Practical formation of verification rules for building information models

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Abstract. Evaluation of machine-readable rules based on the regulation requirements is the first step towards automated examination of design documentation. The article is devoted to practical implementation of previously evaluated algorithm of rules formation for verification of building information models based on rule modeling language. The methodological basis of the algorithm is the RuleML rule modeling language, first- and higher-order logic, and the Industry Foundation Classes (IFC) standard. The author describes testing the software implementation of the algorithm on the example of one of the regulation standards of the Russian Federation. As a result, the main groups of requirements found in the standard were identified. An example of formalization and translation of a specific statement of the standard is given, which confirms the assumption that above-mentioned algorithm is appropriate. Promising areas of research have been identified in order to solve problems related to the inability to translate certain provisions of the standard.

1. Introduction
Examination of design documentation is a mandatory stage of the life cycle of any constructed object that estimates and then ensures the quality of the developed project documentation, to provide safety and quality of the proposed construction object. The importance of this stage is determined by the large number of potential consequences caused by undetected design errors.

Digitalization of the construction industry in Russia has started with the design stage and now this trend is spread to the examination stage. Since 2014, the authorities of the Russian Federation have adopted regulatory legal acts aimed at switching to a life cycle management system for capital construction projects based on information modeling technologies [1-4].

Examination of design results (in the format of information model) if performed in an automated mode generally includes the following stages:
1. Formation of verification rules
2. Preparation of information model
3. Verification
4. Report evaluation on verification results [5-7]

At the same time, the major problem is to obtain so-called verification rules or machine-readable counterparts of requirements of regulatory documents adopted in a specific country.

Based on the available press-releases of the state examination bodies of the Russian Federation, it can be concluded that the final decision on use of a particular tool for obtaining verification rules has not yet been made. A number of approaches world-wide has already been developed in this direction,
such as programming in high-level languages or using parametric tables. However, these technologies and systems despite of being widespread in certain countries do not always lead to the expected results. In case of examination this mainly depends on the local aspects and adaptability of the approaches to the regulation system of a particular country.

The author previously [8] proposed and justified the use of the “RuleML” rule modeling language for verification purposes, which is the actual standard for describing and presenting rules in any subject area. In this article, author has a goal to describe application in practice of verification rules obtaining for building information models based on the RuleML algorithm.

2. Material and Methods
The author have earlier described algorithm of rules creating for verification of building information models based on the rules modeling language [9-12]. The scheme of the algorithm in BPMN notation is shown in Figure 1, and the detail of the first stage of the algorithm is shown in Figure 2.

![Figure 1. Algorithm scheme for rule verification of building information models based on RuleML](image1)

![Figure 2. Scheme of algorithm first stage](image2)

The above-mentioned algorithm is based on the following methods:
1. Rule modelling language RuleML
   RuleML is a system of web rule modeling language families designed for unified representation and exchange of basic types of web rules between different logics and platforms [13], which includes three families: Deliberation RuleML, Reaction RuleML, and Consumer RuleML.
   Since the construction regulations are essentially a description of the way a building or facility should be and they can be interpreted as declarative rules, this algorithm uses the Deliberation RuleML family [9].
2. The logic of the first and highest order
   The Deliberation RuleML family is semantically based on higher-order logic, which in turn is based on first-order logic [14,15].
First-order logic (also called first-order predicate logic or simply predicate logic) is an extension of utterance logic and studies ways of mathematical reasoning involving quantifiers on objects [16, 17]. As part of the algorithm evaluation, some definitions of this logic concepts (for which there are equivalents in the language of Deliberation RuleML) were introduced, which are necessary for understanding its mathematical model. Within the rules forming, first-order logic was used to pre-formalize the statements of regulatory documents, followed by translation into the RuleML language.

3. Standard for data description of information models IFC.

As the technologies of information modeling spread, there were many appropriate software tools appeared that store data in their own data formats. In case when more than one design software tool should be implemented, it is natural to develop a unified format for description of information models, which became IFC-Industry Foundation Classes, currently supported by the international organization buildingSMART. IFC allows storing data about entities, properties of entities that are combined into sets of entities (p-sets), and relationships that link multiple entities of the model [18-20].

In construction standards, as a result of formalization and translation, subject variables, subject constants and predicates can be identified. An option is needed to compare them with the description of the information model in order to check the generated rules. This option is achieved by applying the IFC scheme and pre-translation into it the terms of the natural language terms identified in the formal description of the requirement.

3. Results

The software implementation of the rules generating algorithm for verification of building information models was obtained by developing an application in the “Visual Basic for Application” language. It should be noted that there are built-in tools for text markup recommended by the RuleML organization (for example, Lime), which, however, may be poorly adopted into Russian and have a difficult to understand interface, so the implementation of Russian subsystem is essential. The features of the software subsystem provides that the rules can be formed directly by an expert in the field of a specific standard, who has certain skills of how it should be interpreted, and it does not require the involvement of a programmer.

The rules generating algorithm for verification of building information models and its software implementation were tested to obtain rules based on the text of the standard SP 54.13330.2016 "Residential multi-apartment buildings". This standard was chosen because it contains several sections that affect different structural elements of residential buildings in terms of different groups of requirements. The standard contains 131 rules, which can be sub-divided into 349 atomic statements. At the same time, statements can be divided into two large groups: statements that include requirements and informative statements, the ratio between them is shown on Figure 3. The entire volume of statements containing requirements can be divided into five main groups as shown in the Figure 4.
The data obtained shows that the major part of requirements refers to the first group. At the same time, the data presented in tables can be subjected to fast processing by the algorithm, since they are already partially formalized. Existing syntactic structure of the provisions of the standards provides their formalization in an automated, but not automatic, mode.

As an example, a rule was examined based on a statement 9.3 of SP 54.13330.2016 "Residential multi-apartment buildings":

9.3 If making a thermotechnical design of the fencing structures of residential buildings then temperature of the internal air of the heated rooms should be at least 20 ° C, relative humidity - 50%.

Screenshots of the subsystem interface are shown in the Figures 5-8.
Figure 5. First atom data input

Figure 6. Second atom data input
As far as IFC scheme has no option for “heated” rooms, every room of the apartment was considered as heated.

Based on the input data, a decision table was formed (Figure 9), which is the third stage of the rule generation algorithm.
At the output of the subsystem, a machine-readable and executable rule was obtained, strictly linked to the IFC model representation scheme. The specified subsystem can be hereinafter supplemented with the option to set attributes of markup elements. Based on the received rule, elements of the information model and their properties were determined in the automated mode, the presence and completeness of which are necessary for verification, as shown in Figure 10. All specified elements and properties are provided by the IFC scheme.

**Figure 10.** List of elements and properties, required to verify statement 9.3 of SP 54.13330.2016

| IfcSpace | OccupancyType | SpaceTemperature | SpaceHumidity |
|----------|---------------|------------------|--------------|
|          | living        |                  |              |
|          |                |                  |              |

4. Conclusion

1. There were results of the SP standard 54.13330.2016 "Residential multi-apartment buildings" requirements translation into a machine-readable format based on the RuleML algorithm obtained. The main groups of statements and requirements of the standard were identified.

2. Certain statements of the standard may not be easily translated into a machine-readable format. Further research is needed to develop approaches for processing of the requirements that have not been translated into a machine-readable format.

3. A special focus is required on the requirements that contain links to other standards, as well as on adding entities, properties, and relationships to the IFC scheme that allow automating the verification of specific requirements, that is now not possible.

4. A further research is needed to develop approaches and recommendations to reduce the number of uncertain provisions within the development of standards.

5. The given example of rule processing clearly demonstrated and confirmed that the algorithm based on the rules modeling language may be simply interpreted by wide pool of users (experts in construction).

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