Use case for Automated Code Compliance Checking of Accessibility Rules in BIM models using the IDS standard

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Abstract
Automated Code Compliance Checking in BIM models is a use pointed out as a promoter of greater productivity and reliability, especially in the design phase of AEC projects. Several application efforts have been made at different scales, but many barriers were encountered, such as the difficulty of transcribing rules written in human language into a structured and machine-readable language, the lack of modeling standards driven to automated checking, and the fact that the checker software code is not easily accessed. Currently, the evolution of neutral and open-source standards for information exchange turns this BIM use into a more versatile and scalable one. This paper presents the practical application of an automated code compliance checking process for accessibility rules, based on the neutral and open standards IFC and IDS, and presents the successes and limitations of this application, as well as the recommendations for its evolution.

Keywords: BIM, Automated Code Checking Compliance, IDS

1 Introduction
The Architecture, Engineering, and Construction (AEC) industry is highly regulated by laws, codes, and standards, as well as increasingly complex design requirements. The automated or semi-automated checking of Building Information Modeling (BIM) models regulation compliance is one of the most effective uses of BIM technology (Nawari 2018) and a promoter of greater productivity. A common approach to automated code checking is a systematic comparison. The confrontation of each object or system of a digital building model with standards' requirements is a common example (Dimyadi & Amor 2013).

However, the biggest challenge of this BIM use is the search for practical and mutually compatible digital representations of the rules and the model (Nawari 2012). The rules are usually written in a human language, which is difficult for machines to interpret. In addition, today's building codes are the result of many years of experience, trial, and error, sometimes inspired by accidents or disasters, which turns them into extensive and complex compilations that inevitably grow, renew, evolve, and transform (Solihin 2016). One of the main barriers to overcoming these challenges, in the past decade, was the unavailability of a standard information specification (Dimyadi & Amor 2013).

Domain-specific approaches, i.e. systems of rule entries and models, developed for the automated verification of a specific subject (structural analysis, for example) and carried out by authorial software, have already been successfully tried. However, they are of limited application, due to the restricted subject of verification or to the rigidity of the verification software, which is hardcoded. In addition, the systems do not keep up with the evolution of the regulations because their updating often depends on a programming expert, who often does not master the rules that are being incorporated into the code. In summary, the challenges are: (i) the conversion of normative texts (rules) into machine-readable languages; and (ii) the standardization of information exchange, so that both rules and the digital model can be compared and updated by non-programmer users.

Extensive research over the last decades pointed out promising paths: (i) the use of codes common to humans and machines for the rewriting of standards, such as the Extensible Markup Language (XML); and (ii) the adoption of neutral and open modeling schemes, such as the Industry Foundation Classes (IFC), and standards for information delivery specifications, such as the Information Delivery Manual (IDM). The structuring of an automated rule verification system should seek simplicity and a combination of uses of information model management principles and neutral standards (Nawari 2018).

It is also important to note the difference between prescriptive and performance regulations. Performance regulations dictate the expected behavior of a building, not exactly how to do it; Prescriptive norms, on the other hand, indicate constraints, albeit through variables. In the case of highly prescriptive rules, (Grangaard & Gottlieb 2019) have pointed out that by translating accessibility requirements into a checklist, the spirit of universal design is lost, often resulting in designs that are inaccessible or limited to repetition.

This paper presents a work in progress that aims at the development of a practical application that processes automated verification of accessibility rules based on the Brazilian standard ABNT NBR 9050:2015. This is made in a BIM model based on IFC and Information Delivery Specification (IDS) neutral data languages and standards, through free and open-source tools, to be documented as a use case. The achievements are presented, such as the possibility of configuration and reuse of a check by non-programming experts, and the limitations, such as the demand for extensions of the IDS scheme for geometric and topological validations, as well as recommendations for the application in real cases, aiming its continuous evolution.

2 State of the Art

The idea of automating the process of checking compliance with building codes has been explored since the 1960s. However, from the second half of the 1990s onwards, there was a profusion of initiatives, coinciding with the development of neutral standards, such as the IFC (Dimyadi & Amor 2013). The current moment seems to be very promising, due to the development and improvement of neutral standards for information exchange. There is, nevertheless, an arduous task that precedes efficient and reliable automation. According to (Eastman et al. 2009), there are four phases of Automated Compliance Checking (ACC): (i) rule interpretation; (ii) Building model preparation; (iii) rule execution; and (iv) rule check reporting, or communication of results, which may still require human actions.

(Nawari 2018) and (Nawari 2019) proposed a Generalized Adaptive Framework (GAF) for a neutral data standard. The approach gives a theoretical basis for an adaptive framework that supports a neutral data standard to transform the regulations and rules of the written code into a computable model and defines several modules required for the computerization of the code. The process proceeds to the execution phase, through algorithms based on Language-integrated Query (LINQ) programming objects to extract, access, and link BIM and regulatory data via ifcXML.

(BIM Speed 2022) designed a process of verification of properties present in the most typical elements of residential renovation. Even using an authoring tool, the author points out that the same information can be described in numerous ways in a BIM model, making the process more complex. An advantage of this approach is the assistance it provides to the user, by offering a range of design possibilities that would not be noticed without using the tool, still compliant with the project requirements. (Abualdenien et al. 2021) and (Abualdenien et al. 2022) developed one use case in two versions, one for Royal Institute of British Architects (RIBA) standards and the other for International standards, by developing a Model View Definition (MVD) for Occupant Movement Analysis and enriching the IFC with data for building evacuation simulation. This corroborates the hypothesis of producing specific models for specific uses. Hence, the need to link the intended use with ISO 19650 is highlighted, more specifically with the description of the Level of Information Need (LOIN), which defines the requirements that must be specified to establish the context information, one of them being the purpose, in addition to other definitions (Tomczak et al. 2022).

The Object-centric, bottom-up approach made by (Doukari et al. 2022) starts from the analysis of the smallest physical components of a BIM object, such as a floor or a wall, and moves toward the analysis of more complex and interrelated elements. Despite describing IFC element properties in their methodology, the practical application took place on proprietary formats, both in the rules preparation phase, using a commercial plugin called SYNEG, and in the modeling phase.

(Corona 2023) conducted a complete experiment involving all phases of verification and in depth, through three case studies. A significant contribution was the experimentation of artificial intelligence in the interpretation phase of the rules. Phind AI, Chat GPT, Google Bard, and Notion AI tools were used and instructed to apply the RASE methodology in the interpretation of normative clauses of the Slovenian building code. RASE is a semantics-based concept for transforming normative documents into well-defined rules that can be implemented in BIM/IFC-based model verification software (Hjelseth & Nisbet 2011). (Corona 2023) highlights the importance of human supervision in the results produced, nonetheless, the approach contributes by presenting a process based on Visual Programming Language (VPL), providing transparency and flexibility for the reuse of rules repositories.

(Kremer & Beetz 2023) proposes an extension of the IDS schema to overcome a barrier inherent to its current version, of not being able to verify topological relationships between objects in a model, and explicit geometric data (buildingSMART International 2022). The rationale for this extension is that the IFC schema provides options to explicitly represent geometry-related properties and topological relationships between two or more elements through, for example, the IfcRelContainedInSpatialStructure entity. In this way, the IDS schema extension includes a new facet consisting of a link and an expected value. This link points to an external service that performs the necessary calculations to search the model for implicit or hard-to-access values via the "common facets" of the IDS, and the expected value behaves like the other "facets". However, the authors warn that in some situations, given the flexibility allowed by the IFC schema, data models may become inconsistent, and geometry-related information included only implicitly may become impractical or impossible to explicitly map to the data model.

(Nuyts et al. 2024) carried out a comparative analysis of eight different approaches for ACC against the same set of rules. The approaches vary in the type of construction project data (IFC, JSON – JavaScript Object Notation, XML, and RDF – Resource Description Framework) and the type of query used for checking. The authors conclude that the Linked Data-based Shapes Constraint Language (SHACL) is, according to their criteria, the best suited for ACC, despite some limitations.

An ecosystem approach to the problem is proposed by (Beach et al. 2024), instead of solutions based on a single application, through a composition of different software and data sources. The authors highlight scalability, with the potential to analyze around 85% of regulatory documents, compared to 51% for singular approaches.

(Bloch et al. 2023) present a holistic perspective using graph-based machine learning methods that seek to resolve the discrepancy between the semantics in regulatory documents and building design ontology, which do not overlap sufficiently. By treating the verification process as a whole, instead of the regulation and the model separately, the authors overcome the barrier of difficult transcription of codes into computer language, as they take advantage of the fact that "ready-made" models already incorporate compliance with the restrictions.

(Nisbet et al. 2024) describe an approach to the documentation of semantic expectations by actors in the AEC domain to bridge the gap between the application of static compliance knowledge and the accurate and efficient application of correction, enrichment, and enhancement knowledge. The authors add “semantic correction” for situations where errors are detected in the model by extending the RASE methodology.

(Pauwels et al. 2024) focus on system architecture and procedures that enable validating vague constraints and computationally complex constraints through the semantic web, based on the RDF as a data model and SHACL as the standard for validation of RDF data, favoring continuous checks during the design development phase.

Finally, (Tomczak et al. 2022) compared various ways to request information about digital construction projects, in the face of evaluation criteria related to information fields, value constraints, content, geometry, and metadata. Product Data Templates (PDT), Model View Definition XML (mvdXML), IDM, LOIN, Data Dictionaries (ISO12006), IFC Property templates, IDS, SHACL, non-standard textual or spreadsheet documents (DOC and XLS), proprietary solutions, and others, such as dedicated visual programming scripts, were compared. The authors identified the advantages and disadvantages of each method leading to the conclusion that no method covers all the aspects discussed and the selection must be made consciously and based on a purpose. (Bloch & Fauth, 2023) mapped the existing research efforts and pointed to unbalanced research into digitization and automation of the building permit process. The authors investigate approaches ranging from document management to information management, up to full automation process supporting decision making, and conclude that it is necessary for research to advance in the level of detail of approaches and to evaluate the user experience.

3 Methodology

The ongoing research is based on the Design Science Research (DSR) methodology, which has a pragmatic and solution-oriented nature for the development of an artifact (Dresch et al. 2020). Previous research focused on the interpretation and structuring phase of Brazilian accessibility rules was carried out by (Mendonça et al. 2020), based on the T3 and RASE methodologies proposed by (Hjelseth & Nisbet 2011). Many approaches for rule interpretation demand technological apparatus and multidisciplinary knowledge that is hardly available to common users. In this experiment, differently, a manual conversion and structuring was conducted, allowing its individual application by any non-expert programming user. Thus, the current research focuses on the rule and model preparation, and execution phase, fully based on standardized and neutral information exchange schemes adopted internationally.

4 Development

The T3 methodology proposes three classifications for the information present in written regulations: (T1) Transcribe: applicable to instructions that can be directly transcribed into computable rules; (T2) Transform: applicable to instructions in regulations that can be transformed (rewritten or restructured) in a way where the scope is maintained; and (T3) Transfer: when the requirements are expressed imprecisely, without any link between the objectives of the regulation and the identified indicators, and automated verification is not possible, but must be transferred to the analysis of a specialized professional (Hjelseth 2015). After this classification in the original text, T1 and rewritten T2 sentences may be submitted to RASE.

The RASE methodology consists of identifying, in each statement, four logical operators: Requirement (R), Applicability (A), Selection (S), and Exception (E). Clauses marked with the four operators, R, A, S, and E, will contain metric phrases, to which they can be systematically assigned: an object, a property, a comparator, and a target value. Ideally, the object and property should be elaborated from terms classified by standardized systems. The target value can be numeric, with any unit, for which the comparator will be "equal", "less", "greater" or their variants. If the target value is descriptive, the only relevant comparators will be "equal to" or "different". If it still refers to a group of elements, the comparators can be "includes" or "excludes" for any element in the group (Hjelseth & Nisbet 2011).

Information Delivery Specification can be defined as a digital document that describes the requirements for model information exchange so that it is easily read by humans and interpreted by computers. Through facets, it is a scheme that defines objects, classifications, materials, properties, and even values that need to be exchanged. While IDS can be used to specify any type of data in the built asset industry, it works best on data structured according to the IFC standard (buildingSMART International 2022). The first version of IDS targets basic information and relationships in IFC, which are common to all disciplines. However, IDS cannot be used to define project requirements or so-called "rules" (buildingSMART International 2024c). More advanced information requirements are currently outside the scope of the IDS, but this study sought to ascertain what types of information in a regulation can be validated. For example, geometry, calculated or dynamic values, reference data outside the IFC model, or domain-specific IFC relationships are not possible to be checked (buildingSMART International 2022). IDS supports the inclusion of links (formally called a Uniform Resource Identifier - URI) with more information about a property or classification code. Following this URI will provide the user (human or machine) with more information about a property, beyond the level of detail that can be specified in IFC (buildingSMART International 2022).

The buildingSMART Data Dictionary (bSDD) is a collection of interconnected data dictionaries with definitions of terms to describe the built environment and can store relationships between definitions and mapping between different classifications (buildingSMART International 2024a). It hosts detailed and standardized information about definitions, units, relationships to other objects, etc.

Finally, Use Case Management (UCM) is buildingSMART's online use case management service that enables the exchange of experiences and best practices in a collaborative environment accessible to the entire AEC industry. Throughout the entire design, construction, and operation process, information exchange requirements must be defined for each BIM use case based on the IDM methodology, where operational processes and the exact definition of information flow between the respective project participants are described, allowing collaborative work and efficient and error-free data exchange. The exchange of experiences provided by the UCM contributes to a better understanding of the BIM approach, to the faster provision of Information Delivery Manuals, and to the overall improvement of BIM projects (buildingSMART International 2024b). The present work will be submitted to this service so that it is available for evaluation and improvement by other members of the international community and will also be shared in the GitHub repository of IDS developers, a collaborative development platform, for the same purpose.

4.1 Use Case

Use Cases define the purpose and scope of the information delivery. It is also the first step towards the development of the IDM that proposes "a methodology for capturing and specifying processes and information flow during the life cycle of a facility" (buildingSMART International 2024c). (Jeon et al. 2021) propose a format called *smart* for the development of IDMs. *Smart* (Standardized-(and)-Machine-Applicable-Readable-Transferable) standardizes and turns IDM easily exchanged and reused. The present study, however, is not currently focused on the development of an IDM. Therefore, spreadsheets and traditional texts are used and follow the definition of Use Case proposed by (Jeon et al. 2021) of a "specific instance of information use that involves the **aims**, **scope,** and **context** of how, why, when, and by whom the data is used", similar to the definition "It is defined who needs what information at which point of time in which format and in which level of detail to achieve a specific result" (buildingSMART International 2024b).

The **aim** of this Use Case is to propose and evaluate a process of automated verification of rules in BIM models, through the neutral data standards IFC and IDS, using open-source tools. Its **scope** is delimited by the clauses of section 6 – "Access and Circulation" of the Brazilian accessibility standard ABNT NBR 9050:2015.

The **context** for the application of this process takes place in the licensing phase of the architectural project. However, it can also be used in the previous phase of project development by the designer himself to notice errors early and reduce the number of non-conformities in the approvals phase. The process is described in 3.2. Its use aims to provide agility and reliability in the development, coordination, and verification of a project. It can be applied during the design phases and approvals, by designers, architects, engineers, and project analysts.

In this paper, the following adapted clause of the ABNT NBR-9050:2015 standard will be used: "*6.1.1.1 - The areas of any space or building for public or collective use must be served by one or more accessible routes. Multi-family residential buildings, condominiums, and housing complexes* *need to be accessible in their common use areas. Areas of restricted use (…) do not need to meet the accessibility conditions of this Standard.*" (ABNT 2015).

4.2 Process map

ISO 29481-1 recommends evaluating if the use case offers conditions to achieve the defined objectives, that is, if it contains clear and objective descriptions of what is expected to be achieved, the process is mapped (ISO 2016). In this study, the process was written in the Business Process Model and Notation (BPMN), shown in Figure 1. It is worth noting that, during the process implementation, it may be necessary for the Rule Expert to review the conversion, if requested by the Project Analyst.

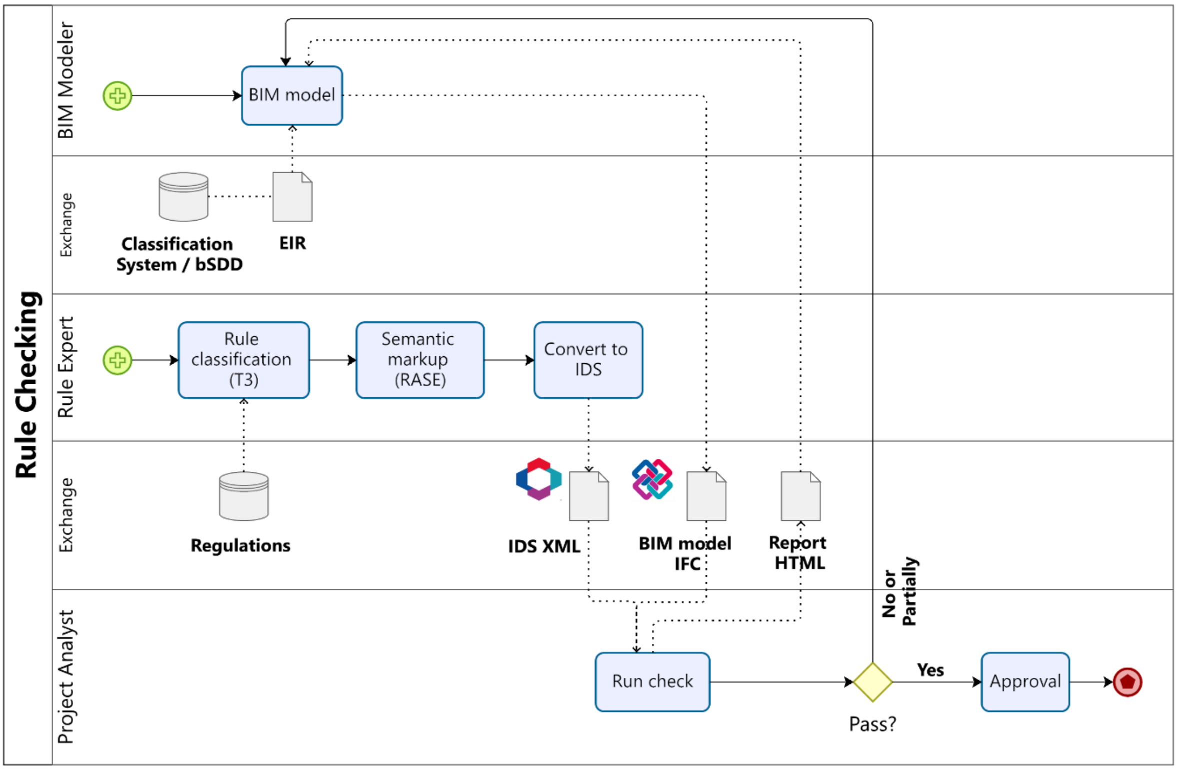

Figure 1. Information exchange process map for automated code checking using IDS

4.3 Exchange Information Requirements (EIR)

Practical application requires the definition of the exchange requirements as the next step in the development of an IDM, and are part of the process map presented. Table 1 shows the EIR used in this study. Terminology and organization applied in this table follows an example of an EIR prepared by (buildingSMART Portugal 2024), due to its compatibility with the original language of this study. Also, it offers a logical and objective structure to inform the necessary data, satisfying the ISO-19650-2:2018 standards on organization and digitization of information in the asset delivery phase (ISO 2018), and EN 17412-1:2020 on the LOIN (BS 2020). The template used includes the minimum requirements of geometric information, omitted in this study because they are not currently verified by the IDS standard.

4.4 Application

The clause considered in this study is classified as T2 according to the T3 methodology and should be rewritten in smaller sentences. Two of these sentences were chosen as examples because they contain the four characteristics of the RASE (Table 2): "*Multifamily residential buildings, condominiums and housing complexes need to be accessible in their common use areas*" and "*Areas of restricted use (…) do not need to meet the accessibility conditions of this Standard*".

The next step is to establish the relationship between the EIR (Table 1) and the standard specifications rewritten and marked according to the RASE (Table 2). It is recommended to anticipate the use according to the IDS scheme. For this purpose, there are both open-source or free authorial tools for creating an IDS file, as well as templates available on the IDS GitHub page (buildingSMART International 2022) that can be reused. IDS Converter (Dias 2024) which generates IDS files from XLS files was used. The preference for this tool was due to the easy correlation between the EIR and the IDS, in addition to providing a more flexible manipulation.

Table 1. Exchange Information Requirements for Space objects

Objects: Spaces	**Applicant Actor:** Analyst	**Supplier Actor:** Architectural Designer	
Project Phase / Delivery Milestone: Licensing Project		**IFC schema version:** IFC 4.3.2.0	
Purpose: Obtaining the licenses, permits, and authorizations for the execution of the asset			
Minimum alphanumeric information requirements:			Required
Attributes			
	Name	As defined in BEP (BIM Execution Plan)	Yes
	IFC Class	*IfcSpace*	Yes
	Predefined Type	*IfcSpaceTypeEnum*	Yes
Property Sets			
	Property	**Property Set**	
	Reference	*Pset_SpaceCommon*	Yes
	IsExternal	*Pset_SpaceCommon*	Yes
	PubliclyAccessible	*Pset_SpaceCommon*	Yes
	HandicapAccessible	*Pset_SpaceCommon*	Yes
Classification System: As defined in BEP		**Table:** As defined in BEP	Yes

Table 2. RASE features applied to the clause of the rewritten regulation in minor sentences

Requirement	Applicability	Selection	Exception
need to be accessible	*Multi-family residential buildings, condominiums and housing developments*	*common use areas*	*Areas of restricted use*

The IDS Converter consists of a template in XLS format composed of three main spreadsheets – specifications, applicability, and requirements – to be used for the conversion of the IDS, as well as a supporting spreadsheet with look-up tables to restrict the data filled. The applicability and requirement worksheets allow the user to input entities, attributes, properties, and values (among other data), that are related to the IDS facets and the cardinality of each specification. Table 3 shows the cell contents filled in the XLS file for applicability and requirements, respectively, of the analyzed clause.

Table 3. Input data in the Applicability worksheet of the IDS Converter tool

Applicability					
ENTITY		PROPERTY			
entity name	predefined type	property name	data type	property set	property value
IfcSpace	IfcSpaceTypeEnum	PubliclyAccessible	IFCBOOLEAN	Pset_SpaceCommon	true

In this case, the exception is handled in the model properties. If a space is restricted in use, it should be classified as PubliclyAccessible = false.

The IDS Converter tool is responsible for transcribing this content into an XML .ids format file. Listing 1 shows an excerpt of the file content, containing the applicability of the clause in the IDS schema.

To evaluate the process, a model was produced natively in .ifc format with the Blender software and BlenderBIM Add-on, with four objects representing spaces:

- Space A meets the Class and the Predefined Type, but does not have the Property Sets defined;

- Space B meets the Class and the Predefined Type, but has the property PubliclyAccessible = false;
- Space C meets all applicability criteria and has the property HandicapAccessible = false;
- Space D meets all applicability criteria and has the property HandicapAccessible = true.

This model has been submitted to the IFC Tester available in the Quality Control section of BlenderBIM, which compares the IFC model with the IDS file. The result was an HTML file containing a summary and details of how many specifications and requirements have been checked, stating how many have passed and how many have failed. In this case, Spaces A and B were not checked, because they did not meet the Applicability criteria. Spaces C and D were checked, with Space C failing because it did not meet the Requirements and Space D passed. The reason for the failure and the respective element GlobalId are listed, so that subsequent actions (such as reporting the error or correcting it) can be carried out.

Listing 1. Conditions of Applicability contained in the .ids format file written in XML

```
<applicability>
  <entity>
    <name>
      <simpleValue>IfcSpace</simpleValue>
    </name>
    <predefinedType>
      <simpleValue>IfcSpaceTypeEnum</simpleValue>
    </predefinedType>
  </entity>
  <attribute>
    <name>
      <simpleValue>Name</simpleValue>
    </name>
  </attribute>
<property datatype="IFCBOOLEAN">
<propertySet>
      <simpleValue>Pset_SpaceCommon</simpleValue>
    </propertySet>
    <name>
      <simpleValue>PubliclyAccessible</simpleValue>
    </name>
    <value>
      <simpleValue>true</simpleValue>
    </value>
  </property>
</applicability>
```

5 Results and discussion

A practical application of automated accessibility rule checking in a BIM model using neutral IFC and IDS exchange standards was presented. Complexity reduction is crucial for developing methods that support automation or semi-automation of code checking (Nawari 2018). However, building models for automated code checking must meet stricter requirements than general-purpose 2D and 3D models. Some properties, like non-slip flooring, are essential for accessibility analysis but unnecessary for other purposes (e.g., energy analysis). To achieve effective automated verification, models should be enriched with relevant information without excess. Information Exchange Requirements and Level of Information Need guide designers in enriching BIM models according to the IFC schema for accurate element classification and later verification.

The RASE methodology's straightforward alignment with the IDS schema highlights this process's advantages. Requirements, Applicability, Selection, and Exception RASE's features are clearly mapped in IDS, although they require attention and logical reasoning during the process. Verification occurs during project licensing, involving various actors without requiring additional programming knowledge. This streamlined process allows a single actor, even in a small office, to self-check project compliance before submission. The human-readable structure of produced documents enables EIR and IDS repository reuse for verifying rules across different subjects.

This automation provides productivity gains, nevertheless, a project licensing process will require human supervision or some additional form of verification, as verifiable properties can be easily manipulated in a model. Also, the IDS schema, which was under development at the time of writing, does not allow geometric verifications, since it was created for model validation. There is the possibility of including dimensional values in alphanumeric properties, easily verifiable via IDS through their facets. This option, however, is not recommended as it is subject to human error. On the contrary, it is recommended to make use of the URI binding for topological checking externally to the .ids file. Likewise, it is not recommended to use custom properties (or user-defined Psets) in the model, but rather the properties extensively offered by the IFC specification.

This study perceived the lack of standardization among IDS-generating tools. The same instructions given to two different tools resulted in different syntaxes and spellings (dataType and datatype, or name and baseName, for example), causing different readings and results by the checker software.

6 Conclusions

The study focused on automated code compliance checking based on neutral information exchange schemes and standards, applicable by non-programming experts. Even though more experimentation is needed, with more complex clauses of the evaluated topic, and regulations of other domains, a gap highlighted in previous research was filled. This was made by advancing the level of detail of the experiment and, also, getting closer to the experience of a regular user (architects, engineers, designers, and project analysts).

The most important finding was the alignment between RASE and IDS. Texts restructured through RASE methodology (either manually or computationally) produce features that can be mapped directly to the specification schema. The research objective was also achieved by proposing a process in simple language to the user and favorable to adoption on a larger scale.

However, this approach is not recommended for the building permit process, without human supervision. Failures in this process can occur in the rule transcription phase, especially if it was made manually. Also, inconsistency of model data can exist, due to deficient definitions of customized properties or topological relations, both of which can lead to false-positive results and need additional checks in external applications.

Considering previous research demonstrating that only one approach is not sufficient for automated compliance verification in different domains or phases of the project, the present study contributes to the existing approaches, offering a process in simple language that is easy to apply by regular users of the AEC industry.

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