue tracker interface offering a clear navigation towards the clash. In general, the first impression of Revizto is really pleasant and it provides a clear and simple user interface.

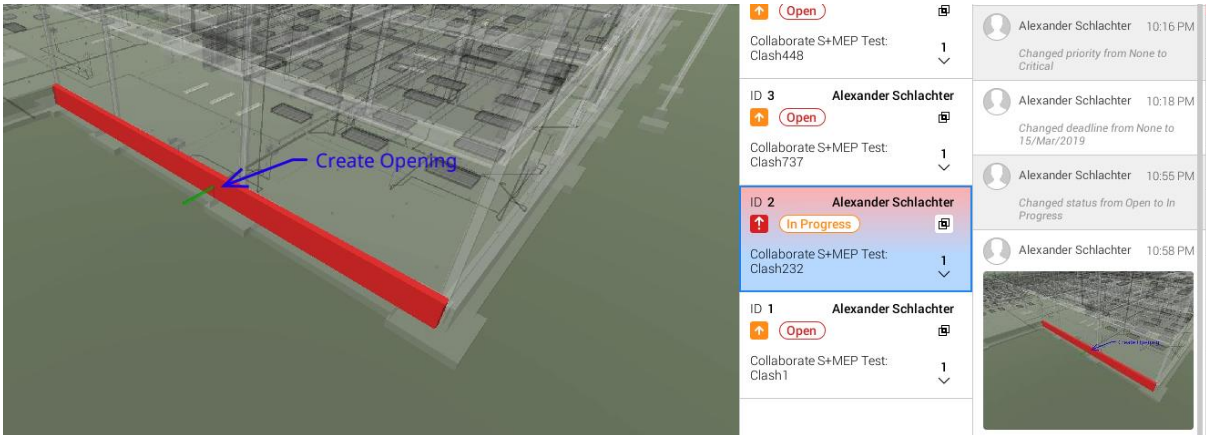


The issue tracking interface is set up as a communication platform between the involved project participants. The reporter can coordinate the resolving process of each issue with the assigned person and trace back the information to the creation of the issue. This does not only create transparency between the different disciplines but also highly reduces the required time to communicate issues by having all information in a centralized system and removes the traditional and conservative collaboration barriers by integrating all disciplines into one platform. So Revizto also acts as an issue management log, where information about issues is stored and managed centrally. Especially for long-term and complex project this feature can be of great benefit as all solved, in progress and open issues including the evolution of each issue can be accessed through the Revizto cloud.

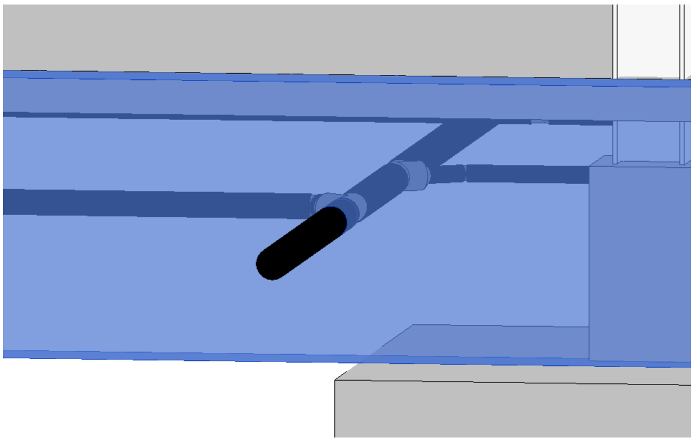
3. Issue management loop

The issue management workflow in Revizto is a completely interconnected system between Navisworks, Revizto and Revit. The issues are first identified with Navisworks and then exported to Revizto for clash review and issue management. After the issues are assigned to the responsible person to resolve them, these persons can open the issue tracker in Revit which allows them to have all the assigned issues directly available in the authoring software.

In Revit, clicking the issue tracker symbol will directly navigate you back to Revizto where the issue to be resolved needs to be selected. Here, the following issue has been selected to be resolved by the structural engineer (same as in BIMcollab):



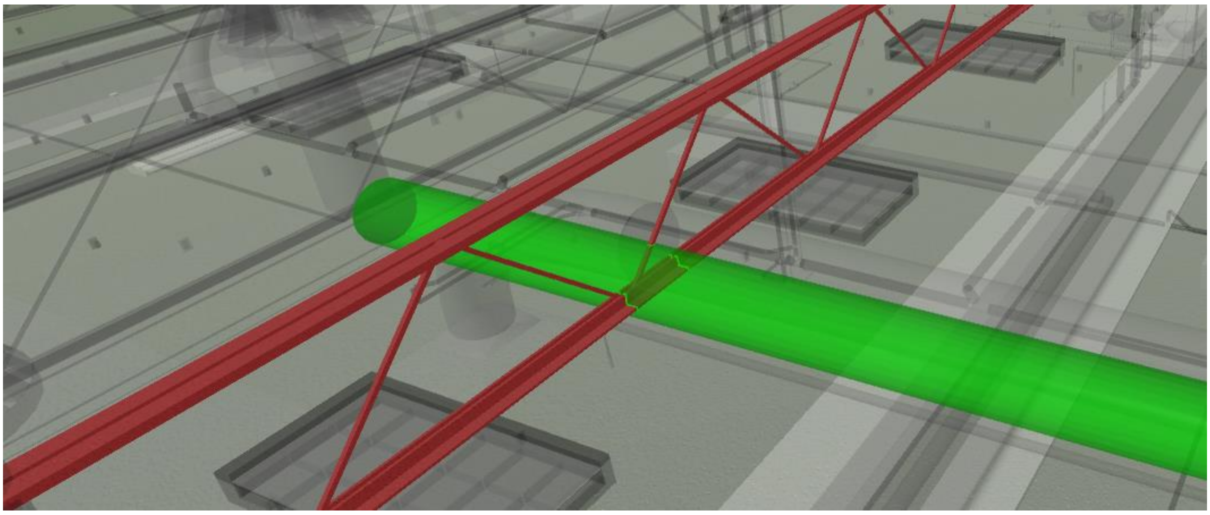
By double clicking on the issue, Revit automatically opens a Revizto temporary view, where the BIM objects of the issue can be selected and then modified in a chosen editing view. Here, the opening has been created in the default 3D view:



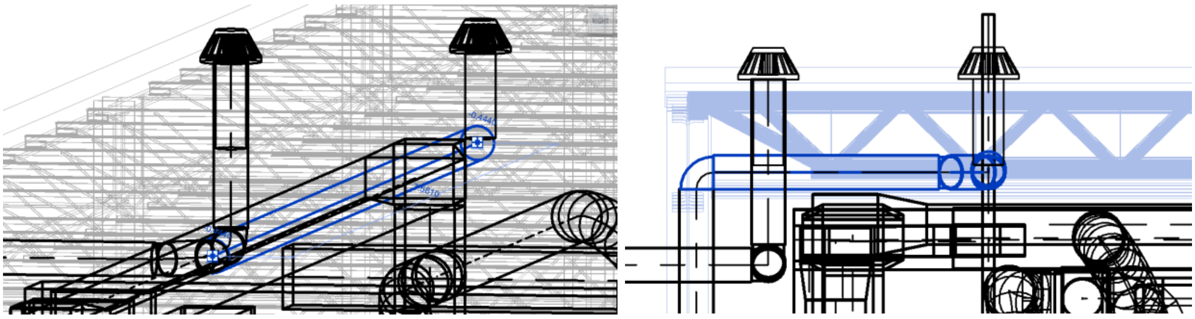
Here again, an opening in the wall has been created in order to resolve the clash. The Revizto plug-in does not allow to directly send the information of the resolved issue through Revit to the cloud but this has to be done manually in Revizto. But as the Revizto application is also needed to identify and navigate to the selected issue, this can be done easily.

Another approach would be to export the Revit file again into Navisworks and then update the clash detection results into Revizto, which automatically identifies the resolved issues as closed.

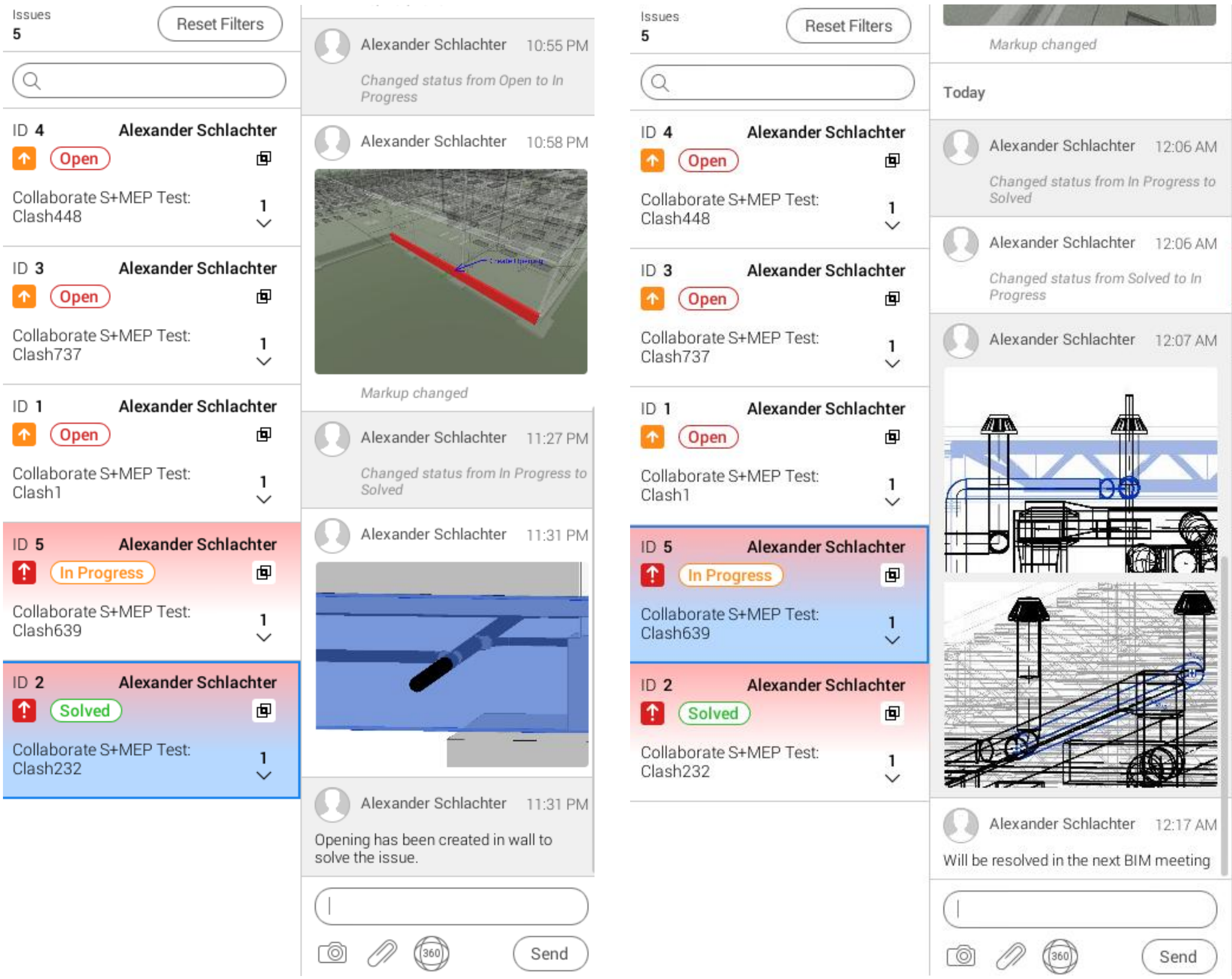
As a second example, the following issue has been selected to perform the issue remediation as an MEP engineer.



In Revizto, this issue looks quite simple and it is assumed that the remediation can be easily done by moving the pipe and its connections down a little bit. But when reviewing it in Revit, the issue looks much more complex and it is difficult to navigate through it. As the MEP engineer does not want to solve the issue without consulting the BIM coordinator and the other disciplines, this issue will be discussed in the next BIM meeting and then resolved afterwards.



Final result of this iteration loop:



Appendix 4

Checklists 1-3

Project Setup - Structure

Checklist 1 - Project Setup
Project number:
Project name:

Checked by: XXX (XX.XX.XX)

Technical University of Denmark

55%

Action points	*Checked or not*	*Date*	*Comment*
Project Setup & General Aspects			
ICT-Agreement is **signed** by all parties involved in BIM-based design			
ICT-Agreement is speifying interrelations between the involved parties regarding digital information exchange, communication and design & building model management			
ICT-Agreement is specifying all workflows/ requirements regarding the collaborateive QA-process			
Discipline is able to use the agreed software applications and file formats for the design			
The overall QA-process as well as its sub-workflows are understood and are followed for each design phase.			
Access to project server (agreed folder structure is used)			
Established internal QA-Tools for clash detection in the authoring software			
Established internal QA-Tools formodel checking (BIM Validation, clash detection & code checking)			
Example xx			
BIM Validation (Initial)			
Project template is used in the modeling software (Revit etc.)			
Model name according to Project Spec			
Level name/number according to Project spec			
Shared Coordinates according to Project spec			
Grids coordinated with site file			
Agreed version of Revit			
Worksharing is set up in descipline worksets allowing for a collaborative design development			
Levels and grids placed in Shared Levels and Grids workset			
Quality, internal consistency, parametric attributes and modeling procedures & progress (LOD) are understood and set up the right way			
Example xx			
Example xx			
BIM Validation (Continuous)			
Utilization of agreed property data and classification types			
Level based objects are associated to correct levels			
Use of of correct building objects in modelling building components			
All necessary parameters (type & instance) are set up and continuously updated for all objects in the model			
Utilization of Breadcrumbs for logging changes			
Modelling in accordance with agreed-upon level of information			
All rooms are named and numbered according to Project spec			
All load carrying elements are defined af "Structural"			
Relevant discipline models are linked to the model to use live clash detection avoiding a significant amount of created clashes			
Elimination of unnecesary objects and doublets in the model			
Example xx			
Example xx			
Progress in the model			(Does not contribute to score)
Basement	**In progress**		
Section A			
Section B			
Section C			

Internal Model Checking - Structure

Checklist 2 - Internal Model Checking
Project number:
Project name:

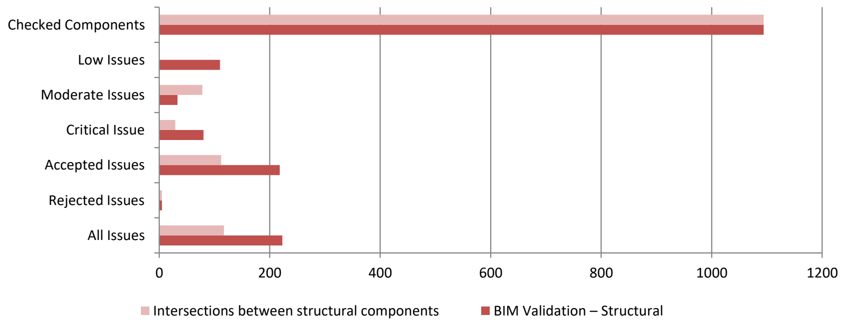
Checked by: XXX (XX.XX.XX)

Technical University of Denmark

20%

Action points	Checked or not	Date	Comment
BIM Validation (continuous)			
Utilization of agreed property data and classification types	☐		
Level based objects are associated to correct levels	☐		
Use of of correct building objects in modelling building components	☐		
All necessary parameters (type & instance) are set up and continuously updated for all objects in the model	☐		
Utilization of Breadcrumbs for logging changes	☑		
Modelling in accordance with agreed-upon level of information	☑		
All rooms are named and numbered according to Project spec	☑		
All load carrying elements are defined af "Structural"	☑		
Relevant discipline models are linked to the model to use live clash detection avoiding a significant amount of created clashes	☐		
Elimination of unnecesary objects and doublets in the model	☐		
Example xx	☐		
Example xx	☐		
Example xx	☐		
Example xx	☐		

Clash detection overview for each ruleset



Action points	Checked or not	Date	Comment
Clash assessment (internal)			
Collisions between walls and slab	Critical		3 Clashes
Collisions between beams and columns	Minor		23 Clashes
Collisions between beams and walls	Not checked		
Collisions between columns and walls	Not checked		
Collisions between slab and slab	Critical		84 Clashes
Collisions between beam/ Reinforcement bar and slab	Critical		10 Clashes
Slab components have wrong value	Major		6 Clashes
Other collisions	Not checked		
Progress in the model			(Does not contribute to score)
Basement	**In progress**		
Section A			
Section B			
Section C			

Model Checking - Collaborate Model

Checklist 3 - Collaborate Model Checking
Project number:
Project name:

Checked by: XXX (XX.XX.XX)

Technical University of Denmark

29%

Action points	*Checked or not*	*Date*	*Comment*
Initial revision			
All decipline check lists are set up	☑		Checklists are updated with the information of Revit and Solibri
The ICT Agreement is signed and its content validated according to the Project spec	☑		
The overall competencies of the BIM team are ensured. Members are able to handle the model and coordinate issues	☑		Questions can be raised in the BIM meeting
The project specific Quality Assurance Process is mapped out and communicated to the involved members of the project	☑		
The project specific time schedule for QA is planned and the QA-workflow, the deadlines as well as the loop plan is specified	☑		
The project specific rule set (Solibri or Navisworks) are adjusted according to the rule set templates	☑		Rulesets could not be adjusted default ones were used for the model
A QA Test Workshop is planned with the aim to test the process. Every member should know their role and responsibilities prior to the workshop.	☑		
The procedure for communication is laid out, including the adoption of BCF-file exchange and communication for the issue remediation	☑		
The site file is set up for model coordination and colaboration	☑		
The model base point and global positioning follow the agreement and is coordinated with other deciplines	☑		
Continuous revision			
Deliverances are set for the next phase	☑		Resolve the clashes individually and in collaboration where collission have been
The collaborate model has the agreed-upon name	☑		
The collaborate model is correctly located on ProjectWeb in the agreed-upon archive structure	☑		
	☑		
	☑		
	☐		
	☑		
	☑		
Collision assessment			
Collision checks between architecture vs. Engineering			
ARC vs. STR			
ARC vs. HVAC			
ARC vs. PLU			
ARC vs. EL			
Collision checks between structures vs. MEP			
STR vs. PLU	Critical		38 clashes (6 Critical/ 32 Major) have been detected. Mostly intersections
STR vs. HVAC			
STR vs. EL			
Collision checks among MEP			
HVAC vs. PLU			
HVAC vs. EL			
PLU vs. EL			

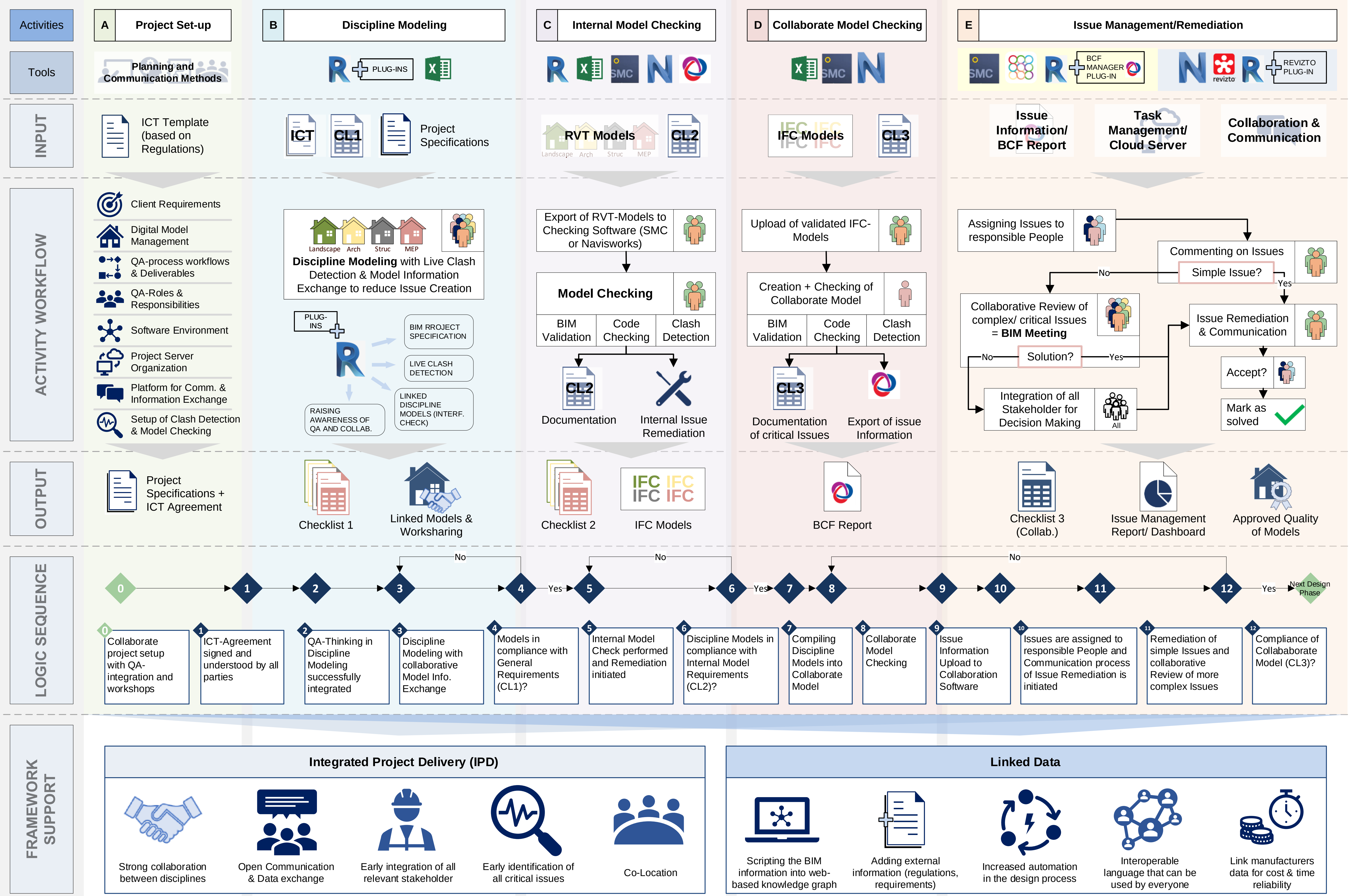
Appendix 5

QA-Activities & Supportive Framework

QA-ACTIVITIES & FRAMEWORK | QUALITY ASSURANCE IN BIM-BASED INTEGRATED DESIGN

BIM Coordinator · BIM Project Manager · Architect · BIM Project Leader · Client · Discipline Engineers

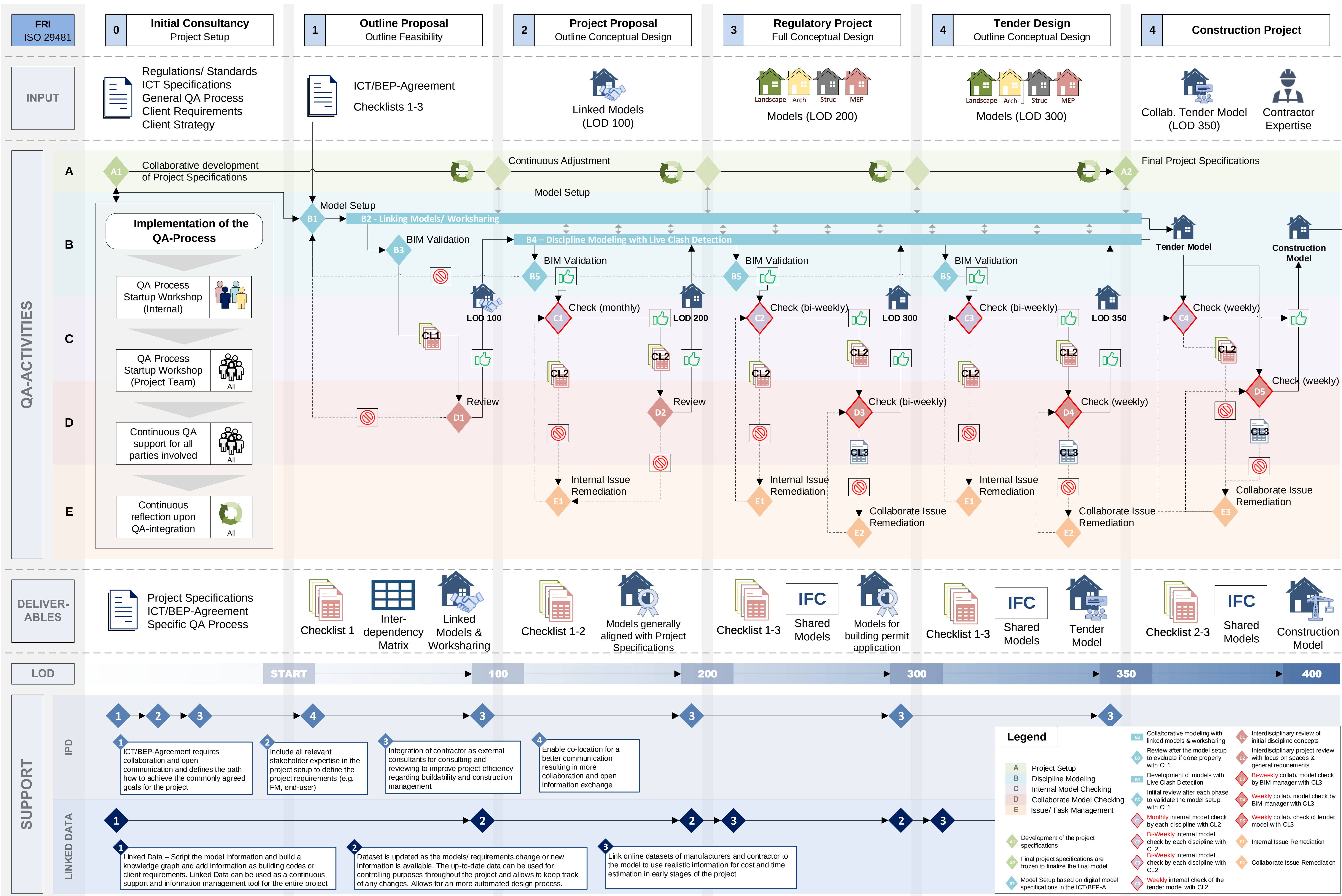
DTU Technical University of Denmark



Appendix 6
QA-Process Workflow

QA-PROCESS WORKFLOW | QUALITY ASSURANCE IN BIM-BASED INTEGRATED DESIGN

DTU Technical University of Denmark



Alexander Schlachter 13.05.2019