INFORMATION REQUIREMENTS FOR BIM: CURRENT PRACTICE AND IMPLEMENTATION IN GERMANY

Martina Mellenthin Filardo, M.Sc.
Construction Engineering and Management, Bauhaus-Universität Weimar, Weimar, Germany
https://orcid.org/0000-0001-7759-7579
martina.mellenthin.filardo@uni-weimar.de

Florinda Ruppert, M.Sc.
Construction Engineering and Management, Bauhaus-Universität Weimar, Weimar, Germany
https://orcid.org/0009-0009-6653-4789
florinda.meret.ruppert@uni-weimar.de

Jürgen Melzner, Professor
Construction Engineering and Management, Bauhaus-Universität Weimar, Weimar, Germany
https://orcid.org/0000-0002-6435-0283
juergen.melzner@uni-weimar.de

SUMMARY: *Information Requirements constitute a fundamental component of the Building Information Modelling (BIM) method, specifying client requirements for information provision and exchange during delivery processes. In Germany, these contractually binding documents undergo continuous evolution in response to BIM proliferation, technological advancements, and standardization efforts, leading to modifications in requirements specification. This study examines the evolution of Employer Information Requirements (EIR) documents in Germany across two periods (2017-2019 and 2021-2024). Employing a mixed methodology – qualitative document analysis of twelve representative infrastructure EIRs using the VDI 2552 Sheet 10 reference structure applying quantitative metrics. The research identifies substantial improvements in precision, professionalism, and standardization. These advancements stem from growing BIM expertise and industry initiatives. However, findings reveal incomplete implementation of whole-lifecycle considerations and inadequate machine readability of EIR documents, indicating areas for further development. The findings yield recommendations for EIR advancement: continuously updating standards, enhancing training initiatives, and promoting machine-readable documentation solutions. Future research should examine EIR's long-term impact on building lifecycles and integration with existing contractual frameworks.*

KEYWORDS: *information requirements, BIM, employer information requirements, EIR, information management, EIR content analysis.*

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1. INTRODUCTION

Information requirements (IR) are crucial for efficient project management, providing transparency and planning security (Borrmann *et al.*, 2021). Early integration of IR into construction projects is essential for successful implementation of the Building Information Modelling (BIM) method (German Federal Ministry of the Interior and German Federal Ministry of Defence, 2021). IR relevance extends beyond planning and construction, enabling efficient data use throughout a building's lifecycle and supporting new technologies. As BIM adoption increases, continuous development of IR documents (known as Employer Information Requirements, EIR, in Germany) becomes increasingly important due to evolving standards and growing practical experience.

Despite growing standardization efforts, systematic empirical evidence on the structural completeness and formal quality of EIR documents in public procurement remains limited. Prior studies have examined EIR practices or specific national contexts (Hafeez *et al.*, 2016, 2016; Bouras *et al.*, 2016), but longitudinal comparative analyses assessing whether and how EIR document quality has evolved in response to mandatory BIM implementation policies are absent from literature. This gap is particularly relevant in Germany, where federal BIM mandates introduced in 2015 and 2020 created a traceable policy intervention against which document quality changes can be assessed empirically. This study addresses this gap by formulating the following research questions:

To what extent do German public sector EIR documents comply with established content criteria, and what categories of information requirements are consistently present of absent across documents? How has the structural completeness and formal quality of German public sector EIR documents evolved between the early BIM adoption period (2017-2019) and the post-mandate period (2021-2024)? To what extent are evaluation results of EIR documents sensitive to the choice of reference framework, and what does this reveal about the stability of core EIR content requirements over time?

The objective of this study is the evaluation of structural completeness and formal quality of German EIR documents by public tenders from two time periods (2017-2019 and 2021-2024) against a comprehensive 35-criterion framework to assess compliance patterns and identify consistently applicable categories for standardized BIM project implementation. This study focuses on German EIR documents given the mandatory implementation of BIM for federal infrastructure projects initiated in 2020, establishing Germany as a relevant case for empirical analysis of public-sector BIM procurement practices. By systematically evaluating the scope and articulation of BIM-related project requirements in German tender documents, this research contributes to evidence-based refinement of BIM standardization frameworks and supports enhanced transparency in public procurement digitalization processes. This study applies mixed methods to the evaluation of EIR documents. The evaluation consists of a qualitative content analysis of EIR documents. To enable comparability, quantitative instruments have been applied.

This article is structured into a background section in Section 2 outlining the information delivery framework, procurement, EIR contents, and state of research. A methodology section is presented in Section 3. The analysis framework and criteria for evaluation are presented in Section 4. The analysis results for the content evaluation are presented in Section 5, as well as the formal structural evaluation. A comparison of EIR document evaluation with different reference frameworks and the limitations of this study are also presented in Section 5. Results and limitations are discussed in Section 6 and conclusion and outlook are given in Section 7.

2. BACKGROUND

2.1 Information delivery framework

EIR documents cannot be considered without their context. Model-based approaches in the architecture, engineering, construction, operation, and maintenance (AECOM) industry extend beyond geometric modeling to comprehensive information management throughout a project's lifecycle, enabling collaborative data creation and utilization by all stakeholders (Borrmann *et al.*, 2021; Hartmann, 2023). Structured information management enables data-driven decision-making and forms BIM's core (Mellenthin Filardo *et al.*, 2024), with the ISO 19650 standard series detailing a standardized information delivery process spanning planning, construction, and commissioning phases (ISO, 2018).

The process follows a sequential framework, starting with the requirements assessment, where information management specialists are appointed to determine requirements, establish project milestones, and develop standards for information structuring (ISO, 2019). Then follows the tendering phase, where EIR are formulated with specific, measurable criteria for information exchange at project milestones (ISO, 2019; Hartmann, 2023), followed by the offer submission, where offering companies develop a preliminary BIM Execution Plan (BEP) describing their planned approach, standards, and technologies (ISO, 2019). The information ordering takes place when the selected provider's BEP is finalized, transitioning from requirements specification (EIR) to obligation specification (BEP) (Borrmann *et al.*, 2021). The mobilization phase consists of tests and training implemented as a trial run for actual information provision. The collaborative information generation follows, with teams creating information according to defined standards, with a project-wide federation strategy ensuring coherent integration. The information (model) delivery consists of a multi-stage review process and enables quality assurance before final submission to the information-requesting party. The project completion occurs after information delivery, where models and associated data are archived in the quality established within the EIR (ISO, 2019).

In addition to key international standard such as ISO 19650 standard series, national supplements may apply to the information delivery framework. For Germany, the industry-oriented VDI 2552 guideline series was collaboratively developed by the association of German engineers (Verein Deutscher Ingenieure, VDI). VDI guidelines constitute non-binding recommendations and hold significant practical authority within the German AECOM industry. They are recognized as acknowledged rules of technology, meaning they can serve as benchmarks for technical standards in contractual agreements and liability determinations. Regarding IR, VDI guideline series 2552 was developed to function complementarily to ISO 19650 standard series. VDI guideline 2552 part 10 operationalizes information management principles specifically for German procurement and project delivery contexts though detailed guidance and contents of EIR and BEP, thus making ISO 19650 principles implementable in the German tendering process (VDI - Association of German Engineers, 2021).

Therefore, the EIR contents outlined in section 2.2 that result in the 27 content criteria applied in the analysis, stem from this guideline. EIR contents are very broad and subject to interpretation. To address that and to allow for easier replicability, all EIR contents according to VDI guideline 2552 part 10 are described in depth in section 2.2 to show how they were interpreted in this evaluation.

2.2 EIR contents

2.2.1 Introduction, project specifics, objectives and use cases

The introduction to an EIR document has the essential function of providing basic instructions for use and references to other parts of the agreement, such as the BEP (Borrmann *et al.*, 2021: 301). It provides a compact overview of the structure of the EIR, explains the expectations of the commissioning party and refers to relevant requirements and the objectives of the document. The introduction also contains information on the structure of the tender and other applicable documents (VDI - Association of German Engineers, 2021). Another component is the EIR declaration of commitment, which ensures that the specified requirements are also maintained when passing them on to subcontractors (Hartmann, 2023: 432).

The general framework conditions of an EIR document define the legal, organizational and project-specific requirements that are relevant for its application. This includes the standards and guidelines to be applied, as well as references to other relevant framework conditions and project-specific framework conditions and project-specific features (VDI - Association of German Engineers, 2021). Besides general ISO and local standards (e.g., DIN for Germany), specific object catalogs, such as for bridges or geotechnics, can also be taken into account (German Federal Ministry of Transport and Digital Infrastructure, 2021: 47). In addition, regulations, standards and regional regulations that must be explicitly observed in order to create a uniform basis for all project participants (Hartmann, 2023: 432).

The project specifics within an EIR represent an essential source of information for those involved, as they depict the specific features of the project. These specific circumstances must be presented precisely and without redundant repetitions from other documents such as the general terms of contract or the project manual. In particular, information that is relevant for the concrete implementation of the BIM objectives of the commissioning party (Hartmann, 2023: 433; VDI - Association of German Engineers, 2021). The essential aspects of the project specifics include the basic project task, project-related circumstances that influence the use and processing of data,

as well as scheduling conditions. In addition, a brief project description of the planning services and BIM use cases to be considered, with reference to detailed tender information in order to avoid redundancies. The EIR is created individually for each tender or contractual assignment and addresses the respective service phases that are relevant in the context of the project. In the project overview, the various sections are recorded with basic information in order give those involved an overview of the entire project and to clearly show the dependencies between the project phases. A competent contact person, often the BIM management of the commissioning party, is also named (German Federal Ministry of Transport and Digital Infrastructure, 2021: 19).

BIM use cases describe the purpose for which data is extracted or enriched from a digital building model (VDI - Association of German Engineers, 2020b). They serve as a basis for defining the model requirements and the processes to be integrated as well as for determining the project participants (Borrmann *et al.*, 2021: 301). These use cases are defined as part of the EIR, whereby the services to be provided must be clearly and comprehensibly formulated for each use case. The selection of use cases is directly dependent on the specific objectives of the project and it should be checked which ones are required for the specific project. Further specific use cases can be defined by the commissioning party (German Federal Ministry of Transport and Digital Infrastructure, 2021: 22).

The data and information requirements refer to the digital deliverables that must be created, checked and handed over to the ordering party as part of a project. These deliverables, such as digital models, 2D plans, test reports and other relevant documents, are to be defined in the EIR for each project phase or milestone. They represent the results of the implemented BIM use cases and must be exchanged regularly, ideally via a CDE, to ensure efficient project control and coordination (German Federal Ministry of Transport and Digital Infrastructure, 2021: 26). An important aspect of BIM projects is the scheduling of deliverables, which must be adapted to the specific project phases, for example in accordance with the service phases of the Fee Structure for Architects and Engineers (Federal Republic of Germany, 2021). These phases can be supplemented by additional milestones, especially in projects with step-by-step commissioning. Continuous interim submissions of the digital deliverables are also required in order to identify potential problems at an early stage, e.g., through regular project meetings. The deadlines set and the exchange of data are linked to the project specifications and the scheduling of the commissioning party (VDI - Association of German Engineers, 2021; German Federal Ministry of Transport and Digital Infrastructure, 2021).

2.2.2 Organization, roles, suitability requirements and processes

The definition of roles, responsibilities and tasks in a BIM project is a central component of successful project management and ensures that all parties involved understand their tasks and work together efficiently. The introduction of the BIM methodology changes both the structure and the people involved in a project, creating new roles for specific tasks (Borrmann *et al.*, 2021: 20). These roles must be clearly defined in the EIR (VDI - Association of German Engineers, 2021).

The information management (BIM management) role on the client side holds a key position, capturing EIR, defining BIM objectives, and managing BIM processes throughout the building lifecycle. This role coordinates BIM usage, serves as primary contact, and manages the CDE while conducting model reviews (Borrmann *et al.*, 2021: 355; VDI - Association of German Engineers, 2020c). The information coordination (BIM coordination) role assumes central operational responsibility for implementing BIM objectives across all lifecycle phases. In larger projects, this divides into overall BIM coordination and discipline-specific BIM coordination, with the lead discipline typically managing overall coordination (Borrmann *et al.*, 2021: 357; VDI - Association of German Engineers, 2020c). The information authorship (BIM authorship/BIM modeling) role creates and maintains data models throughout the building lifecycle, working in coordination with information coordination while adhering to contractual quality standards and BIM requirements defined in the EIR. They maintain data sovereignty over their created discipline and sub-models. Information users (BIM users) access building information models to extract relevant data without making modifications or adding new information, serving various project areas including construction execution, authorities, and experts (VDI - Association of German Engineers, 2020c; Borrmann *et al.*, 2021: 360).

Data and information management requires clearly defined, consistent processes for exchange and coordination (VDI - Association of German Engineers, 2021). Key processes include coordination procedures where separate discipline models are regularly combined into coordination models for quality assurance, with conflicts resolved through model-based documentation using the BIM Collaboration Format (BIM Deutschland Initiative, 2022: 22).

Quality assurance processes focus on systematic examination of digital deliverables for completeness, redundancy-free content, consistency, and uniformity of geometric and alphanumeric data, rather than technical content review (German Federal Ministry of Transport and Digital Infrastructure, 2021: 45, 2019: 13). This processual framework requires precise documentation in EIR and BEP while maintaining standardized nomenclature and file naming conventions for efficient CDE utilization (VDI - Association of German Engineers, 2018; BIM Deutschland Initiative, 2022: 32).

2.2.3 Technology, data and information

Technical requirements and data management protocols for BIM project implementation are also outlined in the EIR, emphasizing the balance between specification precision and methodological freedom.

Regarding hardware and software requirements, the EIR must specify both client-used systems and, in exceptional cases, contractor-required technologies including versions, while maintaining methodological freedom and avoiding manufacturer-specific requirements to ensure non-discriminatory procurement (VDI - Association of German Engineers, 2021). Contractors retain software selection freedom as long as their tools can generate or export required digital deliverables in specified data formats while meeting contractual security standards (BIM Deutschland Initiative, 2022: 33). EIR must also provide detailed technical implementation descriptions of the CDE and required interface definitions, including whether browser-based access or contractor system installations are necessary (VDI - Association of German Engineers, 2021). CDE procurement may occur through either client or contractor, with clearly defined functional requirements. Typically provided by the client, CDE specifications must address access rights, IT security, naming conventions, and data exchange requirements according to DIN EN ISO 19650-1 and VDI 2552 Sheet 5 (German Federal Ministry of Transport and Digital Infrastructure, 2021: 42). EIR must define client-provided input data including type, origin, and transfer format. For large projects or ongoing BIM methodology implementation, external input data in various formats (including paper) must be integrated into existing models. Transparent data listings aid contractor calculations and should specify quality, creation timeframe, and scope (Mellenthin Filardo and Krischler, 2020: 29). All use case-relevant foundations such as digital 2D plans, utility information, or soil reports require exact specification, with existing digital models provided to contractors (German Federal Ministry of Transport and Digital Infrastructure, 2021: 25). Data quality and scope represent essential factors for successful exchange between clients and contractors, defined in EIR through specific requirements for data exchange formats, version numbers, and potentially Model View Definitions (MVD) usage. Open and neutral formats are preferred to ensure manufacturer-independent communication, with final format determination occurring in the BEP (German Federal Ministry of Transport and Digital Infrastructure, 2021; BIM Deutschland Initiative, 2022: 18). Regarding model structure and development, zoning and partitioning are also included in the EIR. Model subdivision may occur by discipline, trades, or spatial sections, considering geographical extent and scope. Clients ideally define model divisions tabularly in EIR (if known), with the BEP providing concrete specifications (VDI - Association of German Engineers, 2021; German Federal Ministry of Transport and Digital Infrastructure, 2021: 38).

Level of Information Need (LOIN): Current EIR practice has evolved from LOD (Level of Development) concepts toward LOIN implementation, specifically designed for clients requiring precise information need definition throughout project execution. LOIN represents specialized development rather than simple LOD substitution (German Federal Ministry of Defence, German Federal Ministry for Housing, Urban Development and Building, and Federal Agency for Real Estate Tasks, 2022). Information requirements, oriented to ISO 7817-1, define necessary alphanumerical information, geometrical information, and documentation according to a defined breakdown structure and specific prerequisites (ISO, 2024). Beyond information requirement definitions, effective BIM model reuse requires specific model construction and content design requirements, defined use case-specifically in EIR and BEP (VDI - Association of German Engineers, 2020b). Clients should develop general modeling guidelines adaptable across projects, focusing on expected results rather than strict methodological requirements to preserve contractor flexibility (German Federal Ministry of Transport and Digital Infrastructure, 2021: 36). Consistent coordinate and unit system definition represents a central aspect for efficient discipline model coordination. EIR must define clear coordinate system specifications including position and elevation systems, plus project reference point (VDI - Association of German Engineers, 2020b). BIM overall coordination creates project-specific BIM reference files in IFC format containing defined coordinate systems and project reference points, stored in CDE for accurate digital model positioning (German Federal Ministry of Transport and Digital Infrastructure, 2021: 41). EIR require comprehensive data protection and security concepts ensuring model

and project data confidentiality, integrity, and availability throughout project duration (VDI - Association of German Engineers, 2020a: 26). Concepts must address user and copyright protection, treating all project data as confidential with contractors transferring usage rights to clients upon data provision (German Federal Ministry of Defence, German Federal Ministry for Housing, Urban Development and Building, and Federal Agency for Real Estate Tasks, 2022: 62; BIM Deutschland Initiative, 2022: 33).

2.3 State of research

The analysis of EIR documents in BIM implementation research remains limited across current studies. A search was carried out using the Scopus database and aligned with findings by Chadegani *et al.*, 2013, focusing on the period of 2020-2025, and using a set of keywords (information, requirements, BIM, comparison, analysis). The search fields were limited to those related to construction, thus excluding fields such as social sciences, agriculture, and astronomy. Of the thirteen papers examined, only one explicitly addresses information requirements documentation and analysis. Cooney *et al.*, 2023 developed a heritage BIM framework that incorporated an exchange information requirement component alongside plain language questions to identify documentation required for safe heritage building refurbishment. Their methodology included creating a documentation management system to enable structured information exchange, though no comparison with existing industry EIR documents was conducted. The remaining studies focus primarily on technical BIM applications without examining information requirements systematically. Akbas *et al.*, 2025 developed a holistic approach to information requirements by integrating two machine-interpretable concepts aiding IR definition: the Information Delivery Specification (IDS) and Level of Information Need (LOIN) XML schemas. Their methodology involved analyzing both methods to discover integration possibilities, focusing on machine-readable information requirements specification. However, the study did not compare these frameworks with EIR documents used in practice or examine how employers specify their information needs. Ren *et al.*, 2022 developed an information checking and provision framework for BIM data integration but did not analyze formal information requirements documentation. Similarly, Sobhkhiz *et al.*, 2021 addressed data management issues in BIM lifecycle assessment applications using semantic web technologies without examining employer-specified information requirements. Abualdenien and Borrmann, 2022 conducted a comprehensive literature review analyzing concepts commonly found in EIR documents: Level of Development, Level of Detail, and Level of Information Need, among others. Their methodology included reviewing 58 guidelines and conducting a systematic literature review of 299 peer-reviewed publications. While the study identified 16 common use cases for applying LOD standards, it did not examine how these standards relate to EIR. Several studies (Pavard *et al.*, 2025; Kaashi and Vilventhan, 2023; Castañeda *et al.*, 2021) developed frameworks for BIM adoption and decision-making but did not incorporate analysis of IR documentation or compare these with industry practice standards.

None of the reviewed studies employed comparative analysis of IR documents, such as EIR, used in practice. The research predominantly focuses on technical system development and implementation frameworks rather than examining how IR are specified, documented, and standardized across different project contexts or industry sectors. This represents a significant methodological gap in current BIM research, particularly given the critical role of well-defined IR in successful BIM implementation and project delivery.

3. METHODOLOGY

This study follows a mixed methods approach. Overall, the contents of representative EIR documents in Germany are analyzed qualitatively by comparing documents by public tenders from 2017-2019 and 2021-2024 to identify significant developments as well as trends and limitations of EIR document usage. To enable comparison, quantitative instruments (evaluation criteria, point system) were applied. The methodology followed in this study consists of five stages, as outlined in Figure 1 and described in the following.

This qualitative analysis builds upon a previously published study of seven EIR documents from 2019 (Mellenthin Filardo, 2019). An unpublished update conducted in January 2023 reexamined eight EIR documents from the period 2017-2019 and incorporated additional documents, revealing temporal changes that necessitated a comparative analysis across discrete time periods. The study was structured in three stages. Stage 1 delimits and contextualizes the temporal evolution of EIR documents. Public tenders were selected given the mandatory German Roadmap for BIM implementation (German Federal Ministry of Transport and Digital Infrastructure, 2015). As EIR constitute an integral component of the information delivery framework for BIM-based projects,

this process is outlined in Section 2.1. Section 2.2 synthesizes current research to inform the study objective: A comparative evaluation of EIR documents from two time periods based on their content and formal structure (stage 2).
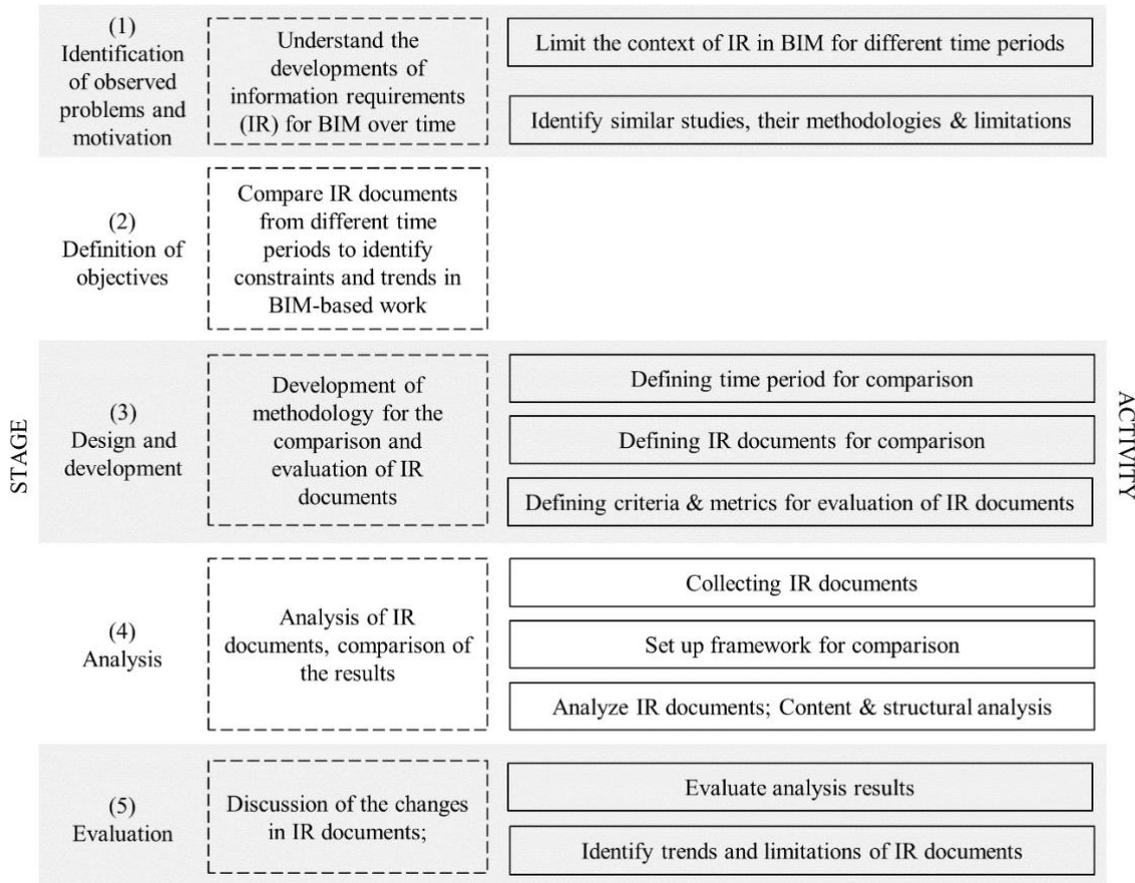

Figure 1: Followed research methodology adopted from Saavedra et al., 2025.

Stage 3 establishes a quantitative framework for this comparison. The first time period (2017-2019) corresponds to the official introduction of the BIM method on a federal level in Germany in 2015, with an onboarding period of two years. The period is limited to 2019 to exclude potentially atypical documents from the covid-19 pandemic period. The second time period begins by the end of the covid-19 pandemic and extends to 2024 to allow the comparison to cover current practice. The analysis (stage 4) examines twelve EIR documents from German public institutions: six project-specific documents (2017-2019 period; sourced from the 2023 study and anonymized) and six further EIR documents (2021-2023, collected in November 2024). Half of the analyzed documents originate from federal-level institutions tasked with or aiding in BIM-based planning and construction of buildings, road and rail infrastructure. These documents were developed as templates on federal level (e.g., Federal BIM initiative) for cascading implementation at state and municipal levels as well as EIR documents from dedicated institutions governing highway and railway projects nationwide (e.g., national railway company and national motorway planning and construction company). Analysis of these federal templates is assumed to encompass a substantial proportion of German BIM tendering activity as each of these templates is used in a large number of projects. Quantifying the coverage of chosen EIR documents remains challenging, as German public procurement statistics do not disaggregate by BIM criteria. No comprehensive statistics on the total number of tendering projects for e.g., planning and construction phases in 2024 in Germany are available in public reports or official communications. Public institutions disclose statistics on projects (e.g., built kilometers and total spendings) and maintain digital procurement platforms that list active tenders, though historical annual totals are not published. Spending volumes are disclosed but not disaggregated into number of projects. Consequently, there are no official numbers for BIM projects. Also, the number of projects gives no indication about the size of the project (is it a piece of road, how

long is it, does it include bridges etc.) and the number of contracts, where EIR were included. BIM is mandatory since 2020 for public tenders in Germany. The lack of disclosure in that regard may point to non-fulfillment.

Email inquiries to document owners in October 2025 regarding EIR template application (EIR Nr. 7-12) during the time period of 2024/2025 yielded limited responses. However, available data indicates EIR Nr. 07 was applied in approximately 500 BIM projects during 2024/2025, while, EIR Nr. 11 was utilized in over 150 separate contracts, including 30 during 2024/2025. This data does not allow a complete sum of applied EIR, but indicates the representativity of the analyzed documents.

While the documents from the first period under review (2017-2019) were anonymized in order to avoid drawing conclusions about individual institutions, anonymization was not applied to the documents from the second period (2021-2024), as these are publicly accessible EIR template documents published on the internet. A comparison based solely on current and previous versions of EIR documents from the same institutions was disregarded, given that some federal institutions were created or only started using EIR documents after 2019, which would result in a slimmer coverage of documents and possibly weaker results. An overview of the analyzed documents and their key characteristics can be found in Table 1.

Table 1: Analyzed EIR documents and their sources.

EIR Nr.	Source of EIR document	Release year	Published	Template (T) or project-specific (P)
01	German state-owned project management company for complex infrastructure projects	2017	no	P
02	German state level institution focused on road/bridge infrastructure	2017	no	P
03	German state level institution focused on road/bridge infrastructure	2017	no	P
04	German state level institution focused on buildings	2018	no	P
05	German state level institution focused on road/bridge infrastructure	2019	no	P
06	German state level institution focused on road/bridge infrastructure	2019	no	P
07	German state-owned project management company for complex infrastructure projects (Deutsche Einheit Fernstraßenplanungs- und -bau GmbH, 2021)	2021	yes	T
08	German Federal Ministry of Transport and Digital Infrastructure (Bundesministerium für Verkehr und digitale Infrastruktur, 2022)	2022	yes	T
09	Federal BIM initiative standards (BIM Deutschland Initiative, 2022: 33)	2022	yes	T
10	Federal BIM initiative (BIM Deutschland Initiative, 2023)	2023	yes	T
11	German railway company (DB InfraGO, 2023)	2023	yes	T
12	BIM-focused initiative of a German city (BIM.Hamburg, 2024)	2024	yes	T

The criteria and metrics of the comparison were developed based on (a) EIR content and (b) document structure and build together the reference framework with the comparison is carried out. Both are described separately and thoroughly in Sections 4.1 and 4.2, since they are the core of the comparison framework. The evaluation of EIR documents was done by one person with a second one inspecting the evaluation results and cross checking with the EIR documents. Criteria evaluations that stood out were discussed and an agreed evaluation was documented in the study, thus reducing false positives due to misinterpretations. This procedure was done both for content and formal evaluations.

The EIR document analysis (stage 4) presents a comprehensive comparative qualitative study of the evaluated EIR documents. The analysis is structured into two sections designed to capture and interpret both structural and content-related developments in EIR document design. The analysis is described in Sections 4.1 to 4.3.

Results from the content analysis based on the developed reference framework are further compared with findings from the previous evaluation to identify commonalities and differences. This section, chapter 4.4, focuses on comparing the two analyzed time periods, considering both content and formal analysis results to provide a comprehensive overview of developments. The objective is to identify differences, similarities, and change trends between periods. Based on this comparison, initial assumptions explaining observed developments are formulated (stage 5). This structured approach enables systematic capture and interpretation of changes in EIR document design and content over time.

4. ANALYSIS OF EIR DOCUMENTS

4.1 EIR Analysis framework

The methodological approach described in Section 3 involves systematic analysis of selected representative EIR documents using a standardized comparative framework. It should be noted that this evaluation method does not claim universal validity. This research employs defined geographical, temporal, content, and methodological boundaries to facilitate rigorous examination of EIR document evolution. The analysis focuses specifically on EIR documents published by German public institutions during two distinct periods: 2017-2019 and 2021-2024. The initial period represents Germany's early structured BIM implementation during its extended pilot phase (German Federal Ministry of Transport and Digital Infrastructure, 2015), while the second period reflects accumulated BIM application experience.

The EIR analysis framework is divided in two components: content analysis and analysis of document structure, as described in Section 4.1. EIR documents are compared to a reference structure. The contents of EIR documents are outlined in Section 2.2 and result in the criteria outlined in 4.2, followed by the analysis results presented in Section 5.

4.2 Criteria for evaluation

The structural and content evaluation framework comprises 27 criteria distributed across nine primary categories. The core documentation elements include three fundamental components: introduction, general framework, and glossary. These elements establish the foundational context and terminology necessary for project comprehension. Project specifics encompass two criteria focusing on project-specific introduction and basic project task definition. These elements provide tailored project context and define core project objectives and scope. The objectives and use cases category contains four criteria addressing overall project objectives, project-relevant BIM objectives, BIM use cases, and data and information requirements including data drops specifications.

Organization, roles, and suitability requirements comprise three elements covering the definition of roles, responsibilities, and tasks, required skills, and education and training measures. These criteria establish team structure and competency requirements essential for project execution. Process-related criteria include five components addressing data and information management processes, communication processes, coordination processes, quality assurance processes, and BIM use case processes. These elements define the operational workflows and procedural frameworks necessary for effective project implementation. Technology criteria encompass three areas: hardware and software specifications, CDE requirements, and license or software provision arrangements. These criteria establish the technical infrastructure necessary for project execution.

Data and information criteria comprise seven components covering input data requirements, information on data quality and data extent, specifications for zoning and partitioning of models, details on the level of detail of information, geometry, and the model development, specifications for the model structure, coordinate systems and reference points, and data security requirements.

A binary scale is used to assess the content of the EIR documents. For each of the 27 defined evaluation criteria, it is checked whether the corresponding content is present or not. A value of 0 is assigned in cases where the corresponding content is not mapped in the EIR document. A value of 1 is assigned if the content is present in the EIR document. This results in a maximum achievable value of 27 points, which is shown as a percentage. It should be emphasized that the analysis goes beyond a mere consideration of the headlines. Rather, a qualitative analysis of the content is carried out, in which the actual criteria of the reference outline is evaluated. In doing so, all content

of the reference structure is weighted equally to ensure a fair and balanced assessment. Content that cannot be assigned to the defined evaluation criteria of the reference structure is not taken into account in the evaluation.

The formal design of a document is critical for its usability and comprehensibility. A well-structured format supports not only readability but also content traceability and efficient information processing. The following formal evaluation criteria for EIR documents are assessed on a scale from 1 to 4 points. These criteria serve as the foundation for systematic evaluation of EIR documents in the subsequent analysis.

The structure and comprehencibility criteria: Clear structure and organization constitute the foundation of a usable EIR document. The highest rating of 4 points is achieved when the table of contents unambiguously references clearly structured chapters and subchapters. A score of 3 points is assigned when content demarcation is partially incomplete or the table of contents is absent, but the main structure remains traceable. Repetitive or missing sections result in 2 points. The lowest rating of 1 point is given when no table of contents exists and topic arrangement appears arbitrary.

The use of headings criteria: Headings must be informative and systematically designed to structure the content of EIR documents. The maximum score is awarded when each heading precisely reflects the section content, for example '3.1 Data Quality Requirements.' Overly generic headings result in 3 points. Missing chapter headings receive 2 points, while continuous text without visual structuring receives only 1 point.

The versioning system criteria: Traceability of versions and their modifications in EIR documents is essential. A complete version history with tabular documentation of all changes, dates, and responsible parties receives 4 points. Documented versions with occasional information gaps are rated 3 points. Rudimentary references to previous versions result in 2 points, while absence of version identification receives only 1 point.

Continuous text proportions criteria: Continuous text in EIR documents should be characterized by conciseness and explain complex issues in a comprehensible manner. It is critical that text volume remains appropriate to ensure comprehensibility and applicability for all stakeholders. Concise explanations of complex issues, supplemented by tables and graphics, receive the maximum score. A rating of 3 points is assigned when sections are partially too brief or too detailed. Long, unstructured paragraphs result in 2 points, while nearly exclusive text without supporting elements receives only 1 point.

Tables and spreadsheets criteria: Purposeful utilization of tables for structured presentation of data and information in EIR documents constitutes another criterion. Fully labeled, clearly structured, and intuitively comprehensible tables receive 4 points. Overloaded or suboptimally labeled tables receive 3 points. Missing labels or inconsistent formatting result in 2 points, while data embedded in continuous text that would be better presented in tabular form receive only 1 point.

Aiding graphics criteria: Supporting visualization through graphics and diagrams is also evaluated. Clear illustrations of processes and relationships receive 4 points. Overloaded, poorly legible, or incompletely labeled graphics result in 3 points. Excessive use providing limited added value receives 2 points. Missing visualizations for critical content receive only 1 point.

Machine readability criteria: Machine readability of EIR documents plays a central role in efficient and automated processing of project information. To ensure both human and machine readability and processability, EIR documents must be available in structured, electronic formats. Conventional continuous text and PDF files do not fulfill these requirements, as they are not readily interpretable by machines (Mellenthin Filardo, 2019: 4). For optimal machine processing, information should be provided in widely adopted, open standard formats. Such formats enable structured data representation and facilitate automated evaluation and further processing (Hartmann, 2023: 183). Suitability for machine processing is evaluated using a point scale. Fully structured documents, such as those in XML format or comparable, receive the highest rating of 4 points. Semi-structured content with partial machine readability receives 3 points. Semi-structured but non-machine-readable PDF content receives 2 points, while unstructured PDF documents receive only 1 point.

Lastly, the intergration of appendices/annexes criteria: Appendices serve to supplement and expand content of the main EIR document. Completeness and relevance of attached documents constitute the final evaluation criterion. The maximum score is awarded when all relevant appendices are included and textual references exist. Appendices with missing descriptions or incomplete attachments receive 3 points. When appendices are present but not

referenced, 2 points are assigned. References to external sources not provided or missing but meaningful appendices result in the minimum score of 1 point.

The evaluation of the structure and form criteria is carried out using a differentiated four-point scale, as outline above. This enables a finer gradation of the characteristics examined. Since for a scale of four evaluation levels is used for each of the eight criteria, this results in a maximum achievable score of 32, which is also shown as a percentage. This basis for comparison forms the methodological foundation for the evaluation of the EIR documents and ensures a uniform and objective analysis. It enables both a differentiated comparison of the documents within the time periods as well as a comparison of developments over the years.

5. ANALYSIS RESULTS

The initial phase of this investigation comprises a comprehensive analysis of six EIR documents produced between 2017 and 2019. The documents evaluated in Table 2 and Table 3 demonstrate considerable variation in both scope and adherence to the examined criteria. The analyzed EIR documents range significantly in length from 17 to 54 pages, with EIR 3 representing the most extensive document at 54 pages.

Table 2: Content evaluation of EIR documents (2017-2019).

Nr.	EIR documents (2017-2019)	EIR 1	EIR 2	EIR 3	EIR 4	EIR 5	EIR 6	Sum Ø
	Pages	*17*	*19*	*54*	*50*	*19*	*27*	
	Reference structure							
1	Introduction	1	1	1	1	1	1	6/6
2	General framework	0	1	1	1	1	1	5/6
3	Glossary	0	0	1	1	1	0	3/6
4	Project specifics							
4.1	Project-specific introduction	0	0	0	0	0	1	1/6
4.2	Basic project task	0	0	0	0	1	1	2/6
5	Objectives and use cases							
5.1	Overall project objectives	0	0	1	0	0	1	2/6
5.2	Project-relevant BIM objectives	1	0	1	1	1	1	5/6
5.3	BIM use cases	1	1	1	1	1	1	6/6
5.4	Data and Information requirements (data drops)	0	1	1	1	1	1	5/6
6	Organization, roles, and suitability requirements							
6.1	Definition of roles, responsibilities and tasks	1	0	1	1	1	1	5/6
6.2	Skills	0	0	1	1	0	0	2/6
6.3	Education and training measures	0	0	1	1	0	0	2/6
7	Processes							
7.1	Data and information management processes	0	1	1	1	1	1	5/6
7.2	Communication processes	1	0	1	0	0	1	3/6
7.3	Coordination processes	1	0	1	1	0	1	4/6
7.4	Quality assurance processes	1	1	1	1	1	1	6/6
7.5	BIM use cases processes	1	0	0	0	0	1	2/6
8	Technology							
8.1	Details for the hardware and software	1	1	1	1	0	0	4/6
8.2	Common data environment (CDE)	0	1	1	1	0	1	4/6
8.3	Providing licenses or software	1	1	1	1	1	1	6/6
9	Data and information							
9.1	Input data	0	0	1	0	1	1	3/6
9.2	Information on data quality and data extent	1	1	1	1	1	1	6/6
9.3	specifications for zoning and partitioning of models	1	1	1	1	1	1	6/6
9.4	details on the level of detail of information, geometry, and the model development	1	1	1	1	1	1	6/6
9.5	specifications for the model structure	1	0	1	1	1	1	5/6
9.6	coordinate systems and reference points	1	1	1	1	1	1	5/6
9.7	data security	0	0	1	0	0	0	1/6
	Sum	15	13	24	20	17	22	
	Sum [%]	56 %	48 %	89 %	74 %	63 %	81 %	Ø 69%

5.1 2017-2019 period

Content evaluation using the reference framework reveals an average compliance rate of 69 % between the examined EIR documents and the reference structure content. The highest-rated document (EIR 3) achieves

89 % compliance, while the lowest-rated fulfills only 48 % of the criteria. This variation indicates heterogeneous quality across the analyzed documents.

Notably, eight of the 27 examined criteria are fully satisfied across all documents, including: introduction, BIM use cases, quality assurance processes, information on data quality and data extent, model partitioning and zoning requirements, level of detail specifications, coordinate systems, and reference points. As demonstrated in Table 2, five additional criteria are met by the majority (5/6 fulfillment points) of documents. EIR 1 (56 %) uniquely fails to specify relevant framework conditions, data and information requirements, or data and information management processes. The document shows particular weakness in organizational aspects and information management processes, indicating a minimal approach to EIR implementation that covers only essential technical specifications. EIR 3 (89 %) demonstrates strong implementation of all major structural components, including complete project-specific sections, organizational requirements, and process documentation. The primary deficiency lies in training provisions and data security measures, though the overall approach represents a near-optimal EIR implementation that addresses both technical and organizational project requirements. The lowest-performing document (EIR 2) reaches only 48 % compliance, primarily due to deficiencies in project-specific sections, basic project tasks, and organizational requirements.

EIR 4 (74 %) maintains adequate technical specifications and process documentation, it fails to address project-specific introduction, training requirements, and comprehensive organizational development. It represents a technically competent approach that addresses most operational requirements while showing deficiencies in stakeholder development and project-specific contextualization. The performance of EIR 5 (63 %) indicates a process-focused implementation that neglects essential project management components. Finally, EIR 6 (81 %) shows particular strength in technical specifications, process documentation, and information management requirements, while maintaining adequate organizational structure. Notable weaknesses include incomplete training provisions and limited data security measures, though the overall approach represents a well-balanced EIR implementation.

Several criteria show markedly lower compliance rates and are consequently inadequately addressed, including project specifics, skills and training measures, BIM use case processes, and data security requirements. The combined assessment reveals that while technical and procedural aspects are generally well-addressed, organizational development, security considerations, and document management aspects require significant improvement. The average performance rate of 69 % suggests that EIR documentation practices in that period meet basic requirements but fall short of comprehensive implementation standards. The analysis of EIR documents from the 2017-2019 time period is shown in Table 2.

5.2 2021-2024 period

The analyzed EIR documents represent template documents from German public institutions. Three documents (EIR 8, EIR 9, EIR10) exhibit dual structure comprising project-specific and generally applicable sections, resulting in comparatively high volumes of 59-89 pages, with individual sections varying between 34-44 pages. The remaining three documents range between 36-50 pages.

Most examined documents feature integrated instruction fields providing application guidance and necessary project-specific adaptations. EIR 12 forms part of a standardization project encompassing additional documents, requiring incorporation of the institution's published BIM guide for comprehensive evaluation. Other EIR documents reference supplementary materials such as use case profiles, which were included in the analysis for comprehensive assessment. The analysis of EIR documents from the 2021-2024 time period are shown in Table 3.

Content evaluation using the reference structure criteria shows two of six examined documents (EIR 8, EIR 9) achieve complete 100 % fulfillment rates. The remaining four documents demonstrate rates between 85-93 %, yielding an average fulfillment rate of 92 %, indicating high correspondence between all EIR documents and the reference structure (VDI guideline 2552 Sheet 10). Detailed analysis reveals numerous content requirements fulfilled across all six EIR documents. The main categories (introduction, project specifics, processes, and technology) are universally present in all documents without exception. The data and information category criteria achieve near-complete coverage with occasional content gaps. Particularly, the criteria skills, education and training measures, overall project objectives, and data security demonstrate highest deficits with three or four of

six points. Three categories – general framework, glossary, and project-relevant BIM objectives – appear in five of six examined documents.

Notably, EIR 11 contains no general framework and lacks a glossary, while EIR 10 omits project-relevant BIM objectives. The absence of BIM objectives in EIR 10 and associated BIM guide may indicate authorship consideration of BIM use cases derived from BIM objectives as sufficient, potentially viewing additional objective elaboration as redundant. Regarding glossary absence in EIR 11, increasing industry-wide common understanding of BIM terminology may play a role, suggesting authors assume relevant terms are sufficiently established, eliminating separate glossary necessity.

Table 3: Content evaluation of EIR documents (2021-2024).

Nr.	EIR documents (2021-2024)	EIR 7	EIR 8	EIR 9	EIR 10	EIR 11	EIR 12	Sum Ø
	Pages	*50*	*40*	*34*	*44*	*36*	*38*	
	Reference structure							
1	Introduction	1	1	1	1	1	1	6/6
2	General framework	1	1	1	1	0	1	5/6
3	Glossary	1	1	1	1	0	1	5/6
4	Project specifics							
4.1	Project-specific introduction	1	1	1	1	1	1	6/6
4.2	Basic project task	1	1	1	1	1	1	6/6
5	Objectives and use cases							
5.1	Overall project objectives	0	1	1	0	1	0	3/6
5.2	Project-relevant BIM objectives	1	1	1	1	1	0	5/6
5.3	BIM use cases	1	1	1	1	1	1	6/6
5.4	Data and Information requirements (data drops)	1	1	1	1	1	1	6/6
6	Organization, roles, and suitability requirements							
6.1	Definition of roles, responsibilities and tasks	1	1	1	1	1	1	6/6
6.2	Skills	0	1	1	0	0	1	3/6
6.3	Education and training measures	1	1	1	0	1	0	4/6
7	Processes							
7.1	Data and information management processes	1	1	1	1	1	1	6/6
7.2	Communication processes	1	1	1	1	1	1	6/6
7.3	Coordination processes	1	1	1	1	1	1	6/6
7.4	Quality assurance processes	1	1	1	1	1	1	6/6
7.5	BIM use cases processes	1	1	1	1	1	1	6/6
8	Technology							
8.1	Details for the hardware and software	1	1	1	1	1	1	6/6
8.2	Common data environment (CDE)	1	1	1	1	1	1	6/6
8.3	Providing licenses or software	1	1	1	1	1	1	6/6
9	Data and information							
9.1	Input data	1	1	1	1	1	1	6/6
9.2	Information on data quality and data extent	1	1	1	1	1	1	6/6
9.3	specifications for zoning and partitioning of models	1	1	1	1	1	1	6/6
9.4	details on the level of detail of information, geometry, and the model development	1	1	1	1	1	1	6/6
9.5	specifications for the model structure	1	1	1	1	1	1	6/6
9.6	coordinate systems and reference points	1	1	1	1	1	1	6/6
9.7	data security	1	1	1	1	0	0	4/6
	Sum	25	27	27	24	23	23	
	Sum [%]	93 %	100 %	100 %	89 %	85 %	85 %	92 %

Document content structure analysis reveals high structural correspondence between EIR 7, EIR 8, EIR 9, EIR 10, and EIR 12. Introduction sections explain scope and EIR briefly, reference BEP, followed by graphical representations of BIM-relevant document interactions. Subsequent sections describe project specifics containing tabular project information, commissioning details, project areas, and involved disciplines. Following chapters present BIM objectives and BIM use cases in tabular format, referencing standardized BIM use cases and profiles from the German governmental institution BIM Deutschland, as well as national guidelines (German Federal Ministry of the Interior and German Federal Ministry of Defence, 2021).

Documents tabularly list client organization-provided materials (input data), followed by data and information requirements presentation (milestones), tabularly listing digital deliverables and delivery timepoints. 'organization

and roles' sections describe respective tasks and roles tabularly, frequently supplemented by standardized role description references according to VDI 2552 Sheet 7 (2020c) and competency verification specifications. Subsequent 'collaboration strategy' chapters describe communication and coordination processes. Further sections address quality assurance describing relevant processes. Model structure and content receive detailed presentation with modeling principles, Level of Information Need, and discipline and sub-models tabularly listed, including file naming convention specifications. Subsequent sections describe coordinate systems and project units. Technological requirements including CDE, software, licenses, data exchange formats, and data security follow. Glossaries and relevant standards and guidelines references typically appear at document end before appendices.

Despite slight structural variations, high content, structural, and formal correspondence exists across all examined EIR documents. EIR 11 demonstrates comparable fulfillment rates while structuring content differently than other examined documents, potentially reflecting specific requirements or preferences of the creating organization.

5.3 Formal and structural evaluation

Formal evaluation of the EIR documents for the first period (Table 4) indicates that EIR 3 achieves the highest rating at 88 %, while documents EIR 4 and EIR 5 score approximately 60 %. These results highlight differences in formal design quality and reveal substantial deficiencies in document structuring.

All EIR documents consistently receive high ratings (3 or 4 points on a 4-point scale) for structure and comprehensibility, as well as heading usage. However, highly heterogeneous structural organization exists between documents. Additional disparities appear in other formal criteria, primarily versioning system, continuous text proportion, tables, graphics, and appendix integration. EIR 4 exhibits extensive unstructured continuous text with unlabeled tables, while EIR 5 contains no supporting figures or graphics. Versioning practices vary considerably: EIR 2 and EIR 3 provide only title page version numbers, whereas EIR 3 and EIR 6 maintain comprehensive revision logs with detailed revision information. Appendix integration also shows heterogeneous assessment. EIR 2 and EIR 3 incorporate appendices directly within the document with textual references, while other EIR documents (EIR 1, EIR 5, EIR 6) reference separate appendices that are not included in the available documents.

A particularly notable finding is the consistently poor machine readability rating across all documents. All EIR documents from 2017-2019 are exclusively available in PDF format – at least publicly. Semi-structured content in simple table form can be partially identified. The structural and formal evaluation of EIR documents, as shown in Table 4, highlights recognizable formal deficits in the quality and structure of the examined documents and points to considerable potential for standardization and optimization.

Table 4: Form and structure evaluation of contemporary EIR documents (2017-2019).

Nr.	EIR documents (2017-2019)	EIR 1	EIR 2	EIR 3	EIR 4	EIR 5	EIR 6
	Criteria (form)						
1	Structure & comprehensibility	4	4	4	3	3	4
2	Use of headings	4	4	4	4	4	4
3	Versioning system	2	2	4	2	4	4
4	Continuous text proportion	3	4	3	2	3	4
5	Tables and spreadsheets	3	4	4	1	2	3
6	Aiding graphics (visualizations)	3	2	3	3	1	3
7	Machine readability	2	2	2	2	2	2
8	Integration of appendices/annexes	1	4	4	2	1	1
	Sum	22	26	28	19	20	25
	Sum [%]	69 %	81 %	88 %	59 %	63 %	78 %

The formal evaluation from the second time period based on the assessment structure (Table 5) shows that the overall assessment of all six EIR documents ranges between 81 % and 94 %. The highest assessment of 94 % was given to EIR 9, EIR 10, and EIR 12. It is striking that the criteria structure and comprehensibility, use of headings, and integration of appendices achieve the maximum score of four points in all six documents. The high score of all documents shows that the structure of the documents is well organized. This is related to the previously described, similarly structured outline of the documents. The effect is also supported by the largely homogeneous wording of the headings.

In the area of versioning, however, there is a certain degree of heterogeneity: EIR 7 and EIR 8 contain hardly any references to the version of the document, while the other documents have a complete revision index that contains information on the revision itself, the reason for the revision, the date of the change, and, in some cases, the persons

responsible. The criteria of continuous text proportion, tables and aiding graphics consistently achieve high scores (3 or 4 points) in all EIR documents. EIR 8 achieves a slightly lower score (3/4 points) in the category of graphics and diagrams due to insufficient image quality in the process representations.

The criterion of machine readability also emerges as a weak point in the period 2021-2024, receiving a rating of only two points in all documents. The EIR documents are available as PDF files and contain some semi-structured information in tabular form. In this context, the references to machine-readable annexes are worth mentioning. In summary, the results show that the analyzed EIR documents from 2021 to 2024, despite isolated weaknesses, are of high quality in terms of content and form as shown in Table 5.

Table 5: Form and structure evaluation of contemporary EIR documents (2021-2024).

Nr.	EIR documents (2021-2024)	EIR 7	EIR 8	EIR 9	EIR 10	EIR 11	EIR 12
	Criteria (form)						
1	Structure & comprehensibility	4	4	4	4	4	4
2	Use of headings	4	4	4	4	4	4
3	Versioning system	2	1	4	4	4	4
4	Continuous text proportion	3	4	4	4	3	4
5	Tables and spreadsheets	4	4	4	4	3	4
6	Aiding graphics (visualizations)	3	4	4	4	3	4
7	Machine readability	2	2	2	2	2	2
8	Integration of appendices/annexes	4	4	4	4	4	4
	Sum	26	27	30	30	27	30
	Sum [%]	81 %	84 %	94 %	94 %	84 %	94 %

5.4 Influence of reference frameworks on evaluation results

This section compares evaluation results of identical EIR documents from 2017-2019 using two different reference frameworks. The frameworks differ in structure, number of criteria, terminology, and conceptual approach. The original reference framework, developed previously as the basis for the 2019/2023 study, was based on the Northern Ireland Finance Department's EIR (Employer's Information Requirements) template (Department of Finance, North Ireland, 2018). It was created according to the then most advanced standard, PAS 1192 (British Standards Institution, 2013), at the time (2019). The framework points and explanations were adapted to specific requirements of the German construction industry, resulting in a three-part structure with 23 evaluation criteria (Mellenthin Filardo, 2019). The newly developed reference framework in this study follows guideline VDI 2552 Part 10 (2021) and comprises 27 criteria divided into nine main themes. Analysis of EIR documents shows that average overall ratings are nearly identical for both reference frameworks, as illustrated in Table 6. Evaluation using the new reference framework yields an average rating of 69 %, while the original framework produces an average EIR document rating of 68 %. Individual document percentage results differ only marginally between the two evaluation methods, with new framework results varying by -10 % to +7 % from the original method.

Table 6: Comparison of EIR document scores with both comparison bases (2017-2019).

EIR documents 2017-2019	EIR 1	EIR 2	EIR 3	EIR 4	EIR 5	EIR 6	Ø EIR
Analysis results 2023	57 %	57 %	91 %	65 %	57 %	74 %	Ø 68 %
Analysis results 2025	56 %	48 %	89 %	74 %	63 %	81 %	Ø 69 %

Despite similarities in overall results, differences exist in evaluation foundations. While the original framework presupposes general project information (introduction) as basic content and therefore does not evaluate it separately, the new framework explicitly includes it in the analysis. The new framework with 27 criteria considers content such as introduction, project specifics, glossary, differentiation between overall and project-relevant BIM objectives, skills and competency verification, and BIM use case processes. These elements are not included in the original 2023 framework, resulting in the maximum sum difference of 23 and 27 criteria accordingly. Conversely, criteria from the original framework such as 'delivery strategy for asset information' and 'COBie requirements' are not considered in the new reference framework. However, the 2023 analysis shows that none of the examined EIR documents fulfilled these two criteria. Another difference appears in criterion terminology. Many original evaluation points are addressed in the new reference framework under different terms, while content intention is mostly preserved. Examples include technical requirements such as data exchange formats, coordinates, delivery timepoints, and project results, which are considered in both frameworks albeit with slightly varying terminology.

The high similarity of overall results despite content differences between reference frameworks can be partially explained by the origin of the first framework. The original template was based on the British PAS 1192 standard, which as a key document also forms the foundation for many international and national standards, including ISO 19650 standard series (ISO, 2018) and the German VDI 2552 guideline series (Borrmann *et al.*, 2021). The comparison of reference frameworks and their development over time reveals an interesting insight: Although formulations and partially structures have changed, fundamental principles and requirements remain largely constant. This observation indicates that certain core elements have proven effective in practice and were therefore adopted into newer frameworks, albeit sometimes in modified form or with additions.

5.5 Results of evaluated documents

The analysis compares German EIR documents across two distinct time periods: 2017-2019 and 2021-2024. The evaluation employs a comprehensive scoring system that incorporates both structural content criteria and formal criteria to assess document quality and completeness.

Regarding a temporal performance comparison, the documents from the 2017-2019 period (EIR 1-6) demonstrated an average structure and content score of 69 %, with individual document scores ranging from 48 % to 89 %. Form criteria averaged 73 % across this period, with scores ranging from 59 % to 88 %. The 2021-2024 period (EIR 7-12) showed substantial improvement, with structure and content criteria averaging 92 % and individual scores ranging from 85 % to 100 %. Form criteria averaged 89 % during this period, with scores ranging from 81 % to 94 %. Project specifics showed the most dramatic improvement, increasing from 50 % average coverage in the earlier period to 100 % in the later period. Objectives and use cases improved from 73 % to 95 % average coverage, while organization and roles criteria increased from 60 % to 84 % average coverage. Data and information criteria improved from 67 % to 96 % average coverage. Certain categories maintained consistently strong performance across both periods. BIM use cases achieved 100 % coverage in both temporal periods, as did quality assurance processes. Technology requirements also demonstrated strong performance across both evaluation periods. Several areas continue to require attention despite overall improvements. Machine readability maintained consistently low scores of approximately 50 % across both periods. Data security improved from 17 % to 67 % but remained variable in implementation. Versioning showed inconsistent implementation patterns across the evaluation periods.

6. DISCUSSION AND LIMITATIONS

The analysis reveals systematic deficiencies in EIR documentation quality across multiple categories. Organizational competency management criteria demonstrate the most persistent poor performance, with qualification specifications and training requirements remaining at around 33 % compliance even in recent documents. Machine readability represents a critical technical limitation, showing no improvement across the analyzed temporal periods.

Still, the analysis reveals substantial maturation in German BIM EIR documents between the 2017-2019 and 2021-2024 periods. The improvement in completeness, consistency, and standardization reflects the establishment of national BIM standards and templates. This evolution demonstrates a progression toward more comprehensive and systematic approaches to IR specification within the German AECOM industry. The temporal analysis indicates overall improvement in structural completeness (69 % to 92 %) while formal quality metrics show more modest advancement (73 % to 87 %), suggesting that content standardization has progressed more rapidly than technical implementation standards. The persistent challenges in machine readability and variable implementation of certain criteria suggest areas requiring continued attention in future document development. The establishment of high-performing templates, particularly EIR 9 with 97 % overall performance, provides evidence of achievable standards and best practices within the sector.

The three research questions formulated in this study are answered as follows: The content analysis against the 35-criterion reference framework demonstrates that German public sector EIR documents consistently address technical categories including BIM use cases, quality assurance processes, and technology requirements, while organizational competency management, data security, and machine readability represent persistent deficits across both analyzed periods. Regarding the structural completeness, values improved substantially while formal quality metrics advanced more modestly, indicating that content standardization has progressed more rapidly than formal implementation standards. Machine readability showed no measurable improvement across periods, representing a critical and unresolved limitation. The comparative application of two reference frameworks – one derived from

British PAS 1192 and one from German VDI 2552 Part 10 – to identical EIR documents yielded an average overall rating difference of one percentage point (68 % vs. 69 %), demonstrating that evaluation outcomes are robust to framework choice and that core EIR content requirements have remained substantively stable across the evolution of national and international BIM standards.

The findings of this study contribute empirical evidence to a body of literature that has primarily addressed BIM information requirements from normative or conceptual perspectives. Prior research has established frameworks for EIR content and examined BIM adoption barriers in public procurement contexts (Pérez-García *et al.*, 2024; Ozcan-Deniz *et al.*, 2025), but longitudinal empirical evaluation of actual EIR document quality against standardized criteria remains underrepresented. The substantial improvement in structural completeness from 69 % to 92 % between the two analyzed periods corroborates findings by studies attributing quality improvements in BIM documentation to standardization mandates. However, this study adds specificity by disaggregating improvement patterns across content categories, revealing that progress has been uneven: technical and procedural categories converged rapidly toward full compliance, while organizational competency management and machine readability showed persistent deficits irrespective of the policy environment. This differentiated picture extends beyond what aggregate adoption metrics or standard compliance checklists typically reveal and suggests that BIM standardization in Germany has prioritized technical specification over organizational and digital readiness dimensions.

The comparison of two reference frameworks provides additional evidence that core EIR content requirements have remained substantively stable across the evolution from PAS 1192 to ISO 19650 and VDI 2552, a finding not previously empirically demonstrated in the literature. This stability in core content requirements across different standardization frameworks suggests that a fundamental consensus exists regarding essential EIR elements, providing a reliable foundation for future BIM practice development, tool development, and international harmonization efforts. From a practical standpoint, the findings carry implications for both document authors and procuring institutions.

The convergence toward a common structural template among federal-level documents in the 2021-2024 period, observable in the high structural and terminological homogeneity across EIR documents 7 through 12, suggests that template-driven standardization has been effective as a dissemination mechanism. This finding provides empirical evidence that standardization efforts through guideline development and template provision can achieve measurable improvements in document quality and consistency across decentralized procurement practices.

The persistent absence of machine-readable formats across both periods – despite growing availability of structured data standards such as ISO 7817-3 and IDS – indicates a gap between standardization developments at the research and policy level and actual procurement practice, with practical implications for automated compliance checking and lifecycle information management ambitions in the German public sector.

While the analysis presented in this research provides a thorough evaluation of past and current EIR practices, limitations should be acknowledged. Although the followed methodology involves systematic qualitative analysis of selected EIR documents using a standardized comparative framework based on quantitative instruments, this evaluation method does not claim universal validity. This research is limited by geographical, temporal, content, and methodological boundaries. Therefore, the selection of EIR documents is limited: From the first period (where BIM projects were few and usually in the piloting phase) project-specific EIR documents were selected to support the understanding of BIM implementation in its early adoption years (and given the lack of templates in early years). In the second period, templates were chosen from key national institutions to enable nationwide representativity. The selection of these template documents is based on the assumption that the Federal BIM roadmap is followed and implemented and the templates applied in all projects according to established directives. An evaluation of current, project-specific EIR documents based on the evaluated templates should be carried out additionally. Template documents aggregate knowledge and experience from previous projects, but the reasons for changes in the documents, which could point to bigger underlying problems (e.g., procurement or project management practices, technological issues, training deficits) are not systematically documented. The criteria for EIR content originate from standardization practices. The interpretation of the criteria in this evaluation was outlined. Nonetheless, interpretation of certain EIR contents require an in-depth knowledge of BIM practices and technological solutions and software possibilities, which can vary according to the training and background of the actors.

7. CONCLUSION AND OUTLOOK

This comparative analysis of German EIR documents across two distinct temporal periods demonstrates significant advancement in BIM information requirements documentation, with overall performance improving from 69 % to 92 % between 2017-2019 and 2021-2024. The substantial enhancement in structural completeness and formal quality reflects the maturation of BIM standards used in Germany and the establishment of systematic approaches to IR specification within the AECOM industry. The progression from variable, project-specific implementations to standardized, comprehensive documentation frameworks indicates successful integration of national BIM guidelines and professional experience accumulation. This study contributes to the growing body of knowledge on BIM implementation effectiveness and provides practitioners with evidence-based guidance for EIR development. The temporal comparison methodology and comprehensive evaluation framework offer replicable approaches for ongoing assessment of information requirements documentation quality across different national contexts and project typologies.

The identification of consistently high-performing categories, including BIM use cases, quality assurance processes, and technology requirements, provides empirical evidence for standardized implementation approaches across diverse project contexts. The dramatic improvement in project-specific documents from 50 % to 100 % coverage demonstrates the evolution toward more contextually appropriate and stakeholder-oriented information requirements. However, persistent challenges in machine readability and variable implementation of data security provisions indicate areas requiring continued methodological development and technological advancement. The establishment of exemplary document templates, particularly those achieving over 90 % overall performance, provides tangible benchmarks for industry standardization efforts. These high-performing documents demonstrate that comprehensive EIR implementation is achievable through systematic attention to both technical specifications and organizational requirements. The findings suggest that successful EIR development requires balanced integration of process documentation, stakeholder communication, and technological infrastructure considerations.

Future research should focus on developing automated assessment tools to enhance machine readability and standardize evaluation processes. Investigation of the relationship between EIR quality and project performance outcomes would provide valuable insights into the practical implications of documentation completeness. Additionally, comparative analysis of international EIR standards and practices could inform global harmonization efforts and identify transferable best practices. The evolving landscape of construction digitalization necessitates continued adaptation of information requirements frameworks to accommodate emerging technologies such as artificial intelligence, digital twins, and automated construction processes. Future EIR development should anticipate these technological advancements while maintaining focus on fundamental project communication and coordination requirements. The establishment of continuous improvement mechanisms and regular evaluation protocols will ensure that EIR documentation remains relevant and effective as BIM implementation practices continue to evolve.

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