Building product suggestions for a BIM model based on rule sets and a semantic reasoning engine

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Abstract

The architecture, engineering and construction (AEC) industry today relies on different information systems and computational tools built to support and assist in the building design and construction. However, these systems and tools typically provide this support in isolation from each other. A good combination of these systems and tools is beneficial for a better coordination and information management. Semantic web technologies and a Linked Data approach can be used to fulfil this aim. In this paper, we indicate how these technologies can be applied for one particular objective, namely to check a building information model (BIM) and make suggestions for that model regarding the building elements. These suggestions are based on information obtained from different data sources, including a BIM model, regulations and catalogues of locally available building components. In this paper, we briefly discuss the results obtained in the application of this approach in a case study based on structural safety requirements.

Keywords: Semantic Web, Linked Data, Rule checking, Regulations, Building Products

1 Introduction

In the construction industry, in the same way as happens with other industries, specialised applications often make specific use of data for a particular purpose. This approach provides a high level of performance to meet the task for which they were created, but in which part of the knowledge model is embedded in the application. This feature greatly limits the ability to exchange data and knowledge among different programs, especially in multidisciplinary environments such as the development of architectural projects. To overcome this limitation, one can apply a Linked Data approach based on semantic web technologies to decoupling data from the applications to which they belong. Currently there is an increasing number of datasets described according to the principles of the Linked Data approach. Many of them are published as Linked Open Data (LOD), allowing experts, services and applications to exploit this information available on the Web.

Data from different domains described in RDF and OWL languages can be linked through semantic rules, including data from BIM models described in these languages. This way, checking operations on the model can be carried out by using such rules resulting in a highly flexible rule checking process (Venugopal et al 2011, Eastman et al 2009). Some authors (Weise et al 2009, Esfahani et al 2014) refer to it as a "rule-based linking approach", where rules are defined as "IF-THEN" clauses containing logical functions and operations expressed in rule languages (Rattanasawad et al 2013). The application of this approach requires two conditions to be fulfilled. On the one hand, the modelled part of the building that needs to be checked should have enough information in order to allow proper evaluation. On the other hand, there must be an understanding of how this model can be evaluated and completed by applying standard rules for each type of checking.

According to this idea, this paper addresses the question of how BIM models can be checked with rules decoupled from applications by using semantic web technologies. The answer to this question may generate two additional benefits. First, it allows to check the building components of a building information model (BIM), and second, it allows to make suggestions for that model regarding the building elements that might be used to construct the building. The idea is to provide suggestions based on information obtained from different data sources. To achieve this aim using semantic web technologies, the information should be described semantically and linked to facilitate reasoning processes on BIM models (or parts of them). We have carried out several experiments to evaluate the feasibility of applying this approach in a case study described in the last section of this paper. We have tested this case with precast concrete products for structural modelling in order to facilitate the pre-dimensioning task. By applying this approach, a system can suggest which precast concrete products are suitable for application, thus meeting user requirements and structural safety requirements.

2 Checking BIM models with semantic technologies

The Architectural, Engineering and Construction (AEC) industry integrates different domains of information (materials, products, regulations, costs, building models, etc.). Part of this information is accessed and used in the process of building design and modelling. In current project development, this process results in the creation of different models of the building, according to each discipline that can be involved (architectural design, structural calculation, facility management, etc.). This reality poses a difficulty for coordination, since both integration and information exchange lead to various associated problems already known: information needs to be remodelled; some information is lost in the exchange; there is a lack of rules and restrictions for change propagation; and so forth. To overcome this situation, Semantic Web technologies can be suggested to address part of the problem.

2.1 Semantic web technologies and rules

Several authors (Patil et al 2005, Beetz et al 2009, Pauwels et al 2011) have proposed different ideas and approaches over the last years about how to enhance interoperability in the BIM processes, based on semantic web technologies. First, these technologies allow to create links between different data sources on the Web, a concept referred to as a Linked Data approach (Bizer et al 2009). To create these links, information must be formalised in the representation language used within the semantic web domain, namely the Resource Description Framework (RDF) (Manola et al 2004), a flexible data model that is based on directed labelled graphs. If the information of a domain is represented and interlinked with information from other domains using this language, it can be read and processed automatically by programs and services capable of parsing this language.

Second, the RDF data model allows to formally represent inference rules (IF=>THEN statements) in conjunction with the data represented using RDF. These inference rules facilitate the extension of the represented data (IF-part of the rule) with data that can be logically inferred (THEN-part of the rule) from that represented data (Weise et al 2009). Through a number of interrelated inference rules, one is able to 'check' the data in the RDF graph and make conclusions accordingly. The IF-parts of these rules hereby capture the different conditions and constraints that need to be met, whereas the THEN-parts of the rules capture the conclusions that need to be made accordingly. According to (Eastman et al 2009), outputs from such rules can provide results such as "pass", "fail", "warning" or "unknown" according to the type of checking required for each possible situation.

These features of semantic web technologies can be relied upon to address different situations around the management of building information (BIM data), especially when the combination of information from different domains is required. In section 3 of this paper, we will look into one particular use case in which these rules can be applied, not only for checking operations, but also to suggest possible alternatives, in this case based on the most suitable building components for a building design.

2.2 Application in the selection of building products

In the phases of design and construction may be situations in which architects or construction specialists may wish to replace the components in their BIM models with more precise building components that are:

1) easily available in the neighbourhood of the construction site;
2) within the current budget of the project;
3) within structural (or project) requirements;
4) conform to the European, national, and local regulations.

With this information online accessible, semantic web technologies can be used to provide a way to combine all these data to provide a homogeneous view of the information to end users and applications (Wache et al 2001). The first step to provide the interlinking between these domains is to represent the information by using Semantic Web languages, namely RDF, RDFS (Brickley & Guha 2004) and OWL (McGuinness & van Harmelen 2004). These are well established languages created by W3C to describe ontology models in a formal way by means of classes, properties, data types, relations and axioms.

2.3 Modelling structural precast components

For precast concrete structures, a good combination of precast building components needs to be chosen according to the project requirements. Each of these components has a type associated that determines the order in which it can be connected with the other components. One of the most critical issues in the design is related to the dimensions of these structural components. The less amount of precast concrete is used for a component, the cheaper it is to manufacture the component. Therefore, the dimensions of the concrete components should be as thin or slender as possible (design criterion 1), nevertheless keeping compliance with the structural integrity and the associated regulations (criterion 2 and 3). Often, to achieve the best combination it is necessary to carry out several iterations through the modelling program and the calculation tools. These iterations are necessary to obtain compliance with all the criteria that are set for the component. This leads to having to reconfigure or modify the models multiple times, also when they are almost finished, as a result of noncompliance in the restrictions of the model.

So the general idea argued for in this paper is to minimise this iteration process by applying different types of "checking" and by providing possible "suggestions" on certain types of structural components (e.g. beams, slabs, corbels) of the building model. With "checking", we refer to the process of verifying whether the current components comply with one or more associated regulations (e.g. rules for limit state design for slab components imposed by the regulation considering self-weight and loads). With "providing suggestions", we refer to the process of recommending which products comply with the current building model state and with the associated regulations (e.g. products from a specific company are the most appropriate considering the features, manufacturing location, etc.). Namely, architects may have used building components from a library not associated with existing products in the market to create the model. Those components can be automatically replaced considering some of their parameters (e.g. dimensions) as references.

2.4 Improving structural model assembly with semantic rules

In this paper, we argue for the usage of semantic web rules for enabling the checking and the suggesting processes. This argument is to a large extent based on the pointers provided by Eastman et al. 2009. These authors suggest that automated rule-checking processes could have a wide deployment in particular tasks, such as building code checking at different scales (national, regional or municipality), even when these rules only have information from a specific building project, for example, requirements for spaces, circulation and others that can be imposed by the owners and final clients.

The combination of diverse semantic data sets and sets of computable rules enables the extraction of new knowledge derived from logical inferences. As such, the implicit building

model information may become explicit, for example, by inferring conclusions about checks on the model. Some approaches of automated rule-checking processes based on semantic web technologies can be found in the review of the state of the art. For example, Pauwels et al. 2011b proposed a rule-checking environment for building design and construction where the rules are stored in a knowledge base. They applied this approach in the implementation of a test case for acoustic performance checking, highlighting the advantages in terms of modularity and flexibility by using semantic web technologies compared to alternative traditional approaches.

In our investigation, we have focused on the requirements that surround the choice and checking of components and building products. We aimed at composing and applying those rules that are required to check whether a building model consisting of structural components fulfils the structural safety regulations, and also to suggest alternative product components for unidirectional ceiling slabs of a building. These rules are manually created from information extracted from the regulations.

3 The use case: replacing BIM model components with building products

In this paper, we focus on a particular use case in which information from different sources needs to be combined in a logically sound manner. We have considered building a system that automatically checks a modelled part of a building structure in the Autodesk Revit program and, based on this check, provides possible suggestions of product components that may be applied to actually build the structure. In doing the BIM model check and retrieving possible suggestions, the system uses product catalogues and a set of rules that formalises structural building regulations.

To test this approach, we use a part of a model extracted from a full real project provided by the Precat company to perform the experiment. For practical reasons and for simplicity in the explanations for each step in the experiment, we have chosen to use only a part of the model to demonstrate the proposed approach. This part of the model is composed of four columns and several floor levels. Figure 1 shows the model baseline and the final result to be obtained in an automated way.
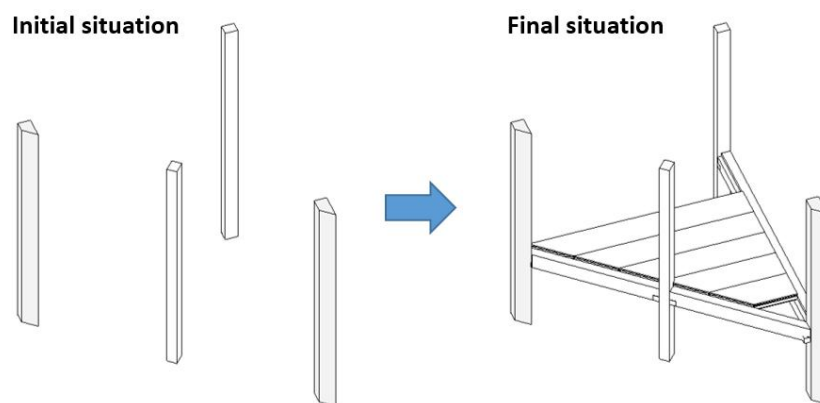
Figure 1 BIM model baseline and the final result to be obtained.

We are relying on both features of semantic web technologies outlined in the previous section, namely the possibility to link multiple data sources and the possibility to combine this also with formal rules. On one hand, we have BIM models described following a specific ontology according to the application used to create them, in this case Autodesk Revit Structure 2014. On the other hand, there are two external data sources involved: 1) the Spanish regulation for safety calculation in concrete structures: EHE (Instrucción Española del Hormigón Estructural), and 2) the BAUKOM building product catalogue (Costa & Madrazo 2014).

We have extracted the part of the EHE regulation corresponding to the safety calculation on hollow-core slabs (EHE 50.2.2.1) to check the case proposed. This part of the regulation is based on an estimation based on the minimum height of the slab:

$$h_{min} = \sqrt{\frac{q}{7}} * \left(\frac{L}{6}\right)^{\frac{1}{4}} * \frac{L}{C}$$

with:

q: total load (in KN/m^2).
L: length of the slab (in meters). Typically, this is the distance between two beams supporting the slab.
C: coefficient from a table of cracking safety values for slab elements. It can be 36 (partitions and walls) or 45 (roofs).

The calculation by using this simple formula (according to EHE 50.2.2.1) avoids the complex flexural strength calculation (EHE 50.1). However, two conditions are required to be applied: 1) the distance between the columns cannot exceed 12 meters and its overload must be greater than 4 KN/m^2, and 2) hollow-core slabs do not exceed their flexural cracking as a consequence of an infrequent combination of charges.

In addition to the EHE regulation, information from the BAUKOM building product catalogue is also used. This includes parametric BIM models provided in different formats and associated information described in semantic web languages. The BAUKOM building product catalogue is the result of a research project aimed at developing online catalogues of building products for the AEC industry. Only products of the Precat Company are currently provided in the catalogue but it is enough to carry out this proof of concept. The BAUKOM catalogue provides an open online SPARQL endpoint (Prud'hommeaux & Seaborne 2008) for querying the information available in the catalogue.

4 The proposed rule-checking and suggestion system

In this section, we document our methodology and technical setup regarding the creation and usage of semantic rules for checking BIM models and suggesting building products as valid candidates in this specific BIM model. The components in the technical setup and how they are connected are outlined in Figure 2. Of key importance in the figure is the modelling program (left in Figure 2), which is Revit in our study. A plugin is developed for Revit, which relies on a Revit BIM ontology to communicate with AEC services on the web (see towards the right in the schema in Figure 2). These AEC services are connected with 'Product Catalogues Services', which supply databases of building products, and 'Public Administration Services', which supply databases with rules about regulations that need to be followed. These rules are extracted from the official documents in a separate, mostly manual process (extreme right of Figure 2).
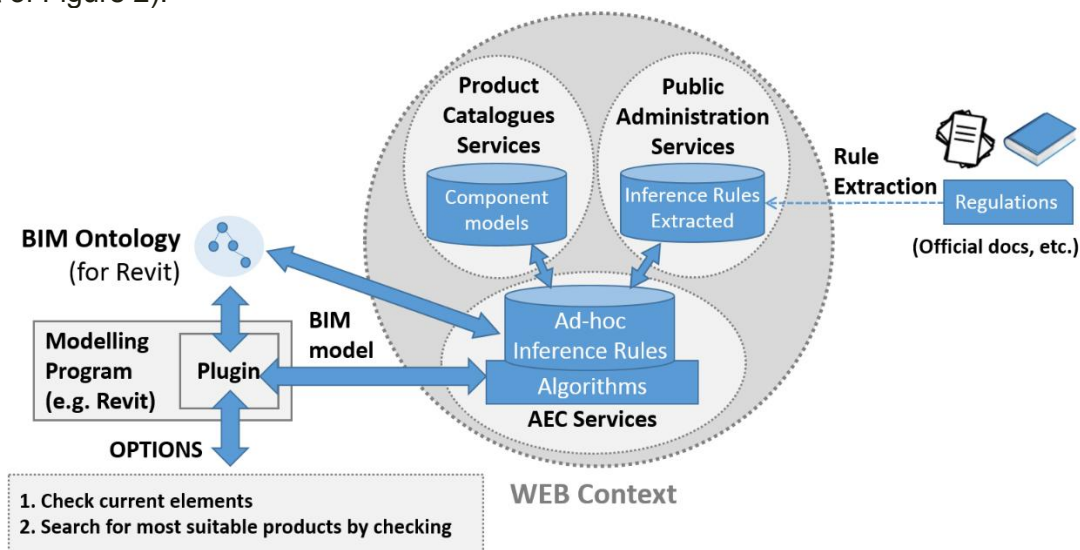
Figure 2 Diagram showing the connection between the three components involved in the rule processing: modelling program, plugin and AEC web services.

4.1 Making a homogeneous view available on the data sources

There are two basic approaches to provide the data interlinking using semantic web languages. In the first approach, information of each domain is transformed and described completely in RDF —as a representation of logic-based declarative statements—, which can be provided in different file formats or syntaxes (rdf/xml, n3, turtle, etc.), or through a SPARQL endpoint (e.g. by a triple store such as OpenLink Virtuoso, Fuseki, etc.). In the second approach, data is provided through data federation, where the role of the RDF data model is to resolve the query processing operations through query mediation (Sattler et al 2005). This approach is more appropriate when the RDF data model is used to reconcile information from different (legacy) data sources which can be physically distributed. Using an OWL ontology and mappings to each data source, queries in SPARQL can be performed to access the data in a unified way. Languages such as D2RM (Bizer & Seaborne 2004) or R2RML (Das et al 2014) can be used to perform and maintain these mappings between relational databases and RDF datasets. In this approach, data (instances) are retrieved from each data source through a 'mediator' component that resolves the query processing, for example, Ontop/Quest (Rodrıguez-Muro & Calvanese 2012).

In our use case, we consider the three following data sources:

1. BIM model in a BIM modelling environment (data).
2. Building product data in open product catalogues (data).
3. Regulation in a public administration office (rules).

For this use case, we limit ourselves with example data sets. Figure 3 shows the BIM model on which we relied and the way in which it was represented in RDF. In this case, the most relevant part of the ontology and the corresponding instance graph is shown. The ontology consist of five related OWL classes and illustrates how part of the scheme of this model is structured.
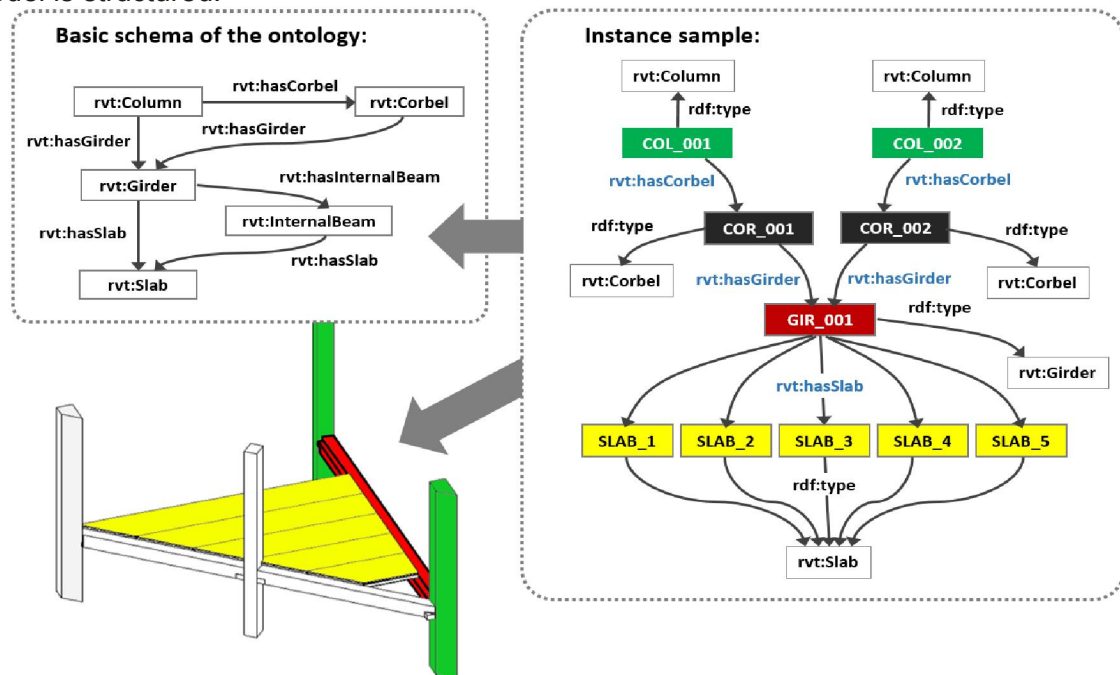

Figure 3 Basic part of the ontology and its instantiation for the proposed example as an RDF graph.

The BAUKOM building components catalogue is provided in a very similar fashion, thus presenting RDF graphs with material information (data). The regulations are provided in a slightly different manner, as they are specifically supplied as specialised rules. These rules also have an RDF graph representation, but they take the shape of IF-THEN statements, rather than the factual RDF triple statements. At present, these rules are not provided in any semantic format by the public administrations. For this reason, we have created an own limited

set of rules to be applied in our proof of concept —as an example for this third data source. An example rule is given in Figure 4.
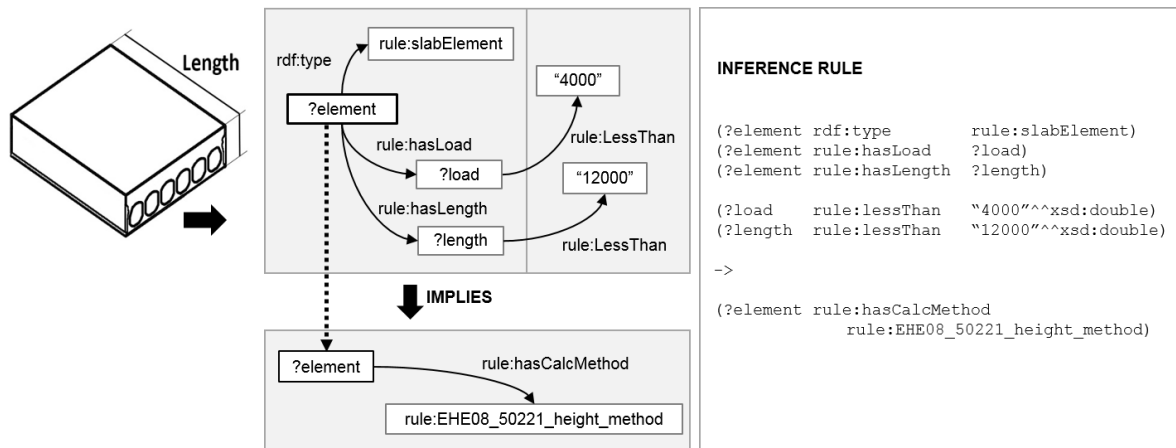
Figure 4 Basic example of a rule (in JenaRule language) allowing to infer the most appropriate calculation method (namely, rule:EHE08_50221_height_method) for elements of type rule:slabElement with a load less than 4000 KN/m² and a length less than 12000 millimetres.

4.2 The rule checking and suggestion system

Considering the three data sources described above, as inputs for the rule-checking and suggestion system, the idea is that specialists can combine the required parts of the schemes and rules of these data sources to create ad-hoc inference rules. Following the example of checking for the safety calculation on hollow-core slabs (EHE 50.2.2.1) described in section 3, we describe here an inference rule using required information from three data sources. In this case, we need to infer if the calculated value for the variable "slabHeightValue" meets the condition of minimal "height" for each hollow-core slab component of a BIM model. The code in Figure 5, 6 and 7, described in the JenaRule language, shows three parts of the rule we consider here.

Figure 5 Part of the rule describing the required information from the building model RDF graph (PART 1).

The first part of the considered rule (Figure 5) allows to retrieve instances of hollow-core slabs elements from input BIM models using the Revit ontology. The requested instances are represented by the "?slabDummy" variable in the code. For each instance, a number of parameter values are required to calculate part of the formula for the checking: maximum variable load, length, width, height, weight and the height of the compression layer.

The next part of the rule (Figure 6) shows, on one hand, a list of operations required to perform the calculation of the formula for the minimum height of the slab $h_{min} = \sqrt{(q/7)} * (L/6)1/4 * (L/C)$, obtaining the value in the "?slabHeightValue" variable. On the other hand, it includes the final checking, where difference between the height of the current instance and the

calculated value need to be less than zero. If this condition is validated, then the conclusion part does too.
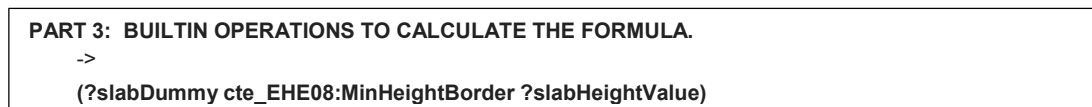

PART 2: BUILTIN OPERATIONS TO CALCULATE THE FORMULA.
```
quotient(?weight "1.2"^^xsd:double ?HCS_Weight_PerUnit)
product(?comprLayerHeight "2.5"^^xsd:double ?ComprVariableLoad1)
product(?ComprVariableLoad1 "9.8"^^xsd:double ?ComprVariableLoad)
sum(?variableLoad ?ComprVariableLoad ?totalLoad_q1)
sum(?totalLoad_q1 ?HCS_Weight_PerUnit ?totalLoad_q)
quotient(?totalLoad_q "7"^^xsd:double ?SqrtValue)
sqrt(?SqrtValue ?HCS_Value_Sqrt)
quotient(?length "6"^^xsd:double ?HCS_Lenght_Div)
pow(?HCS_Lenght_Div "0.25"^^xsd:double ?HCS_Lenght_Pow)
quotient(?length "36.0"^^xsd:double ?HCS_Lenght_Height_Div)
product(?HCS_Value_Sqrt ?HCS_Lenght_Pow ?sum1)
product(?sum1 ?HCS_Lenght_Height_Div ?sum2)
difference(?sum2 ?comprLayerHeight ?sumTotal)
product(?sumTotal "100.0"^^xsd:double ?sum3)
difference(?sum3 ?height ?slabHeightValue)
lessThan(?slabHeightValue "0.0"^^xsd:double)
```

$$h_{min} = \sqrt{\frac{q}{7}} * \left(\frac{L}{6}\right)^{\frac{1}{4}} * \frac{L}{C}$$

Figure 6 Part of the rule describing the calculation according to the EHE 50.2.2.1 formula used to derive the minimum height of valid hollow-core slabs (PART 2).

Based on parts (1) and (2), it is possible to infer a list of facts specified in the conclusion part (Figure 7). Since we require to check if a formula is valid for an instance slab element of the BIM model, resulting output specifies that the condition is fulfilled with a specific value. This is specified in form of aggregated statements available in the RDF graph of the BIM model.

PART 3: BUILTIN OPERATIONS TO CALCULATE THE FORMULA.
```
->
```
(?slabDummy cte_EHE08:MinHeightBorder ?slabHeightValue)

Figure 7 Conclusion part of the rule with the fact to be inferred (PART 3).

The result of the checking process carried out by the Java inference engine for an inference rule like this, in the form of RDF statements, is added to the RDF graph as a possible update of the original BIM model. This new version can be stored in an online triple store (e.g. Fuseki), be provided to the BIM applications, for example, via a direct connection through a plugin developed to facilitate this process, or be saved in a file.

4.3 Results provided by the system

Inference rules can be applied to check if components in the model are valid, or otherwise, the key attributes of the components can be replaced with product attributes in order to find products which may be valid candidates or alternatives. Following the example of the inference rule described in the previous section 4.2, Figure 8 shows a part of the BIM model updated with the new data inferred after its application.

If the result inferred of a checking process for a slab component from the model is false, valid slab products from the BAUKOM catalogue are included in the BIM model via property "rvt:hasSuggestedProducts" (e.g. cat:LP40, cat:LP50, cat:LP63). In this case, the total list of slab products from the catalogue is retrieved before the inference rule is applied. This list is obtained by querying via SPARQL against the BAUKOM catalogue according to this type of component, retrieving the part of the RDF graph with the parameters required for the checking process.

The advantage of the proposed method and system is that it could also be applied for the rest of the calculations required for the pre-dimensioning task, following the same procedure. In this way, different rules can be created to process each required calculation and regulation compliance check. This approach is presented as more efficient when one considers that these rules can be defined in a standard and formal language. This way, by using inference

rules in the context of linked data, the development of programs for checking BIM models becomes easier, with rules and data kept external to the actual programming code.

```
@prefix rvt: <http://www.autodesk.com/revit/ontology/revit2015#> .
@prefix cat: <http://www.baukom-catalog.org/baukom/cpo/product#> .
@prefix cte: <http://www.codigotecnico.org/cte/export/sites/default/web/galerias/archivos/DB_SE-AE_abril_2009#> .
...
rvtm:slab_1
    a                    owl:NamedIndividual , rvt:slabElement;        │ Input values required for calculation │
    rvt:variableLoad     "6.0"^^xsd:double ;
    rvt:length           "10.000"^^xsd:double ;
    rvt:width            "1.200"^^xsd:double ;
    rvt:comprLayerHeight "0.05"^^xsd:double ;

    rvt:height               "32.0"^^xsd:double ;                       │ Check failed for the current "height" │
    cte:50221_MinHeightCheck "false"^^xsd:string .

    rvt:hasSuggestedProducts cat:LP40 ,                                 │ Alternative references of products    │
                             cat:LP50 ,                                 │ inferred                              │
                             cat:LP63 ;
```

Figure 8 Part of code of a BIM in which information about the checking of precast regulation EHE08:50221 is provided, and possible three valid product alternatives of the catalogue for an instance (rvtm:slab_1) is suggested.

5 Conclusion

The exploratory study in this paper demonstrates the calculation context for the specific part of the problem regarding the hollow-core slab components. However, the same process can be applied for the rest of the calculations required for the pre-dimensioning following the same procedure. In this way, different rules can be created to process each required calculation and checking. This approach is presented as more efficient when you consider that these rules can be defined in a standard manner. This way, by using inference rules in the context of linked data, the development of programs for checking BIM models becomes easier, while rules and data are external to the actual programming code.

Currently, there exist different information systems and computational tools that are built to support and assist in architectural design and construction industry, but in isolation. Building tools to try to cover all the domains is infeasible and pointless. Instead of trying to integrate packages into one platform or framework, a decentralised solution can focus on connecting the data of specific domains as required using the appropriate technologies and contexts of use. However, to make a profit of this linked data, programs must also integrate capabilities that enable the interaction with these types of information, namely information represented using the RDF data model.

This paper shows how semantic technologies can be applied in a semantic rule-checking approach to check elements of a BIM model and provide suggestions based on possible alternative products —from a catalogue—, while fulfilling the structural safety standards. Since the information of each of the data sources that may be required for processing a rule is described as RDF graphs, required parts of each data source can be easily combined.

Although structural calculations are usually made by very powerful and sophisticated programs, a high number of iterations is typically necessary between the architectural modelling programs and these structural modelling programs, which are responsible for carrying out the structural calculation. Because architectural and structural modelling are two separate functions in the BIM process —carried out by different actors—, this makes each iteration expensive in terms of management. One way to avoid the number of iterations is to ensure that the architectural model fits from the beginning to the structural safety standards and design criteria, reducing the required number of iterations as much as possible. The approach proposed here is intended as a solution to achieve this goal. Additionally, one may opt to do the same for other domains handling building data (e.g. energy efficiency, acoustics and others) and generate rules from the associated regulations, so that they can be applied to building models using the same process.

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