An A Priori EIR-Compliant Modelling Approach

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Abstract

Achieving model conformity with Exchange Information Requirements (EIR) conventionally poses the risks of inefficiency and error-proneness, due to the iterative and manual nature of the process. The conducted research shows the need for facilitating the process of EIR-compliant modelling and model checking with the potential of enabling the much-discussed topic of semantic enrichment. This article furthermore proposes an A Priori approach for creating an EIR-compliant modelling template before the actual modelling process. In comparison to state of praxis approaches like Ex Post and Ex Ante compliance checking, the A Priori approach prevents errors and inaccuracies in the information supplement process, while reducing manual effort. A corresponding proof-of-concept study verifies this approach using a commercial modelling software and visual scripting and indicates the need for a machine-readable standard for information requirements to ensure a digitalised and automated EIR-compliant design process.

Keywords: A Priori Compliance, Exchange Information Requirements, EIR, Building Information Modeling

1 Introduction

One of the most significant challenges of the 21st century is digitalisation. For the architecture, engineering, construction, and operation (AECO) industry this is reflected in the introduction of the Building Information Modeling (BIM) method of integral planning, which promises increased efficiency and productivity [1]. With this cross-lifecycle approach, digital models accumulate geometric as well as semantic information of a built facility. When using the BIM method, specifications of traditional planning can and often must be applied to the model. But model-based processes require additional specifications regarding data generation, management, and collaboration aspects. This insight may seem insignificant, but it is decisive for tender and contractual phases, which in turn can influence the success of a project significantly. These contractual documents defined by the ordering party regarding the data to be delivered, along with associated delivery dates and change management aspects, among other data-related requirements, are defined in the Exchange Information Requirements (EIR). In Germany, the content of these documents was defined in 2019 [2]. Further contents of EIR documents were described in 2020 [3].

Based on requirements from the EIR, compliance checks of ordered BIM models are currently often performed manually. As described in Chapters 2.4 and 2.5, these inefficient processes are divided into Ex Ante (before the data drop) and Ex Post (after the data drop) EIR compliance checks. These conformity checks are associated with high effort, due to the number of iterations needed to fulfil the agreed upon requirements using different software applications and workflows. A common issue is that mandatory elements are often not modelled and/or do not have the ordered information depth [4], which is currently only ascertained in the Ex Post verification, which is too late to influence modelling decisions and leads to backdoor changes. EIR present the data to be delivered, which means they can and, as proposed in this paper, should be used to transfer the information requirements to the native authoring software in an automated way prior to the modelling act itself, which is essential not only for an efficient but also for an effective process. This is described in the proposed A Priori approach (A Priori referring to prior to modelling). The use of information requirements in further processes is also supported by the current buildingSMART Technical Roadmap [5]. EIR documents are often distributed in the unstructured PDF format, as described by [6] and [4]. The proposed approach shows the possibility of including information into the authoring environment based on a structured EIR data source and narrowing down future needed structure and implementation for a robust and automated EIR compliance.

To achieve an automated transfer of information from the EIR to the authoring software application, the A Priori model-based EIR compliance approach is proposed. As described in Chapter 3.1, this approach uses the information from the EIR, specifically from structured object and attribute lists, to automate the supplementation of semantic information to the model. This approach is validated by the implementation of a software tool, described in Chapter 4.1.

2 Background

A condensed introduction, reduced to the delimitation of EIR and the application of model checking, directly linked to the use of information requirements, as well as a brief introduction to semantic enrichment, potentially facilitated by the proposed A Priori approach, are given in the following chapter. Subsequently, the scope of EIR compliance as well as the conventional processes of Ex Post and Ex Ante EIR compliance verification are outlined, so that the proposed A Priori concept proposed in this paper, can be described in chapter 3.

2.1 Exchange Information Requirements

Requirements regarding data delivery and exchange are defined in [7] as well as [8] and [2]. According to a 2012 buildingSMART International directive [9], Exchange Requirements are a part of Information Delivery Manuals (IDM), as well as Process Maps, Exchange Requirements Models including Exchange Concepts, which are linked to Model View Definitions (MVD), and the corresponding documentation, which is also sustained by [10], [4] and [11]. This paper considers the concept of EIRs and IDMs as being the necessary foundation for successful information exchange, regardless of hierarchy between documents. Additionally, IDMs assume the function of foundation for the development of MVDs. MVDs depict a subset of product data models [11], which are usually applied to the open standard IFC (Industry Foundation Classes) and concern the process of exporting data from e.g., the authoring environment. Since the proposed A Priori requirement transfer occurs before modelling, and thus prior to the export, compatibility with MVDs was not an issue in the proof-of-concept study, outlined in chapter 4. A similar notion to EIR are Information Delivery Specifications (IDS), which are under development and define information requirements in a machine-readable data set [5].

This study focuses on EIR as a reliable source of modelling requirements, since the content is agreed upon by contracting and contracted party and thus legally binding [12]. The nature of these requirements as contractual documents outlines the data to be delivered for the data drop and offer an ideal foundation for the proposed A Priori approach, further described in chapter 3.

2.2 Model Checking and Semantic Enrichment

The topic of model checking is a central issue in the application of BIM, which is defined as "the automated examination of the model on the basis of rules" [13]. With the help of model checking, the geometric and semantic information content and thus the quality of BIM models can be assessed and consistently tracked [14] by checking the model for its conformity with predefined specifications and requirements. Solihin and Eastman assign the types of automated rule checks to six different classes [15], including checking for conformity with standards and regulations as well as with customer requirements. Based on different case studies, (semi-)automated testing procedures are already being implemented [16], e.g. in connection with the testing of building models for compliance with fire protection [17] and building regulations [18] as well as for the planning of construction processes [19].

An assessment of the information content can only be made if the model has been appropriately semantically and geometrically enriched. Semantic enrichment is described by [20] as the "(semi-)automated addition of relevant information to a digital model to identify new building information and relationships by software that can deduce new information by processing rules". If the automated, AI-based enriching process, as described by [11], is seen as the goal on how to make BIM models match the requirements derived from predefined use cases, EIR must be considered, since they define the exchange data requirements for a digital model of a built facility and thus appear predestined as a basis for systematic semantic enrichment. The EIR-compliant preparation of a model thus serves a transitional purpose on the way to an AI-supported approach to BIM. To that goal, the efficient use of machine-readable EIRs involves processing the EIR content in a logical form so that interpretation can be performed by algorithms and information can be evaluated on the model according to rules.

2.3 EIR Compliance

When talking about EIR compliance, a classification in the context with adjacent topics must be made. EIR documents contain various requirements, e.g., semantic and geometric requirements, which affect the concepts of Level of Development (LOD), Level of Geometry (LoG) and Level of Information (LoI) [21] as well as the Level of Information Need (LOIN) [7], which is under development. Requirements, for example, regarding workflows for model-based collaboration, as well as data exchange and communication culture, are also contractually fixed [7,8,22]. The difference between the requirements is mainly that not all of them can and should be represented within the model and thus only indirectly relate to the data to be delivered. An example of requirements, that are ineffectual within a model, are delivery dates, which need to be contractually binding, but have no relevant purpose within a model. An EIR-compliant BIM model must therefore meet such requirements that relate directly to it, such as the semantic information content in the form of attributes and the level of detail and granularity of the geometric representation or the position in a coordinate system and the local reference point. EIR conformity is a prerequisite for contractual fulfilment and must therefore be verified during the modelling process and after delivery of the models [22,23], thereby ensuring usability for the intended use cases.

A large part of the EIR conformity can be achieved by attribution of geometric objects. Appropriate checking rules allow quantitative statements about the degree of completion of the model and about compliance with the EIRs. Different approaches as well as the technical possibilities for rule checking for compliance have already been evaluated and performed in other contexts [15–17,24–26]. For example, "IF-THEN" concatenations, represent a simple but powerful form of implementation [15,17,25,26].

2.4 Conventional Ex Post EIR Compliance

In the context of this work, the Ex Post process is understood to be a check for EIR compliance after the modelling phase and export from the native authoring software for the purpose of delivery at a defined time and quality (data drop). As depicted in Figure 1, the conventional Ex Post process involves the generation of rule checks based on the requirements formulated in the EIRs. These are applied to the respective model state after being exported from the native authoring software. The rule checking results provide a quantitative indication of the progress of the model and highlight information that is still missing, which is mirrored back to the native modelling environment and resolved in an iterative process before the model is again exported. Once the model product meets the requirements, it is ready for the contractual data drop at a time specified in the respective EIRs, which is also the end of the Ex Post process for the particular model index.

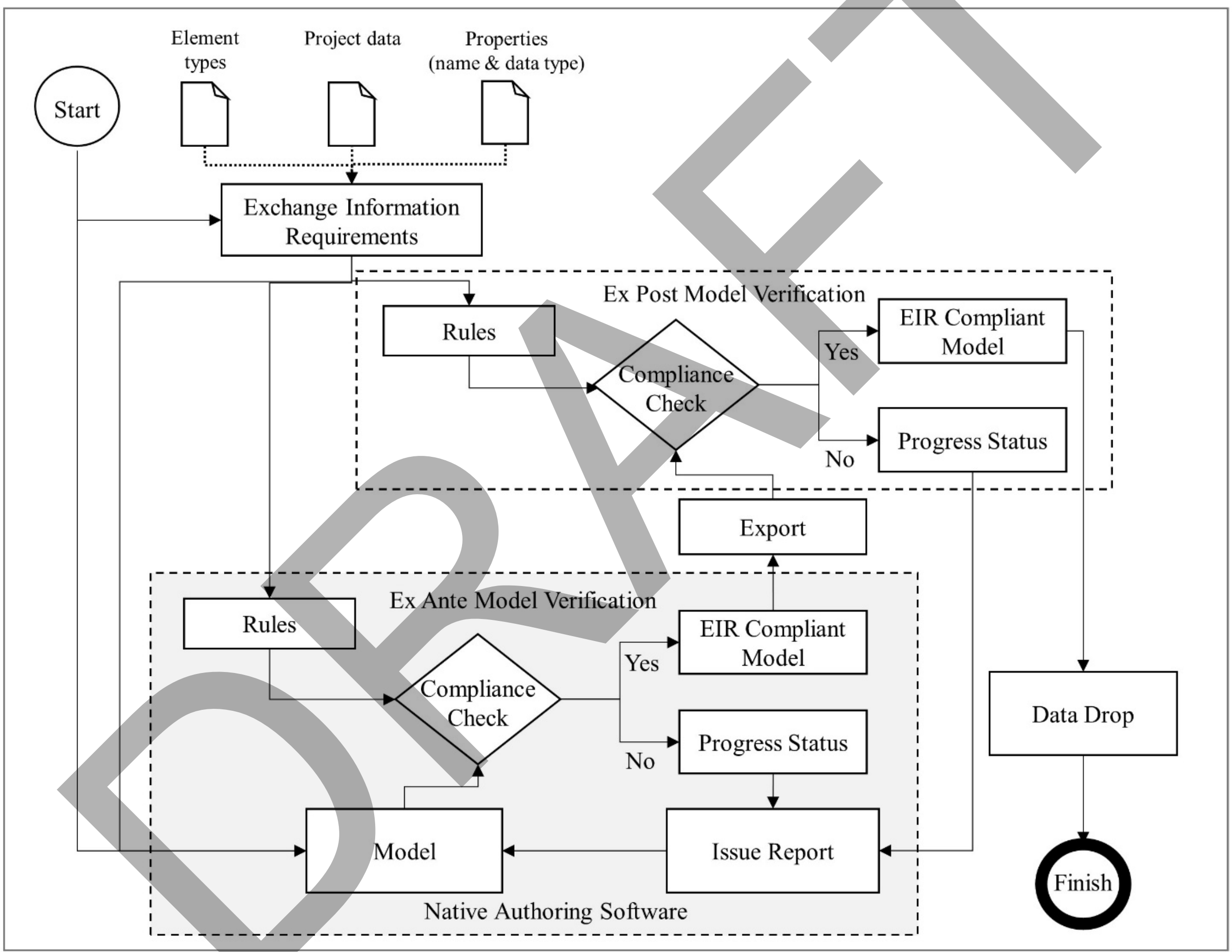

Figure 1: Workflow of the conventional Ex Post and Ex Ante EIR compliance checks, representing the status quo in the industry

The Ex Post review can take place on both the ordering and contracting sides. In this case, the data drop marks only the official, final model handovers at contract-relevant project milestones. Model checks can also be performed on intermediate results during the modelling phase and can therefore be used before official data drops to spot missing information.

2.5 Ex Ante EIR Compliance

An Ex Ante EIR compliance check is conventionally performed by the delivering party regularly prior to minor and major data drops in order to identify possible mistakes and reduce correction iterations in the process of Ex Post verification. As shown in Figure 1, the Ex Ante

EIR compliance check is performed within the authoring software and thus before exporting the model into a prevalent open format, such as IFC. Similar to the Ex Post process, the Ex Ante compliance checking derives rules from the requirements defined in the EIR, with issue reports being generated and corrections or additions to the model being made in iterations. Currently, these compliance checks are often performed manually. The result is an EIR-compliant model, that can subsequently be exported for the contractually agreed upon Ex Post model verification, associated with the data drop. Usually, a combination of often manually performed Ex Ante and Ex Post verification takes place, since EIR compliance is also regularly checked during the modelling phase.

3 Proposed Concept for EIR Compliance

To achieve a more efficient workflow than the current status quo (manual Ex Post and Ex Ante verification), the automated supplement of information from the EIR prior not only to the data drop, but also to modelling itself is proposed, as described in Chapter 3.1. This approach can be combined with the automated Ex Ante EIR compliance, as described in Chapter 3.2. The implementation follows in Chapter 4.

The biggest advantage of the proposed workflow is aggregating project-specific information in a machine-readable format, that can be incorporated into the modelling automatically environment, thus reducing the modelling effort by potentially eliminating the need for additional documents, since the BIM Execution Plan (BEP) would follow the same schema. Furthermore, the proposed A Priori approach increases transparency for clients by ensuring the automated compliance with client-given requirements with a reduced effort (after implementation).

3.1 A Priori EIR Compliance

In contrast to Ex Post verification, the A Priori EIR compliance approach, proposed in this paper, introduces a semantic supplement of the model prior to the modelling process itself, as depicted in Figure 2.

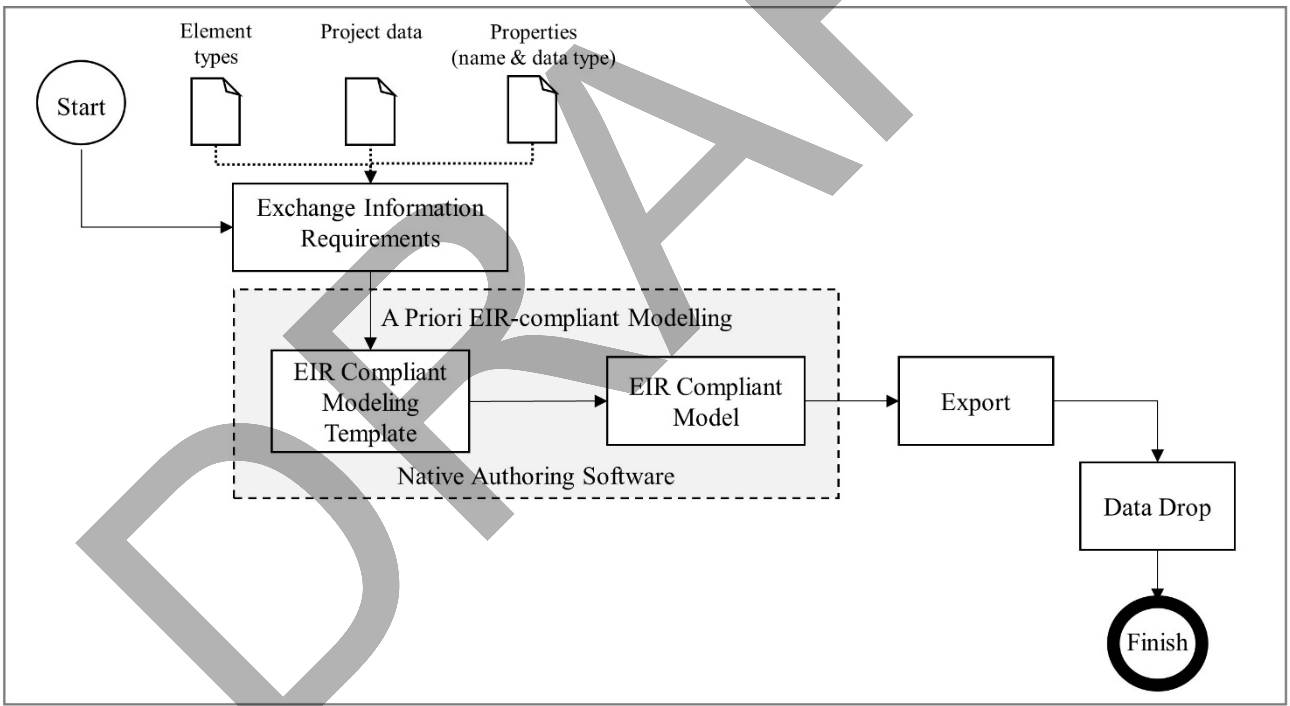

Figure 2: Workflow of the A Priori EIR compliance approach, proposed in this paper

Based on project specific EIRs, an EIR-compliant, automated template is generated in the native modelling software, in this case using a developed script as part of the proof-of-concept study. The script takes required properties from a given source, e.g., a structured object and attribute list as part of an EIR document, and assigns them to element types with defined data types. This results in a predefined structure with necessary properties for all relevant modelling elements, that are in accordance with the contractual agreement and project-specific requirements, allowing model authors to focus on the actual design practice. The resulting pre-configured, project-specific environment is comparable to a template. This project-specific template creation represents an automated transfer of semantic information and relieves model authors of the additional effort of transferring the required information to the modelling environment and adjusting attributes, data types and property sets in the model by hand and from various sources (paper, PDF documents), which involves both manual effort and a higher susceptibility to errors. This approach produces a semantically rich, EIR-compliant building information model, that can further be verified using either the Ex Ante or the Ex Post approaches, if deemed necessary.

3.2 Automated Ex Ante EIR Compliance

The automated Ex Ante model checking approach, as shown in Figure 3, is a variation of the previously mentioned Ex Ante EIR compliance and can be applied to verify the automated assignment of attributes, properties as well as acceptable data types within the native modelling environment and thus before exporting to an open data format.

An automated Ex Ante EIR compliance checking can be easily implemented based on the proposed A Priori model-based EIR compliance approach. The goal is to relieve the burden of the various iterations needed both in the traditional Ex Ante and Ex Post model checking processes, with the latter one involving increased effort since the checking traditionally takes place outside the modelling environment.

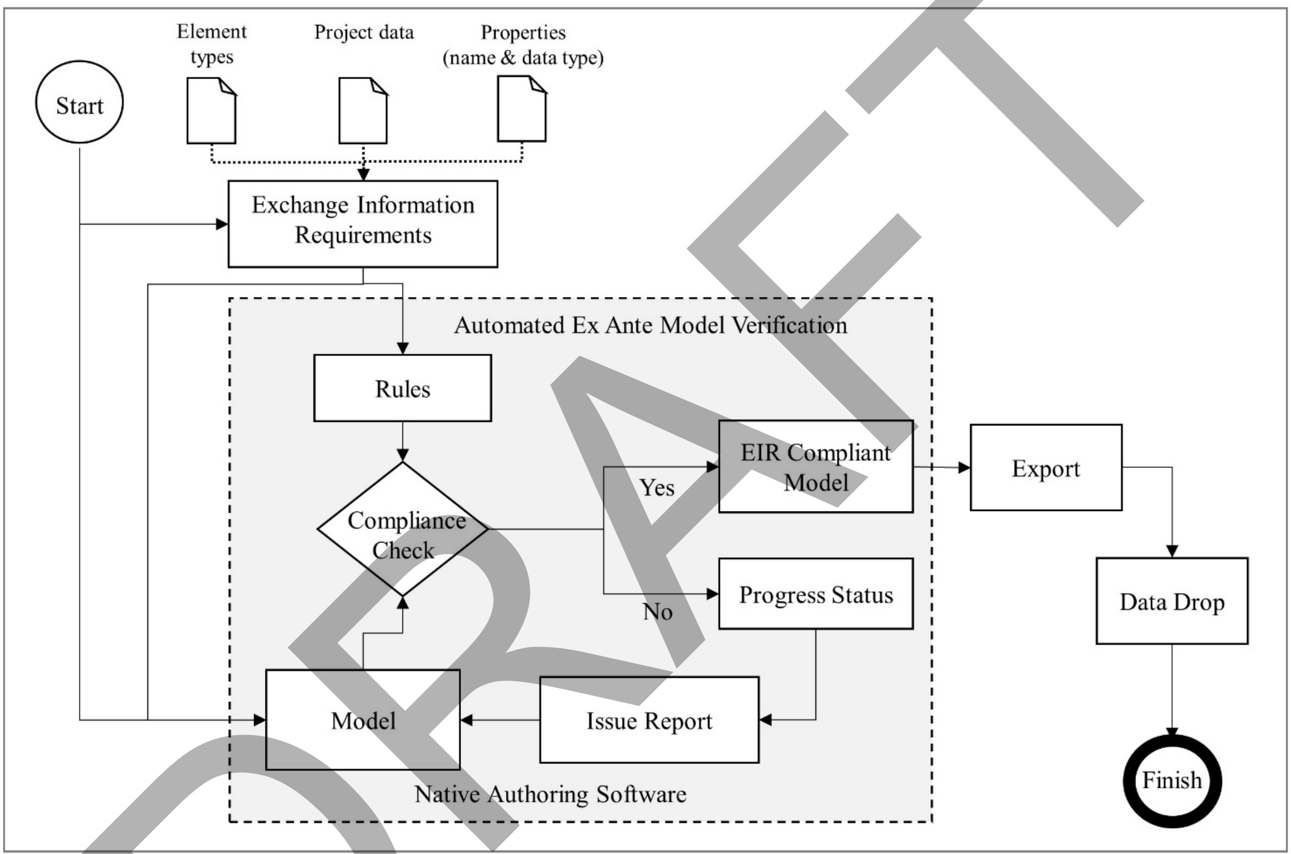

Figure 3: Workflow of the automated Ex Ante EIR compliance check

With the automated Ex Ante approach, checking for EIR compliance can be done continuously, e.g., at each save operation, provided it was implemented in the used modelling application. By allowing error reports to be generated during the modelling process and within the modelling environment, correction iterations are significantly less arduous. This approach also allows intermediate statuses of the model to be effortlessly EIR-compliant, allowing discrepancies between ordering and contracting parties to be addressed earlier (as opposed to after export for a data drop). In this scenario, the Ex Post EIR compliance check is only performed pro forma, since the model has already been verified multiple times. An adequate implementation of the A Priori model-based EIR compliance, linked to an automated Ex Ante EIR compliance check, would result in the long-term elimination of the redundant Ex Post EIR approach. The automated Ex Ante process could also be extended to involve checks regarding the allocated values to the attributes, checking the plausibility of planning content using recuring rules, thus eliminating the need for project-specific rulesets.

4 Proof-of-Concept Study

To validate the feasibility of the proposed concept of an early automated assignment of properties to the modelling environment, which would enable a truly digital project management with increased effectivity in the modelling phase, a script demonstrating the proposed A Priori process and functionalities was developed. The script was implemented using the Dynamo visual programming tool, since the study encompasses only a proof of concept. With positive results, future resources will be applied to developing a thorough solution for the automated A Priori EIR compliance based on machine-readable requirements.

4.1 Implementation of the A Priori EIR-Compliant Modelling Approach

The created script first reads from a chosen file, in this case the simplified object and attribute list (a spreadsheet structured after an exemplary document used in a practical infrastructure project, where attributes are assigned to objects and phases, with defined data types) using the Revit API. In this project, object categories, e.g., doors or walls, were defined as having a corresponding IFC class implemented in the modelling environment. Care to the IFC consistency is relevant given that the export from the authoring software is crucial for the data delivery. By adding the parameters at the beginning of the modelling process, defined properties are also considered during the export from the modelling environment in IFC. Categories as the overall hierarchy level in the chosen modelling environment, above Families and Elements, are chosen in this example to conditionally assigning attributes. Object categories can be divided into sub-categories, e.g., external doors, which correlate with certain properties (as opposed to internal doors, which might have other properties). It must be noted, that the IFC standard was not developed for end-users to define requirements beforehand [5] and that the correspondence of categories with IFC classes was possible, in this study, due to the reduced nature of chosen objects.

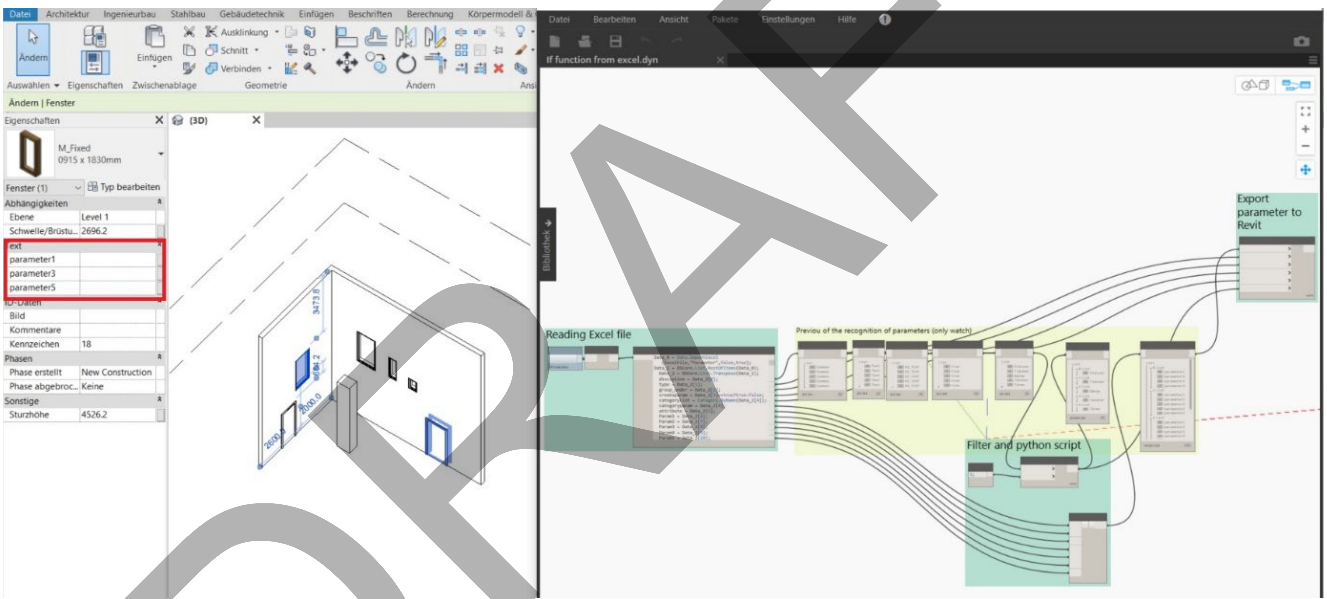

Figure 4: Implementation of visual scripting and resulting object categories with assigned properties in the authoring environment

The script runs over the simplified object and attribute list, where each entry concerns an object category and its specific properties and attaches only the specific properties to their respective categories in the Revit project before the start of modelling. Consequently, all columns, walls, windows, and doors later designed or modelled in this project, already have the ordered properties, as depicted in Figure 4. Since the properties were assigned with specific data types, the need for rules regarding acceptable values is no longer required, since the property values can only be filled out in the specified data type (e.g., string, double or Boolean). This does not extend to checking if the value, given in the correct data type, is plausible, since this is a planning decision, that depends on various factors, that cannot be solved with an overall rule. The assignment of properties on the category level allows all created families, types, and elements to inherit the specified EIR requirements and data types. Furthermore, the script allows modelling authors to check if the transferred properties were assigned values during the modelling process, in the manner of an automated Ex Ante verification, further aiding the continuous EIR conformity and reducing error-proneness.

4.2 Results and Significance

The result of the presented proof-of-concept study is an EIR-compliant modelling environment, comparable to a project-specific template, that meets the requirements from a contractually agreed upon data source, e.g., an object and attributes list from the client. After applying the visual script to an empty Revit project, all subsequently modelled objects of the corresponding category were automatically assigned the selected properties. This simplified procedure prior to the modelling act itself prevents incorrect or missing semantic information in the subsequent modelling phase by creating an EIR-compliant modelling foundation at the beginning. The automatically generated EIR conformity increases robustness of the modelling process regarding the compliance with contractual conditions and renders subsequent tests redundant. The need for specific rule generation and application is reduced by taking advantage of built-in constraints, such as limitation of values to a predefined data type, common in all modelling environments. This proof-of-concept study refers to supplying semantic information to the model in the form of property assignments. Extensions are conceivable regarding other requirements defined in the EIRs, such as project origin or location, coordinate and elevation systems, among others, as well as the addition or real-time update of requirements during the modelling process. Further extensions should also address the assignment of cascading properties to categories, types and elements based on other so-called marker properties, to attend more complex property constellations.

The proof-of-concept study achieved the expected, positive results by allowing project-specific information to be assigned A Priori, meaning before the modelling phase, to reduce error-proneness and increase effectivity during the modelling act itself as well as in later data drop related model checks, since properties and data types do not have to be assigned manually to each object category. The proposed workflow can potentially be used for the assignment of properties relevant for specific projects, such as predefined properties for later maintenance (which are closely defined for e. g. infrastructure projects) and other individual requirements, that are not part of norms and standards, but nonetheless crucial for the project success and which tend to be overlooked in the current process by differing stakeholders.

This study was delimited to the process of model checking within the data drop process. Further advantages of the proposed workflow include the structure of subsequent BIM Execution Plans (BEP) to the same schema as Exchange Information Requirements, thus increasing traceability of requirements and decisions based on the machine-readability of the EIR, thus reducing the need for PDF files and meeting protocols in addition to the effectivity increase previously described in this paper.

5 Conclusion and Outlook

This paper proposes to restructure the process of EIR compliance to increase checking transparency, automation, and objectivity by incorporating requirements into the modelling environment prior to modelling, proposed as the A Priori Approach. This contrasts with the current practice of separate and downstream checking processes, where compliance is checked only for the purpose of delivery. The goal of this paper is fundamental: Reduce and, if possible, eliminate late quality controls and error sources, by preponing and automating the incorporation of information into the modelling environment, and thus to the model, right from the beginning. The proposed A Priori approach allows the generation of a continuous EIR compliance, by automatically assigning properties with matching data types to the modelling environment prior to modelling, hence the name A Priori. This is done based on contractually binding documents, which can be EIR or BEP documents, since the latter are the continuation of the former and therefore follow the same structure with updates throughout the project. The used object and attribute list is usually part of the EIR and offers a structured data delivery scope.

Future studies regarding the automated assignment of required semantic information should address the range and possibilities of established schemas such as mvdXML, ifdXML and idmXML in order to identify gaps, which can be assumed given the wide usage of tables for object and attribute lists as well as efforts regarding the creation of new such schemas, such as IDS and LOIN. The conducted proof-of-concept study demonstrated that the proposed early and automated information transfer from contractually binding structured documents, such as object and attribute lists, in the form of an EIR-compliant modelling template, is conceivable. The study showed promising extensions regarding requirements that can be reasonably added to the modelling environment to aid the design process, as mentioned in chapter 4.2. It also showed that the potential for incorporating cascading properties, where certain properties are assigned to various element types based on the presence of other marker properties, should be investigated further. In a system that supports the modelling authors by automatically adjusting the templates for the individual parts based on certain marker properties, the productivity can be improved significantly, as authors do not need to refer to the provided materials but can rely on their software to already have adopted the properties of the part.

The usage of a data source to describe the information requirements was proven suitable, as expected, and underlines the need for a machine-readable standard for information requirements, which is also supported by [5]. The conducted proof-of-concept study used a fundamental structure and a generalised design for the implementation, which indicates, that the development of such machine-readable exchange requirements is an achievable goal and great potential lies in more advanced designs, that can model more dependencies and aspects of an EIR-compliant model. To enable broad application of the proposed approach, a generalisation of the mentioned standard for information requirements needs to be developed and implemented by software applications to be accessible by end-users, thus making the EIR-compliant design more effective and de facto digitalised.

Finally, these can be the first steps in the direction of smart design support systems, where software informed with semantical and structural knowledge can assist the users by maintaining compliance with client-side requirements from the beginning, e.g., through EIR or comparable standards, highlighting possible conflicts or gaps in the design and guiding them with suggestions for better designs, all while being adjustable to the specific requirements of each project and stakeholder.

6 References

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