Enhancing Compliance and Efficiency in Infrastructure Projects through Smart Standards

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Abstract: The BIM master plan aims to achieve comprehensive implementation of BIM technology in federal road construction by 2025. This technology is already being used extensively in the planning phase, supported by integrating digital models created and exchanged by existing standards and guidelines. Rule-based, semi-automated test procedures ensure model quality and compliance with regulations. However, one drawback is that the necessary information is usually only available in non-machine-readable continuous texts and illustrations. An essential part of the project is therefore the conversion of traditional regulations into Smart Standards, which are serialized as XML documents according to the NISO STS to optimize their management and the provision of the contained information. In preparation, the suitability of existing regulations was analyzed and ten regulations were transferred to the NISO STS, considering the current version of the federal road construction object catalog. Furthermore, a concept for the description of information requirements and checking rules in the regulations was developed. The converted Smart Standards are integrated into the checking systems and the checking rules entered are tested on a model. Finally, recommendations for the management and administration of the Smart Standards were formulated.

Keywords: Building information modeling (BIM), design automation, algorithms, energy simulation

Erschienen in Tagungsband 35. Forum Bauinformatik 2024, Hamburg, Deutschland, DOI: 10.15480/882.13537

1 Introduction

Building Information Modeling (BIM) is a collaborative working method in the construction industry that accompanies and supports the increasing digitization in planning, construction, and operation. BIM models can contain geometric information, alphanumeric information, and documentation. They can be used for planning control, construction process simulation, quantity and cost estimation, and many other applications [1]. In a BIM-based project, each discipline, such as structural engineering, creates a discipline-specific model corresponding to their work. These models vary in content depending on the intended purpose and the project phase. The individual discipline models are integrated into a coordination model, at designated times This integration enables interdisciplinary collaboration, coordination, and review. This step ensures that the content of the models is as error-free as possible both, individually and in the shared context [2].

The successful implementation of BIM in the federal highway construction sector relies on the continuous development and maintenance of exchange formats and software programs. This enables organizations such as the Autobahn GmbH, the DEGES, and state road construction administrations to utilize BIM in multiple projects [3]. However, implementing such projects is not solely dependent on technical aspects. Adherence to existing standards, regulations, and guidelines is also a crucial factor. These requirements, which are typically available in printed or digital formats such as PDFs, serve as the foundation for the planning and execution of construction projects. Integrating these non-machine-readable requirements into the various BIM processes is a time-consuming and error-prone challenge [4].

This research aims to develop a procedure for the creation, management, and application of so-called Smart Standards for federal highway construction. The National Information Standards Organization (NISO) Standard Tag Suite (NISO STS) will be utilized for this purpose. NISO STS provides an XML-based data format for the comprehensive description of standards, norms, and regulations. [5] This will facilitate the accessibility of regulatory requirements in a machine-readable format, thereby enabling their integration into verification tools or modeling instruments. In the long term, this should result in increasing compliance with regulatory requirements during the creation and implementation of planning models, as well as facilitating the conformity check of models, for example, within building permit reviews. To prepare for the conversion, the existing regulations are analyzed to ascertain their suitability. Ten regulations are then transferred into NISO STS, taking into account the current version of the Federal Highway Construction Object Catalog. Furthermore, a conceptual schema for delineating information requirements and validation rules within the regulations is devised. The implemented Smart Standards were integrated into a verification system, and the entered verification rules were tested on a model. Finally, procedures for managing and administering Smart Standards, that address technical and organizational issues, were presented.

2 Background

This chapter provides an overview of the relevant research and concepts for this study. It specifically addresses verifying information requirements and validation rules concerning building models and the concept of Smart Standards.

The BIM methodology allows that digital models are consistently utilized throughout the entire lifecycle of the modeled structure. When creating such a 3D model, numerous guidelines from modeling standards and regulations are typically considered and integrated into the building model [1]. With the help of quality assurance measures, such as geometric collision checks and the verification of semantic conditions, the correctness of the model data can be guaranteed. This involves developing examinations that first perform a formal check of information requirements and then conduct a technical rule check to ensure accurate representation and modeling of building elements [6]. Based on the work of Nuyts, Bonduel, and Verstraeten [7], these two types of checks can be further specified and divided. The formal validation first checks for the presence of all relevant attributes of an object, and then ensures that the specified values meet the specified requirements. (e.g., data type, unit, and value range). The following technical rule check is divided into checking relational dependencies, mathematical formulas, and conditional constraints [7].

The technical implementation of model checking can be realized using different checking and query languages separable in IFC-based, open data, and semantic web approaches [7]. IFC-based approaches focus on technologies like MVD [8] and IDS [9]. The open data approaches focus on more generalized technologies like the XML-Schema Definition (XSD) and the Extensible Stylesheet Language Transformation (XSLT) to validate the correctness of model data. Within semantic web approaches ontologies like the ISOProps Ontologies [10] are used together with SPARQL [11] and SHACL [12] to validate the contents of a building model. A more detailed overview of rule languages and their use, is given by Nuyts, Bonduel, and Verstraeten [7], Stepien, Vonthron, and König [6] and Tomczak, Berlo, Krijnen, *et al.* [1].

In the construction industry, regulations are an important tool for defining legally binding requirements for the design and execution of construction projects. The growing number of text-based standards makes compliance difficult, as the required specifications must be manually extracted and prepared for digital use. [1] In addition, current information exchange is often limited to specific data catalogs, which hinders cross-domain collaboration and increases workload. To address these limitations, the Initiative Digital Standards (IDiS) of DIN e.V. focuses on creating digital standards that are accessible and usable by both humans and machines. To achieve this, specific action plans have been developed that outline the necessary steps to ensure that standards are mature, readable, implementable, and interpretable. This process outlines five distinct levels of autonomy in the way standards are created and used, leading to the development of Smart Standards [4].

The levels of autonomy range from paper format (Level 0) and digital documents (Level 1) to machine-readable documents (Level 2) where the structure and granular contents can be extracted. This progresses to machine-readable contents with identifiable information units and their relationships (Level 3), machine-interpretable contents linked with execution and application data (Level 4), and finally, machine-controllable contents that can be autonomously adjusted and published by automated processes (Level 5). To effectively implement the rules for automated compliance checking of Building Information Models, Level 3 or higher digital standards are required. This means that the standards must be mature enough to be interpreted and applied by humans and machines. In this work, the standards considered are first converted into Level 2 documents and then extended to Level 4.

3 Initial Review of Road Construction Regulations

This chapter focuses on the preliminary investigations conducted on road construction regulations to identify which ten regulations are most suitable for conversion into smart standards at Autonomy Level 2 in terms of effort and benefit, and which two are chosen to be implemented as Level 4 standards in the scope of this paper. For this purpose, the first step was to define metrics for the cost-benefit assessment.

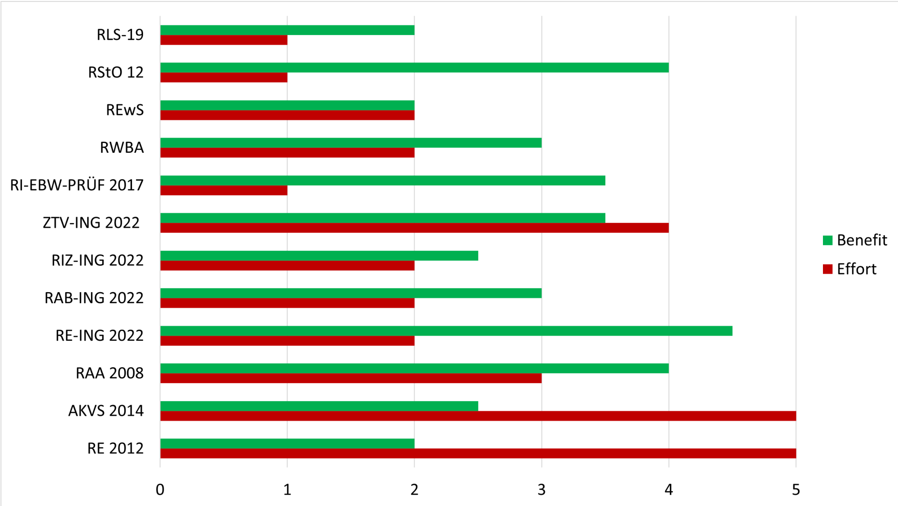

Figure 1: Result of the cost/benefit assessment

The criteria for estimating the effort required to convert road construction regulations into the NISO STS format include several key factors. First, the scope of the regulations is analyzed, considering the length and volume of texts, tables, illustrations, charts, and forms within the documents. The total number of pages serves as an initial indicator of the content to be converted, with larger volumes requiring more time and resources. Second, the complexity of the text structure plays a crucial role in the conversion process. Third, the presence and complexity of tables and figures within the regulations significantly impact the conversion effort. Complex tables and detailed illustrations require precise handling to ensure an accurate transfer and to avoid errors. Lastly, the informational content within figures and forms must be assessed. It is essential to differentiate whether these elements contain critical information or serve merely as supplementary aids for human understanding.
The following benefit assessment of the regulations involves evaluating two main criteria on a scale from one to five. The first criterion is the practical market relevance and frequency of use, where regulations frequently applied and highly relevant to everyday work processes receive higher ratings. The second criterion is the derivability of checking rules, which includes the potential for automating validation processes and simplifying workflows through transforming regulations. This criterion depends on the structure and clarity of the regulation, as only clearly formulated and verifiable contents can be automated.

After completing the effort and benefit assessment, the results were summarized by contrasting the effort required to digitize each regulation (Figure 1 red lines) with the benefit of having the regulation available in digital form (Figure 1 green lines). Based on the effort and benefit assessments, ten regulations were selected for conversion into NISO STS documents with autonomy Level 2. Additionally, the RE-ING and the RStO are chosen for the enrichment to autonomy Level 4 due to their good benefit-to-effort ratio.

4 Creation of Digital Standards

Creating a digital standard at Autonomy Level 2 involves converting text-based regulations, such as PDF and Word documents, into a format that is readable and processable by both humans and machines. The NISO STS standard, used for this purpose, offers extensive capabilities for structuring documents in XML. The conversion begins with selecting the appropriate XML version and integrating the necessary Document Type Definitions (DTD) and an optional stylesheet for later formatting. Subsequently, the title page is described separately from the document body. In the next step, the text body structures, like text, illustrations, tables, charts, forms, and formulas, are converted into XML following NISO STS guidelines. A detailed technical description of this conversion process is beyond the scope of this paper instead, the technical documentation of NISO STS is referenced. [4].

The created digital standard is enriched with information requirements and validation rules to create a Level 4 standard. For clarity, the terms *information requirements* and *validation rule* are collectively referred to as *information elements* below. The integration of information elements is done through *term sections*, which are defined at the end of each text-bearing section. A *section type* attribute distinguishes whether the section contains information requirements or validation rules. The information elements mentioned for the first time in the relevant section are listed in each of these sections.

The *term section* for information requirements contains *term entries*, which describe terms and concepts found in information elements. Each entry in a *term section* is assigned a globally unique ID (GUID) generated according to RFC 4122 standards. After specifying the ID, an *index term*, containing *term* element, indicates whether the defined information requirement is a property or a property group. Within a *language set* element, the language of the information element can be defined and additional details can be provided within a *definition* element. *TIG (Term Information Group)* elements allow for various descriptions, such as a preferred term, an accepted synonym (*admittedTerm*), acronyms, and a name for digital processing.

Similar to the approach for information requirements, the validation rule is organized within an XML structure to define and manage the rules and their associated information elements. Each validation rule is identified by a globally unique identifier (GUID). The main definition of the validation rule resides within the *term entry*, where it is specified as a validation rule using a *term* element. An additional *source* element may reference an external file, such as an IDS file, which contains the implemented validation rule. The rest of the definition follows the structure used for information requirements.

In addition, the concept of validation rules includes multiple lists, for example, one list defines the conditions for the validation rule, while another list defines the objects to be included in the validation. This concept can be extended by further lists if necessary. The standardization body should prescribe the allowed values for the *list-type* attribute ensuring uniform naming conventions across different working groups. The elements for *code* and *formulas* can provide detailed information on the implementation and necessary parameters. The *code* element allows pseudocode or fully developed code in a programming language, which is useful when validation rules are not delivered as ready-to-implement components with the standard document. The *formula* element is used to include mathematical formulas written in Mathematical Markup Language (MathML), illustrating essential calculations or

Figure 2: Developed Desite BIM Plugin and the tested BIM Model

logic of the validation rule. The definition of the validation rule is concluded with an optional *paragraph* element, which provides a comprehensive explanation for enhancing human understanding.

5 Evaluation

To verify the applicability and machine processability of the concept presented in section 4, a plugin for DESITE BIM was developed. DESITE BIM[1] is a BIM software solution from thinkproject that serves as a coordination platform used during planning, execution, and facility management. It enables project-related BIM applications by visualizing, analyzing, checking, and linking model data, supporting various functions such as model and collision checks, schedule creation through 4D simulations, and quantity take-offs. The result of the development and an example bridge model are shown in Figure 2.

The first step in checking the validation requirements of the selected regulation is to read the prepared, machine-interpretable validation rules. Therefore the loaded standard is scanned for term sections containing information elements.
The extracted term sections can then be searched for additional tags to retrieve overarching information, such as the name or definition of the validation rule. Once the basic data is captured, the lists, code, and source elements can be accessed for validation requirements.
In the example shown in Figure 2, a checking rule was loaded to validate the clearance height under the newly designed bridge. The formal check first verifies whether the model contains all objects and attributes required for the subsequent technical validation, and that the attributes are valid in terms of data type, characteristics, and value ranges. The succeeding technical validation uses the previously checked objects and attributes to check that the requirements specified in the check rules are also met. The illustrated example checks whether the modeled clearance profiles (yellow boxes in Figure 2) have a minimum height of 4.70 m and whether they interfere with the planned bridge at any point. There are no collisions present in the shown example, there the check is successful.
The evaluation shows that using digital standards facilitates the extraction and preparation of constraints and creates an improved basis for integrating and using such constraints in common software

[1] https://www.thinkproject.com/de/products/vdc-manager/

products. The use of digital standards contributes to increased efficiency and harmonization in the areas of standardization, testing, and rule management. However, the process of creating such digital standards is currently relatively labor-intensive. For continuous use, methods need to be developed to partially or fully automate the conversion to XML-based standards and the integration of information requirements and test rules.

6 Conclusion

The BIM masterplan aims for comprehensive implementation in federal highway construction. BIM applications in road construction and civil engineering are carried out under existing standards and guidelines, with digital models being used for data exchange and quality assurance. These models enable both the implementation of specific use cases and general project evaluations, whereby the model quality and conformity with guidelines can be checked, in some cases automatically. Standards and regulations will be digitized in the future to enable more efficient testing processes like digital standards.

The present study evaluates digital standards in terms of their benefits and effort and examines the creation and management of digital regulations. Ten regulations were converted to Level 2 and two were extended additionally to Level 4, based on the autonomy levels of the Smart Standards initiative. The conversion process included the current object catalog of the German Federal Highway Administration. Methods for describing and integrating information requirements and validation rules in digital standards were developed. The applicability of the developed concept was demonstrated using a self-implemented plugin for DESITE BIM.

The results of this study highlight the benefits of digital regulations combined with model checks and advocate for the digitization of analog regulations. However, several key points must be addressed to enable the widespread use of digital standards. Firstly, software solutions must be developed to create and manage standards that directly generate NISO STS-compliant documents. While existing solutions are available on the market, their practical suitability still needs to be assessed. In addition to technical adjustments, the approach to developing standards should be revised. This includes ensuring that requirements are explicitly formulated during the creation or versioning of regulations to facilitate the generation of information requirements and validation rules. Furthermore, images and illustrations in regulations should only be used as supplementary elements to aid human understanding, as automated processes struggle to extract explicit knowledge that is not textually depicted.

In conclusion, it is important to note that the digitization of regulations as digital standards provides significant opportunities to streamline the use of standards, thereby enhancing compliance in planning, construction, and implementation processes.

Acknowledgments

This paper is based on parts of the research project carried out at the request of the Federal Ministry For Digital and Transport and its Network of Experts “Knowledge - Ability - Action”, represented by the Federal Highway Research Institute, under research project FE-No. 02.0463/2022/ARB. The authors are solely responsible for the content. We would like to thank the members of our project’s advisory board for their useful advice and feedback.

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