In: Borrmann, A.; König, M.; Koch, C.; Beetz, J. (Eds): Building Information Modeling - Technology Foundations and Industry Practice, Springer, 2018, DOI: 10.1007/978-3-319-92862-3

Chapter 15
Common Data Environment

Cornelius Preidel, André Borrmann, Hannah Mattern, Markus König, Sven-Eric Schapke

Abstract Building Information Modeling, as a model-based approach, has various implications for the information and data management of construction projects. In particular, data exchange during the planning and execution of BIM-based projects creates unique demands for the management of data, since the participants involved exchange different kinds of information at various levels of detail according to their individual requirements, and not just once but repeatedly and back and forth. To address this, procedures for structuring, combining, distributing, managing and archiving digital information must be set up and technically supported within a framework for integral model-based project management. It is widely recognized that for the implementation of BIM-based projects and the related collaborative processes, digital collaboration platforms are highly suitable. The British Publicly Available Specification (PAS) 1192 offers a general framework for the implementation of such central platforms based on a so-called Common Data Environment (CDE). The CDE is defined as a common digital project space that provides distinct access areas for the different project stakeholders combined with clear status definitions and a robust workflow description for sharing and approval processes. This chapter presents the technical aspects of the CDE and introduces selected practical aspects.

Cornelius Preidel · André Borrmann
Technical University of Munich, Chair of Computational Modeling and Simulation, Arcisstraße 21, 80333 Munich, Germany
e-mail: cornelius.preidel@tum.de, andre.borrmann@tum.de

Hannah Mattern · Markus König
Ruhr-Universität Bochum, Chair of Computing in Engineering, Universitätsstraße 150, 44780 Bochum, Germany
e-mail: hannah.mattern@rub.de, koenig@inf.bi.rub.de

Sven-Eric Schapke
think project! GmbH, Zamdorfer Straße 100, 81677 Munich, Germany
e-mail: sven-eric.schapke@thinkproject.com

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15.1 Introduction

In a BIM-based construction project, several project participants create a digital representation of a building or infrastructure facility using different authoring tools in a collaborative process. During the planning, construction, and operation of a building, the project participants exchange various information from different domains based on agreed procedures. Practical experience has shown that the direct use of a single shared model is not recommended for a number of reasons, not least because this approach does not support accountability which is a problem for legal aspects.

For this reason, various guidelines, such as the Singapore BIM Guide (BCA Singapore, 2013) or the British Publicly Available Specification PAS 1192, implement a collaborative approach based on the principle of domain-specific federated models (Fig. 15.1). This method only gives model authors full access to the domain-specific sub-model for which they are responsible. Each sub-model is an individual aspect of the overall model and is usually called a discipline or domain-specific partial model.

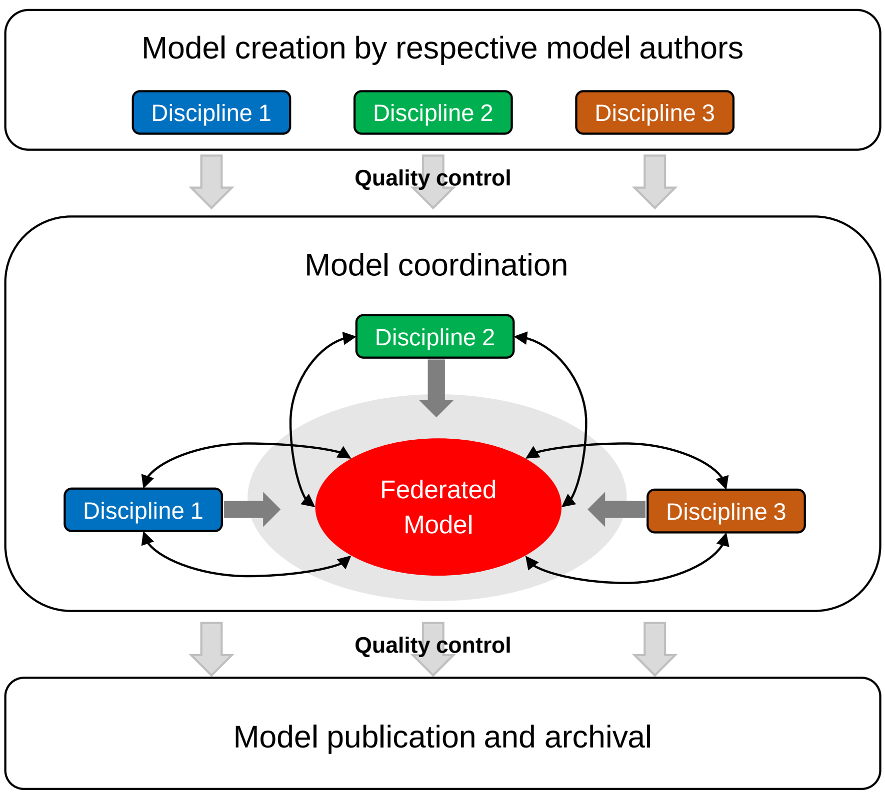

Fig. 15.1 Principle of the federated model approach: Domain-specific sub-models are created independently but coordinated at fixed intervals (based on BCA Singapore, 2013).

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According to this federated model approach, each assigned author maintains their domain-specific model exclusively so that the responsibilities for and authorship of building elements, as well as any subsequent changes, are managed unambiguously. However, this results in an enormous number of interfaces and data transition points, which must be coordinated to maintain the consistency and validity of the overall model.

A primary challenge of a BIM-based project is, therefore, to manage the information processing and exchange processes described above during the lifecycle of the construction project. To address this, procedures for structuring, combining, distributing, managing and archiving digital information must be set up and technically supported within a framework for integral model-based project management. It is widely recognized that for the implementation of BIM-based projects and the related collaborative processes, digital collaboration platforms are highly suitable. When implementing such a platform, the following general aspects should be considered:

- **Adequacy:** The objectives, the effort and the benefits of the selected measures and procedures should be proportionate.
- **Neutrality:** The selected procedures and measures should be independent of particular software products so that the companies involved can use their chosen software.
- **Applicability:** The selected procedures and actions should apply to enterprises and projects in various sizes and fields of application.

15.2 Basic technical aspects

An essential aspect of the data management of digital construction processes is the centralization of data and information as a basis for all collaborative processes. ISO/DIS 19650-1 (2017) (which is mostly based on the British PAS 1192-2, 2014) specifies the characteristics of a technical solution to this requirement: the Common Data Environment (CDE).

ISO 19650 specifies two parts of the BIM-based execution of construction projects: project management and information delivery. Project management describes all process steps necessary to set up a BIM project, including the definition of the Employer Information Requirements (EIR), and the following tendering and contractual processes, as well as the preparation of the BIM Execution Plan (BEP). Information delivery, in turn, describes all steps that are necessary for model creation and delivery, including the use of a Common Data Environment (CDE). In this chapter, we focus solely on the aspect of information delivery.

The CDE represents a central space for collecting, managing, evaluating and sharing information. All project participants retrieve input data from the CDE and in turn store their output data in it. The common data environment stores all domain-specific partial models and documents which are necessary for the coordination and

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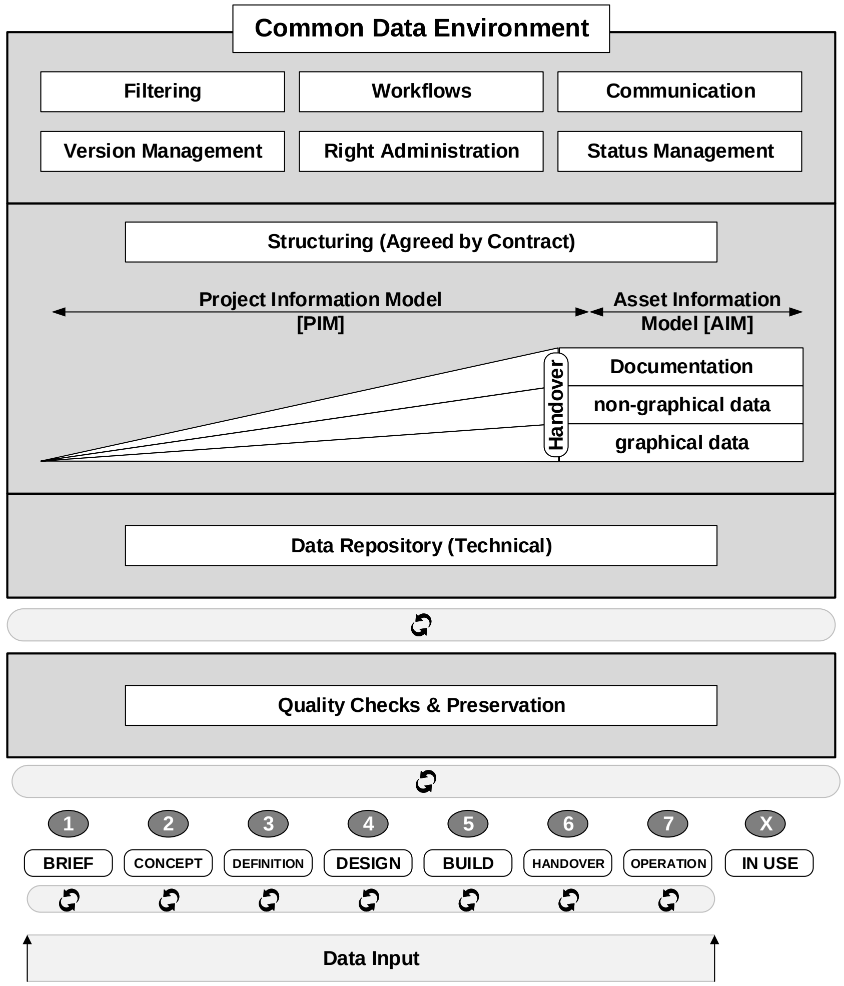

Fig. 15.2 Common Data Environment represented as a layered structure composed of the individual technical elements (based on PAS 1192-2, 2014)

execution of a project. The primary task is to provide a platform for information exchange, while at the same time ensuring a consistent data model that meets the required criteria. For this purpose, the data management system enforces procedures and techniques that all stakeholders must adhere to in order to ensure the high quality of data required. Most importantly, the CDE assigns formal states to individual data items and defines quality checking procedures that are undertaken after each state change to properly manage the maturity and reliability of the provided information. The CDE, therefore, serves as the basis for a well-defined way of cooperating among all participating stakeholders.

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The centralization of data storage within the CDE reduces the risk 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 the project participants, it should be used as a platform for BIM-based collaborative processes. It should be noted, that the PAS 1192 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 (Preidel et al., 2016). This setup of a CDE adheres to the aspects described in the introduction: adequacy, neutrality, and applicability.

Despite its broad description, it outlines sufficient information to identify the basic functionalities and elements that a CDE platform must provide. Figure 15.2 shows its typical system architecture presented as a layered structure that describes the minimum requirements for its implementation, which we shall discuss below in detail.

15.2.1 Data repository

The core part of the entire system is the data repository, which describes the technical space in which all data is physically stored. Since all the information created during the BIM processes over the lifecycle of the building project is stored in the environment, a presumably large amount of data should be considered when establishing a CDE. The volume of data will almost certainly increase in the coming years as storage requirements as well as BIM technologies develop. In principle, there are no specifications that detail where data should be precisely located or which technology is to be used. A central criterion, however, is that data should be accessible at any time from any location for the involved stakeholders. For this reason, technologies that make content easily and directly accessible via the internet (especially cloud systems) should be considered as a technological foundation.

15.2.2 Data structuring

In addition to the data repository, the structure of the stored information is an essential part of the CDE. This structure must be agreed on at the beginning of a project and should be updated and reviewed on an ongoing basis – a requirement that is frequently made a contractual obligation. Based on the complex characteristics of a building project and the identifiable resources, BIM data can be structured in various ways. Commonly used structuring categories might be divided into technical and functional aspects. Technical categories refer to handled data and can be divided

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into different levels of aggregation (models and documents and collections thereof, element groups or single elements, element attributes and property sets). As a basis for model-based information management, the collected data is structured into information resources so that software applications or users can interpret it. For efficient management, information resources are hierarchically grouped and combined into superordinate information resources. Technical structuring approaches comprise

- Domains (e.g., concrete works, earthworks, finishing works),
- Phases (the temporal development of a building project with a corresponding increasing amount of information and the current planning status),
- Zones (spatial structure of a building),
- Systems (aggregation of building elements fulfilling a common function, e.g., building supply systems).

The content and structure of information required from the different resources are based on metadata which are commonly used to define file naming conventions. The project-specific application of metadata for different information resources should be agreed, if necessary contractually. An example for the use of metadata is shown in Fig. 15.3. Furthermore, any information resource has an identifier (UID) that uniquely identifies a data object and should not be changed afterward. This makes it possible to reference data objects without the need to transfer the complete data, which makes the overall system more efficient.

In a BIM-related context, the selected structure should be applied consistently and according to the given project prerequisites, thus enabling efficient information management and the combination of sub-models despite high data volumes. The Employer Information Requirements (EIR), which define the digital requirements of the client and, in turn, the content of the final Asset Information Model (AIM),

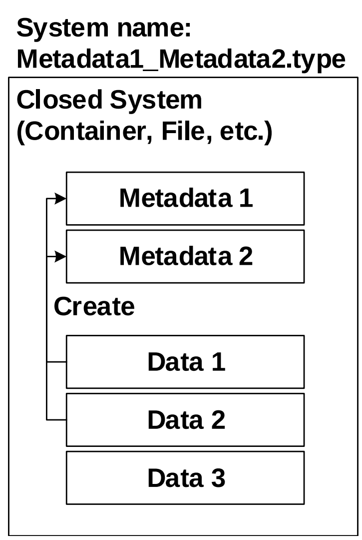

Fig. 15.3 Example of using metadata (VDI 2552 Blatt 5, 2017)

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offer a degree of basic orientation. A consistent and adequate data structure also supports the automation of processes that need to be performed frequently (e.g., linking and combining sub-models, model quality checking).

The approach and level of detail when structuring project data depends on the project size, type of building, supported BIM application cases as well as the software tools used. Minimizing the effort required to structure information should be a key consideration when defining methods for structuring a project-specific CDE. In the German standard VDI 2552 Blatt 5 (2017), the following approach is proposed to define an applicable data structure:

1. Select and define project-specific BIM use cases
2. Define required information and data structure derived from the combination of BIM use cases
3. Analyze the required data structure with respect to concepts which may derive from software tools and data formats
4. Contractually define the structuring concept (e.g., within the BIM execution plan, modeling guidelines, standard terms, and conditions)
5. Regularly review adherence to the defined data structure

The data structure should correspond to the following prerequisites:

a) The granularity of data sets and objects must reflect the chosen BIM use cases and support linking external data sets and objects ("Linked Data")
b) Subsets of data and objects resulting from the BIM use cases can be identified within the entire data pool by characteristic criteria (provision of description methods that are independent of object IDs)
c) Information in data sets or objects that results from the criteria described in b) need to be provided in the required format

Classification systems can support the definition of a consistent and standardized data structure. Any classification systems used should be predefined in the BIM Execution Plan (BEP). Guidelines on the use of classification systems are currently under development. An example of using classification systems in the context of databases is shown in Fig. 15.4.

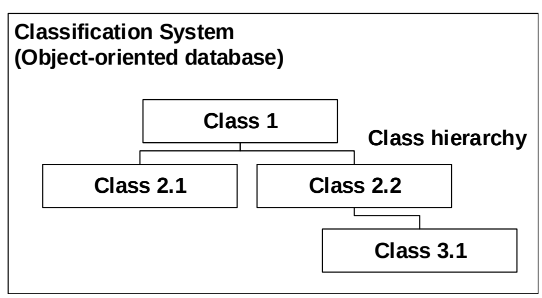

Fig. 15.4 Example of using classification systems in the context of databases

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15.2.3 Access rights administration

An essential basis for the consistency of information is the allocation and management of property and access rights for the identifiable information resources. These rights control access to data and therefore protect information against unauthorized access. The assigned rights determine the type of access that project participants have to which information resources or which processes they can initiate. The allocation of the rights determines clear responsibilities and prevents errors resulting from unauthorized access. The definition of rights can assign different stakeholders to different roles, which are linked to various combinations of rights. In principle, these functions and the corresponding rights can be defined as required, but it is advisable to keep this hierarchy as close as possible to the organization of the underlying building project.

The granularity of the assigned access rights plays an important role here since these can be linked to different sets of data objects. A right can, therefore, refer only to a single data object, e.g. a single building element, or to complete sub-models, e.g. a construction section. The granularity of assigned rights should be defined according to the application requirements.

15.2.4 Workflows and information delivery

BIM-based collaboration requires all project partners to exchange well-defined information between each other at certain times, which are contractually agreed. The exchange should take place exclusively via the CDE so that bilateral exchange without storing information in the CDE is prevented. To ensure each project participant has the required, up-to-date information for the respective processes, the author must enter created model content at agreed times. For this purpose, a corresponding time and performance plan, the Master Information Delivery Plan (MIDP), is required, and often contractually stipulated. The MIDP determines how frequently, and at which degree of detail ("LoD = LoI + LoG") and between which partners information is exchanged. The CDE manages the delivery of new or changed model data and coordinates all work packages. The transfer frequency depends mainly on the intensity of cooperation and coordination of individual or several partners over a given period. The extent of information and frequency with which it is entered into the environment have a significant influence on the technical realization of the CDE.

15.2.5 Version and documentation management

Each time a change is made to a data entity in the CDE, a new data resource is created with a new version. The content of the modification is, therefore, recognizable by comparing it with the previous version. As a result, any stakeholder can trace the

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course of changes when required. Since old versions can be accurately restored, old model variants can be recovered. Another important aspect of construction projects is the documentation and archiving of all relevant data. Since any information can also be retrieved later, the CDE serves as a central archive. This stored information is essential both for the subsequent operation phase and for possible legal questions.

15.2.6 Status management

To coordinate cooperation, the status of a registered data object or model can be determined with the help of its planning status (see Fig. 15.5). These states indicate if the corresponding data set can be used for the intended purpose or in which state they currently are. A digital plan status is an intermediate result of a particular planning process, which is stored and, if necessary, made available or released to other planning participants. For example, a multi-stage digital release process from model states within a planning phase can be characterized by different processing degrees. ISO/DIS 19650-1 (2017) outlines useful definitions to define the current stage of a document or model:

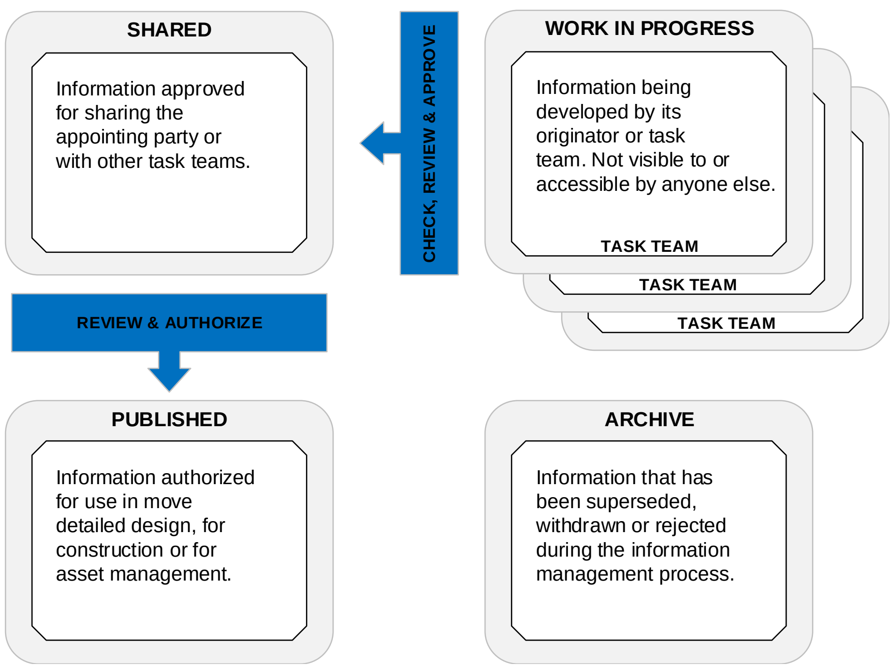

Fig. 15.5 Status management according to ISO/DIS 19650-1 (2017)

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The **work in progress state** is used for information while it is being developed by its originator or task team. Data in this state should not be visible or accessible to any task team apart from its originator.

The **check/review/approve transition** compares the data against the information delivery plan and against the agreed standards, methods and procedures for generating information.

The **shared state** is used for information that has been approved for sharing with the appointing party or with other appropriate appointed parties or task teams. Data in this state should be visible and accessible to them but should not be editable. If editing is required, the data should be returned to the work in progress state.

Information in the shared state should be consulted by all appropriate appointed parties and used to check the coordination, completeness, and accuracy of their own information. The shared state is also used for data that has been approved for sharing with the project client or with the asset owner/operator and are ready for authorization. A separate information state, client shared, might be used for such data in cases where the CDE is distributed over different systems or where there are security considerations.

The **review/authorize transition** state tests all the data in an information exchange for coordination, completeness, and accuracy against the information requirements. If the data or data sets pass these tests, their state is changed to published. Authorization differentiates information (in the published state) that may be relied on for the next stage of project delivery, including more detailed design or construction, or for asset management, from information that might still be subject to change (in the work in progress state or the shared state).

The **published state** is used for information that has been authorized for use, either in the construction of a new project or in the operation of an asset. The project information model at the end of a project or the asset information model during asset operation contains only data and information in the published state or the archived state.

The **archived state** is used to hold a complete record of all superseded data that has been shared and published during the information management process. Data sets in the archived state that were previously in the published state represent information that might previously have been relied on for more detailed design work, for construction or for asset management.

15.2.7 Filtering

A major challenge is to make the stored information accessible to all parties so that the information can quickly be queried and retrieved as required. The structuring of the information resources allows the filtering of data, which makes the extraction of desired information much easier. Based on the structured information and the contained characteristics of the information, configurable and reusable filter func-

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tionalities can be implemented. Filters are often used in the context of workflows to quickly provide an editor with relevant information.

15.2.8 Project communication

Another important aspect of project management is internal communications between the parties involved. By centralizing all information in the CDE, this can also serve as a central communication platform. A significant advantage is that the information transmitted can be directly linked to information from the model and thus significantly increases the power of expression; redundant communication paths are avoided. For example, the CDE can be used for central issue management using the BIM Collaboration Format (BCF), (BuildingSmart, 2016a). In a 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 kinds of information on communications. To connect the topic details with the digital building model, they can be directly linked by storing a particular view position as well as the 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. In principle, this kind of communication replaces the revision cloud as is used in conventional drawing-based processes. This BIM-based communication plays an important 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 store for these topics, since it also contains the corresponding model data with which the topics are linked. As model and topic data are kept consistent, this is much more robust than systems that exclusively store and manage topics.

15.2.9 Quality checks and maintaining model quality

While the contents in the environment are always updated or changed, the quality of the domain-specific models, as well as the overall model, must continually be maintained at a high level.

An essential tool for maintaining model quality are projects standards, which are agreed upon at the beginning of the project and by the EIR. Project standards include definitions of how information needs to be structured as well as modeling guidelines. The agreed standards set legally binding requirements for the way data is stored. The created model information should, therefore, be checked iteratively against these criteria.

For the description of specific data exchange requirements that must be met for particular process steps BuildingSmart (2016b) developed the Model View Definition Concept (MVD). This concept can also be used to map data integrity rules.

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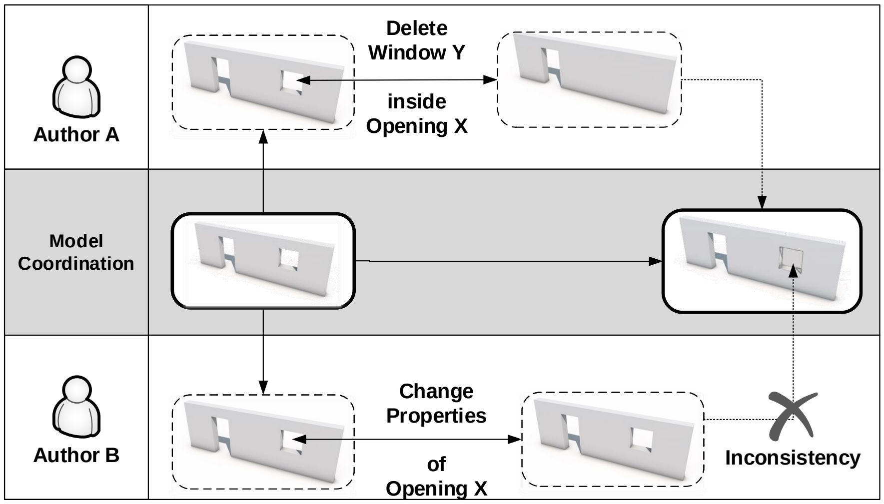

Fig. 15.6 Example of inconsistency in a BIM-based collaboration process

These can describe, for example, whether an attribute is assigned a value for a specific value range, which is especially important for additional attributes that are to be used for material properties (units).

Before information is imported as models by the project participants, the quality of the information must be checked. Since the input and output streams of the information are centralized within the CDE, these can be centrally controlled. As a result, models can be individually checked before they enter the environment. Afterwards, they can also be checked for consistency using other models already stored in the environment. The consistency of data implies that stored information is unified and therefore valid as a whole. In the federated model approach, these inconsistencies occur especially when domain-specific models are merged into the coordination model.

An example of an inconsistency is shown in Fig. 15.6. In this example, user A modifies a model object Y, which is only valid in the context of the model object X. If user B tries subsequently to access object Y, an inconsistency arises since the data is no longer valid. In the example, author A deletes the opening, but author B modifies its properties at the same time. If the delete operation is executed prior to the property modification, the data object is no longer valid, resulting in an inconsistency error (Preidel et al., 2016).

Redundancies occur when the same information is stored in different objects or properties. In the context of collaborative BIM processes, redundancies are often unavoidable or are sometimes even desirable. If redundancies are present or desired, it is important these do not lead to inconsistencies. BIM data management must make clear which redundancies exist, and for what purpose.

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15.3 Summary

The BIM method and the accompanying federated model approach present fundamental challenges and require that collaborative processes in the construction industry be adapted. The introduction of the CDE represents a major step towards the digitalization of these processes. By centralizing data storage as well as bundling information and data streams, the enormous amount of data stored in models and data objects can be coordinated consistently. At the same time, essential aspects, such as data and model quality, can be considered. The key aspects described above provide an overview of the structure of a CDE and the capabilities it must fulfill. The complexity and dynamic nature of building projects mean that the evolution of BIM-data is a highly dynamic process. When defining the content and functionality of a project-specific CDE, it is necessary to ensure that the chosen system can meet these changing requirements.

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