BIM standards and classification systems in data validation

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Abstract. Digitalisation has been proven vital to transition the construction industry into more sustainable ways of working. One of the ways the construction industry is digitalising is through Building Information Modelling. An important part of BIM is consistent and trustworthy data. However, effective automation of BIM data validation remains an issue for the construction industry. This paper uses a semi-structured literature review to investigate the use and challenges for BIM standards and building classification systems in relation to BIM data validation. To better understand what is hindering the development and successful implementation of these standards as data validation content. Findings from the review highlight multiple challenges hindering the implementation of standardised data validation workflows in the construction industry. It also shows that software vendors have an important role, where they must provide platform facilities that better support the heterogeneity of rules needed for the construction industry.

1. Introduction

Better quality data is vital to achieving changes and helping the transition to more sustainable practices in the construction industry (CI) (Designing Buildings Ltd., 2021). Digital technologies, like BIM, are necessary to achieve these goals. To deliver high-quality BIM data, compliance checking becomes important (EU BIM Task Group, 2017). However, the language of BIM is built on shifting sands. Terms and definitions have changed over time and will continue to adapt and evolve. The world of BIM is complicated and sometimes confusing. Too often terms are used in contexts that blur their meaning. If BIM data validation, is to be simplified, we must refer to common reference points, such as standards, that "anchor" our approach. Data validation is generally defined as an activity aimed at verifying whether the value of a data item comes from the given set of acceptable values, to ensure a certain level of quality of the data (Zio *et al.*, 2016). Data validation in relation to the CI is also referred to as compliance checking or model checking and is a means to check the project data deliverables against those specified in the project requirements (Amor and Dimyadi, 2021). Data validation ensures that the information delivered at a particular project stage is correct and in accordance with the responsibilities of the party who have delivered it. This helps to ensure interoperability, which is a characteristic of good quality data (SDG, 2018). However, interoperability has been identified as one of the main barriers to data exchange in the CI (A. Poirier, Forgues and Staub-French, 2014; Castro-Lacouture, Irizarry and Ashuri, 2014, pp. 1987–1996).

To ensure interoperable data, the data must be consistently validated before it is shared and used. This paper focuses on the initial pre-check which can be used to ensure reliable data for subsequent code checking and BIM-based analysis (Ciribini et al., 2014). To do so, standardised templates (also called rulesets) become essential to definite and store validation rules in a machine-readable and reusable format. Templates can help to reduce manual errors and automate workflows, by providing predefined and verified content. In its essence, data validation templates share a lot of commonalities with data templates for construction objects, as defined in ISO 23387:2020. These data templates provide a data structure used to ensure that construction objects are machine-readable, versatile, and consistent, so they can be used in

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different software. By structuring rules and requirements in a data validation template, the information can be used to check and verify the BIM models and objects.

Standardisation of data validation templates becomes an important part of ensuring data interoperability. Because standards and building classification systems, establish a consensus and provide a formula on the best way of doing something. This enables an unambiguous exchange of information, facilitates better communication, and better exchange of information between different stakeholders. In general, the purpose of data validation templates becomes to standardise and automate how BIM data is checked, to enable consistency and interoperability. However, there seems to be a missing connection between BIM standards and their availability in current data validation workflows used in the CI. Therefore, this study aims to answer the research question:

"Given the importance of standardised workflows, what are the current challenges for the efficient use of BIM standards and building classification systems as part of BIM data validation templates?".

To answer the research question a semi-structured literature review (SSLR) was conducted. The SSLR investigates the importance and challenges regarding BIM standards and building classification systems in relation to BIM data validation in the CI. To better understand what is hindering the development and successful implementation of these standards as data validation content. In addition, grey literature is used to collect information that is produced outside traditional publishing, including existing information about data validation solutions and initiatives, for example from buildingSMART. Grey literature is used to help describe more current information concerning the research area and provide important contributions not found within commercially published literature, to provide a more balanced view of the evidence (Paez, 2017). The literature review is conducted as initial research to better understand how BIM standards can become specific in BIM data validation templates, as the current standards and guidelines are experienced as vague and don't facilitate practical solutions for data validation in the CI.

2. Methodology

A semi-systematic literature review is used as a structured procedure to identify and synthesise relevant sources to obtain a comprehensive overview of the literature published for the specific research question and create new knowledge by compiling the existing works (Snyder, 2019). Additional grey literature is used to identify the current solutions and initiatives concerning BIM standards and building classification systems for the purpose of data validation in the CI. The semi-structured approach is used because of the diverse disciplines and various groups of researchers involved in the CI, which can hinder a successful full systematic review process (Wong *et al.*, 2013).

The SSLR is performed in 4 steps: (1) designing the review, (2) conducting the review, (3) analysis, and (4) writing up the review (Tranfield, Denyer and Smart, 2003; Snyder, 2019). The selected databases were Science Direct, Scopus and Semantic Scholar, with the search being limited to results in English language, in the period from 2015 to 2022. This period was chosen because of the speed at which both BIM standards and data validation in general, is developing and advancing in the CI. The grey literature was found through a web search using Google and Google Scholar. However, as grey literature is not published in peer-reviewed publications and comes in varying quality, the use of this literature must be done with caution (Paez, 2017). The grey literature is combined with the findings from the literature, with the purpose of better understanding how BIM standards and building classification systems can become specific to data validation as templates, and the related challenges. Based on the research question, relevant keywords are identified, and a search is performed in the selected databases. From the objective of the research, the keywords identified were ‘BIM’, ‘AEC’, ‘data validation’, ‘classification’ and ‘standard’. Alternative search terms (Table 1) were also searched to ensure adequate coverage of the literature.

Table 1: Search terms.

Keyword	Search terms
BIM	‘BIM’, ‘Building Information Modelling’, ‘VDC’, ‘Virtual design and construction’, ‘3D modelling’
AEC	‘AEC’, ‘AEC-FM’, ‘Architecture, Engineering and Construction’, ‘Architect*’, ‘Engineer*’, ‘Construction industry’, ‘Construction’
Data validation	‘Data validation’, ‘validation’, ‘model checking’, ‘checking’
Classification	‘Classification’, ‘Classifications’
Standard	‘Standard*’, ‘BIM standard’

From the database search, 335 publications were found using the search strings in Table 2, with the inclusion criteria being articles published between 2015 and 2022 and in English language.

Table 2: Search strings.

Database	Search string	Number of results
Science Direct	(BIM OR VDC) AND (AEC OR Construction) AND (Validation OR Checking) AND ((Classification) OR (Standards OR “BIM standards”))	34
Scopus	(BIM OR “Building Information Modelling” OR VDC OR Virtual design and construction OR “3D modelling”) AND (AEC OR AEC-FM OR “Architecture, Engineering and Construction” OR “Architect*” OR “Engineer*” OR “Construction industry” OR “Construction”) AND (“Data validation” OR Validation OR “Model checking” OR Checking) AND ((Classification*) OR (Standard* OR “BIM standard*”))	88
Semantic Scholar	BIM Construction Data Validation Model Checking Classification Standard	213

The results collected from the database search were then filtered by the exclusion criteria based on their title, abstract and keywords. The exclusion criteria are articles that are not related to the construction industry, articles that do not consider BIM standards and/or building classification systems, articles that do not concern data validation/model checking for BIM data, and non-peer-reviewed publications and whitepapers. To keep track of the collected publications in the qualification of the search results, a research protocol is used. The research protocol contains the title, author, year, number of citations, abstract, and keywords.

By assessing the articles based on the inclusion and exclusion criteria, 55 publications were selected. Additionally, further relevant literature was collected by checking the references of the collected publications (snowball approach). From the final list of articles, a thematic analysis was performed similarly to a qualitative approach (Ward, House and Hamer, 2009). The thematic analysis was carried out in 4 phases: (1) initialisation, (2) construction, (3) rectification, and (4) finalisation, as described by Ward, House and Hamer (2009). In the initial phase, the articles were read through while reflective notes and coding were performed, by letting themes emerge naturally. In the construction phase, the codes were compared and organised in terms of similarities and differences in relation to the research question. In the rectification phase, the data was checked and confirmed by connecting themes and subthemes and integrating these with each other. The analysis was finalised by developing a “storyline” to create a coherent story answering the research question.

3. Results

The SSLR findings have been categorised into four main topics: (1) BIM standards and (2) building classification systems in relation to BIM data validation. Followed by (3) standardisation of BIM data validation, and finally (4) identified themes related to challenges that are hindering standardised data validation templates in the CI. These themes include insufficient data and data requirements, a current approach prioritising experts, and the challenges of expressing complex rules in a machine-readable format.

3.1 BIM Standards

From the SSLR it is found that BIM standards are developed by international, national, and regional organisations, and by businesses or other organisations for their internal use. They can also be developed by a consortium of businesses to address a specific marketplace need, or by government departments to support regulations (ISO, 2021). These BIM standards are usually adopted through the consensus of organisations involved with the technology and are rarely mandated by a national government agency (Sacks, Gurevich and Shrestha, 2016). The use of BIM standards should enable all project participants to collaborate efficiently, and share compatible BIM models and information (Ganah and Lea, 2021). However, detailed descriptions or guidelines on how data validation should be carried out appear to be missing.

International BIM standards. On an international level, different organisations are working on the creation of international BIM standards. An international standard is a high-level principle-based standard developed in collaboration with other relevant bodies. They define the structure and mechanisms of BIM data exchange. By doing so, standards facilitate communication which is critical when working across domains, disciplines, and national boundaries. The main international organisations identified in the literature were ISO (International Organization for Standardization) and buildingSMART. With buildingSMART being a leading authority behind open standards like the IFC file format and is heavily involved in the internationalisation of the common approach to data interoperability and open BIM.

National BIM standards. On a national level, it is found that government and industry bodies assist in the production of BIM standards. BIM implementation plans are dictated by the government, initiatives in the CI, or a combination of both. Meanwhile, some countries (including the United States, the United Kingdom, France and Denmark) have also issued national BIM mandates on government projects (McAuley, Hore and West, 2017). The development and promotion of BIM standards are found to be driven by national real estate agencies and CI organisations (Ganah and Lea, 2021), to facilitate better outcomes on BIM projects. Overall, multiple national actors are seen working on a variety of standards, creating a growing number of standards for the CI.

3.2 Building classification systems

Building classification systems are identified as one of the tools used to digitalise construction data, by facilitating a way of structuring the BIM information so it can be managed and sorted (CoBuilder, 2021). During data validation processes, building classification systems (like UniClass) become essential. They provide a means to describe construction elements and their interrelationships in a standardised and machine-readable way, which is necessary for templates to work. Classification systems enable query and check of sharply targeted sets of BIM data, without requiring a BIM expert and proprietary software (Sattler *et al.*, 2019). However, research undertaken by Jin Wu and Jiansong Zhang (2018, p. 2) on automating the classification of BIM objects showed that automated BIM object classification and error-free classification is an approach that is currently difficult given the associated complexities in creating the necessary rule sets to do so (Heaton, Parlikad and Schooling, 2019, p. 184). Therefore, it becomes necessary to apply standardised classification systems from the beginning of a project. In that way, manual and time-consuming tasks of selecting individual objects and classifying them can be removed, which become a decisive factor for automating data validation workflow.

3.3 Automating data validation with standardised templates

Data validation is a means to ensure that data is correct, complete, and compliant. However, there is no standard on how to check BIM projects against requirements (Lee, Solihin and Eastman, 2019; Lee, Eastman and Solihin, 2021). Therefore, a major part of the data validation process is rule definitions. Rules can be developed not only by standards and building classification systems but also by multiple other sources such as codes, best practice guidelines, and project-based requirements (Dimyadi, Solihin and Hjelseth, 2016). To create these data validation templates, different actors are working on interpreting BIM standards, building codes and other requirements for the CI. The purpose become to facilitate tools and templates that automate and improve the data validation workflow, which can lead to financial savings and increased quality in construction projects. However, the CI is still challenged when it comes to the flow of digital information on projects. Because different stakeholders are responsible for different domains of design, construction, and operation, the supply chain is complex and generates large amounts of information. This information can get misinterpreted or even lost in exchanges or handovers (DSCiBE, 2014). This is further complicated when some data is being shared using unstructured formats (PDF, XLS) or sometimes 3rd-party solutions. The use of recognised standards can help enable interoperability within the entire supply chain on a construction project (DSCiBE, 2014). In addition, large software companies can also influence how CI actors participate in the digital supply chain, by having the tools on the market which support a certain way of working (E.g., Autodesk Revit and BIM 360). However, this creates a risk of bottlenecks for data exchange which can diminish the advantages of digital supply chains (DSCiBE, 2014), because software solutions might contradict standards and guidelines.

From an EU perspective, the digital standardisation of the CI is led by the European body CEN. The Technical Committee TE/442 oversees the standardisation work concerning all information in the built environment. Among the first open BIM standards adopted by the CEN were the ISO 12006-3:2007, ISO 16739:2013 and ISO 29481-2:2012 from the buildingSMART International standards. According to DSCiBE (2014), these three standards are widely known as the three pillars of interoperability and set out a common format for data exchange, data-semantic concepts, data relations and a standard for specifying required information. The ISO 29481 can also be used for guidance when developing data validation templates according to Hjelseth (2015). An example of an international initiative, which is standardising data validation templates is found from buildingSMART. buildingSMART is currently developing the buildingSMART Data Dictionary (bSSD). The bSDD hosts standards, classifications, properties, allowed values, units, and translations, and can be used to access different standards to enrich BIM models. Furthermore, it can also be used for checking data validity and compliance (buildingSMART, 2021). On a national level, initiatives are also found. For example, the BART (Byggeriet's Automatic Rule Check) project in Denmark is researching how to translate project-specific requirements into machine-readable rules for construction. It is working on creating templates for checking whether the requirements of the Building Regulations (BR18) have been complied with (Rasmussen and Schlachter, 2021). Apart from the international and national initiatives, numerous software vendors are also found working on improving data validation in the CI. Some of these solutions offer the function to create templates to remove repetitive tasks and secure high data quality through standardisation. These solutions include, but are not limited to, the Solibri Ruleset Manager, BIMvision, BEXEL Manager, and Verifi3D by Xinaps.

3.4 Challenges with data validation templates

From the SSLR a consensus is found, to standardise the data validation approach for it to be successful in the CI. There seems to be a general agreement in the literature, that manual checking is unnecessarily time-consuming and subject to error. Because the currently manual workflow relies on the accuracy, experience, and expertise of the person or people performing the checks, the results can vary and be subject to certain inaccuracies. However, the task of standardising data validation in the CI is found to be hindered by a combination of multiple challenges. This section goes through the challenges identified by the SSLR.

Data presence and naming. To begin with, different standards and national codes require different and detailed information. These pieces of information must be present in the BIM models in a certain way and be of high quality before they can be used for compliance checking (Amor and Dimyadi, 2021). Because there are different approaches to BIM, different representations of the information are created and used. For example, IFC (Industry Foundation Classes) property sets are used. Overall, different naming conventions and data formats seem to remain a fundamental problem for ensuring high data quality.

Insufficiently detailed requirements. Another challenge hindering data validation templates is the insufficiently detailed requirements in the BIM standards and guidelines. Most BIM guidelines refer to data validation, or model checking, but only highlight its importance rather than providing clear instructions regarding the way forward (Choi, Lee and Kim, 2020, p. 3). Choi et al. (2020) report that detailed components and the methodology for quality control are lacking and therefore limitations are found when adopting these guidelines into machine-readable templates for data validation.

Machine-readable compliance. One of the main challenges identified in the literature is the fact that BIM standards and similar documents are typically written in human-oriented languages. To enable automated data validation, the content needs to be translated into a machine-readable format, which requires interpretation of the data. This is further complicated, when the documents are often expressed in a way, which is very different from the expressions used in BIM. Depending on the specific case, expert knowledge is often required to interpret the meaning or semantics of the BIM standards and requirements. The interpretation must take into account the intent, base and hidden assumptions assumed general knowledge of the subjects, and dependencies with other rules (Solihin and Eastman, 2015). This implies that the specification of rules can be a task of its own (Dimyadi, Solihin and Hjelseth, 2016), which makes the data validation process time- and resource-heavy. The creation of machine-readable templates also involves testing and verification of the content, to confirm it is solid and it can be trustworthy, adding more work to the process.

Proprietary data. Since current templates are often found to be created by specialists, the result is often a black-box representation with no guarantee of the translation being 100 % equivalent to the original version (Amor and Dimyadi, 2021). In general, the use of siloed data approaches, and hard-coded expressions, risks resulting in less quality and failure during use. Besides and associated with silos, there are also loss of information, loss of knowledge and wasted effort (Pedro Mêda, Hipólito Sousa and Eilif Hjelseth, 2020). Furthermore, custom machine-readable versions of a standard or code also constitute an additional version, which might not be automatically connected to the source. This version also has to be maintained, adding additional costs (Amor and Dimyadi, 2021) and the risk of human errors and data consistency issues (Lee, Solihin and Eastman, 2019). When a data validation template is written in a proprietary language, it requires in-depth knowledge of the technical structures to utilise.

The complexity of rules. Another challenge identified, hindering the successful implementation of data validation templates, is the complexities inherent in the rules themselves. Combined with the breadth of conditions to which they need to apply. Due to the high number of different BIM standards, classification systems and codes, there is a theoretically infinite number of rules that can be defined. Combined with the limitation of the technical expression of rule templates, more advanced data validation is often hindered due to the complexity of the rule expressions themselves. To be able to handle large and diverse amounts of BIM requirements and data, each rule or class of rules must apply to a subset of the data to make it tractable (Solihin and Eastman, 2015). However, defining formalised rules that address all possible values, properties, and relationships is still complex and demanding (Lee, Solihin and Eastman, 2019). This is made further difficult since there currently is no standardised way of creating a machine-interpretable version of codes and BIM standards. Therefore it is critical to have an effective method for translating and distributing machine-readable versions (Amor and Dimyadi, 2021). This can systematise the rules and templates to make the task of data validation tractable (Solihin and Eastman, 2015).

4. Discussion

In the SSLR it is found that BIM implementation in the EU has reached a high level of maturity. However, the EU countries need to share best practices because non-standardised approaches will lead to a fragmented market where information is being siloed (Charef *et al.*, 2019). As BIM has become the industry norm, templates (rulesets) become increasingly important for model coordination and data validation. If these templates are to be successful, they need to be based on standards.

4.1 BIM standards and building classification system

This review shows that BIM standards and building classification systems are dictated by geographic factors and many of them are inherited from standards that previously served 2D workflows. The BIM standards and building classification systems become specific at a project and discipline level within a country. Individual organisations agree to BIM requirements on a project basis, these project requirements are adapted in accordance with the client's scope of services. Therefore, the development and refinement of standards specific to 3D workflows are still in progress. This would appear to be linked to a workflow, which is partly digitalised but still relies on manual checking for the purpose of data validation. Though many of these standards are similar, they remain different, which can lead to confusion and mistakes when having to apply different standards on multiple different projects. This can make it difficult to easily ensure that deliverables are following the agreed standard (Sacks, Gurevich and Shrestha, 2016). In the end, there is a risk of making the standards and requirements seen as more of a burden than an asset, if the documentation isn't clear. In general, it is found that while BIM has led to improvements in projects the benefits have not been fully realised. However, templates can still help minimise errors by automating repetitive parts of the data validation process.

4.2 Automating data validation with standardised templates

A high number of BIM standards and building classification systems exist and more are still being developed on both national and international levels. These standards can be used for data validation of BIM data in the CI. However, digital tools and templates are needed to support data validation because manual checking is unnecessarily time-consuming and subject to error. An example of a current initiative is the bSDD, which removes the human translation and interpretation process from the equation and uses a machine-readable format from the beginning. These initiatives are an important step towards a standardised approach to data and data validation in the CI. By combining systems in databases like bSDD, solutions to name mapping and object naming problems can be found. For example, bSDD provides standardised data templates for national classification systems (Like UniClass) and application-specific standards (Like IfcAirport). When the bSDD gets to a point where it also supports fully developed Information Delivery Manuals (IDMs), software vendors can connect to the bSDD database. This opens the door for end-users to access and use international harmonised templates for the purpose of data validation in the CI. This can potentially enable the use of a single source of truth format, which is both human and machine-readable. Development of such standardised tools and templates is needed to support data validation of BIM data, to ensure high data quality. For such solutions to be a success, the role of software vendors becomes increasingly important. The software vendors must adapt and facilitate these standards, to make the content available for the end-users in the CI. The software vendors must provide platform facilities that better support the heterogeneity of rules needed for the CI (Solihin and Eastman, 2015). However, this adoption still seems to be hindered by the challenges such as those identified in the SSLR. In addition, it seems like those developing the data validation tools are not involved in the creation of the standards. Therefore, each tool is at risk of becoming a standalone solution without connection to a standardised approach including an open data format.

In general, the current approach to data validation within the CI seems to be a stronghold for "experts" resulting in a siloed workflow based on individual capabilities rather than collective cooperation. The true potential of open BIM is not fully served by this approach. Creating machine-readable versions of BIM standards or codes is currently a high-cost process undertaken by experts. Instead, data validation needs to be made more accessible to all participants in the CI. As highlighted by Hjelseth (2015), model checking software in the CI is still a specialist tool, operated by a limited number of professionals. Hjelseth (2015) further argues that for improved information exchange and project-based collaboration the role of data validation becomes critically important. Though, the process is hindered by different factors, as highlighted in the SSLR. For BIM standards, their commonality is that they are written in a human-oriented language. This entails the requirement of significant domain knowledge to interpret these standards into a machine-readable format, that allows for digital data validation. Furthermore, existing data validation templates are often written in a proprietary language and limited in their capabilities due to the complexity of the rules themselves and the breadth of conditions to which they need to apply. In short, data validation is still the domain of industry experts, and the currently manual workflow relies on the accuracy, experience, and expertise of the person or people performing the checks. As of now, the automated data validation process still needs to rely on human input and decisions to achieve trustworthy results. This semi-automated workflow was also identified by Dimyadi and Amor (2013).

5. Conclusion

BIM standards have the potential to be defined into a machine-readable template format that allows for improved, and to some degree automated, data validation. This gives opportunities to data validation solution providers, to provide flexible tools that enable BIM standards and building classification systems for the purpose of simplifying the approach to data validation in the CI. Templates can be a way of making data validation faster and more accessible to all participants in a construction project, by creating a standardised and reliable data validation process. BIM standards and classification systems are of the highest importance in the creation of these templates, to reach a successful data validation process. For a collaborative use of BIM standards, different naming conventions across countries must be considered. Instead of each country and software vendor creating siloed formats and standards, international standards need to facilitate a common approach, to minimise errors, improve collaboration and increase interoperability in the end. These standards must still be specific enough to create practical and machine-readable solutions. While the current standards and guidelines seem vague and don't facilitate practical solutions for data validation in the CI, but only describe and highlight the importance of data validation. Further research is suggested to investigate how software vendors can adapt to and connect with current BIM standards to meet the end-users needs and enable standardised data validation workflows across the CI.

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