Seamless Integration of Common Data Environment Access into BIM Authoring Applications: the BIM Integration Framework

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ABSTRACT: In today's construction industry collaborative processes have received increasing attention due to new digital methods such as Building Information Modeling (BIM). This method bases on the application of digital 3D building models enriched by semantic information. Since a construction project is a composition of several collaborating processes executed by many project participants, a federated model approach has emerged as the most practical solution. It is widely recognized, that for the implementation of this approach and the related collaborative processes digital platforms are required. The Common Data Environment (CDE) is defined as a common digital project space, which provides well-defined access areas for the project stakeholders combined with clear status definitions and a robust workflow description for sharing and approval processes. Since most of today's software solutions lack direct accessibility and integration, we introduce a framework that allows for seamless integration of CDE access and management functionality into standard BIM authoring and analysis applications.

1 INTRODUCTION

Due to the rapid development of digital methods in construction industry during the last years, collaborative processes have become a highly current topic. A substantial part of the technological transformation in construction sector is the Building Information Modeling (BIM) method, which bases on the application of 3D digital building models enriched by semantic information. These models are able to store any information, which is created during the execution of a construction project, and therefore represent a comprehensive digital description of the facility to be constructed. Many of today's work and communication processes can be improved by the help of these structured building models. Therefore, the BIM method can serve as an essential tool for collaborative processes (Borrmann et al. 2015, Young et al. 2009). During the execution of a construction project, the involved engineers and architects cooperate for a long period in various disciplines and different formations. Moreover, a construction project is a composition of several phases starting with the design, following the construction and finally the operating stage. Due to the large quantity of disciplines, project participants and different phases, the requirements for the technical support of this collaboration in terms of consistency and coherence are very high. An essential requirement for a collaborative BIM-based planning is a resilient and technically supported definition of management, data and communication processes. Therefore, technical solutions must be developed in order to implement these. It is widely recognized, that a common data platform can be a solution, since it brings all information together and serves as central data management tool.

The essential requirements and challenges of a digital BIM-based collaboration are presented in this paper. Based on that, current academic as well as commercial approaches for the implementation of such data platforms are discussed. Finally, the authors' own approach towards overcoming the insufficiencies of the presented software products is introduced.

2 BIM-BASED COLLABORATIVE PROCESSES

2.1 *Model-based Collaboration*

Starting point for the model-based collaboration is the digital representation of the overall construction process. This representation is created in cooperation of several project participants, who use various BIM-based authoring tools. It has meanwhile become clear, that a direct usage of a single model is not recommended for a number of reasons. Since the working areas of different disciplines may overlap in a single model, the responsibilities cannot be assigned clear and unambiguously. Yet another reason is, that the project stakeholders have usually no interest, to share their intermediate models due to framework conditions such as the contract constellation. Therefore, various guidelines such as the Singapore BIM Guide (BCA Singapore 2013) or the British Publicly Available Specification (PAS) 1192 (British Standards Institution 2013) implement a domain-specific approach, which means, that model authors have full access only to the domain-specific sub-model they responsible for. These subsets describe a certain aspect of the overall model and so they are usually called discipline or domain-specific partial model. According to this resulting federated model approach each domain-specific model is maintained only by an assigned author himself. In this way the responsibilities and authorship of building elements as well as changes during the execution of the construction project are managed unambiguously.

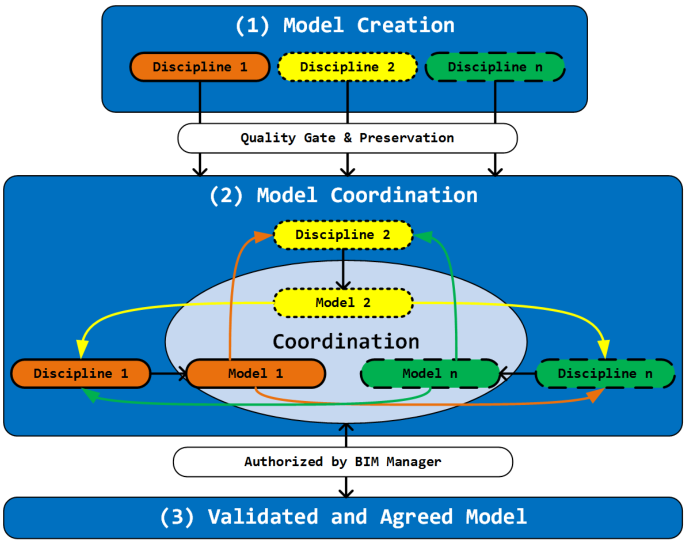

Figure 1. BIM Modelling and Collaboration Procedures according to BCA Singapore (2013)

To ensure the integrity and consistency of the overall model, the domain-specific models have to be compared and checked for inconsistencies or collisions at defined regular intervals. For this purpose, the federated model approach provides a central coordination model (Solihin et al. 2016). This model stores the validated and agreed merged information and in turn provides exactly the information, which is required for the collaboration of at least two disciplines. In this way, the coordination model serves not only as a starting point, but also as a checking base for inconsistencies in single domain-specific models. Due to the outstanding importance of the coordination model, its quality must unconditionally comply the agreed project standards at any time. To catch possible errors as early as possible, a further important safety measure is the quality barrier or gate. A domain-specific model has to pass this gate before it can be merged with the coordination model. The quality gate represents specific checking procedures regarding the agreed project standards such as a completeness, clash or suitability check. Depending on the project agreements this first compliance check can be a prerequisite for the merge and therefore has to be executed on side of the discipline model author. As shown in Figure 2, shows the development of the domain-specific due to this intermediate steps until it can finally be merged with the other valid data since it complies the project standards by now.

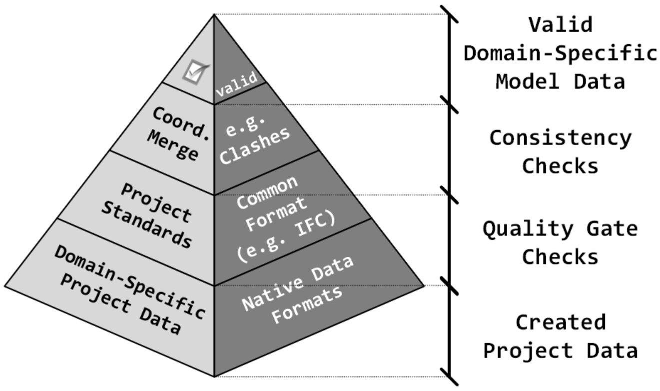

Figure 2. Project data development during collaboration in a BIM-based construction project

2.2 *Common Data Environment*

As discussed in Section 2.1 the management of the digital information and the related processes is a major task during the BIM-based execution of a construction project. It is widely recognized, that for the storage and administration of the different models and to enable the above-mentioned processes, digital data platforms are required. At this point the PAS 1192 (British Standards Institution 2013) specifies a technological foundation, the Common Data Environment (CDE). The CDE basically represents a central space for collecting, managing, evaluating and sharing information. All project participants retrieve the data from the CDE and in turn store their data here. The CDE stores the coordination model, all domain-specific partial models, data bases and documents, which are necessary during the execution of the project. Therefore, it describes the comprehensive BIM-process. The centralization of data storage within the CDE reduces the jeopardy of data redundancy and ensures the availability of up-to-date data at any time. Furthermore, the CDE leads to a higher rate of reusability of information, simplifies the aggregation of model information and simultaneously serves as a central archive for documentation. Since this environment is accessible for all of the project participants, it can be used as a platform for BIM-based collaborative processes. It should be

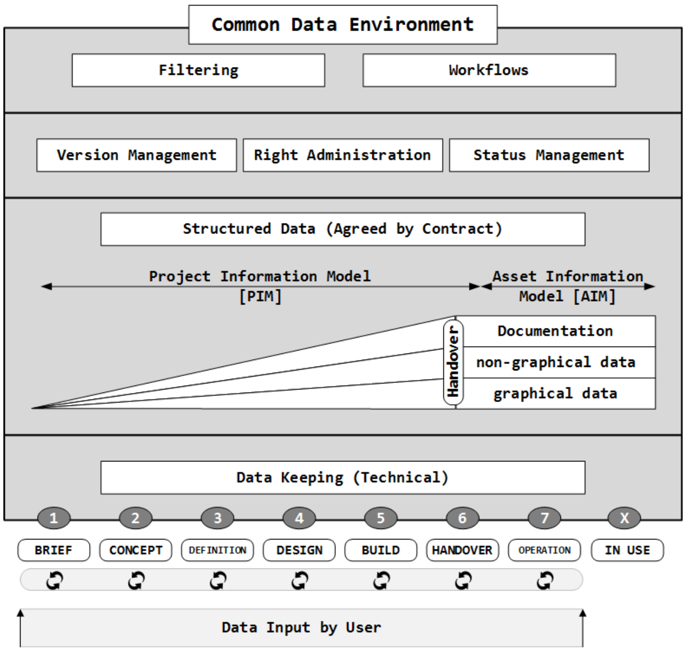

Figure 3. Layer model of a Common Data Environment, inspired by (British Standards Institution 2013)

noted, that the PAS 1192 basically provides recommendations for the technological as well as management-process-based implementation. In this sense, the guideline describes a broad framework for a CDE, but does not set detailed requirements, so that there is room for interpretations and the technical implementation. This setup of a CDE can depend in a variety of ways effected by the application, project volume and participated parties. Nevertheless, a more detailed implementation of such a CDE shall be presented exemplarily. In general, the architecture of a CDE can be described as a layered structure (see Figure 3). On top of the data keeping, the structuring of the stored information is an essential part of the CDE. This structuring has to be agreed on in the beginning of a project and should be updated – if needed contractual - continuously. Next to the actual storage of the information, different processes and workflows, e.g. for the share of information, reviewing, versioning or archiving should be well-defined. Furthermore, the merging process of various discipline models as described in Section 2.1 should be technically defined in here.

In this way the CDE fulfills the requirements, which were set in Section 2.1, and the first basic prerequisites for a cooperative processing of the information is enabled.

2.3 *Major Challenges*

The presented collaboration processes in the previous sections laid down various requirements and created a framework for technical solutions in order to provide a common environment for BIM-based collaboration processes. A major challenge in this collaboration is the preservation of the overall model quality and the data consistency. An essential tool to keep the model quality continuously on a high level are the agreed project standards, which are valid for any piece of information by merging them with the coordination model at the latest. These standards set legally binding requirements for the way data is stored. Therefore, the created model information has to be checked iteratively regarding these standards. To do so, not only well-defined checking processes are required, but also that any participant is aware of the quality of his created information. Therefore, each author should know and take care about the agreed project standards and must be able to deal with the basic principles of data handling. In order to sensitize the participants for this data handling, the structured information as well as the transportation mechanisms have to be as transparent as possible, so that a user can have an insight and understanding, what the information is and how it is processed. To achieve this, the CDE should be connected smoothly with any kind of BIM-based authoring tool, which is used by the project participants, in order to shorten process paths and to keep the data handling transparent. In order to provide a transparent information transportation, the CDE must provide a full and open access, so that any user is able to have an insight in the processed data at any time. If the data itself or the procedures are black-box processes, the user cannot overtake the responsibility for his data according to his owner- and authorship. This applies in particular for the handling of native data. To prevent this, a smooth implementation of the CDE features directly in the environment of a specific authoring tool reduces significantly the effort for users and therefore represents a step towards breaking down acceptance barriers since unnecessary processing steps are avoided. Furthermore, the communication channels are significantly shortened with this direct implementation and feedback can be directly given to the user.

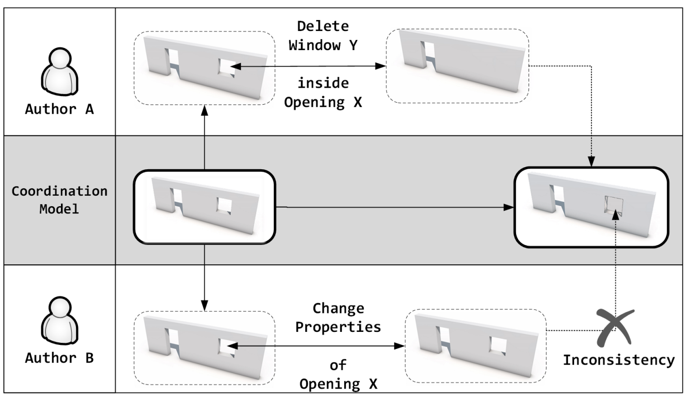

Figure 4. Example for an inconsistency in a BIM-based collaboration process

Another important issue is the consistency of data, which implies that stored information is unified and therefore valid as a whole. Due to the federated model approach, these inconsistencies occur especially, when the domain-specific models are merged with the coordination model. An example for such an inconsistency is shown in Figure 4. In this example user A modifies a model object Y, which only is valid in the context of the model object X. If user B tries subsequently to access object Y, an inconsistency occurs since the data is not valid anymore. In the given example author A deletes the opening, whose properties are modified by author B at the same time. If the delete operation is executed before the property modification, the handled data object is not valid anymore and so an inconsistency error is raised. To solve these inconsistencies, an administration of data and changes, which we call delta management in the following, can be helpful. The authorship for a subset model is not only related to specific user rights, but also to a certain set of information. The size of this information set can vary considerably from a whole building section to a single granular piece of information. Depending on the discipline and the amount of participants, the granularity of these authorships can be finely organized and even shared with other project participants. To handle the simultaneous data access, a locking mechanism can be used. According to this mechanism a certain amount of data, which is handled by an author, is centrally locked. Other users can have an insight to the last version of the locked data, but are not able to modify this information. A big advantage of this method is the level of granularity of the access, which means, that only small amounts of data (measured in kilobytes) are sent over the network in an editing session. In this way, the amount of data is significantly reduced and the delta management is lean. An exemplary locking mechanism is shown in Figure 5.

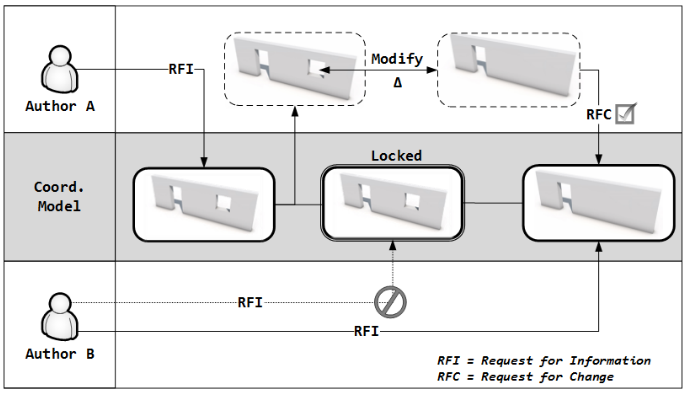

Figure 5. Exemplary locking mechanism for consistency preservation in collaboration processes

A further essential part of the CDE is a robust communication between the collaborating participants. This kind of information can be stored according to the BIM Collaboration Format (BCF), which is an open data schema for BIM-based communication data (buildingSmart 2016). In an BCF-based communication process, the project participants create data objects, called topics, which store several attributes such as a type, a description, a current state and many other kind of information regarding the communication. To connect these details with the digital building model, the topic can be directly linked by storing a certain view position as well as unique identifiers of affected building elements. In this way, the topic is closely related to the building model and helps other project participants to understand the intended meaning of the communication object. In principle this kind of communication replaces the revision cloud as it is used in the 2D-based construction industry. This BIM-based communication plays a special role since it supports not only the assignment of tasks and the exchange of information such as comments but also the documentation of the whole construction process. At this point, the CDE can serve as a central storage for these topics, since it also contains the corresponding model data, which the topics are related with. An exemplary BCF-based communication process is shown in Figure 6.

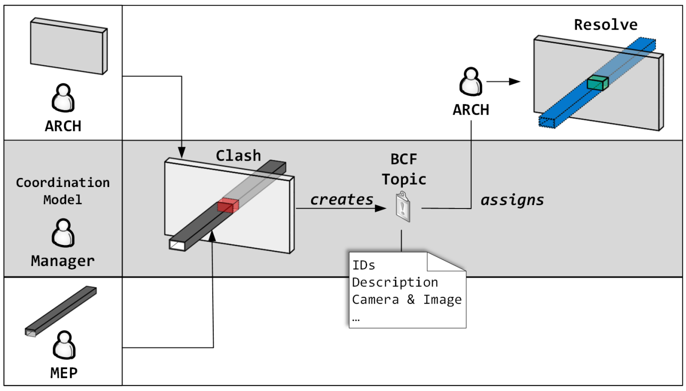

Figure 6. Exemplary BCF-based communication process

3 STATE OF THE ART

Several approaches for a technical implementation of BIM-based model servers are provided by software vendors as well as academia. To judge the suitability for an application as CDE, selected representative approaches are shown in the following subsections.

3.1 *BIMserver.org*

The BIMserver.org project was started in 2010 by Beetz et al. (2010) at TU Eindhoven in order to provide a platform for end-users from construction industry to use shared building information models as well as a development environment for fellow academic researchers and commercial software developers. Built-up on a multi-layered software architecture the BIMserver.org is based-on an IFC-based key-value database. In this web-based framework all

IFC entities are provided as Java classes using an early-binding mechanism, so that the contained information is transformed into a widely accepted data modeling language. In this way the framework simplifies and streamlines the development process. An example for such a development is the Building Information Model Query Language (BIMQL), which is a SQL-based query language for digital building models that can be used to formulate queries on the stored building information (Mazairac 2015, Mazairac & Beetz 2013). A major advantage of the BIMserver.org is the open and full access, so that this platform is technological neutral and therefore can be connected with any kind of BIM-based application. The BIMserver.org project fulfills the general basic prerequisites and therefore is suitable for an application as CDE. However, a direct integration of the provided features in authoring tools are desirable in order to reduce the effort for the user in terms of data handling.

3.2 *A360 & Forge*

A360 is an online project working space for several software products, which are offered by the software vendor Autodesk Inc. (2016a). The platform provides various collaboration features for participants using potentially different Autodesk products in order to share data and use services such as versioning of models or cloud-computing. In most of the Autodesk products the connection to the A360 platform is directly and smoothly integrated, so that all the provided features can be used in a straightforward manner. To realize this, the platform supports the im- and export of various primary native file formats. Furthermore, Autodesk provides a central browser-based application for a cross-platform management of the stored information. Next to this platform, Autodesk Inc. (2016b) offers a development environment for third-party developers, called Forge. Basically it represents a set of cloud services, advanced programming interfaces (API) and software development kits (SDK). With the help of these tool developers can create applications, services and data sets according to their own requirements. However, the A360 services as well as the development environment aims almost exclusively at Autodesk software products and will usually only work with the vendor's BIM tools and proprietary formats. This barrier causes massive problems due to significant data incompatibilities, if A360 services are used as an CDE, and therefore the presented software solution lacks the required accessibility and transparency.

3.3 *BIMcloud*

The Graphisoft (2016a) BIMcloud is a collaboration platform allowing ArchiCAD users to cooperate within a single project of any team size on the basis of native BIM data in real-time. To enable an error-free collaboration the platform provides several technical mechanisms such as a fundamental element reservation system, roles/permission and user logs. The data transactions can be scaled down to any level of granularity so that only very small data packages are transferred. In this way the required bandwidth for collaboration does not need any special network hardware or dedicated fibre lines. In terms of data security BIMcloud can also be set up as a private cloud using a private server as the storage destination. To view and navigate the resulting common model, several applications for desktop and mobile devices – such as Android and iOS - are offered (Graphisoft 2016b, AEC Magazine 2014). The BIMcloud represents a technological mature solution for the BIM-based collaboration. Especially the locking-mechanism and the granular transaction principle build up a solid and resilient base for the collaboration of several project participants. However, the BIMcloud is only available for ArchiCAD users and therefore this software product lacks a major requirement for a CDE – the full interoperability and transparency approach.

3.4 *BIMcollab*

The BIMcollab manager by Kubus (2016) is a web-based platform, which provides communication features for construction projects based on BCF, which was discussed in Section 2.3. For a direct and smooth integration of the communication tools inside of the BIM-based authoring tools, Kubus offers plugins for various tools, such as Autodesk Revit, Graphisoft ArchiCAD or the Solibri Model Checker. With the help of these plugins the provided features of BIMcollab are uniformly integrated in the user interface of the host applications so that the process paths are shortened. In contrast to the previously shown representatives, BIMcollab does not store any model data but only information concerning the communication within a project. Therefore, this approach represents a very helpful communication feature for a collaboration platform but not a CDE itself. Without a simultaneous administration of communication and model objects, there is high risk of inconsistency between these objects, since there is no mandatory connection. For this reason, the user has to maintain the handled models and their validity on his own, which is cumbersome and error-prone.

3.5 *bim+*

bim+ was founded in 2013 and is by now a part of the Allplan GmbH (2016). Unlike the solutions discussed before, bim+ represents a commercial but open access platform. The core of bim+ are the API services, which provide a full and transparent access to each piece of information stored on the platform. In this way, bim+ provides several services e.g. project, user, model, revision and BCF-based communication services. Since these services are RESTful (Jakl 2006), they are technological neutral, can be used by various programming languages and therefore directly integrable in any authoring tool. For the description of information, bim+ provides a proprietary data model, which is well documented and closely related to the IFC data schema. Based on the API services the platform offers a Web SDK as well as several web-based applications, e.g. for viewing geometric and alpha-numeric information or managing projects, teams, users, rights, models and revisions. Furthermore, the platform can be variously extended by local or server-side services, which reduce expensive computing power on user side. In summary, bim+ provides a resilient technical framework and several features, which comply with the latest technical standards and are suitable for an application as an CDE.

3.6 *Trimble connect*

In a similar fashion as bim+ (see Section 3.5), Trimble connect also represents a BIM-based common environment, but is based on GTeam, which is a collaboration platform developed by Gehry Technologies (Gehry Technologies 2016). Recently a RESTful public API has been released, which can be used to access different kind of data stored on the platform. Trimble connect provides a web-based platform including several features such as management base for teams, users and projects or a model viewer. Due to the technologically neutral API services Trimble connect can also be integrated in arbitrary authoring tools. As an example Trimble connect has been integrated directly in SketchUp 2016. Furthermore, the platform provides several document storage features, which are directly integrated and can also be used for a synchronization with offline files. The same principle is well-known from popular document storage environment, e.g. Dropbox, and provides a direct integration in the user interface of the respective operating system. Since Trimble connect provides similar features as bim+ it brings almost the same advantages and therefore represents also a mature approach for a CDE.

4 BIM INTEGRATION FRAMEWORK

4.1 *Methodology*

As discussed in Section 2.3, the BIM-based collaborative processes imply several requirements, which have to be fulfilled in order to provide a resilient technical foundation. However, even the mature approaches for an CDE presented in Section 3 lack an sufficient, direct integration in BIM-based authoring and analysis tools. In order to overcome these deficiencies, we introduce the BIM Integration Framework (BIF) as a light-weight piece of software, which can be easily integrated into various BIM-based software products. In this way it provides a close and steady connection to a central online data platform for each participant no matter which software he uses. So the primary purpose of the Framework is to provide a seamless integration of CDE access functionality into standard BIM modelling and analysis applications. As a prerequisite, a basic data platform must be given, which fulfills the basic requirements of a CDE in terms of accessibility and transparency.

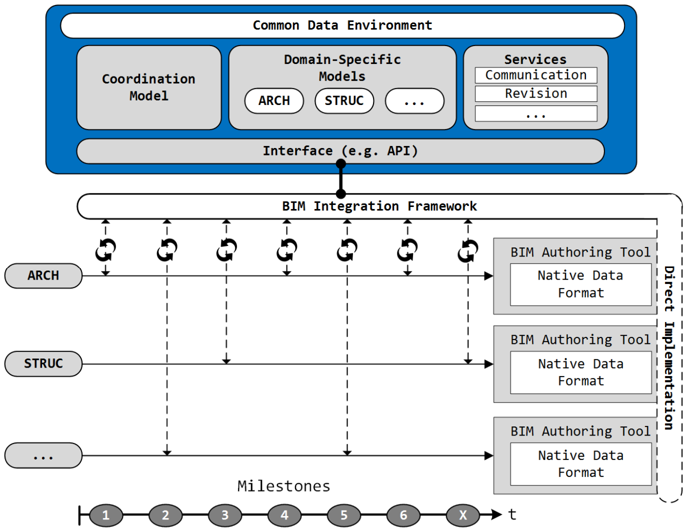

Figure 7. Schematic collaborative process with the help of the BIM Integration Framework

In this way, the provided features of available CDE approaches can be used, extended and finally integrated in various authoring tools. At the same time several of the technical solutions presented in Section 3 cannot be considered since they do not provide a full open access. By the help of an interface, e.g. an API, the BIF wraps the available features of the database and provides them in the appropriate authoring tool, so that a user is able to directly use these features by means of the user interface (UI). The framework focusses especially on features that enable a smooth collaboration. In this way, the effort and complexity for various standard processes in the collaborative processes such as the communication or data exchange are significantly reduced. At the same time, the user has access to the stored data all the time and therefore will get a better understanding for processes as well as the processed information. This applies in particular for the communication and the data exchange processes, which are directly available in the UI. In this way, even a locking mechanism as it was discussed in Section 2.3 can be implemented as long as this is supported by the basis data platform. The primary objective of the BIF is not to unify the information regarding a specific native data format, but to provide a direct access to the central platform and the stored data objects according to the agreed project standards. As shown in Figure 7, the project participants can use any authoring tool and therefore also native data format. When specific milestones are reached, the data has to be dropped on the platform. This data drop step contents first of all the quality checking regarding the project standards and the coordination model as described in Section 2.3. At this point, the data has to be converted according to the agreed project standards and checked for compliance. Subsequently the validated information is stored in the common coordination model, the domain-specific model can be stored in a native format instead. In this way unnecessary conversions of the building information data into exchange formats are prevented and data loss due to the transfer processes is avoided. At the same time, the data is always up to date and the validated information is accessible for everyone according to his property rights. As a result, the collaboration processes via the BIF - in comparison to conventional methods - are significantly shortened. Because of the flexible and scalable design, the BIF can be extended by various services, which are subsequently available in all connected applications, so that all of the participants can make use of them. In this way basic services like a project, model or user management as well as further services like a communication or model checking feature can be provided.

4.2 *Proof of Concept*

As a proof of concept, the BIF was implemented as a prototype based on bim+ (see Section 3.5), since this platform follows the full access concept, provides a fully open programming interface and therefore represents one of the most advanced representatives of a CDE. As shown in Figure 8, the BIF has been implemented as a light-weight library, which is directly connected with the API of bim+ and therefore has full access to any service, which is provided by the platform. From a technological point of view, BIF is a dynamic .NET library, which provides various functionalities for the communication with bim+. Since many BIM authoring tools provide a C++ or C# programming interface, BIF can be integrated directly in these products. Of course the basic principle of the BIF can be also implemented for other programming languages, e.g. Java or Python, since the RESTful API services of bim+ are technology neutral. Furthermore, the software architecture of the BIF allows the dynamic extension of the framework by a plug-in mechanism, which is based on the Managed Extensibility Framework (Microsoft Corp. 2016b).

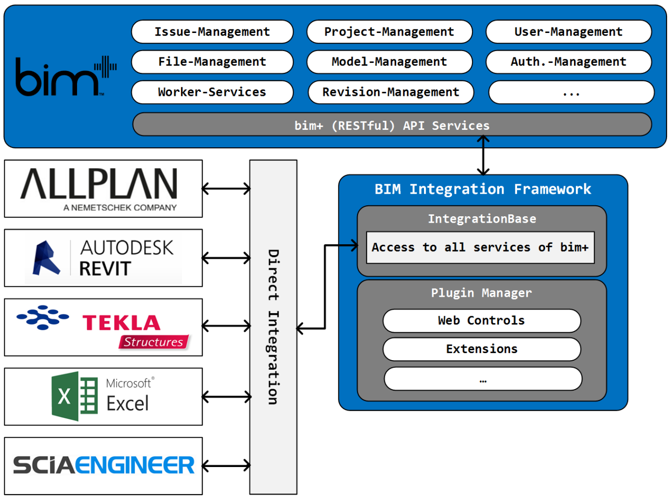

Figure 8. Software architecture of the BIM Integration Framework based on bim+

The plugins can be created and customized according to a certain schema at will and are valid for any version of the BIF, so that they can be reused in any BIF-integrated authoring tool. In this way, a unification of all connected authoring tools as well as a flexible scalability can be guaranteed at the same time. As an example for such a plugin, several web controls, which are provided in the bim+ Web SDK, has been implemented in the BIF, so that these can be reused in the local user interface. In this way, unnecessary double development expenses are avoided and the controls are always up-to-date in any version of the BIF and integrated authoring tool.

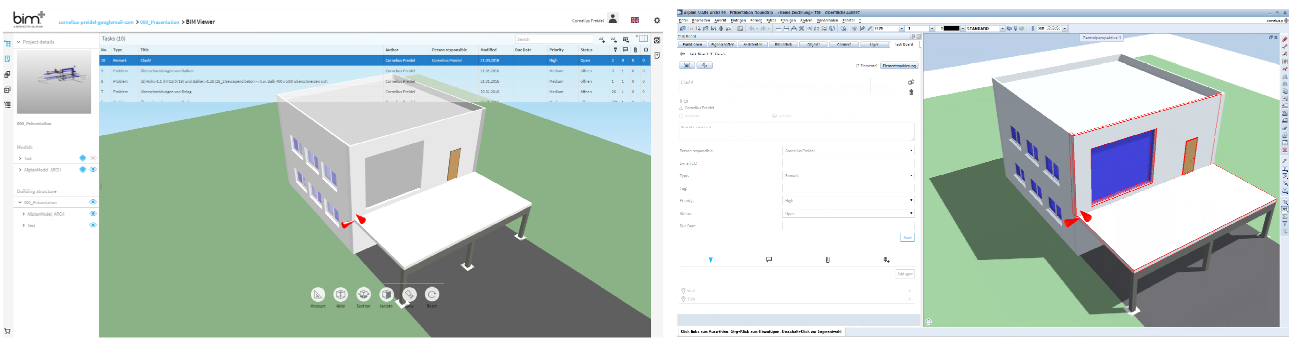

Figure 9. BCF-based communication via the BIM Integration Framework.
Representation of the same topic object in the web application of bim+ (left) and ALLPLAN (right)

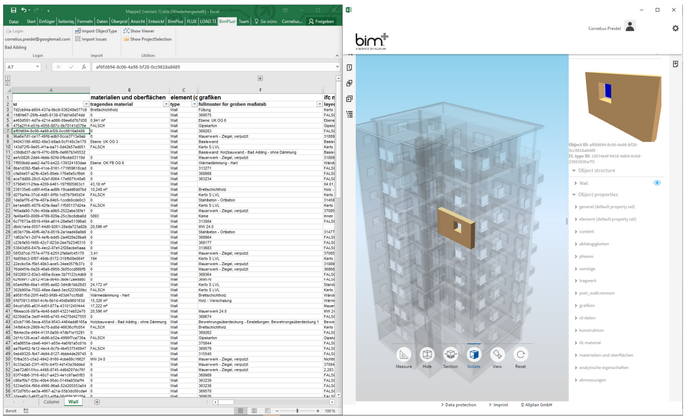

Figure 10. Integration of BIF features in Microsoft Excel

The BIF-prototype has been successfully implemented in several authoring tools, which are extensively used for BIM-based construction projects. These include ALLPLAN, Autodesk Revit, Tekla Structures as well as Scia at the present time (see Figure 12 & Figure 9). Furthermore, non-BIM-based tools can be connected with the BIF. Microsoft Excel (Microsoft Corp. 2016a) is a spreadsheet tool, which is extensively used in 2D- as well as 3D-based construction industry for various application areas. To show the potential of the CDE-based approach, we implemented the BIF features smoothly in the user interface of Excel to provide direct access for the user. Within this plugin the user is able to connect with bim+, choose a specific project and show any kind of data object stored in this project. Since there is no visualization provided, additional connected web controls are used to support the user. If a specific building element is chosen on the spreadsheet, the web control is automatically instructed to choose the corresponding building element in the viewer and to fly to this object. The presented integration principle of the BIF can be applied for any authoring tool, which provides an appropriate interface to access the user interface. With these prerequisites, further features such as a smart management system for collaboration can be implemented. Due to the direct access to each piece of information, any kind of required information can be retrieved during the modeling process. This feature can be helpful in case of a clash resolving. Currently a BCF-based topic just holds the information, which building elements are affected by the clash, and moreover a screenshot. But for an exact adjustment both clashing models must be transferred, so that the modeler can fix the issues. With the direct access via the BIF, the unique identifier of the clashing object is sufficient, since its geometry can be retrieved from the CDE. In this way, the geometry of the clashing object can be shown directly in the authoring tool and just small packages of information are transferred. Furthermore, this transfer of model information could be aligned with the development of the BIM Snippet, which is available in the current BCF by now (buildingSmart 2016).

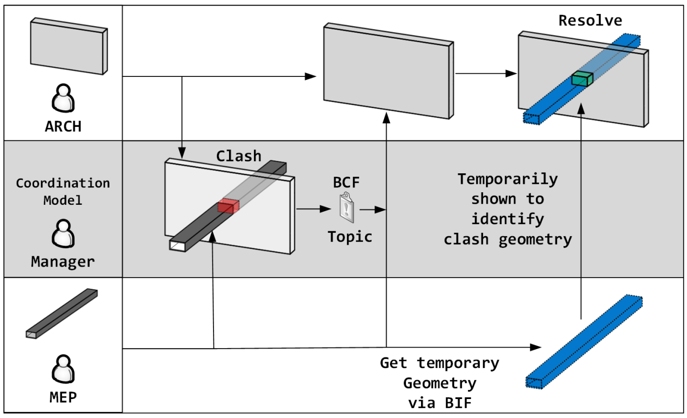

Figure 11. Retrieval of a temporary geometry for a clash detection via the BIF

5 CONCLUSION & OUTLOOK

In the presented paper the importance of BIM-based collaborative processes for today's construction industry is discussed. Due to modern digital methods and the federated model approach there is a sound foundation to enable these. In this context, today's major challenge is to keep the overall consistency

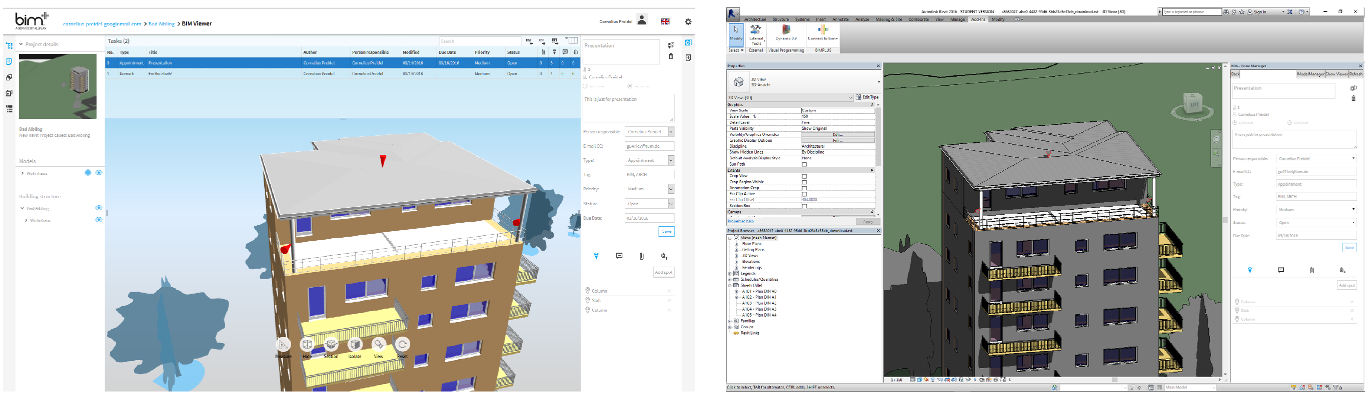

Figure 12: BCF-based communication via the BIM Integration Framework.
Representation of the same topic object in the web application of bim+ (left) and Autodesk Revit (right)

and quality during this collaboration. It is widely recognized, that the best way how to achieve this is to use common data platforms. Various technical solutions are already provided by different software vendors in this area. However, most of these approaches focus too much on native data formats and so they lack full access, data transparency and interoperability. Just few of the presented solutions represent a CDE in the proper sense. However, it must be kept in mind, that pure technical solutions are not enough for the successful implementation of collaboration processes. Well-defined workflows must be defined in order to prevent inconsistencies and low model quality. With the implementation of the BIF, the authors show the potential of smooth and direct integrated CDE-features in authoring tools. On the basis of this framework processes can be defined and at the same time the effort is significantly reduced. Due to the scalability and flexibility of the framework, it can be extended at will in order to establish more sophisticated workflows.

As a conclusion it can be noted that, the BIM-based collaborative processes will play an ever more important role in future. Therefore, the basic principles how to work on the basis of a CDE must be implemented in the construction industry. Furthermore, the current technical developments must focus on the implementation of the collaboration processes concerning all related requirements. In this context, more and more academic as well as industrial research projects are started by now. As an example, Project DRUMBEAT (2016) was launched 2015 in Finland. Its major task is to develop new information and communication technology solutions for distributed publication and utilization of building information models on the web. To realize this, the project focusses on the conversion of BIM models from the standardized IFC format to a web-compatible format, such that a unique web address will be assigned to each building part. By this interactive link, the information content of the models can be used on the web and building parts from different models can be linked to each other or to external information systems and data sources.

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