ce/papers Proceedings in civil engineering

Ernst & Sohn A Wiley Brand

ORIGINAL ARTICLE

EUROSTRUCT

A common data environment for value-driven data management in German road construction

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Abstract

In recent years, the BIM method has been increasingly used in pilot projects for the planning and realization of road construction projects. Due to the strong political demand to expand the applications fields of BIM, there is also an increasing demand for a common data environment (CDE), as the central component of a successful and consistent BIM application [1]. In this context, uniform requirements, which currently exist only to a limited extent, are necessary to implement and successfully use a CDE in road construction. Based on a qualitative research approach questioning employees of state road administrations and a market analysis conducted through a qualitative study with CDE suppliers, a specification book for further CDE usage in road construction is being provided. In this context, functional and non-functional requirements must be complied in order to implement and use a CDE in road construction successfully. Future research needs to take an in-depth look at the operational phase and the challenges that arise when most state road administrations implement a CDE area-wide.

Keywords

Building Information Modeling (BIM), Common Data Environment (CDE), AEC industry, state road administrations in Germany, road construction

1 Introduction

In recent years, the methodology of Building Information Modeling (BIM) has been used more and more frequently in pilot projects for the planning and realization of construction projects. In this context, BIM is based on the idea of enabling the continuous use of digital building models throughout the entire life cycle, from the early design and detailed planning phase through the construction phase to the operational phase [2].

The evolution of BIM can be traced back to the beginnings of computer technology in the 1960s and the emergence of solid modeling programs in the 1970s and 1980s [3]. Subsequently, BIM-based modeling was first applied in pilot projects to support building design by architects and engineers in the early 2000s [4]. Although the definitions vary, there is consensus that BIM is changing the way activities and processes are carried out in the built environment [5]. In this regard, BIM stands in contrast to traditional paper- or 2D drawing-based workflows [6].

The Reform Commission on the Construction of Major Building Projects laid the foundation for a digital planning culture in Germany back in 2013 [7]. In order to increase the cost and schedule reliability of large construction projects, the endeavor to first build digitally and later build in reality was established in this context.

The increased political will to use the digital method BIM is also evident in road construction. Since 2020, the use of BIM has been mandatory for projects in the infrastructure sector. This goal emerges from the "Digital Planen und Bauen" step by step plan published by the Federal Ministry of Transport and Digital Infrastructure [8]. Therefore, a rethinking of the way processes are carried out and projects are managed is required by all stakeholders involved in construction projects.

The efforts to promote the use of the digital planning method BIM were subsequently underlined by the "*Masterplan Bauen 4.0*" [9], the "*Masterplan BIM Bundesfernstraßen*" [10] and the "*Masterplan BIM für Bundesbauten*" [11]. As part of the "Masterplan Bauen 4.0", which was published in 2017, 20 additional BIM pilot projects are launched on rail, road and waterways, with a total investment of 30 million euros.

https://doi.org/10.1002/cepa.2032

In the context of increased BIM usage, a common data environment (CDE), as the central component of a successful and consistent BIM application, has gained the interest and attention of the AEC industry [10]. In road construction, however, there are still only limited uniform guidelines and standards in this regard. Although pilot projects and standards such as DIN EN ISO 19650 and DIN SPEC 91391 can be identified, there does not exist any standardization that takes into account the specific requirements of road construction, also with regard to the connection of government institutions at different levels through the CDE while maintaining their respective data and resource sovereignty. Therefore, specific requirements need to be developed to ensure standardized and value-driven data management in road construction.

The objective of this paper is to identify specific requirements for the successful implementation and use of a CDE for road construction projects. Therefore, first a definition including an overview of the main purposes of a CDE is given. Subsequently, based on a quantitative research approach questioning 14 different state road administrations, relevant aspects for project execution and an overview of CDE usage in the different state road administrations are given. Furthermore, requirements for a CDE usage in road construction are provided. Afterwards, a market analysis questioning 14 different CDE suppliers to determine the extent to which current software solutions cover the specific requirements is provided. The results are then clustered and summarized in a specification book. Subsequently, the results are discussed in detail. In conclusion, the key facts of this paper are provided and an outlook for future research is given.

2 Common data environment (CDE)

The CDE is the key component of a successful and consistent BIM application [1]. A CDE is a digital platform that represents the central data organization for digital building models and is used for the collaboration of different stakeholders [12]. When used correctly, this affects all project stakeholders across the lifecycle phases, so that the CDE acts as the central application for all communication and approval processes. According to the "Masterplan BIM für Bundesbauten" [11], the main purpose of a CDE is to organize, collect, evaluate, coordinate, archive, and make digital data available to all project stakeholders. Data is therefore stored in the CDE and shared with the individual project participants.

3 Findings

This section first presents the results of the qualitative study in which employees from various state road administrations were interviewed. Then the results of the market analysis, in which different CDE providers were surveyed, are presented.

3.1 Demand

According to the participants, model-based planning represents the most relevant aspect for project execution in road construction, based on the five aspects mentioned (figure 1). Approximately 87 % rated this aspect as very relevant. The remaining approximately 13 % defined this aspect as relevant. Therefore, according to all interviewed road administration employees, model-based planning is considered to be of high importance, as it is considered to be always relevant or very relevant for project execution.

The second highest level of agreement is visible in connection with the aspect of transparency in project communication. Approximately 67 % rated this aspect as very relevant, while the remaining assigned it a relevant position. No participant rated this aspect as neutral, less relevant, or not relevant at all. Therefore, this aspect is also given high importance in the project execution of road construction projects.

The majority (60 %) of the participants defined consistent data management in the planning and construction phase as very relevant. At the same time, one out of three participants (33.3 %) defined this aspect as relevant while approximately 7 % remained neutral about this aspect. No participant gave this aspect low or no relevance. 6 out of 10 participants defined uniform workflow management with clear responsibilities as very relevant. About 27 % described this aspect as relevant, while it was rated as neutral by the remaining participants (13.3 %). Again, no participant assigned little or no importance to this aspect.

The lowest relevance is identified in conjunction with the aspect of adequate documentation for operation. The majority (46.7 %) defined this aspect as relevant. At the same time, 40 % defined this aspect as very relevant and approximately 7 % were neutral in this regard. For about 7 % of the participants, this aspect has a low significance. Therefore, this aspect is the only one that has a low relevance according to some participants. Nevertheless, this aspect can also be classified as generally relevant for project execution.

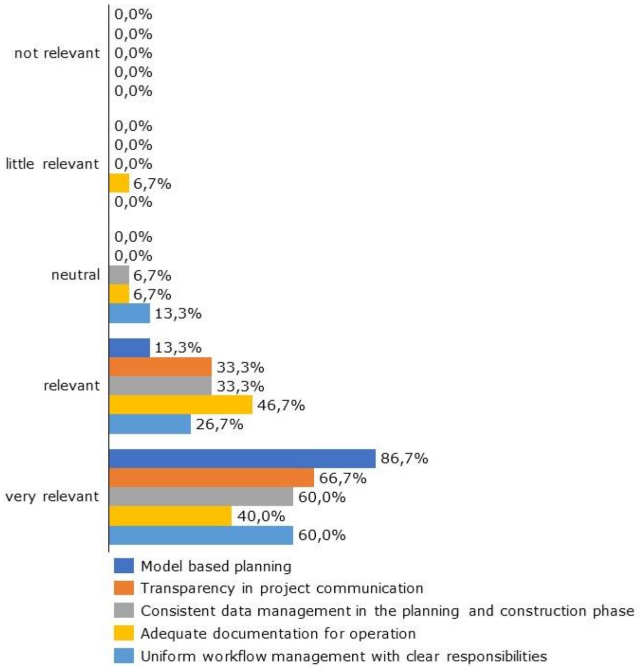

Figure 1 Relevant aspects for project execution in road construction

According to the conducted interviews, most of the 14 different state road administrations in Germany have a CDE in use during pilot projects. This applies to 6 out of 14 interviewed states, corresponding to approximately 43% in total. Three different state road administrations do not currently use a CDE but plan to use one in the future, while the same number of administrations use a CDE frequently. This corresponds to approximately 22 % of the interviewed state road administrations. One of 14 different road administrations does not use CDE and does not plan to do so in the future. The same figure applies to the state road administrations, which already have a CDE implemented area wide. In summary, nearly all state road administrations interviewed are at least engaged in the planning of a CDE implementation.

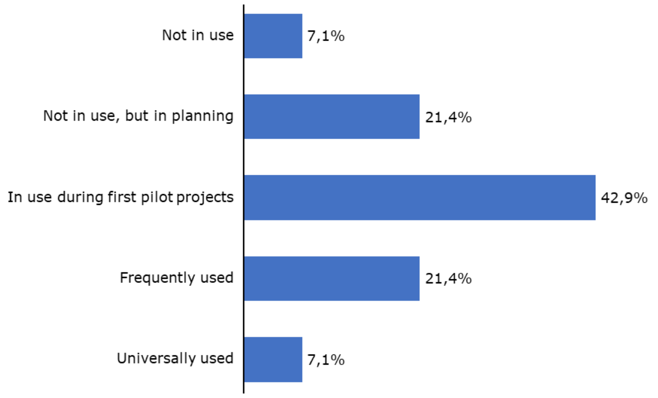

Figure 2 CDE usage in public road administrations

Based on the qualitative study, different requirements for the use of a CDE in road construction are identified. In total 38 requirements are determined. These are listed below based on the number of mentions.

Table 1 Requirements for a CDE usage in road construction

number	number of mentions	requirement
1	7	3D model viewer
2	7	Interfaces to e.g. modelling software and data bases
3	6	Issue management
4	4	Role and rights system
5	4	Rule based checking
6	4	File linking
7	4	Support
8	4	User-friendliness
9	4	Dashboard
10	4	Server location in Germany
11	3	Compatibility of different file formats
12	3	Digital workflows
13	3	GIS data usage
14	3	Collision checking
15	3	BIM Collaboration Format (BCF) and Industry Foundation Format (IFC) management
16	3	Status management
17	3	Web based solution
18	3	Archiving and version management
19	3	Long-term data storage
20	3	Search and filter functions
21	3	Data security based on GDPR
22	2	Temporal access
23	2	Reporting
24	2	Data availability
25	1	Bidirectional data exchange
26	1	Language settings
27	1	Collaboration opportunity
28	1	Name conversion of data and models
29	1	Workflow mapping
30	1	Accessibility
31	1	2D plan derivation
32	1	Mobile application
33	1	AR and VR linkage
34	1	Local data hosting
35	1	Mail Notification
36	1	Adaptability
37	1	Data backup
38	1	Offline access

The requirements mentioned the most are the provision of a 3D model viewer and the availability of interfaces to for example modelling software and data bases. These two requirements are followed by the request of an issue management. Other frequently stated requirements are a role and rights system, rules-based checking, file linking, support, and user-friendliness. In addition, a dashboard and a server location in Germany were named often. These are the 10 most frequently mentioned requirements.

Other frequently mentioned requirements include the compatibility of different file formats, the ability of digital workflows and the use of GIS data. Compared to these requirements, requests such as the 2D plan derivation, mobile application, and AR and VR linkage, are mentioned only once.

3.2 Supply

Based on the market analysis, questioning 14 different CDE suppliers, it was possible to determine whether the requirements were met. The following table provides an overview of the requirements, including an indication of how many of the 14 companies fulfil them. The order is based on the requirements with the highest compliance rate.

Table 2 Market analysis

Requirement	Requirement fulfilled	Requirement not fulfilled
BCF and IFC management	14/14	0/14
3D model viewer	14/14	0/14
Data security based on GDPR	13/14	1/14
Server location in Germany	13/14	1/14
Web-based solution	12/14	2/14
Support	8/14	6/14
GIS data usage	6/14	8/14
Local data hosting	3/14	11/14
AR and VR linkage	2/14	12/14
Mobile application	2/14	12/14

According to all CDE suppliers, BCF and IFC management and a 3D model viewer are included in each software. Nearly all companies further provide data security based on GDPR, a server location in Germany, and a web-based solution. Only two suppliers offer a desktop version instead of a web version. Slightly more than half of the interviewed companies offer support to their IT solution. From the perspective of using Geographic Information Systems (GIS) data, slightly less than half of the companies can meet this requirement. The requirements for local data hosting, AR and VR linkage, and a mobile application are present in only a few software solutions. In this context, most of the CDE suppliers do not meet these requirements.

4 Specification book

The total of 38 collected requirements in chapter 4.1 can be assigned functional and non-functional requirements. Functional requirements can be defined as those necessary to the intended purpose of the CDE. Non-functional requirements in contrast are requirements that are necessary for the execution and the further development and evolution of quality.

In total, 11 functional and 9 non-functional requirements were created, containing the various sub-requirements identified in the previous qualitative study. These are needed for the successful implementation and use of a CDE in road construction. The specific requirements are described in more detail in the corresponding subchapters, while the following table provides an overview.

Table 3 Specification book

Functional Requirement	**Non-functional requirements**
Compatibility, interfaces, and data exchange	Data protection
Multi-project capability	Training, support, and documentation
Multi-client capability	Accessibility
Model and data management	Language setting
Authorization concept	Data sovereignty
Communication	Individual software development
Workflows	System requirements
Model viewer	Information security
User functionalities	Availability
Usability	
Reporting	

4.1 Functional requirements

Due to the high number of systems used in road construction, specific requirements arise in connection with the topics of *compatibility, interfaces, and data exchange*. Therefore, a bidirectional data exchange (requirement 25) and interfaces to for example modelling software and data bases (requirement 2) are necessary. In this context, the support of the file formats IFC and BCF (requirement 15) the compatibility of further different file formats (requirement 11), and GIS data usage (requirement 13) are additionally needed.

A CDE in road construction must further support the creation and editing of multiple projects while different user groups can be served (requirement 27). This requirement is summarized under the requirement of *multi-project capability* and *multi-client capability*. In addition, functions for the *management of models and data* are required. Therefore, archiving and version management, long-term storage and name conversion of data and models is necessary (requirements 28, 18 & 19). In this regard, file linking, and offline access must be further functionalities (requirement 6 & 38).

The functional requirement *authorization concepts* include functionalities that take into account access roles, access permissions, and temporary access (requirement 4 & 22). Functions considering the issue management (requirement 3) can be summarized under the requirement of *communication*. The requirement *workflows* considers the provision of digital workflows, the status management, and the mapping of the workflow (requirements 12, 16 & 29), while the functional requirements *model viewer* addresses the requirements 3D model viewer (requirement 1), rule based checking (requirement 5) and collision checking (requirement 14). The identified requirement 2D plan deviation (requirement 31) can be counted in the model viewer category as well.

Functional requirements include search and filter functions, mobile applications, VR and AR connectivity, and mail notification (requirements 20, 32, 33 & 35), which can be classified as user functionalities. The functional requirement of usability considers the aspect of user-friendliness (requirement 8), while the aspects of dashboard and reporting (requirements 9 & 23) can be summarized under the functional requirement of *reporting*.

4.2 Non-functional requirements

The identified requirement for data security based on GDPR (requirement 21) can be summarized under the non-functional requirement of *data protection*. The non-functional requirement *training, support, and documentation* covers aspects that consider assistance functions when using a CDE (requirement 7). A further non-functional requirement that a CDE in road construction must fulfil can be summarized under the aspects of language setting and accessibility (requirements 26 & 30). The requirements about the server location (requirement 10) and the local data hosting (requirement 34) represent sub requirements of data sovereignty. Individual software development considering possible extensions and adaptions of the CDE represents another non-functional requirement (requirement 36). Further requirements (requirements 17, 24 & 37) can be categorized as system requirements, availability, and information security.

5 Discussion

According to this paper, 5 aspects can be assigned a high relevance in project execution. Model-based planning followed by transparency in project communication can be assigned the highest relevance. These aspects are followed by consistent data management in the planning and construction phase and uniform workflow management with clear responsibilities. The lowest current relevance can be assigned to adequate documentation for operation. This may be due to the fact that the operational phase has not yet been a focus, and the transition from the planning and construction phase to the operational phase is associated with major challenges. Consequently, it seems possible that the added value and relevance of this aspect have so far been only rudimentary.

Along with this, it can be recognized that the focus of digital methods like BIM and technologies tends to be on planning and construction rather than on operations [13]. This also seems consistent with the focus of a CDE that is specialized in functionalities associated with planning and construction.

The implementation of uniform information management over the entire life cycle in the form of a CDE, as described in the master plan for federal buildings ("Masterplan BIM für Bundesbauten") [11], is also progressing in road construction. Nearly every road administration is at least concerned with the planning of a CDE implementation. Most road construction administrations currently use a CDE in their first pilot projects. Only one state road administration has a CDE deployed across the state, while another has no intention to use one in the future.

Based on the qualitative study questioning employees of state road administrations, 38 sub-requirements could be assigned to 11 functional and 9 non-functional requirements. In this context, general requirements for a CDE but also specific requirements defined from the road construction point of view could be identified as part of the specification book. As an example, the need to use GIS data shows a specific requirement for road construction, since environmental data plays a central role in the operation of a road [15]. Therefore, this study emphasizes the need to meet general and road-specific requirements for the successful implementation and use of the CDE in road construction.

The conducted market analysis shows that these road specific requirements are only partially provided in current CDE solutions. A partial mismatch between demand and supply for 10 exemplary selected requirements is visible. In particular, the required support functions and the use of GIS data, which are especially important for road construction, are currently not fulfilled as a requirement in most cases. This result coincides with the study by Bradley et. al., which found that standards and regulations in the BIM context largely relate to building construction and not to the infrastructure sector [14]. An increased focus on the infrastructure sector and thus on the road sector, accompanied by new standards, will be necessary for the future to compensate for this imbalance.

6 Conclusion

Along with an increased political desire to apply the BIM method in construction projects, an increased interest in CDEs can be recognized. The successful application demands requirements and standards that, for the most part, do not yet exist in road construction.

According to this study nearly all state road administrations in Germany are facing the challenge of implementing and using a CDE for road construction projects. The majority is currently using a CDE in their first pilot projects. In this context, this paper provides a set of requirements for the successful implementation and use of a CDE based on a qualitative study in which state road administration employees were interviewed. The specification book developed for this purpose contains 11 functional and 9 non-functional requirements, which are composed of 38 sub-requirements.

The market analysis carried out shows that demand and supply do not necessarily match each other. Currently developed CDEs seem to be primarily designed for building construction and only partially meet the identified requirements in the context of road construction. An increased focus on the infrastructure sector and thus also on road construction will be necessary for the future to counteract this mismatch.

In summary, this paper provides clear guidance on requirements that need to be considered when implementing and using a CDE for road construction projects. Future research should look at how these requirements have changed when most administrations find themselves in area-wide implementation. In addition, the challenges associated with transferring information to the operational phase need to be explored in more detail. In this regard, the use of a CDE that goes beyond the planning and design phase seems to have a high added value.

References

[1] Klemt-Albert, K. (2018) *Building Information Modeling*. In: Bautabellen für Ingenieure. Vol. 2018.

[2] Borrmann, A.; König, M; Beetz, J. (2018) *Building Information Modeling*. Cham: Springer international Publishing

[3] Smith, P. (2014) *BIM Implementation – Global Strategies*. Procedia Engineering. Vol. 85, p. 482-492.

[4] Volk, R.; Stengel, J.; Schultmann, F. (2014) *Building Information Modeling (BIM) for existing buildings — Literature review and future needs*. Automation in Construction. Vol. 38, p. 109-127.

[5] Zhang, S. Teizer, J., lee, J. K.; Eastman, C. M.; Venugopal, M. (2013) *Building Information Modelling (BIM) and Safety: Automatic Safety Checking of Construction Models and Schedules*. Automation in Construction. Vol. 29, p. 183-195.

[6] Eastman, C. M. (2008) *A guide to building information modeling for owners, managers, designers, engineers, and contractors*. Hoboken N.J.: Wiley.

[7] BMVI (2015) *Roformkomisiion Bau Großprojekte Endbericht*.

[8] BMVI (2015) *Stufenplan Digitales Planen und Bauen. Einführung modernen, IT-gestützter Prozesse und Technologien bei Planung, Bau und Betrieb von Bauwerken*.

[9] BMVI (2017) *Materplan Bauen 4.0*.

[10] BMVI (2021) *Masterplan BIM Bundesfernstraßen.*

[11] BMI (2021) *Masterplan BIM für Bundesbauten. Erläuterungsbericht.*

[12] Bahlau, S.; Klemt-Albert, K. (2017) *Das BIM Modell als Single Source of Truth*. In: Bauwirtschaft, pp. 74-79.

[13] Oti, A. H.; Kurul, E.; Cheung, F.; Tah, J.H.M. (2016) *A framework for the utilization of Building Management System data in building information models for building design and operation*. Automation in Construction. Vol. 72, p. 195-210.

[14] Bradley, A.; Li, R.; Lark, R.; Dunn, S. (2016) *BIM for infrastructure: An overall review and constructor perspective*. Automation in Construction. Vol. 71, p. 139-152.

[15] Becker, R.; Kaden, R.; Blankenbach, J. (2017) *Building Information Modeling (BIM) – new perspectives for Geodesists*. Gis. Business. Vol. 5, p. 50-57.