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BIM SPEED

Semantic design rules and tool for deep renovation design

Deliverable Report D7.3

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BIM-SPEED
Harmonised Building Information Speedway for Energy-Efficient Renovation

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Publishable executive summary

The digitalisation of the construction industry increases continuously, and emphasis is more and more given to the potentials provided by BIM and semantic web regarding the automated evaluation and validation of 3D models. To that context, model checking is more and more demanded to see if a model complies with the required guidelines, standards or specifications. The main objectives of the compliance checking concept is to inform the designer about possible errors, as well as guide them to consider a larger range of realistic solutions than is practical without this support. This is particularly relevant in areas where the designer is not an expert or has limited experience. To this end, the present report presents a set of semantic design rules for deep renovation and their implementation to a BIM-based model checker tool. In particular, the model checker tool in which the design rules are implemented, allow the design teams to automatically perform model checks against thermal and acoustic standards, fire safety and accessibility requirements in residential renovation projects located in the countries where BIM-SPEED demo cases are located. In the cases that the model elements fail to comply with the design rules, alternative elements are proposed using objects from the BIM-SPEED database. The report is a summary of the work carried out under D7.3 and serves as an accompanying document to the rule set file and the model checker tool, so that a holistic understanding is achieved. The model checker tool developed by DEMO is accessible through a web browser and the url https://demo.demobv.nl ,or through the BIMSpeed platform, which has integrated RE Suite link. Complementary to previous one, the rules sheet is available as open data on an Open Research Data Repository on the following link http://dx.doi.org/10.14279/depositonce-12566

List of acronyms and abbreviations

AEC	Architecture, Engineering and Construction
DoA	Description of Action
DSS	Decision Support System
BIM	Building Information Model
HVAC	Heating Ventilation Air Conditioning
IFC	Industry Foundation Classes
LIC	Location Identification Code
MEP	Mechanical Electrical Plumbing
MVD	Model View Definition
nZEB	Nearly Zero-Energy Buildings
OWL	Web Ontology Language
PCD	Point Cloud Data
PIC	Plant Identification Code
PoR	Program of Requirements
RDF	Resource Description Framework
SBVR	Semantics of Business Vocabulary & Business Rules

Definitions

Semantics

Semantics is defined as the branch of linguistics and logic that is concerned with meaning. The two main areas of semantics are logical semantics (concerned with matters such as sense and reference and presupposition and implication) and lexical semantics (concerned with the analysis of word meanings and relations between them).

In the context of BIM, the semantics of a building object are composed by its form, function, and behaviour. These are manifested by its shape (3D geometry), material and mechanical properties, functional classification, topological and aggregation relationships with other objects.

Semantic Design Rules

Under the scope of BIM SPEED, semantic design rules are a set of rules that encapsulate information from building regulations, technical guides, and other standards, as well as experts' experience, emphasising the meaning, reference and relation of these rules. Humans are used in the process of reasoning from one or more statements (premises) to reach a logical conclusion, yet machines need semantics to 'simulate' this process.

Ontology

A set of concepts and categories in a subject area or domain that show their properties and the relations between them.

Semantic Web

Extension of the World Wide Web standards with the objective to make Internet data machine-readable. The main challenge that exists is that machines often cannot analyse the meaning of words and overcome challenges such as vastness, vagueness, uncertainty, inconsistency, and deceit. For this reason, automated reasoning systems have been developed to deal with these issues.

Attribute Value System

An Attribute Value System is a basic knowledge representation framework comprising a table with columns designating 'attributes' (also known as 'properties', 'features', 'dimensions', 'characteristics' etc. depending on the context) and rows designating 'objects' (also known as 'entities', 'instances', 'dependent variables'). Each table cell therefore designates the value (also known as "state") of a particular attribute of a particular object. Attribute value systems have been also mentioned as spreadsheet in part of the literature.

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1. Introduction

1.1 Description of the deliverable content and purpose

Deliverable 7.3 presents a set of semantic design rules for deep renovation designs, as well as their implementation to a BIM model checker tool. Like the model checking process developed under T5.3 in which the renovation model is checked against technical rules (for instance, level of detail, format etc.), deliverable 7.3 also presents the automated rule-based validators developed for checking candidate solutions (building and HVAC elements) against part of the building renovation legislation and highlight all candidates that do not comply with the regulation. In addition to the discarded candidate solutions, alternative solutions that comply with the legislative framework are proposed, using the BIMSPEED database as the solutions´ inventory. As detailed described under D7.2, machine-learning and artificial intelligence can further support the enrichment of the semantic design rules so that the model checking is developed and further aspects are checked, as for example common building pathologies.

The purpose, scope and intended end-users of the work carried out under D7.3 can be summarised as follows:

- **Purpose**: The semantic design rules are developed to represent the denotation of elements and the relationships between these elements. Under the scope of BIM-SPEED project, semantics are useful to 'translate' experts' knowledge about buildings regulations into a language that can be understandable by data experts. Once this knowledge is translated to a computer-based language, the rules are accommodated to the model checker tool, where an automatic regulation compliance checking is performed. The purpose of the checking process is to warn the users for possible failures, as well as to propose them alternative renovation objects that comply with the rules and can be integrated to their designs.
- **Scope:** The design rules focus on the most typical elements for renovation in a residential building, covering the building envelope (roof, wall, windows), HVAC systems (boiler replacement, wall radiators) and common use elements such as stairs and corridors. The semantics include information on four basic criteria: thermal and acoustic comfort, fire safety and accessibility.
- **Intended end-users:** Architects, designers, engineers to check their 3D models against a set of design rules, discard objects that do not comply and find alternative renovation objects that comply.

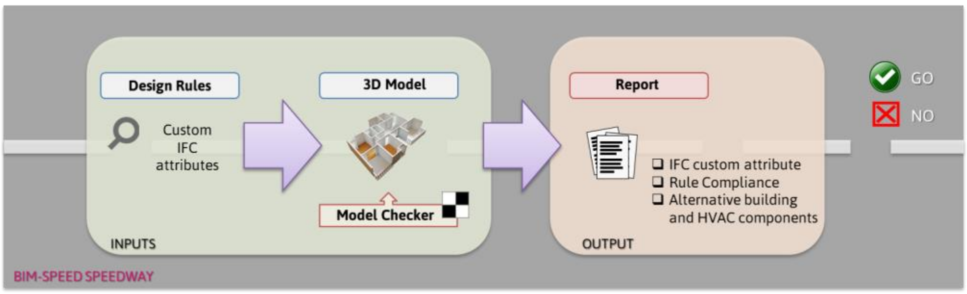

Figure 1. Concept for the development of D7.3.

Figure 1 illustrates the overall objective of

D7.3; to check the 3D model and decide whether it complies with the semantic design rules. Based on that, similar to a ''vehicle'', the model can proceed (Go) or not (No) to the BIM-SPEED speedway. To achieve the checking, additional property sets are imported to the existing 3D model, subject to checking by the model checker and a report is generated to inform the user whether all custom attributes exist and contain data, if the objects comply with the design rules and whether additional objects of BIM-SPEED database can be found to comply with the design rules.

1.2 Methodology and contribution of partners

To develop the set of semantic design rules and configure the BIM-based tool to accommodate them, the following steps were carried out:

- **Review of state of the art:** The review of the existing literature included a variety of topics centred around semantic web technologies, semantic enrichment of BIM models and semantic-based approaches for regulation compliance. Streamer state-of-the-art design configurator[1] was also studied, focusing on the way to implement the semantic design rules to a BIM environment.
- **Design rules specifications:** As described in detail in par. 3.1, various factors affected the set of boundaries for the design rules to be collected. The most important of them are:
    - Focus on building renovation strategies and elements for each demonstration building, as well as common renovation objectives;
    - Emphasis on the most important aspects to check during the early design phase of a residential renovation project based on the experience of BIM-SPEED consortium experts;
    - Availability of components and HVAC products in the BIM-SPEED database, ensuring that the available data will match the requirements set by the design rules.
- **Design rules collection**: Based on the above-specifications, the experts' knowledge, experience, as well as national and international standards were compiled in one excel spreadsheet. Given the excess of topics and standards around them, the above-described boundaries were further specified focusing on thermal and acoustic comfort, fire safety and accessibility, and further limited to rules concerning the refurbishment of the building envelope (façade, roof, windows), the heating systems (boiler and radiator) and the common areas (stairs and corridors) of residential buildings.
- **Design rules implementation and model checker tool:** After the collection of the design rules, a JSON editor was developed to translate the ´´informal´´ rules collected in the excel spreadsheet to JSON files. In addition to the rules set, an IFC model was also prepared for the test and demonstration of the model checker. All custom IFC Attributes were added to the IFC demo-model and the respective values were given. Loading the IFC demo-model and the rule set model checker tool developed by DEMO [2], the model checking was initiated.

[1] https://www.streamer-project.eu/

[2] The tool is accessible through a web browser and the url https://demo.demobv.nl ,or through the BIMSpeed platform, which has integrated RE Suite link.

- **Test and verification of the tool:** The model checking was tested against representative design rules, such as rules about thermal comfort and fire safety. Using the model checker, all the objects of the Spanish demo building of Aldabe 26 were checked against the relevant design rules collected for Spain. The results highlighted the objects not complying with the design rules, as well as objects that they did not contain the respective values so the check could not be performed. In addition, for the highlighted non-complying objects, alternative solutions were proposed by a pool of solutions extracted by the BIM-SPEED database.

The methodology steps are described in detail in the present document. Specifically, the following section (section 2) gives an overview of the existing literature and relevant use-cases regarding the use of semantics integrated to BIM environment. Section 3 presents the specific boundaries set for the collection of design rules and their compilation in an excel spreadsheet so that they can be retrieved by the BIM tool developers. In section 4 the translation of the rules located in the excel spreadsheet to JSON is presented, as well as the development of the BIM tool to perform the model checking against the semantic design rules. Obtained results are also demonstrated by applying the model check to the 3D model of the Spanish demonstration building. Section 5 summarises the overall results obtained by D7.3, as well as barriers, limitations and lessons learnt. The contribution of each partner to the present deliverable can be found in the following Table 1 :

Table 1. Partners Contribution

	Partner	Contribution
1	**LKS**	Leader of the deliverable, coordination of the overall task activity, screening of state-of-the-art, collection of legislative requirements for Spain and compilation of design rules for all the demonstration case countries. Preparation of Spanish demo 3D model for model checking.
2	**TUB**	Link with multi-decision support tool that defines needs and input requirements. Collection of legislative requirements for Germany.
3	**DMO**	State of the art Streamer BIM tool: design configurator. Collection of legislative requirements for Netherlands. Coordination for the implementation of the semantic design rules to the model checker. Test and verification of model checker.
4	**CSTB**	Work on computational implementation of the semantic design rules into a BIM environment.
5	**CARTIF**	Work performed under D7.2: Link with potential optimization of design rules by machine learning.
6	**HTV**	Provided expertise on computational implementation of the semantic design rules into a BIM environment. Link with D5.3, test and verification of model checker.
7	**UNIVPM**	Collection of legislative requirements for Italy.
8	**ARC**	Collection of legislative requirements for Romania.
9	**ASP**	Collection of legislative requirements for Bulgaria.

10	**FAS**	Collection of legislative requirements for Poland.
11	**MOW**	General overview of deliverable to ensure coherence with WP7.

1.3 Interaction with other work packages and tasks

The outcome of task 7.2 is the enhancement of various renovation scenarios through their checking against the design rules. As mentioned in the introduction, the work of the task follows the same principles as the model checking process developed under T5.3, yet T7.2 develops a set of design rules instead of the technical rules developed in T5.3. However, same principles are being used between the two tasks about the developed automated-rule validators. These automated-rule validators can additionally be optimised using the output of D7.2, where machine-learning is demonstrated for the enrichment of the design rules. Using the outputs of the model checking process (i.e. report of objects complying and/or not complying), as well as conventional building and HVAC product solutions defined in BIM-SPEED database (T2.3), different enhanced renovation scenarios can be configured by the user. These renovation scenarios will then serve as inputs for defining the final renovation solutions, taking into consideration the energy performance indicators defined in WP4 and the different stakeholders' decisions using the DSS of T7.3.

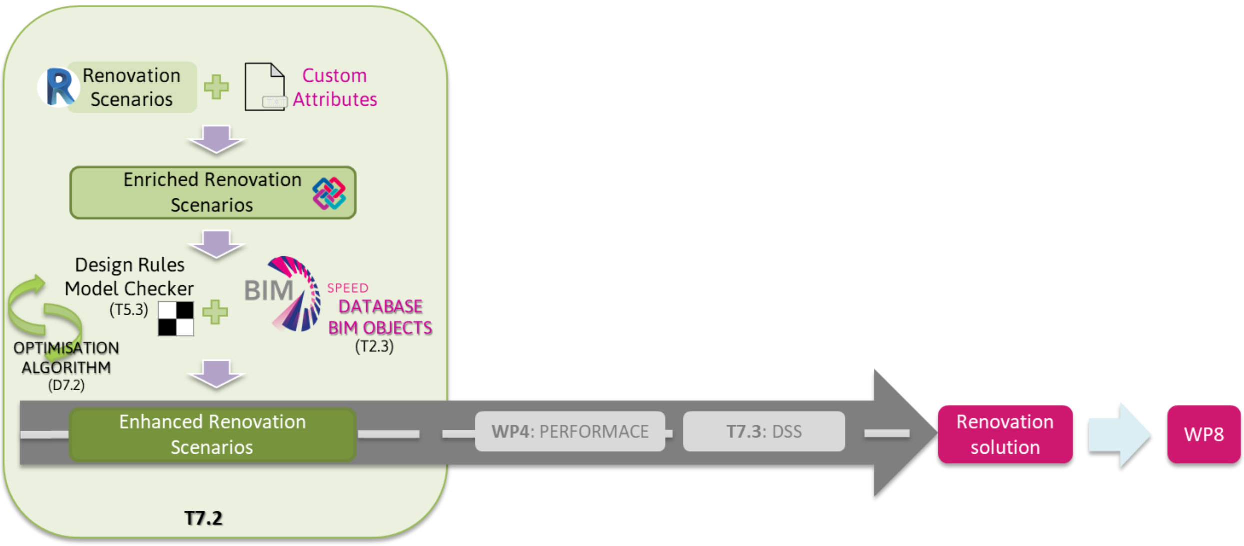

Figure 2. Overview of T7.2 and relation with other task and activities

2. Literature review of semantic design rules integrated in BIM

2.1 Use and Generation

The present paragraph presents an overview of semantics and their field of use in the AEC industry. To begin with, semantic web technology was motivated by the need to improve interoperability in the AEC domain, as an addition to the existing BIM plus IFC approach. In addition to that, further research has been carried out on how to use semantics for the development of automated rule checking workflows of digital models, as well as on how to achieve semantic enrichment of digital building models.

- **Semantics and Semantic Web Technologies in AEC industry**

The semantics evolution by BIM technology has led to a significant shift in research and development in the AEC industry. Researchers started to propose the use of semantic web technologies in the AEC industries in the early 2000 [5] to improve the information exchange and interoperability issues in the construction industry. Specifically, by using semantic web technologies the value of BIM was increased, by linking across domains (i.e. connect BIM and GIS), as well as by enabling logical inference and checks (i.e. check model consistency and completeness). The tendency of using semantic web technologies has been also embraced in the technical roadmap for product support by BuildingSMART[3], according to which the three levels of product support are supplemented by a fourth level. This fourth level includes the 'semantic search in the cloud' and a 'cloud library'. Nowadays, Ontology and Semantic Web approaches are well suited to help moving from human efforts to more automated work and generating consistent, precise, and quantifiable conditions and constraints.

- **Design Rules and their Semantics**

In the AEC industry there is a wide range of rules, standards, codes, and regulations to comply with, based on multiple criteria such as project requirements, solution to implement, design and others. A lot of effort has been made to harmonise some of the above at European level, yet it is a complex and challenging procedure. Moreover, part of rules, standards and codes are subject to experts' interpretation, they require additional operations (for instance, perform specific calculations to comply with a rule) and they are usually learnt in practice. To that direction, the collection of the "semantics" of the rules has been one of the topics of research in the last years. This is due to the difficulty to capture and classify such information, interpret it among all involved experts and make it available for use in BIM. Based on literature screening two main

[3] BuildingSMART (formerly International Alliance for Interoperability (IAI)), is an international organisation which aims to improve the exchange of information between software applications used in the construction industry.

areas of focus have been identified, about rules extraction from regulatory documents focusing on their semantics:

1. the use of semantics for automated rule checking with the objective to assess a concept at an early stage ensuring rule-compliance, and
2. the use of semantics for semantic enrichment of BIM objects to import these objects in various software and perform different activities, as for example modelling, structural design etc.

Under the scope of automated rule checking **(focus area 1),** Eastman & Solihin [10] have distinguished the following four general classes of rules:

- Class-1 rules that require a single or small number of explicit data. This class of rules checks on attributes and references that exist inside the BIM dataset, as for instance if all components of a 'Wall' are well-defined, as well as their relationship.
- Class-2 rules that require simple derived attribute values. The checks are based on single values or small set of values and no new data structures are generated.
- Class-3 rules that require extended data structure, to encapsulate higher level semantic conditions of building data. This rule of class checks on complex geometrical and spatial operations, thus requires extensive computation and probably the creation of a solid modelling library. By doing so, a 'sophisticated geometry engine' can capture new concepts and also to perform advanced geometry operations.
- Class-4 rules that require a 'proof of solution'. This class of rules checks on the performance-based codes or other similar rules and focus more on the solution (which may have more than one acceptable answer). The degree of complexity of this class is not greater than the other classes, yet it requires the capture of knowledge of experts and focuses more on domain specific knowledge.

Regardless the separation of rules in different classes, it is possible that rules which traditionally fall into one class will evolve into other classes when one looks at the problem in a different perspective. Based on the above definition of rules classes, different commercial applications have been developed (APPENDIX 1 – Rules Classification).

Generally, automated rule checking has been recognised well before the advent of BIM with research documented since the 1960s [8], although efforts were additionally intensified with the wide acceptance of the IFC format. Eastman & Solihin [10] mention research focusing on the interpretation of rules into computable forms, the implementation of computable rules using certain standard techniques or rule engines and rule-checking for very specific problem domains. The most notable effort to that direction is the one by Singapore's CORENET ePlanCheck project[4], attempting to automate rule checking at a national level.

[4] http://pes.sg/solutions/egovernment-corenet/eplancheck/

The process of rule checking can be broken down to the following four phases [9]: (i) rule interpretation, (ii) building model preparation, (iii) rule execution and (iv) rule check report (Figure 3). Among all phases, the 'rule interpretation' step is the most challenging because it is where rule experts analyse the rules and discover hidden assumptions, dependencies, ambiguities and exceptions.

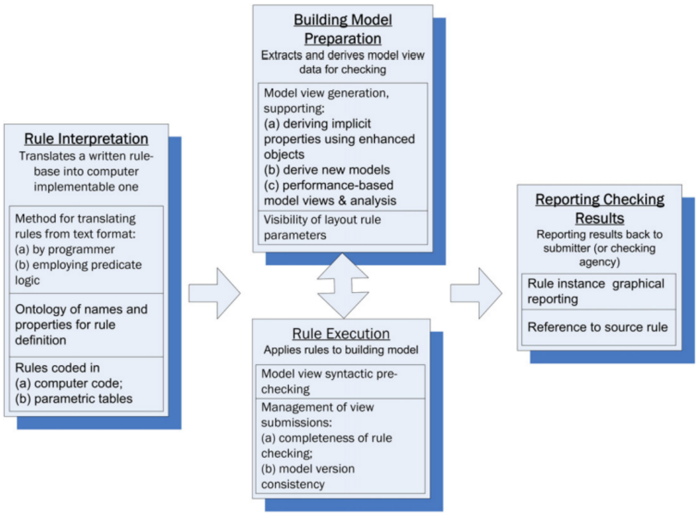

Figure 3. Scheme describing rule checking process (adopted by [9])

Based on Eastman & Solihin [10], the overarching purpose of automated rule checking is to assist a decision support system, where some user involvement may be necessary. Nevertheless, a fully automated rule checking system should free experts to focus on what is important for buildings and allow them to innovate without sacrificing aspects such as safety, sustainability and high environmental performance.

This is also the direction taken by Beach et al. (2015) [11] who describe one of the biggest challenges for all professionals in all sectors as ensuring that their work conforms to a wide range of requirements. Although the use of computer systems to support compliance has become increasingly common, there is still the challenge of effectively converting the often complex and non-binary (true/false) textual regulations that are intended to be human readable into computer executable code. Performing this task is not only challenging, but often requires close co-operation between domain experts with building regulation expertise and software developers. To answer this challenge, Beach et. al. developed a methodology for automated compliance checking which consists of the process of creating the rules (Figure 4), and use of the created rules in industry processes. In Figure 4 the three distinct processes of the methodology are represented by three different colours: (i) in grey the Semantic Framework: series of related ontologies that are either prebuilt or built as part of the regulation extraction process, (ii) in blue the Regulation Extraction: domain that focuses on the process of enhancing regulation documents with metadata by a

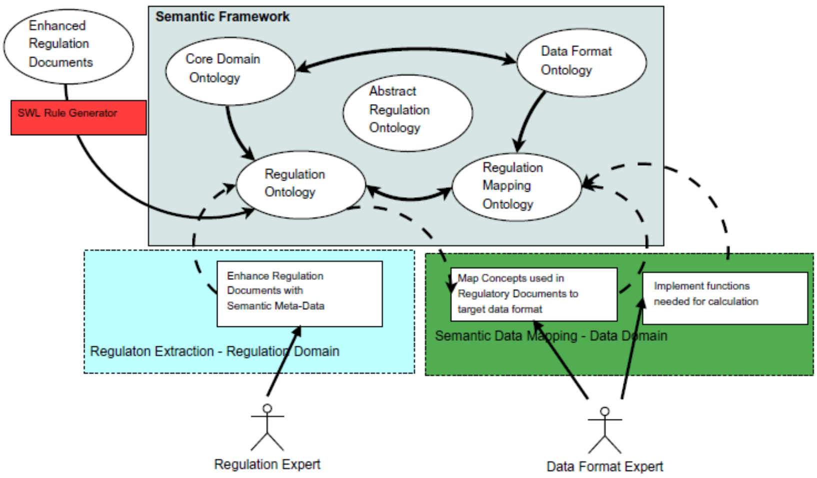

Figure 4. Methodology for automated compliance checking: Process to create the rules (adopted by [10])

regulation expert, and (iii) in green the Semantic Data Mapping: data domain that focuses on the processes an expert in the appropriate industry standard data file format would undertake. Beach et al. tested this methodology by performing an evaluation of a digital model against BREEAM requirements and classified the results based on the level of compliance. It is worth mentioning that the developed methodology should allow users to create and maintain their own regulatory compliance systems, within a semantic domain that is familiar to them.

On the other hand, semantic enrichment of building models **(focus area 2)**, refers to the automatic or semiautomatic addition of meaningful information to a digital model of a building or other structure by software that can deduce new information by processing rules [1]. Sacks et al. (2017) define the inputs to be: an existing building model, information about the building from other sources (for instance a database) and a set of rules that encapsulate expert knowledge of the domain. The rules use the existing information and evaluate the topological, spatial, geometrical and other relationships between the model´s objects. The output is a digital building model that incorporates the new information: new objects, property values, and/or relationships (Figure 5). Moreover, Sacks et. al (2017) mention that semantic enrichment has also been applied to extend the schema of building information models. The development of semantic enrichment for models is motivated by the information interoperability problem and draws on the foundations laid by research on the above-mentioned semantic rule-checking systems for BIM.

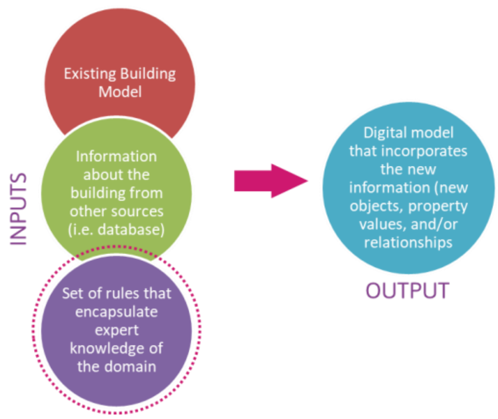

Figure 5. Schematic representation of semantic enrichment inputs and outputs based on [1]

Summarising, both automated rule checking and semantic enrichment require similar inputs, yet semantic enrichment is going a step forward and targets on the creation of semantically rich BIM model, incorporating information regarding objects' identification, relationships, and other alphanumerical data.

2.2 Implementation & Case studies

As mentioned above, the reviewed literature focuses on the use of semantics design rules in BIM environments across two categories: first, semantic rule checking for regulation compliance and second, semantic enrichment for IFC exchange files. Based on the category, the way the rules are implemented in a BIM context and the acquired results differ. In the first category, rule-based systems are used as a model checker to check the inputted model against building codes and standards. The common feature of those rule-based systems is to generate results with words such as "pass", "fail", "warning", or "unknown". In the second case, which seems to be more challenging and for which there are few research results, the expected outcome is an enriched building object which encases complex concepts that form part of building codes and standards. In any of the cases, the semantic rules and their respective results can serve as inputs for design configurator tools, such as the state-of-the-art configurator tool Streamer[5].

About regulatory compliance, BIM-Speed partner CSTB has led the research towards modelling regulatory documents of the building industry using a semantic-based approach, a work motivated by the need for "Smart" Building Codes. In addition to the complexity of regulations in building industry, Bouzidi et al. [12] acknowledge that regulations involve more than one area; they cover products, components, and project implementation. As a result, it is important to develop technical and regulatory texts in the domain of the construction that complement existing regulations, normative and codes. The purpose is to enable an easier reading of technical rules at an early design stage and collect details of execution presenting a wide range of possible implementations, to be used by project owners, contractors, and firms. Under the scope of the research led by Bouzidi et al. [12], the major regulatory requirements presented are relevant to safety, hygiene, accessibility, and performance, based on the product and its implementation. The guides provide an exhaustive description of the available knowledge with the objective to (among other): define risks; diagnose defects; indicate technical solutions; choices and implementation methods and check compatibility with existing rules. The classification method followed by Bouzidi et al. is based on the structure of the guides, based on 3 criteria: (i) organization by documentary source (which is not useful in our case because each country/system has a different documentation coding system), (ii) organisation by domain: each request or set of queries is related to a specific application domain as for example accessibility, security etc. and, (iii) organisation by theme, which refers to the technical solutions references in the guide as for example tile, electricity etc. After collecting the necessary technical guide text, the text is transformed to one ontology and then to rules. To facilitate the process of classification, the authors propose to reformulate the text by using specific vocabulary.

For instance, the following example shows a table reformulated to Semantics of Business Vocabulary & Business Rules (SBVR) rules, which expresses the acceptable slope for a plat tile made by clay. The adopted vocabulary has been highlighted by using different colours:

SBVR Rule example:
If a tile is built in Zone 1 **and** has situation equal to protected **and** has recovery equal to 8 cm **then** it has slope equal to 70%.
Concepts (green) · Literal Values (red) · Properties (blue) · Nouns, Other Information (grey)

In a later stage these rules are implemented in SPARQL language (standardized language for querying RDF graphs and key technology in the development of the semantic web) to define a full complex process for checking a technical document. Finally, the whole process ends with the generation of technical assessments by automating the validation of technical documents. All in all, in model checking systems most of the rules defaulted are global ones, such as rules associated with spatial assessment, structural

[5] https://www.streamer-project.eu/

integrity, safety, energy usage and so on. Rule checking systems can be integrated using one of the following widely used types of platforms:

- As an application tied to a design tool, such as a plug-in. It is available to check the operating model during the design process;
- As a stand-alone application separated from the modelling tools, such as Solibri, which has its own rule structures and is available to multiple models;
- As a web-based application which can be available for designs from various sources.

In the area of semantic enrichment, the project '**SeeBIM: Semantic enrichment engine for BIM (2015-2016)'** [1] is an early software prototype whose primary aim is to establish the feasibility of semantic enrichment of building models. The tool parses an IFC file to extract objects' shapes, relationships, and other attributes. It then applies forward chaining to infer additional facts about the model, using sets of rules compiled in advance by experts in the domain of interest. It records the results in an enriched IFC file. A similar idea was illustrated by Ramaji & Memari (2016) to export and enrich an architectural model to import it into a structural analysis tool. Nevertheless, important drawbacks of SeeBIM 1.0 were identified in its first large-scale application within the framework of the EU FP7 research project SeeBridge: Semantic Enrichment Engine for Bridges (Technion, 2015). Among the drawbacks is that firstly, the compilation of rule sets requires interviewing domain experts to make the most out of their knowledge and compiling it in the form of IF-THEN rules, depending on subjective judgement and hindering the completeness and the precision of rule sets. Secondly, the input is restricted to the IFC model file which in the worst case contains only the geometry, location and orientation of the 3D shapes. However, alphanumeric information such as year of construction can be vital in supporting semantic enrichment as they provide essential clues to support inference rule processing. Such information is often available in other data sources and should be imported with the model. Finally, axis-aligned bounding boxes are being used to approximate a model's geometry which in many cases result in errors where objects have non-conventional shapes or they are non-axis aligned. A further developed '**Procedure for Compiling Inference Rules and Operators for Complex Geometry'** (2017) [2], addressed the above-mentioned limitations of SeeBIM based on the requirements for a specific application domain; that of inspection of reinforced concrete highway bridges. The study focused on the rule-based inference and, on merging BIM model data with information from external sources to finally enhanced geometric and topological operators.

The case study of **Streamer design configurator** was also studied, developed in the STREAMER project; an industry-driven collaborative research project on Energy-efficient Buildings (EeB) with cases of mixed-use healthcare districts, aiming to reduce the energy use and carbon emission of new and retrofitted buildings in healthcare districts in the EU by 50% in the next 10 years. The Early Design Configurator (EDC)[6] developed for the STREAMER project (RE Design) produces automatically generated BIM-models and an assessment

[6] https://www.streamer-project.eu/Downloads/7%20STREAMER%20Early%20Design%20Configurator%20(EDC).pdf

of design alternatives. The tool aims to capture requirements, regulations, and restrictions for new built health care buildings, and support designers and experts during the early design stage. Functionally, given a building outline and a ruleset, the tool partitions available space in the interior by intelligently placing interior walls. BIM-Speed shows a lot of similarities in its use-cases. For renovation purposes a (BIM-Model of) residential building must be evaluated by means of a rule set before changes are suggested and preferably automatically applied. The makeup of rules differs significantly between the two projects with BIM-SPEED introducing significant flexibility and complexity. Additionally, the tools used during STREAMER (dRofus and BriefBuilder) were not available for BIM-SPEED. However, the core problem of reducing logical and semantical rules to mathematically evaluable conditions and requirements was well-researched in STREAMER. As such, this process could be re-applied to arrive at BIM-SPEED compatible rule-software as described in 4.1.

The components for reading, parsing, visualising, interacting with and interpreting semantics in BIM-Models as used by the Early Design Configurator are largely reusable because of their genericity. Extension of these existing components produced effective components for BIM-SPEED purposes. As such the Model Checker developed for the BIM-SPEED project makes efficient use of available resources.

While the Early Design Configurator's (EDC) approach of partitioning interior spaces works well new constructions of healthcare buildings, it does not cover the questions that arise in the renovation of an existing residential building. However, this is not the main purpose of the EDC in the context of STREAMER project was to propose different partitioning scenarios given the available outline and the proposed programme of requirements. This is not however, the focus of BIM-SPEED project as a residential renovation seeks to achieve increased performance along key performance indicators by replacing existing components. Interior partitioning is largely irrelevant. Additionally, automatic element replacement in a BIM-model is significantly complex. For example, if a door is to be replaced by another, not only is a different geometry required, but also flush positioning with the wall in which the door is inserted, as well as adjustment of the hinges and handles. For these reasons, the Early Design Configurator's algorithm and alternative generation functionality cannot be applied directly for BIM-SPEED. Instead, the lessons learned in STREAMER are applied to the Model Checker's evaluation of the rule set. By querying an available library of components, it is still possible to suggest optimal alternatives based on multiple criteria. With sufficient support for said library in editing software (i.e., a Revit plugin) a user can manually replace components and still efficiently arrive at an optimal alternative design.

3. Semantic design rules collection

3.1 Scope for semantic design rules

Following the evolution of semantic design rules as studied in the literature review, the task aspires to develop a representative set of generative design rules that deal with building regulation compliance, both for simple cases as compliance with values, as well as with more complex, such as compliance with conditions with more than one possible solution. To decide on the building regulations to look at, we first considered the renovation objectives for BIM-SPEED demonstration buildings. For the great majority of them, the primary focus is on the renovation of the building envelope, the glazing and the HVAC systems, whereas a secondary objective is the interior layout optimization. In addition, improving accessibility and renovating common spaces (such as corridors, elevators etc.), as well as improving fire safety standards were identified as commonly requested renovation goals for refurbishment projects, given that the relevant regulations have evolved during the last years and many existing buildings do not comply with current standards. Considering the above objectives, we also selected the following three criteria to serve as boundaries for the design rules collection, based on the most important criteria to be checked in a model checking process for renovation projects:

- **Thermal and acoustic comfort**: Rules and processes that allow covering the basic thermal and acoustic comfort requirements for the end user.
- **Fire safety**: Rules and processes that allow covering the basic construction safety requirements in case of fire.
- **Accessibility**: Rules and processes that allow covering the basic accessibility requirements, focusing on the building's common spaces (e.g. stairs and corridors).

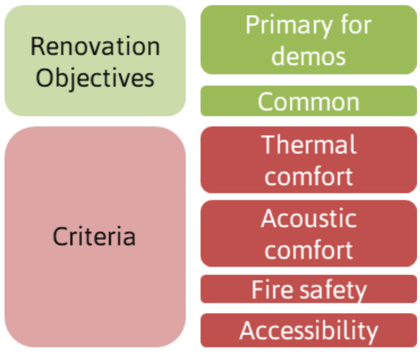

Figure 6. Definition of semantic design rules scope

Considering both the primary renovation objectives and the model checking criteria (Figure 6), the scope of the design rules is concluded as follows (Table 2):

Table 2. Semantic design rules scope

Criteria	Object(s) to check	Checking Feature	Legislation Source
Thermal comfort	Exterior Wall	Thermal transmittance	National standards
	Roof	Thermal transmittance	National standards
	Window	Thermal transmittance	National standards
	MEP Objects	Seasonal Coefficient of Performance (SCOP) of heating systems and Seasonal Energy Efficiency Ratio (SEER) of cooling systems.	National standards/ Experts knowledge
	Wall	Acoustic Rating	Experts knowledge

Acoustic Comfort	Window	Acoustic Rating	European/National Standards Experts knowledge
Accessibility	Staircases	Riser Height	National standards
	Main entrance	Net/Gross Area planned	National standards
	Main entrance	Minimum Height	National standards
Fire Safety	Building zones	Classification with respect to fire risk	European/National Standards Experts knowledge
	Corridors	Fire vestibules and fire exit doors	European/National Standards Experts knowledge
	Staircases	Fire vestibules and fire exit doors	European/National Standards Experts knowledge
	Exterior Walls/Surrounding walls of fire risk areas/Principal structural elements	Reaction to fire Resistance to fire	European/National Standards Experts knowledge

3.2 Semantic design rules interpretation and compilation

Based on the defined scope, an informal set of rules was collected. The objective of the collection is to create a repository of rules for the countries where the demonstration buildings belong to and use them as an example input for the model checking tool, so that checking can be performed for various cases. It is important to acknowledge that collecting design rules that encapsulate higher level semantic conditions of building data from various countries in a homogenous way, is a rather complicated work. This complexity is even more increased when the building experts must “translate” their knowledge in a language that can be readable by data experts, and express the information included in the legislative documents in an accurate way. To perform such activities and create the repository, an excel spreadsheet with a defined structure was prepared. For the rule structure, a IF - THEN approach was followed, so that rules are understandable by data experts, as well as by non-experts. Figure 7 illustrates the informal rule structure:

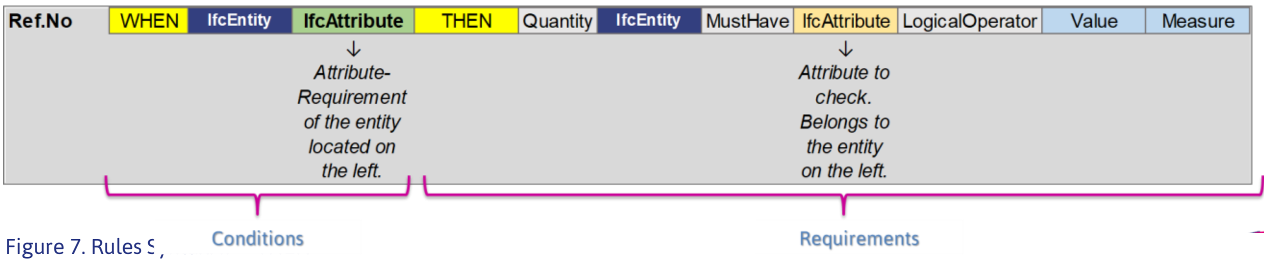

Figure 7. Rules S

The adopted vocabulary of the rule includes:

- Reference number of the rule: **CountryAbbreviation_Number.**
- The rule starts with the condition(s) part **(IF)**, where one or more IFCAttributes (or so-called properties) of the IFCEntities are examined. The entities and their attributes belonging to the 'condition-part' are used for defining the conditions under which specific model objects will be checked.
- The rule continues with the requirement(s) part **(THEN)**, where the main checking process takes place. The quantity of the IFC Entity to be checked is defined where possible, as well as the logical operators to be used in the checking process.

The idea behind the adopted vocabulary is that each building object is linked to an IFC Entity, and the features to check either as conditions, or as requirements, are linked to existing or custom IFC Attributes.

Table 3 illustrates an example of a rule examining a single value: the maximum thermal transmittance value for an exterior wall located in Spain, in particular in Zone α :

Table 3. An example rule of a single value

WHEN	**IfcBuilding**	**BIMSPEED Country = "Spain"**	**ES_BIMSPEED ClimateZone = "Zone α"**	And	**IfcWall**	**BIMSPEED IsExternal = True**	THEN	All	**IfcWall**	Must Have	BIMSPEED Thermal Transmittance	<=	0,80	W/m 2.K

It is easily observed that the above example presents a relatively easy design rule check, given that the rule belongs to class 1; rules that require a single (or small) number of explicit data. The BIM-SPEED rules that fall under this rule class are mainly relevant to thermal/acoustic comfort and accessibility. In addition, it can be observed that the attribute BIMSPEEDClimateZone, begins with the abbreviation of Spain (ES), given that not all countries distinguish zones for setting up the relevant requirement. For all the attributes that are country-specific, the respective country abbreviation has been used in the beginning of the attribute´s name.

BIM-SPEED also examines model checking for more advanced geometry operations, which is demonstrated by checking the model against fire safety regulations. To perform such activity, we mainly focused on the regulations regarding fire safety in Spain, taking as an example the topological relationships between fire exit stairs and their surrounding walls, as well as fire exit stairs and fire exit doors. In particular, Spanish building fire safety regulation differentiates non-protected stairs, protected stairs and special protected stairs. Protected and special protected stairways are the ones leading to a final building exit or a safe place, based on specific characteristics of the building (for instance, its height). Both protected and special protected stairs must be within a fire-resisting enclosure; having a fire vestibule and a fire exit door at their ending and being surrounded by walls resistant to fire. To perform model checking against these requirements, the following IFC Attributes were defined for the IFC Entity equal to IFC Stair:

- FireExit

- Fire Vestibule
- ES_Protected
- ES_Special Protected

The values for the above attributes need to be defined by the user, so that the condition(s) part (WHEN) is fulfilled. However, for the result(s) part (THEN) the IFC Entities to be checked are different ones, hence the definition of the relationship between the two IFC Entities is required. For instance, for the specific example studied, the compliance to be checked is not connected to the stair, but to the surrounding elements, namely the surrounding walls and the doors located close. To create such “relationship” between two or more objects and following the same process defined under T5.3, a location identification code (LIC) has been created for all model´s objects. The values of the LICs are generated automatically by importing a dynamo script to Revit, and their generation starts with the assignment of the LIC to the model´s spaces. Once all spaces have a LIC, all surrounding objects get a common LIC with the space they surround (see Figure 8). Given that an object can surround 2 or more spaces, more than one LICs can be used and are separated by a # (see Figure 9):

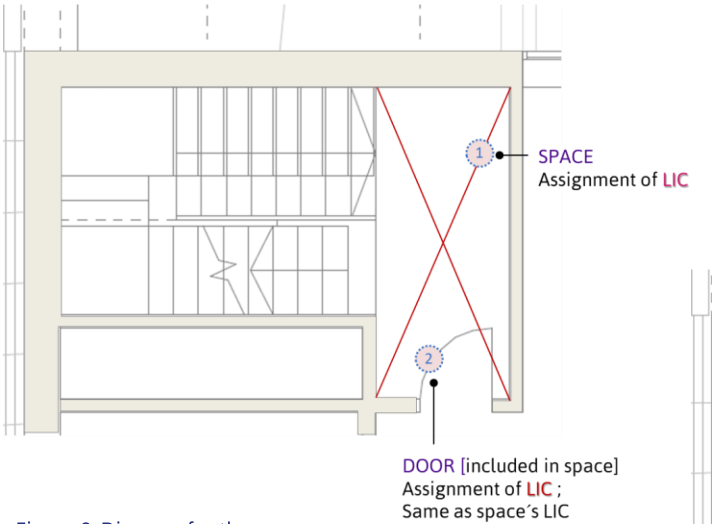

Figure 8. Diagram for the assignment of LIC

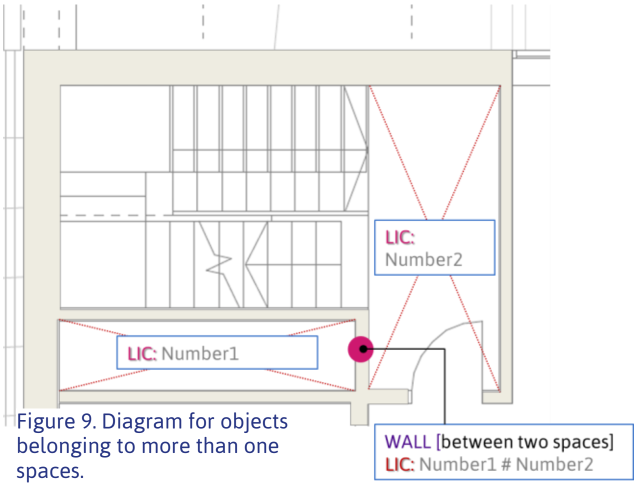

Figure 9. Diagram for objects belonging to more than one spaces.

To better understand the LIC attribute in relationship with the rules, Table 4 illustrates an example of a fire exit door, which has to be surrounded by walls with fire rating equal or greater to the letter B. To identify which of the walls need to be checked, the common LIC between wall and door is used.

Table 4. An example rule for checking objects using the LIC attribute

WHEN	**IfcBuilding**	**BIMSPEED Country = "Spain"**	And	**IfcDoor**	**BIMSPEED FireExit = True**	THEN	All	**IfcWall**	**(LIC = IfcDoor(LIC))**	Must Have	BIMSPEED FireRating	<=	B

In addition to the above examples, another case of rule definition is demonstrated, in which the model checking process is not completely automated but instead, a warning is sent to the end-user. In particular, the following example (Table 5) demonstrates the case of a building which has a fire exit and thus, needs to have a fire door. However, it is not defined where exactly this fire door must be located, but a warning is given to the user(s) for the necessity of such a door, which must be located within a radius of 10 m or less from the stair. This example is intended to illustrate that model checking does not always have the final objective to automate the processes. It can also be used as a means of interaction between the 3D model and the user, especially in the case of users who are not familiar with building regulations.

Table 5. An example rule of message to the user

WHEN	**IfcBuilding**	**BIMSPEED Country = "Spain"**	And	**IFCStair**	**BIMSPEED FireExit =True**	THEN	AtLeast One	**IfcDoor**	Must Have	BIMSPEEDFire Exit=True	**User Warn!**
<u>Message:</u> "Consider the travel distance between IfcDoor and IfcStair. The IfcDoor (FireExit=True) should be located at least in a radius of 10m away from IfcStair."											

All in all, focusing on regulations with many criteria and exceptions (such as regulations regarding fire safety) can result in complex design rules, increasing the number of IFC Attributes that must be assigned to the IFC Entities. In that case, more IFC Attributes result in an extra effort by the modellers who are asked to fill in the data and who often are not regulation experts so that they cannot guarantee the input of correct values. For BIM-SPEED, all the collected informal rules are stored to the accompanying excel spreadsheet. It is worth mentioning that in some cases, the complexity or even the absence of national standards for the scope set made it difficult to maintain the same level of information for all the countries. Nevertheless, an effort was performed to maintain a relatively similar level of information. Table 5 summarises the information that can be found for each one of the countries in the rules set repository (excel spreadsheet).

Table 6. Summary of design rules content by country

Country	Envelope thermal transmittance	Acoustic Rating	Fire Safety	Accessibility	Other
ES	✓	✓	✓	✓	--
PL	✓	✓	✓	✓	Ventilation airflow rate
IT	✓	✓	✓	--	--
DE	✓	✓	✓	--	--
NL	✓	✓	✓	✓	--
RO	✓	✓	✓	--	HVAC efficiency, Lighting
BG	✓	✓	✓	✓	HVAC efficiency

FR	✓	--	✓	✓	--

In addition, the following paragraphs present some remarks for the rules collected for each one of the demonstration countries:

- **Spain**

Energy savings requirements is Spain are regulated by "Documento Básico (HE) – Ahorro de energía" [13], where the standards for thermal comfort are set. Most of the limitations depend on the climatic zone where the building in question belongs to, which is defined based on the province and its altitude from the sea level. Fire safety standards are described in the document "Documento Básico (SI) – Seguridad en caso de incendio" [14] in which the way to protect occupants in the case of a fire is defined. Accessibility requisites with regard to the security of access (i.e. to avoid accidents and ensure accessibility to the buildings) are defined under "Documento Básico (SUA) – Seguridad de utilización y accesibilidad" [15]. It is worth to highlight that in Spain it is possible to meet additional and/or even different requirements based on the exact location of a building, as in the case of BIMSPEED Spanish demo building which belongs to the Basque Country. Specifically, for buildings located in the region of the Basque Country, the document ´´Decreto 68/2000´´ [16] defines among other the minimum standards for accessibility.

- **Poland**

In Poland new buildings and buildings subject to refurbishment need to be designed in agreement to the national technical guidelines [17] issued by the Ministry of development and infrastructure. These guidelines define among other, the maximum value of heat transfer coefficient U [W/(m²K)] for main building components which depends on the interior temperature of the room to which the respective component belongs to. There are three ranges of temperatures defined by the legislation (t): t <8°C, 8≤t<16°C and t≥ 16°C and the modeller/designer is asked to specify the respective range for each space. For the purposes of the design rules, we have defined 3 IFC Attributes based on the following conventions:

- PL_PRIVATE_HEATED: for private spaces with interior temperature equal or more than 16oC, for instance flats, bedrooms, living rooms, bathrooms, etc.
- PL_COMMON_HEATED: for common spaces with interior temperature between 8oC and 16oC (8oC included), for instance stairways and corridors.
- PL_BASEMENT_HEATED: for heated basements with interior temperature less than 8oC, for instance garages or boiler rooms.

In the case of unheated basements there are no requirements.

When it comes to fire rating in Poland, it depends on the building height (number of storeys) and type of the element (if it is load bearing, roof element, etc.). In general, as in all Europe, the higher the building, the stricter fire regulation and limits must be fulfilled. About the ventilation air flow rate in a residential building is determined by the sum of the air flows removed from the ancillary spaces. The ventilation rate depends on the function of the room (kitchen, bathroom, boiler room, bedroom, etc.), on its location in the flat and on window access. The requirements are stricter for the rooms in which vapour condensation occur and in those flats that use natural gas for heating or cooking purposes.

- **Italy**

For Italy, the values for thermal and acoustic comfort have been collected, as found in the "Guide Anit- ISO 9869--ISO 6946". Italy is also a country where the minimum requirements for the building envelope are set by defining zones, where each zone has to comply with different standards. With regard to fire safety, the Italian standards (D.M 9/3/2007- D.M 9/5/2007-DM 3/872015) are quite flexible, allowing combustible materials and thus, a general rule has been included to consider only solutions materials with low to medium combustibility.

- **Germany**

In the case of Germany, the informal rules describe standards about energy efficiency and fire safety. In terms of the energy efficiency requirements, like the legislation of Poland, the German building code defines the maximum limit of U-value based on the interior temperature, thus we had made the following conventions to define the relevant IFCAttributes:

  - DE_PRIVATE_HEATED: for private spaces with interior temperature equal or more than 19°C (e.g. flats);
  - DE_COMMON_HEATED: for common spaces with interior temperature between 12°C and 19°C (12°C included), (e.g. common accessible stairways and corridors).

For the definition of energy efficiency rules in buildings the following documents were studied: Ordinance for energy saving [24] & DIN EN 13947: 2007-07. Regarding the fire safety information, the legislation and regulation are more complex and thus, more difficult to be translated into single design rules. However, after extracting relevant information from Musterbauordnung (MBO) - Aenderung vom 27.09.2019 §28, DIN 4102-1 and DIN EN 13501-1 a set of general rules was established. Particularly, the requirement for fire rating depends on the difference between the height of the last floor height(m) and the height of the first floor (m). To simplify the rule, we translated this height difference to number of storeys, considering that each storey has a height of approximately 3m.

- **Netherlands**

Energy savings requirements in The Netherlands are regulated by the main Building Code "Bouwbesluit" [25]. Chapter 5 relates to 'Technical building regulations related to energy efficiency and environment', and article 5.6 specifically relates to the demands in case of building renovation. Thermal coefficients of insulation, floors, facades, roofs, windows, doors are listed. These demands have been translated into the excel scheme with the semantic design rules. Another important directive effective in The Netherlands is the EPBD III. The 'Dutch Enterprise Agency' (rvo.nl) clearly summarises technical system demands for building systems on their website. These demands relate to space heating, space cooling, ventilation, warm tap water and built-in lighting. The demands are effective when either (a) a new technical building system is installed, or (b) when of existing systems the generator, ventilation unit or a third of the heat delivery elements or built-in lighting armatures is installed, replaced, or improved. Fire safety demands and demands for spaces, listed in the design rules, also originate from Bouwbesluit. For checking sources, the Bouwbesluit can be accessed online[7]. It is divided into chapters as follows: General Provisions, Safety, Health, Usefulness, Energy-efficiency and Environment, Installations and Systems, Building sites and Terrains, Building- and Demolishing activities.

- **Romania**

Energy saving requirements as for instance thermal transmittance and acoustic rating have been collected for Romania. Thermal transmittances are regulated by the C107-1/2005 "Termotechnical calculation of the construction element of buildings". Additional attributes relevant to the interior spaces comfort have also been studied and added in the excel spreadsheet as an example for future work. For instance, based on the functionality of each space (i.e. bedroom, kitchen etc.) the standards for the minimum and maximum acceptable lighting levels have been included, based on the NP061-2002 norm. With respect to fire safety, which is regulated by the P118 Safety norm, for Romania only non-combustible walls are acceptable solutions and fire rating has been expressed as resistance to fire. Some information is also available in the rules repository regarding the efficiency of HVAC objects.

- **Bulgaria**

Energy efficiency law [19] and Ordinance No. 7 [20] of 2004 on the energy efficiency in buildings, as amended in 2015, are the main documents to define the cost-optimal levels of minimum energy performance requirements for buildings (or for individual building units) as well as the energy efficiency technical requirements and indicators. For BIM-SPEED project, the minimum requirements for the building envelope for buildings are listed, as well as for the HVAC systems. It is worth noting that compared to other countries, the user is asked to define further details to check elements against thermal efficiency rules. For instance, to define whether the roof is a warm or cold roof, whether the frame material of the openings is made of PVC, wood or aluminium etc. Ordinance No Iz of 1971 [18], as amended in 2009 defines the technical rules and norms for ensuring fire safety, some of which have been included into the excel spreadsheet. Listed rules regarding geometrical limitations for common accessible spaces have been extracted by Territory Planning Law [22] and Ordinance No 4 [23] on the Design, Construction and Maintenance of Works in Accordance with the Requirements for an Accessible Environment for the Population, Including People with Disabilities.

- **France**

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[7] bouwbesluitonline.nl/docs/wet/bb2012

In the case of France maximum values for the thermal transmittance of the building envelope are included, as well as nine examples of rules regarding fire safety, extracted by a French national project to digitalize fire regulation. In particular, the inputs indicate the required resistance on fire for floors, walls and gateways. Two more examples are available regarding accessibility, indicating the maximum step height and the minimum tread length for staircases.

Overall, for all studied countries thermal comfort has been the easiest part to deal with, given that almost all countries have set specific requirements aligned with EU directives and regulation[8]. On the contrary, fire safety has been the most challenging part, because of the complexity of the rules and the great number of exceptions based on the configuration of the building´s constructive elements. With regard to accessibility, only a small example of rules has been demonstrated and only for publicly-accessible spaces and not private ones (for instance, interior space of a flat), yet relatively similar design principles apply for Europe. However, in the case of design rules for interior spaces, it must be acknowledged that the regulatory framework is extremely complex and that there are significant differences between countries and between regions of the same country, making it difficult to ensure a uniform set of rules at EU level. All in all, regulation interpretation & implementation is not a new topic. It means lots of effort to first interpret the regulations and second, translate them to design rules. For this process, it is of great importance to understand the meaning of the regulations and interpret their semantics: the basic framework, intents, and hidden assumptions, as well as dedicate the necessary efforts for the syntax and grammar of rules. Depending on how regulations are being examined, different rules can be generated. In the scope of BIM-SPEED, various informal rules were created and additional custom IFC Attributes were set for the 3D models (See Annex 2). By inserting the custom IFC Attributes to the 3D model (and setting their respective values) the model checker can perform the check against the design rules for each one of the studied countries. As a demonstration example, the following paragraph presents the example of checking the 3D model of the Spanish demonstration building located in Aldabe 26, against the design rules defined for Spain.
Complementary to previous one, the rules sheet is available as open data on an Open Research Data Repository on the following link http://dx.doi.org/10.14279/depositonce-12566

[8] Directive 2010/31/EC of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings; Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of eco-design requirements for energy-related products; Regulation (EU) 2017/1369 of the European Parliament and of the Council of 4 July 2017 setting a framework for energy labelling.

4. Semantic design rules implementation

The biggest challenge in implementing semantic rules that require knowledge about the relationships between 3D model elements was identifying such rules. As introduced in work package 1 and described within this deliverable in section 3.2, the solution was the implementation of LIC and PIC as additional information attached to the 3D model elements. The LIC relates data and 3D elements to the room, where they are in real life. Assigning the LIC to each file and element outlines the on-site position. Elements with same LIC are in the same room. Same procedure works for equipment of mechanical, electrical, and piping type. By integrating the PIC these MEP elements will also be assigned to the room, they are on-site but additionally a distinct identification is added. By doing so a geometrical reference has been established, which provided the required relationship between the 3D models to enable the design checks.

Deliverable 1.1 of Work Package 1 gives more details on the generation and usage of LIC and PIC. By integrating them to the project data structure, they built the point of connection for all kind of data and information.

Relating to Task 7.2 and 5.3 the integration of LIC into the 3D model elements, enabled the required identification of geometrical relationship between 3D model elements and therefore the smooth usage of Design and Model Checks.

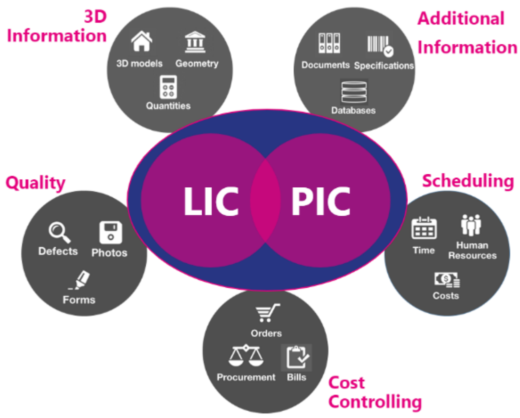

Figure 10. LIC and PIC implementation

After the clear definition of the syntax and the collection and formation of the semantic rules, the following steps were performed to design and develop a semantic model checker:

- Translation of the semantic rules into JSON files by developing a rules JSON editor and insertion of custom IFC Attributes to a 3D model to be used as demonstrator for the model checker.
- Checking the 3D model based on a given set of rules by developing a model checker
- Communicating the results by developing a compliance report generator, as well as demonstrating the opportunity of proposing alternative objects that comply with the rules extracted by BIM-SPEED database.

4.1 Rules conversion to computer understandable code and preparation of demonstrator 3D model

The rules used by the BIM-SPEED model checker are defined in JSON files, which are read and parsed by the model checking during checking of the model. These rule files can be edited with a rules editor which parses the JSON files, presents them in a user-friendly way in the interface and allows the user to modify the rules used for checking models. The interface then translates the user input back to JSON to be stored in the rules file.

A typical simple JSON defined rule looks like this:

```
{
  "rulenumber": 2,
  "quantity": "All",
  "ifcentity": "IFCWall",
  "conditions": [
    { "property": "BIMSPEEDIsExternal", "value": "True" },
    { "property": "BIMSPEEDLoadBearing", "value": "True" },
    { "property": "BIMSPEEDCombustible", "value": "True" },
    { "property": "BIMSPEEDCompartmentation", "value": "True" },
    { "property": "NumberOfStoreys", "value": 8, "operator": "<=" }
  ],
  "requirements": [
    { "property": "BIMSPEEDFireRating", "value": "B", "operator": "<=" }
  ]
},
```

Figure 11: A typical simple JSON defined rule

This rule defines that any IFCWall entity within the model that meets the specified conditions, i.e. that has the specified properties with the specified values, should have a BIMSPEEDFireRating property with a value smaller than or equal to B. If an IFCWall entity is encountered that meets the specified conditions but does not meet the specified requirement(s), the model checker will yield an error and present this error to the user.

JSON defined rules can be more complex. For instance:

```
{
  "rulenumber": 36,
  "quantity": "All",
  "ifcentity": "IFCStairCommon",
  "conditions": [
    { "property": "BIMSPEEDFireExit", "value": "True" },
    { "property": "ES_BIMSPEEDProtected", "value": "False" },
    { "property": "ES_BIMSPEEDSpecial Protected", "value": "True" },
    { "property": "ES_BIMSPEEDFireVestibule", "value": "True" }
  ],
  "rules": [
    {
      "ifcentity": "IFC Door Common",
      "requirements": [
        { "property": "BIMSPEEDFireExit", "value": "True" },
        { "property": "BIMSPEEDFireRating", "value": "A" }
      ]
    },
    {
      "ifcentity": "IfcWall",
      "requirements": [
        { "property": "BIMSPEEDFireRating", "value": "B", "operator": "<=" }
      ]
    }
  ]
},
```

Figure 12: a complex JSON defined rule

This rule specifies that any IFCStairCommon entity encountered within the model that meets the specified conditions (i.e. that has BIMSpeedFireExit=true, ES_BIMSPEEDProtected=false, ES_BIMSPEEDSpecial Protected=true and ES_BIMSPEEDFireVestibule=true) should check associated entities (see 4.2, for association of entities) for a set of requirements. In this case associated entities with type 'IFC Door Common' should have BIMSpeedFireExit=true and BIMSpeedFireRating=A, and associated entities with type 'IFCWall' should have a BIMSpeedFireRating with a value smaller than or equal to B.

Regarding the demonstrator model, the addition of custom IFC Attributes and their respective values is required, so that the model can be checked against the design rules. For the demonstration of the workflow under BIMSPEED, Autodesk Revit has been used as the tool to define custom property sets, for the example of the Spanish demonstration building. Once all custom property sets were defined, a .txt file was created (Figure 13) so that the process of adding the custom IFC Attributes can be potentially automatized and replicated for demonstrators in Spain.

```
#
# User Defined PropertySet Definition File
#
# Format:
#    PropertySet:      <Pset Name>     I[nstance]/T[ype]       <element list separated by ','>
#       <Property Name 1>       <Data type>     <[opt] Revit parameter name, if different from IFC>
#       <Property Name 2>       <Data type>     <[opt] Revit parameter name, if different from IFC>
#       ...
#
# Data types supported: Area, Boolean, ClassificationReference, ColorTemperature, Count, Currency,
#       ElectricalCurrent, ElectricalEfficacy, ElectricalVoltage, Force, Frequency, Identifier,
#       Illuminance, Integer, Label, Length, Logical, LuminousFlux, LuminousIntensity,
#       NormalisedRatio, MassDensity, PlaneAngle, PositiveLength, PositivePlaneAngle, PositiveRatio,
#       Power, Pressure, Ratio, Real, Text, ThermalTransmittance, ThermodynamicTemperature, Volume,
#       VolumetricFlowRate
#
# BIM SPEED Property Set definitions:


PropertySet:    BIMSPEED_Wall           T                       IfcWall
        BIMSPEEDAcousticRating          Text
        BIMSPEEDFireRating              Text
        BIMSPEEDCombustible             Boolean
        BIMSPEEDThermalTransmittance    ThermalTransmittance
        BIMSPEEDIsExternal              Boolean
        BIMSPEEDLoadBearing             Boolean
        BIMSPEEDCompartmentation        Boolean

PropertySet:    BIMSPEED_Roof           T                       IfcRoof
        BIMSPEEDFireRating              Text
        BIMSPEEDIsExternal              Boolean
        BIMSPEEDThermalTransmittance    ThermalTransmittance

PropertySet:    BIMSPEED_Window         T                       IfcWindow
        BIMSPEEDAcousticRating          Text
        BIMSPEEDThermalTransmittance    ThermalTransmittance

PropertySet:    BIMSPEED_Stair          T                       IfcStair
        BIMSPEEDRequiredHeadroom        Length
        BIMSPEEDFireExit                Boolean
        ES_BIMSPEEDProtected            Boolean
        ES_BIMSPEEDSpecial Protected    Boolean
        ES_BIMSPEEDFireVestibule        Boolean

PropertySet:    BIMSPEED_Door           T                       IfcDoor
        BIMSPEEDFireRating              Text
        BIMSPEEDFireExit                Boolean

PropertySet:    BIMSPEED_Building       I                       IfcBuilding
        BIMSPEEDNumberOfStoreys         Text
        BIMSPEEDCountry                 Text
        BIMSPEEDOccupancyType           Text
        ES_BIMSPEEDClimateZone          Text

PropertySet:    BIMSPEED_Space          I                       IfcSpace
        BIMSPEEDCategory                Text

PropertySet:    BIMSPEED_Zone           I                       IfcZone
        BIMSPEEDNetAreaPlanned          Area                    Área ocupada
        BIMSPEEDPubliclyAccessible      Boolean

PropertySet:    BIMSPEED_FlowTerminal   I               IfcFlowTerminal
        BIMSPEEDHeatingSource           Text
```

Figure 13. Text file with user defined property sets

4.2 BIM-based tool: model checker and alternative solutions

After translating the semantic rules to JSON files and preparing the 3D (IFC) model, the objective is to make sure that this IFC model adheres to a set of model requirements, or rules, as defined in the previous chapter. The model checker therefore should be able to read and parse a rules set, read an IFC model, and check if the IFC model meets the requirements defined in the rules set. It then should present the results from the model check to the user in a user-friendly manner. This process is relatively easy for rules defining ´´conditions´´ and ´´requirements´´ (WHEN-THEN) for the same IFC Entity, yet it has been one big challenge to correctly associate in the model IFC Entities that share a kind of relationship (logical, topological, geometrical etc.). As mentioned in section 3.2 and introduction of paragraph 4, the methods chosen to handle the association of entities correctly are LIC and PIC. This means that entities within the model that should be considered 'associated' are labelled with a LIC code (location identification code). So different entities that are associated contain the same LIC code. This allows the model checker to correctly and efficiently determine what to check and what not. To check whether this method can work for the model checker, the following demonstration was performed (Figure 14).

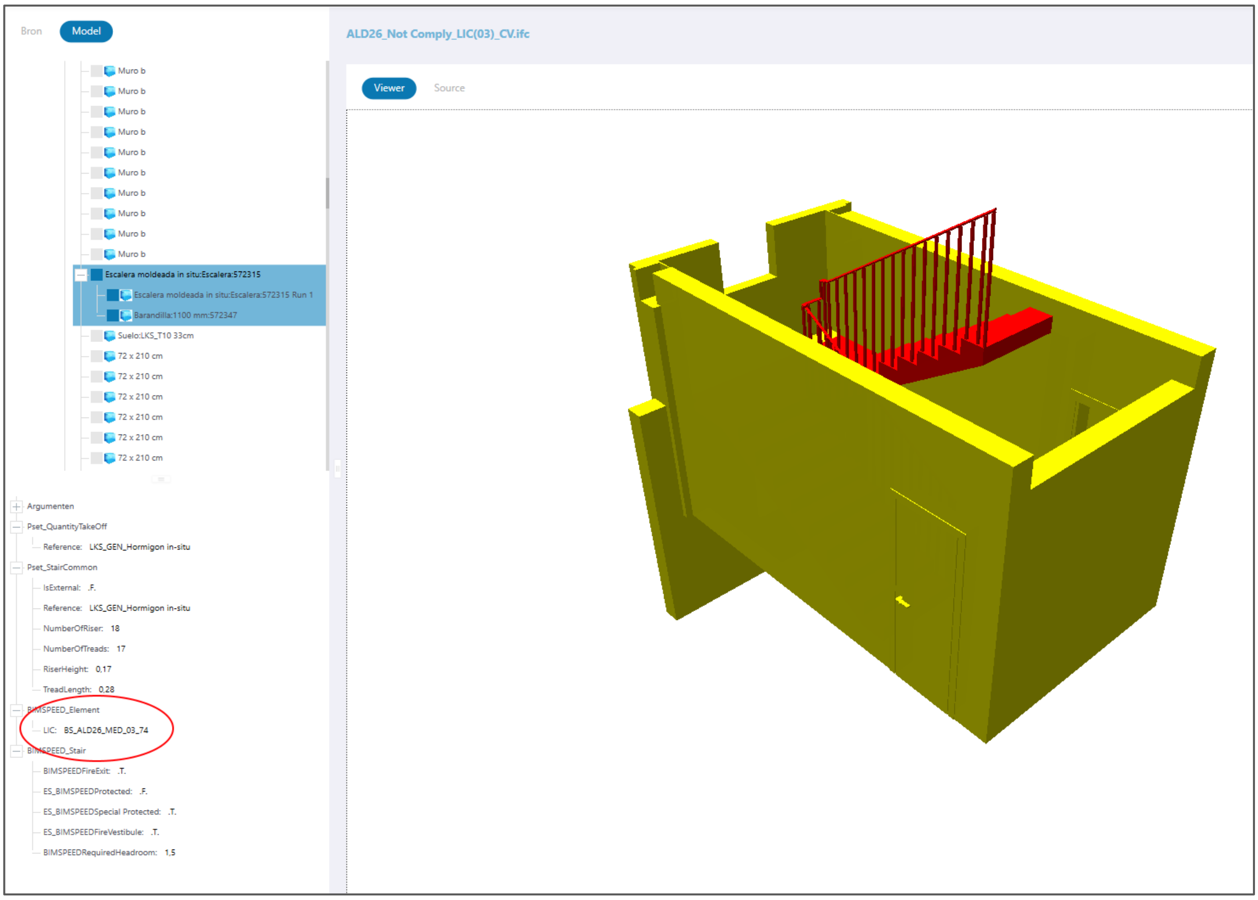

Figure 14: associating entities using LIC

What we see here is a part of an IFC model. An “IFCStairCase” object is selected (red), and all objects that have the same LIC code (or contain the same LIC code) are highlighted in yellow. This allows the model to select entities within the model that should be considered associated with the IFCStairCase entity.

Once all the rules have been translated to JSON (see Figure 15) and the model is loaded, the model can be checked. The process for checking a model is as follows:

- Iterate over all entities within the IFC Model, and for each entity:
- Determine the IFCEntityType
- Gather the rules defined for that IFCEntityType in the rules set, and for each rule:
- Check if the rule conditions are met
- If the conditions are met, check the requirements of the rule
- If the requirements are not met, add a model validation error entry to the list of model errors.

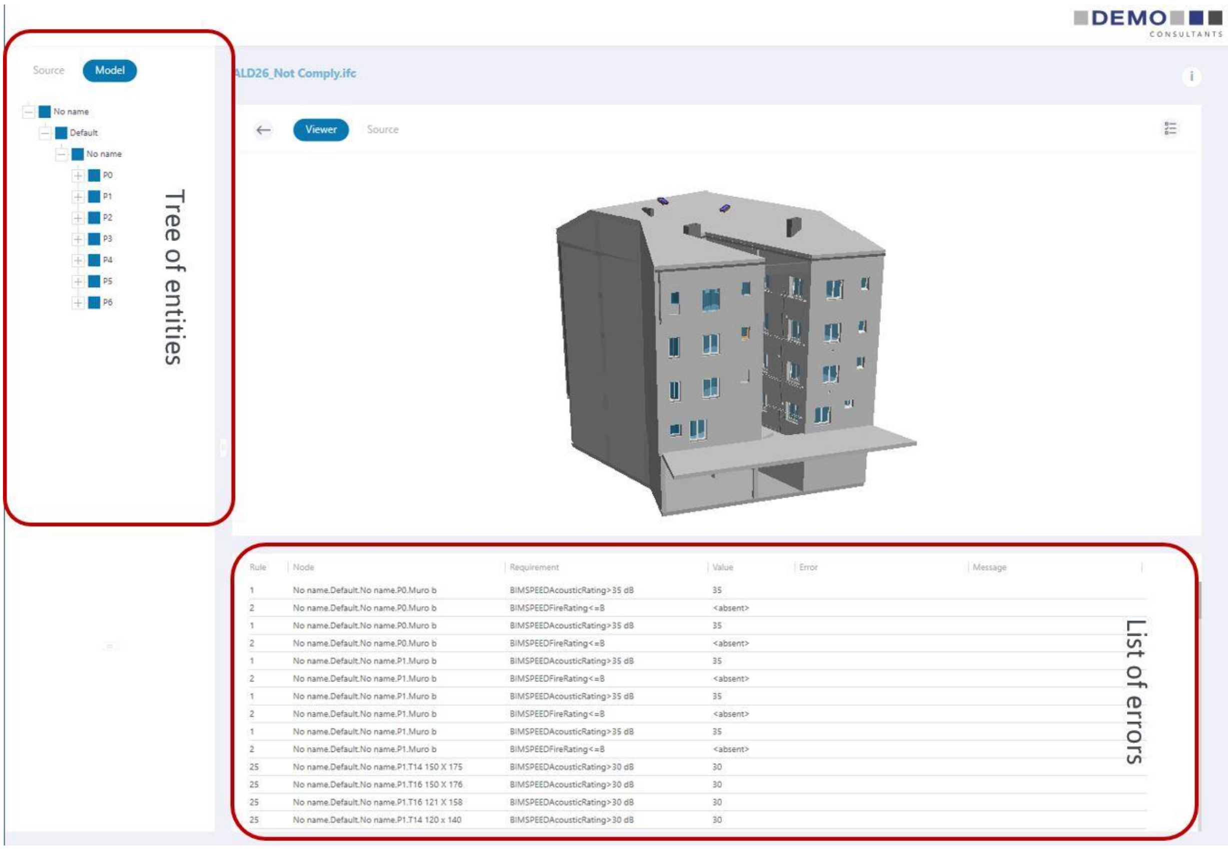

Figure 15: Checked model and its generated report

As Figure 15 illustrates, a tree of entities defined in the model stands to the left. At the top, the model is displayed, and at the bottom a list of errors that have been detected by the model checker is displayed. This list can, as desired, be exported as a .CSV file.

The user also can examine these errors in more detail within the model viewer itself as presented below.

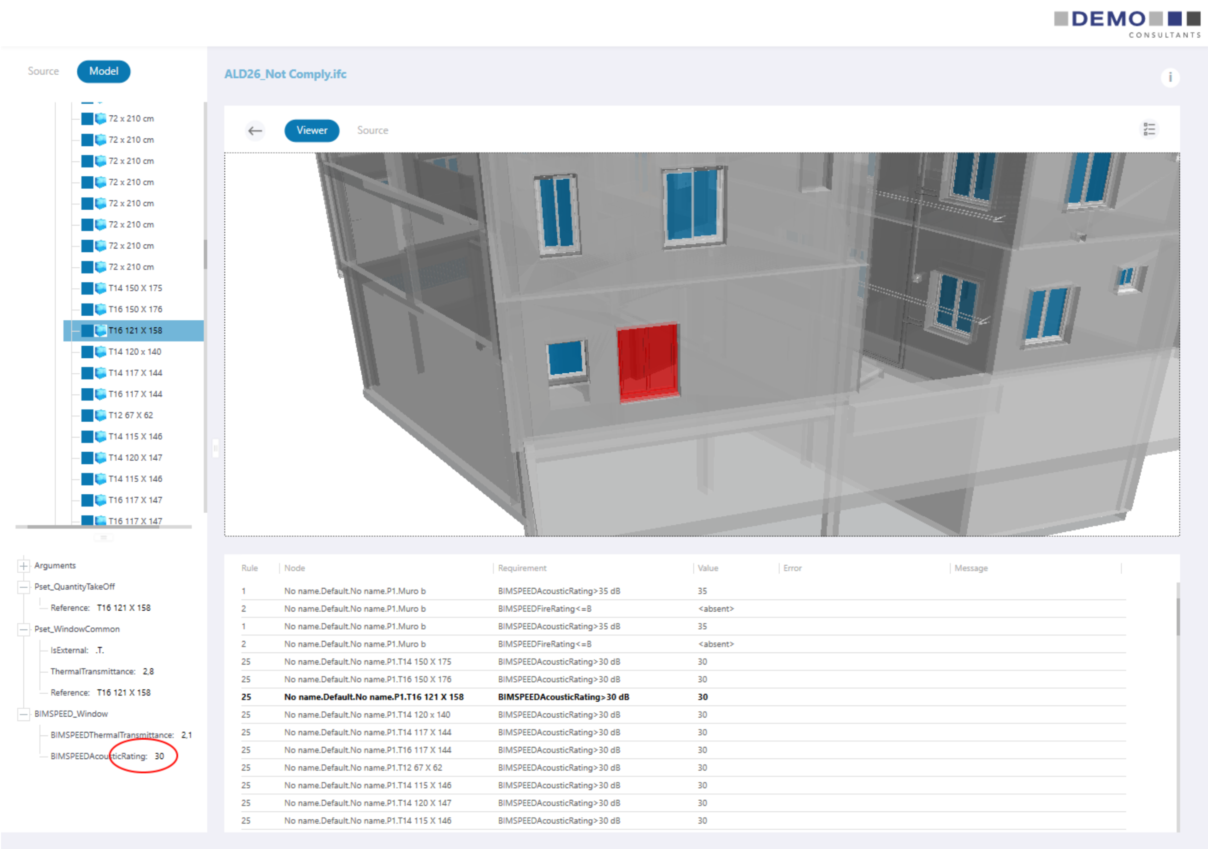

Figure 16. Details of results generated by model checker

In Figure 16, the user has selected one of the entries in the list of errors produced by the model checker. The IFC entity that contains the problem (in this case an IFCWindow object) is highlighted in both the model explorer and in the model viewer. The pane at the lower left displays properties of the selected entity, which confirms the problem: the requirement specifies that the BIMSPEEDAcousticRating should be larger than 30 dB, but the IFCWindow has a BIMSPEEDAcousticRating equal to 30 dB.

With knowledge of what elements do not adhere to specifications the intent is to suggest actions for the user to take. Specifically, to ensure compliance with the specified rules the element that is not up to spec must be replaced with one that is. RE Suite will attempt to suggest such an alternative element. This, however, requires that a suitable population of potential replacement elements is available.
Within the BIM-SPEED project, STRESS has developed a BIM-element database with available components useable in modelling software. At the time of writing this database contains some 200 elements with enough information to perform comparisons. More importantly, the database is accessible through an API[9]. This

[9] https://bimspeed.strategiedigitali.net/api/doc

enables RE Suite to connect to the database and query for matching elements. Additionally, STRESS is investigating development of a Revit plugin so that the element database can be used directly in the modelling software.
After querying the database RE Suite downloads the result set. Because the API query functionality does not support all relevant criteria RE Suite locally compares based on the unevaluated criteria. The remainder is ordered to minimise cost if such data is available. Finally, the topmost element is suggested as replacement element to the user.

4.2.1 Accessing the model checker tool

The model checker tool developed by DEMO is accessible through a web browser and the url https://demo.demobv.nl or through the BIMSpeed platform, which has integrated RE Suite link.

Integration BIMSpeed platform and RE Suite

For the BIMSpeed project, a bidirectional connection between the BIMSpeed platform and the RE Suite has been established. Users can navigate between the two platforms, and exchange data between them.
When a user is on the BIMSpeed platform, it is possible to reach the RE Suite through the User Interface of the BIMSpeed platform. There are two ways to do this: through the general 'External Services' or through IFC's.

1 - Through External Services. RE Suite is always accessible through 'External Services', which can be reached by clicking the External Services button on the top of any project homepage. On the External Services page RE Suite is listed. If the user clicks on 'Go to the service', the service is triggered.
In the background, this makes a call to the RE Suite webservice. The webservice receives the payload that comes with the call and identifies which user is trying to connect. The webservice uses a mapping between BIMSpeed user ID's and RE Suite user ID's. If the user is recognized, the call is forwarded to the SaaS webpage demo.demobv.nl, where the user can proceed with login. If the user is not recognized, a 'bad request' result is returned, and a message is shown to the user: 'KROQI account id {....} not registered in RE Suite. Please email info@demobv.nl and request an account for this KROQI account id'. Users must be registered with RE Suite before they can use it.
From the SaaS page, users can login to the BIMSpeed SaaS environment of RE Suite, with the general credentials 'BIMSpeed' and password 'Renovation'. After that, the user has to login to RE Suite with their personal credentials. After that, the user is inside RE Suite and has access to the applications.

2 - Through IFC's. RE Suite is registered as a service relevant for IFC files. Any IFC file on the BIMSpeed platform can be directly opened in RE Suite by clicking on the '3 dots' menu of the IFC file, then going to 'Access to services', then going to the RE Suite tile and clicking on 'Go to the service'. In the background the webservice of RE Suite is called. The payload contains the file ID from the IFC upon which the service was triggered. After successful login the file is automatically downloaded and shown in the RE Suite 3D viewer. From here multiple BIM related applications are available.

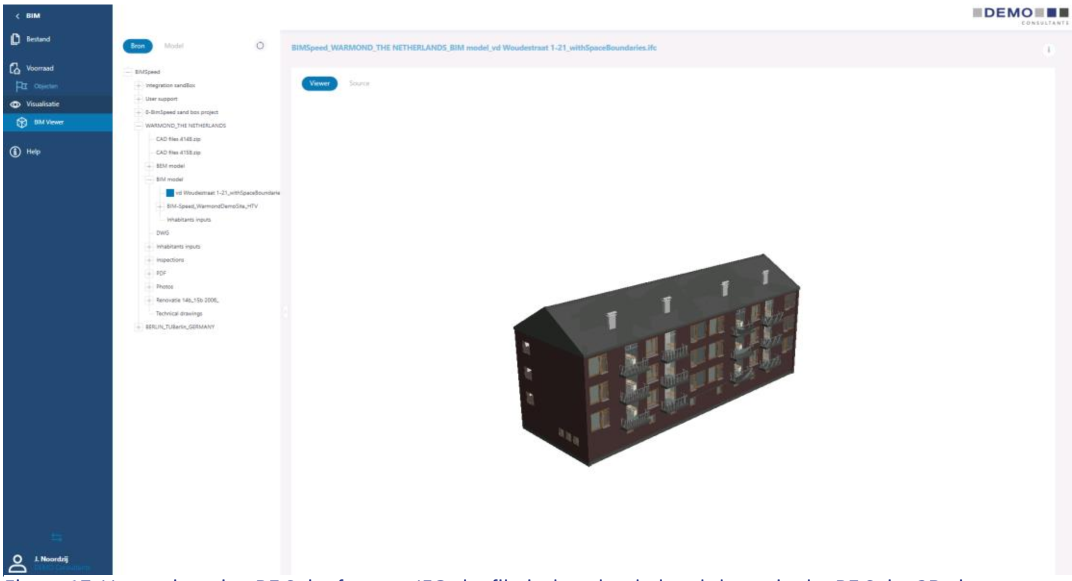

Figure 17. Upon triggering RE Suite from an IFC, the file is downloaded and shown in the RE Suite 3D viewer.

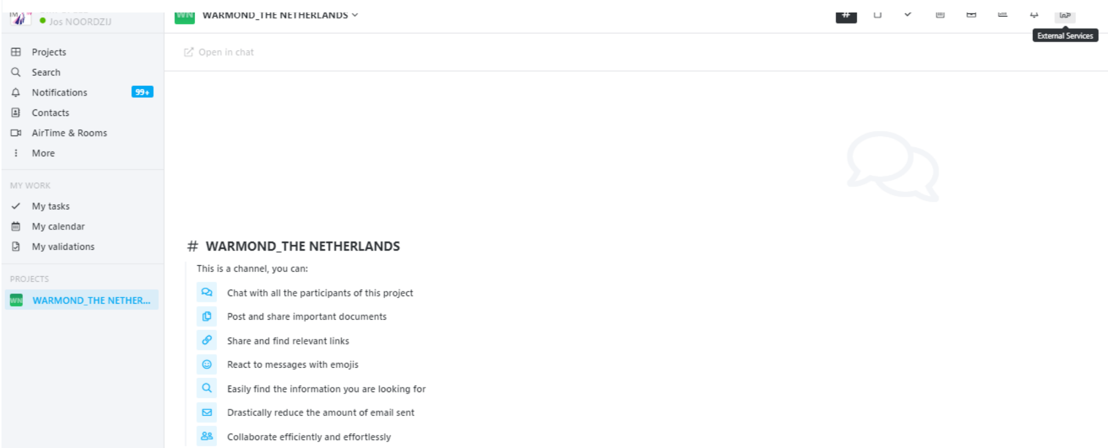

Figure 18. The External Services button, available from any project homepage

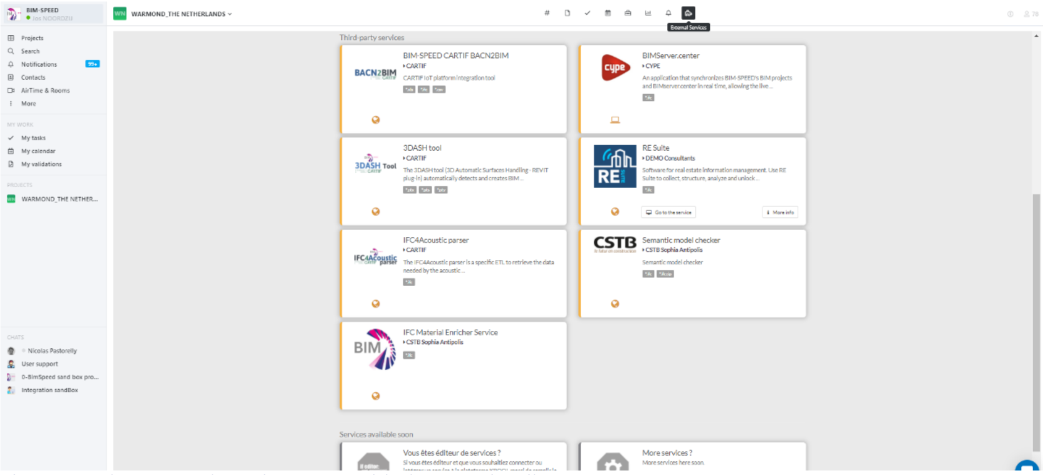

Figure 19. The External Services page with the RE Suite tile

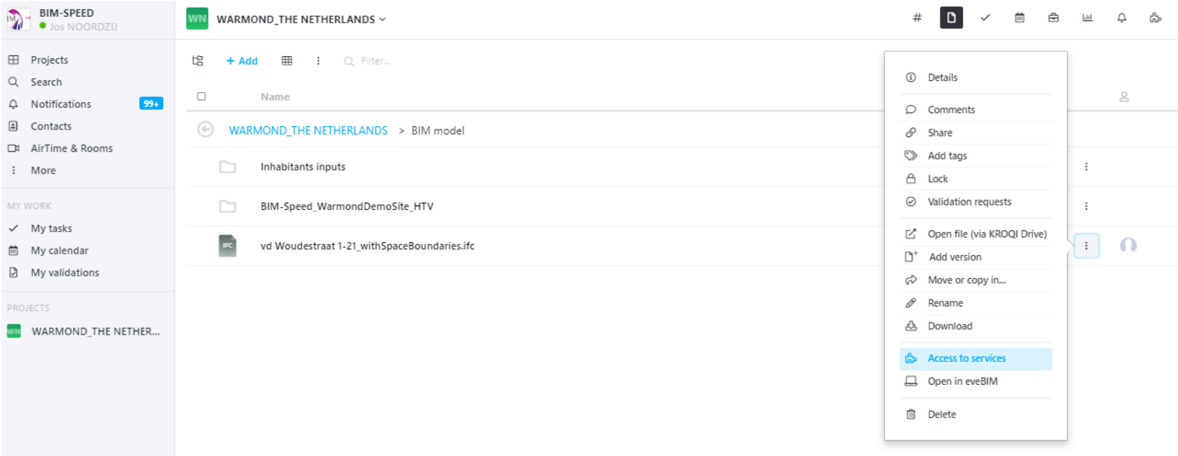

Figure 20. Triggering RE Suite external service from an IFC File

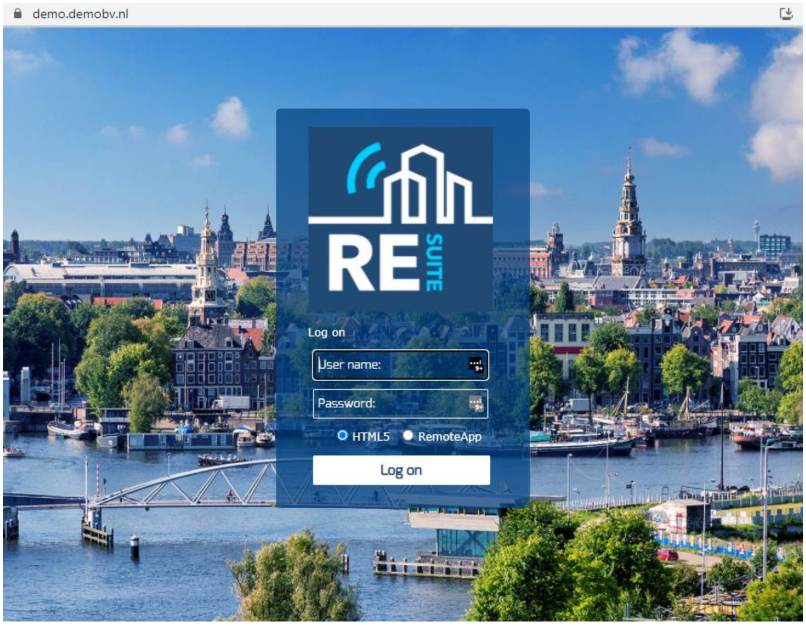

Figure 21. The RE Suite SaaS page

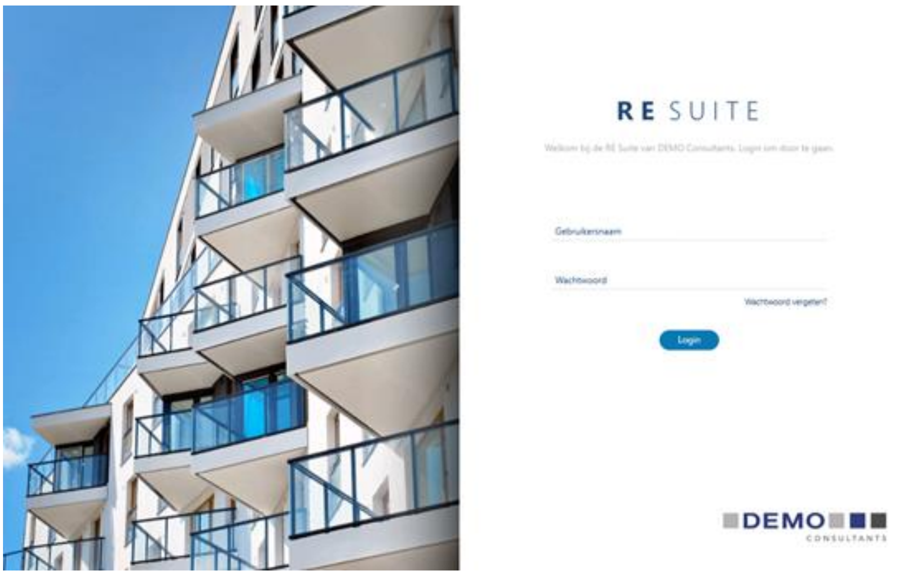

Figure 22. The RE Suite login page

5. Conclusions

Under deliverable 7.3 various sets of design rules were compiled for each one of the countries where the demonstration buildings belong to. Nevertheless, the possibility exists to describe the same information in numerous ways, thus same rules can vary depending on the point of focus. Additionally, BIM SPEED partners have different backgrounds and experience in various countries. Beside the advantages of such variation, it has been challenging to interpret and describe design rules in a homogenous way that is also machine-readable. The selection of design rules to be implemented has been carried out by the consortium experts and hence, intuition and subjective judgement are required. As a result, it is difficult to guarantee the completeness and the precision of rule sets, yet future work can be performed to define a common standardized framework. In addition, future research is required regarding the way to model regulatory documents of the building industry using a semantic-based approach. To accommodate the design rules, a BIM-based model checker tool was developed, building upon the state-of-the-art platform of Streamer project. The model checker tool was tested using the 3D model of the Spanish demonstration building and checking it against the rule set for Spain. A results report was generated, indicating the elements that failed to comply with the design rules, as well as highlighting the elements for which the check failed due to lack of data input. In addition to the automation delivered by the model checker tool, it is worth mentioning that the use of LIC (location identification code) in the model checker has demonstrated the potential for further and more complicated model checks. For the elements that failed to comply, an additional proof-of-concept was carried out, under which the model checker tool provided alternative objects as solutions to comply, extracted by the BIM-SPEED database. To this context, the designer has the option to re-adjust their design, so that finally an enhanced design is achieved. Future work can focus on integrating in a BIM software both the model checker tool, as well as the BIM-SPEED database. By doing so, the user would potentially run the model checking without using external tool and would be able to input alternative objects that comply using the BIM-SPEED database (i.e. as a plug-in).

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7. APPENDIX 1 – Rules Classification & commercial applications

Table 7: List of research works and commercial applications implementing different classes of rules [10]

	Class 1	Class 2	Class 3	Class 4
Def.	**Checks based on explicit data**	**Checks based on simple derived Attribute Values**	**Checks based on extended data structure**	**Checks and suggests corrective actions or solutions**
Commercial Products	Solibri Model Checker	Solibri Model Checker	GA Tech GSA courthouse design circulation check, which is based on Solibri Model Checker	GA Tech's Automatic Safety Checking of Construction Models and Sched
	Automated MVD checks: - IFC2x3 CV2.0 certification by BuildingSMART and iabi - Digital Alchemy, that is used in GSA CD BIM 2010 certification	Applications with Clash detection capability: - Navisworks [55] - Tekla BIMsight [56]	FORNAXTM as implemented in CORENET ePlanCheck	Various proprietary domain specific implementations*, e.g.: - Crane Simulation system by JGC using Navisworks - Autodesk's simulation for Lockheed Martin on risk assessment of moving large objects inside a building based on 3D Studio Max
	Revit Model Review	FORNAXTM that is used as an engine for CORENET ePlanCheck implementation		* No public information available, they are based on Solihin&Eastman' involvements with the developers of the applications.
	Navisworks using search set			
	Research project by QUT, Australia			
	EDM rule schema based: - Norway pilot project - Xabio			

8. APPENDIX 2 – Custom Ifc Attributes

The present appendix presents all the custom Ifc Attributes that were created based on the design rules. They are presented both in a simplified version, as well as in more details. The simplified list (Table 8) facilitates the modelers to understand the kind of data they need to provide for each Ifc Attribute and contributes to the development of BIMSPEED modelling guidelines. The detailed list (Table 9) of custom attributes provides more information and is aligned with BuildingSmart guidelines.

Table 8. Simplified list of custom IFC Attributes

Obj	Attribute Name	Values
BUILDING	**BIMSPEEDCountry**	☐ Spain ☐ Germany ☐ Netherlands ☐ Poland ☐ Romania ☐ Bulgaria ☐Italy ☐France
	BIMSPEEDOccupancyType	☐ Multi Family ☐ Single Family
	BIMSPEEDNumberOfStoreys	Indicate Number: ☐
	ES_BIMSPEEDClimateZone **[Only for demos in Spain]**	☐α ☐ A ☐ B ☐ C ☐ D ☐ E
	IT_BIMSPEEDClimateZone **[Only for demos in Italy]**	☐α ☐ A ☐ B ☐ C ☐ D ☐ E ☐ F
ZONE	**BIMSPEEDPubliclyAccessible**	☐True ☐ False
	BIMSPEEDNetAreaPlanned	Indicate m^2: ☐
	NL_BIMSPEEDFireCompartment **[Only for demos in Netherlands]**	☐True ☐ False
	BG_BIMSPEEDHandicapAccessible **[Only for demos in Bulgaria]**	☐True ☐ False
	NL_BIMSPEEDHeight **[Only for demos in Netherlands]**	Indicate m: ☐
	NL_BIMSPEEDGrossAreaPlanned **[Only for demos in Netherlands]**	Indicate m^2: ☐
	NL_BIMSPEEDDistanceToExit **[Only for demos in Netherlands]**	Indicate m: ☐
SPACE	**BIMSPEEDCategory**	☐ Kitchen ☐ Bathroom ☐ WC ☐ Auxiliary Room ☐ Corridor, Hall ☐ Stairs ☐ Living Room ☐Bedroom
	PL_BIMSPEEDElectricCooker **[Only for demos in Poland]**	☐True ☐ False
	PL_BIMSPEEDOccupancyNumber **[Only for demos in Poland]**	Indicate Number: ☐
	PL_BIMSPEEDVentilationAirFlowrate **[Only for demos in Poland]**	Indicate m^3/h: ☐

WALL	**BIMSPEEDAcousticRating**	Indicate dB: ☐
	BIMSPEEDFireRating	Indicate letter: ☐
	BIMSPEEDCombustible	☐True ☐ False
	BIMSPEEDThermalTransmittance	Indicate W/m².K: ☐
	BIMSPEEDIsExternal	☐True ☐ False
	BIMSPEEDLoadBearing	☐True ☐ False
	BIMSPEEDCompartmentation	☐True ☐ False
	PL_BIMSPEEDHeatLabel **[Only for demos in Poland]**	☐ Private_Heated ☐ Common_Heated ☐ Basement_Heated ☐ Basement_Unheated
	DE_BIMSPEEDHeatLabel **[Only for demos in Germany]**	☐ Private_Heated ☐ Common_Heated
	RO_BIMSPEEDHeatLabel **[Only for demos in Romania]**	☐ Basement_Heated ☐ Basement_Unheated
ROOF	**BIMSPEEDFireRating**	Indicate letter: ☐
	BIMSPEEDIsExternal	☐True ☐ False
	BIMSPEEDThermalTransmittance	Indicate W/m².K: ☐
	BG_BIMSPEEDWarm **[Only for demos in Bulgaria]**	☐True ☐ False
	BG_BIMSPEEDCold **[Only for demos in Bulgaria]**	☐True ☐ False
	PL_BIMSPEEDHeatLabel **[Only for demos in Poland]**	☐ Private_Heated ☐ Common_Heated ☐ Basement_Heated ☐ Basement_Unheated
	DE_BIMSPEEDHeatLabel **[Only for demos in Germany]**	☐ Private_Heated ☐ Common_Heated
WINDOW	**BIMSPEEDAcousticRating**	Indicate dB: ☐
	BIMSPEEDThermalTransmittance	Indicate W/m².K: ☐
	PL_BIMSPEEDHeatLabel **[Only for demos in Poland]**	☐ Private_Heated ☐ Common_Heated ☐ Basement_Heated ☐ Basement_Unheated
	DE_BIMSPEEDHeatLabel **[Only for demos in Germany]**	☐ Private_Heated ☐ Common_Heated
	BG_BIMSPEEDFrameMaterial **[Only for demos in Bulgaria]**	☐ PVC ☐ Wood ☐ Aluminium

	NL_BIMSPEEDGlassLayers [Only for demos in Netherlands]	Indicate Number: ☐
	PL_BIMSPEEDRoofWindow [Only for demos in Poland]	☐True ☐ False
	NL_BIMSPEEDRoofWindow [Only for demos in Netherlands]	☐True ☐ False
STAIR	**BIMSPEEDRequiredHeadroom**	Indicate m: ☐
	BIMSPEEDFireExit	☐True ☐ False
	ES_BIMSPEEDProtected [Only for demos in Spain]	☐True ☐ False
	ES_BIMSPEEDSpecial Protected [Only for demos in Spain]	☐True ☐ False
	ES_BIMSPEEDFireVestibule [Only for demos in Spain]	☐True ☐ False
	PL_BIMSPEEDRiserHeight [Only for demos in Poland]	Indicate m: ☐
	NL_BIMSPEEDRiserHeight [Only for demos in Netherlands]	Indicate m: ☐
	NL_BIMSPEEDTreadLength [Only for demos in Netherlands]	Indicate m: ☐
DOOR	**BIMSPEEDFireRating**	Indicate letter: ☐
	BIMSPEEDFireExit	☐True ☐ False
HVAC	**BIMSPEEDHeatingSource**	☐ Fuel ☐ Gas ☐ Electricity ☐ Hot Water ☐ Steam ☐ Other-Pellet ☐ Other-Wood ☐ Not Known
	BIMSPEEDThermalEfficiency	Indicate %: ☐
	RO_BIMSPEEDOutputCapacity [Only for demos in Romania]	Indicate kW: ☐

Table 9. Detailed list of custom Ifc Attributes

PropertySetName	Applicable Entity	Attribute Name	Property Type	Data Type	Definition	Relevant BIM SPEED Rule No
BIMSPEED_Building	IFCBuilding	BIMSPEEDCountry	IFCPropertyListValue	List Value: IFCReal/USERDEFINED 1. Spain 2. Germany 3. Netherlands 4. Poland 5. Romania 6. Bulgaria 7. Italy 8. France	Identifies the country that the object belongs to.	This attribute is not intended for checking. It is used as a rule condition.
		BIMSPEEDOccupancyType	IFCPropertyListValue	List Value: IFCReal/USERDEFINED 1. Multi Family 2. Single Family	Occupancy type for this object. It is defined according to the presiding national building code.	This attribute is not intended for checking. It is used as a rule condition.
		BIMSPEEDNumberOfStoreys	IFCPropertySingleValue	IFCInteger	Captures the number of storeys within a building.	This attribute is not intended for checking. It is used as a rule condition.
		ES_BIMSPEEDClimateZone	IFCPropertyListValue	List Value: IFCReal/USERDEFINED 1. α	Identifies the climate zone of the objects that belong to Country: Spain	This attribute is not intended for checking. It is used as a rule condition

				2. A 3. B 4. C 5. D 6. E		for objects belonging to BIMSPEEDCountry= Spain.
		IT_BIMSPEEDClimateZone	IFCPropertyListValue	List Value: IFCReal/USERDEFINED 1. α 2. A 3. B 4. C 5. D 6. E 7. F	Identifies the climate zone of the objects that belong to Country: Italy	This attribute is not intended for checking. It is used as a rule condition for objects belonging to BIMSPEEDCountry=Italy.
BIMSPEED_Zone	IFCZone	BIMSPEEDPubliclyAccessible	IFCPropertySingleValue	IFCBoolean	Indication whether this space (in case of e.g., a stair) is designed to serve as a publicly accessible space, e.g., for a common used stair (TRUE) or not (FALSE).	This attribute is not intended for checking. It is used as a rule condition.
		BIMSPEEDNetAreaPlanned	IFCPropertySingleValue	IFCAreaMeasure / AREAUNIT	Total planned net area for the space. Used for programming the space.	NL_14, BG_18 – BG_20
		NL_BIMSPEEDFireCompartment	IFCPropertySingleValue	IFCBoolean	Indication whether the object serves as	This attribute is not intended for

					a fire compartment, (TRUE) or not (FALSE), according to the national fire safety regulation.	checking. It is used as a rule condition for objects belonging to BIMSPEEDCountry= Netherlands.
		BG_BIMSPEEDHandicapAccessible	IFCPropertySingleValue	IFCBoolean	Indication whether this space (in case of e.g., a corridor) is designed to serve as an accessible space for handicapped people, e.g., for a private house corridor (TRUE) or not (FALSE). This information is often used to declare the need for access for the disabled and for special design requirements of this space.	This attribute is not intended for checking. It is used as a rule condition for objects belonging to BIMSPEEDCountry= Bulgaria.
		NL_BIMSPEEDHeight	IFCPropertySingleValue	IFCAreaMeasure / HEIGHTUNIT	Height for the space. This information is often used to indicate whether a	NL_15

					space (e.g. stair) is accessible.	
		NL_BIMSPEEDGrossAreaPlanned	IFCPropertySingleValue	IFCAreaMeasure / AREAUNIT	Total planned gross area for the space. Used for programming the space.	NL_13
BIMSPEED_Space	IFCSpace	BIMSPEEDCategory	IFCPropertySingleValue	List Value: IFCReal/USERDEFINED 1. Kitchen 2. Bathroom 3. WC 4. Auxiliary Room 5. Corridor, Hall 6. Stairs 7. Living Room 8. Bedroom	Category of space usage or utilization of the area. It is defined according to the presiding national building code.	This attribute is not intended for checking. It is used as a rule condition
		PL_BIMSPEEDElectricCooker	IFCPropertySingleValue	IFCBoolean	Indication whether the space contains an electric cooker, (TRUE) or not (FALSE).	This attribute is not intended for checking. It is used as a rule condition for objects belonging to BIMSPEEDCountry=Poland.
		PL_BIMSPEEDOccupancyNumber	IFCPropertySingleValue	IFCCountMeasure	Number of people required for the	This attribute is not intended for checking. It is used

					activity assigned to this space.	as a rule condition for objects belonging to BIMSPEEDCountry= Poland
		PL_BIMSPEEDVentilationAirFlowrate	fcPropertySingleValue	IFCCountMeasure	Indication of the requirement of a particular natural or mechanical air ventilation rate, given in m3 per hour.	PL_30 – PL_34
BIMSPEED_Wall	IFCWall	BIMSPEEDAcousticRating	IFCPropertySingle Value	IFCLabel	Acoustic rating for this object. It is giving according to the national building code. It indicates the sound transmission resistance of this object by an index ration (instead of providing full sound absorbtion values).	ES_01, PL_01, IT_01, DE_01, NL_01, RO_16
		BIMSPEEDFireRating	IFCPropertySingle Value	IFCLabel	Fire rating given according to the national fire safety classification.	ES_02 – ES_18, ES_26 – ES_27, ES_47 – ES_53,

						PL_02 – PL_09, PL_36, IT_02 – IT_03, DE_02 – DE_05, DE_09 – DE_11, NL_12, RO_08, BG_11
		BIMSPEEDCombustible	IFCPropertySingleValue	IFCBoolean	Indication whether the object is made from combustible material (TRUE) or not (FALSE).	This attribute is not intended for checking. It is used as a rule condition.
		BIMSPEEDThermalTransmittance	IFCPropertySingleValue	IFCThermalTransmittanceMeasure / THERMALTRANSMITTANCEUNIT	Thermal transmittance coefficient (U-Value) of a material. Here the total thermal transmittance coefficient through the wall (including all materials).	ES_19 – ES_25, PL_10 – PL_14 IT_04 – IT_11 DE_06 – DE_08, NL_02 – NL_04 RO_01 – RO_03 BG_01 – BG_02
		BIMSPEEDIsExternal	IFCPropertySingleValue	IFCBoolean	Indication whether the element is designed for use in the exterior (TRUE) or not (FALSE). If (TRUE) it is an external element and faces the	This attribute is not intended for checking. It is used as a rule condition.

					outside of the building.	
		BIMSPEEDLoadBearing	IFCPropertySingle Value	IFCBoolean	Indicates whether the object is intended to carry loads (TRUE) or not (FALSE).	This attribute is not intended for checking. It is used as a rule condition.
		BIMSPEEDCompartme ntation	IFCPropertySingle Value	IFCBoolean	Indication whether the object is designed to serve as a fire compartmentation (TRUE) or not (FALSE).	This attribute is not intended for checking. It is used as a rule condition.
		PL_BIMSPEEDHeatLab el	IFCPropertyListVal ue	List Value: IFCReal/USERDEFINE D 1. PRIVATE_HEA TED 2. COMMON_H EATED 3. BASEMENT_H EATED 4. BASEMENT_U NHEATED	Identifies the heat label of the object, based on the interior temperature. The value PRIVATE_HEATED corresponds to areas with temperature equal or more to 16oC (Temp>=16oC). The value COMMON_HEATE D corresponds to areas with temperature equal	This attribute is not intended for checking. It is used as a rule condition for objects belonging to BIMSPEEDCountry= Poland

					or more to 8oC and less that 16oC (16oC> Temp>=8oC). The value BASEMENT_HEATED corresponds to areas with temperature lower to 8oC (8 oC> Temp). The value BASEMENT_UNHEATED corresponds to all the remaining areas that do not reach any of the above-mentioned temperature limits.	
		DE_BIMSPEEDHeatLabel	IFCPropertyListValue	List Value: IFCReal/USERDEFINED 1. PRIVATE_HEATED 2. COMMON_HEATED	Identifies the heat label of the object, based on the interior temperature. The value PRIVATE_HEATED corresponds to areas with temperature equal or more to 19oC (Temp>=19oC).	This attribute is not intended for checking. It is used as a rule condition for objects belonging to BIMSPEEDCountry=Germany

					The value COMMON_HEATED corresponds to areas with temperature equal or more to 12oC and less that 19oC (19oC> Temp>=12oC).	
		RO_BIMSPEEDHeatLabel	IFCPropertyListValue	List Value: IFCReal/USERDEFINED 1. BASEMENT_HEATED 2. BASEMENT_UNHEATED	It is used to identify the heat label of the basement. The value BASEMENT_HEATED corresponds to areas with temperature lower to 8oC and greater or equal to 0oC (8 oC> Temp>= 0oC). The value BASEMENT_UNHEATED corresponds to areas with temperature lower to 0oC Temp< 0oC)	This attribute is not intended for checking. It is used as a rule condition for objects belonging to BIMSPEEDCountry=Romania
BIMSPEED_Roof	IFCRoof	BIMSPEEDFireRating	IFCPropertySingleValue	IFCLabel	Fire rating for this object. It is given according to the national fire safety classification.	PL_16 – PL_19

		BIMSPEEDIsExternal	IFCPropertySingleValue	IFCBoolean	Indication whether the element is designed for use in the exterior (TRUE) or not (FALSE). If (TRUE) it is an external element and faces the outside of the building.	This attribute is not intended for checking. It is used as a rule condition.
		BIMSPEEDThermalTransmittance	IFCPropertySingleValue	IFCThermalTransmittanceMeasure / THERMALTRANSMITTANCEUNIT	Thermal transmittance coefficient (U-Value) of a material. It applies to the total door construction.	ES_28 – ES_34, PL_20 – PL_23 IT_12 – IT_19 NL_05 RO_04 – RO_05 BG_03 – BG_04
		BG_BIMSPEEDWarm	IFCPropertySingleValue	IFCBoolean	Indication whether the roof type is warm (TRUE) or not (FALSE). A warm roof is a type of roof construction in which the thermal insulation layer is located immediately below the roof covering.	This attribute is not intended for checking. It is used as a rule condition for objects belonging to BIMSPEEDCountry=Bulgaria
		BG_BIMSPEEDCold	IFCPropertySingleValue	IFCBoolean	Indication whether the roof type is cold (TRUE) or not	This attribute is not intended for checking. It is used

					(FALSE). A cold roof is roof in which the thermal insulation layer is located immediately above or between the ceiling joists	as a rule condition for objects belonging to BIMSPEEDCountry= Bulgaria
		PL_BIMSPEEDHeatLabel	IFCPropertyListValue	List Value: IFCReal/USERDEFINED 1. PRIVATE_HEATED 2. COMMON_HEATED 3. BASEMENT_HEATED BASEMENT_UNHEATED	Identifies the heat label of the object, based on the interior temperature. The value PRIVATE_HEATED corresponds to areas with temperature equal or more to 16oC (Temp>=16oC). The value COMMON_HEATED corresponds to areas with temperature equal or more to 8oC and less that 16oC (16oC> Temp>=8oC). The value BASEMENT_HEATED corresponds to	This attribute is not intended for checking. It is used as a rule condition for objects belonging to BIMSPEEDCountry= Poland

					areas with temperature lower to 8oC (8 oC> Temp). The value BASEMENT_UNHEATED corresponds to all the remaining areas that do not reach any of the above-mentioned temperature limits.	
		DE_BIMSPEEDHeatLabel	IFCPropertyListValue	List Value: IFCReal/USERDEFINED 1. PRIVATE_HEATED 2. COMMON_HEATED	Identifies the heat label of the object, based on the interior temperature. The value PRIVATE_HEATED corresponds to areas with temperature equal or more to 19oC (Temp>=19oC). The value COMMON_HEATED corresponds to areas with temperature equal or more to 12oC and less that 19oC	This attribute is not intended for checking. It is used as a rule condition for objects belonging to BIMSPEEDCountry=Germany

					(19oC> Temp>=12oC).	
BIMSPEED_Window	IFCWindow	BIMSPEEDAcousticRating	IFCPropertySingleValue	IFCLabel	Acoustic rating for this object. It is giving according to the national building code. It indicates the sound transmission resistance of this object by an index ration (instead of providing full sound absorbtion values).	ES_35, PL_24, IT_20, DE_12, NL_16, RO_17
		BIMSPEEDThermalTransmittance	IFCPropertySingleValue	IFCThermalTransmittanceMeasure / THERMALTRANSMITTANCEUNIT	Thermal transmittance coefficient (U-Value) of a material. It applies to the total door construction.	ES_36 – ES_41 PL_25 – PL_28 IT_21 – IT_27 DE_13 – DE_14, NL_06 RO_06 BG_07 – BG_09
		PL_BIMSPEEDHeatLabel	IFCPropertyListValue	Identifies the heat label of the object, based on the interior temperature. The value PRIVATE_HEATED corresponds to areas with temperature	List Value: IFCReal/USERDEFINED 1. PRIVATE_HEATED 2. COMMON_HEATED	This attribute is not intended for checking. It is used as a rule condition for objects belonging to BIMSPEEDCountry=Poland

				equal or more to 16oC (Temp>=16oC). The value COMMON_HEATED corresponds to areas with temperature equal or more to 8oC and less that 16oC (16oC> Temp>=8oC). The value BASEMENT_HEATED corresponds to areas with temperature lower to 8oC (8 oC> Temp). The value BASEMENT_UNHEATED corresponds to all the remaining areas that do not reach any of the above-mentioned temperature limits.	3. BASEMENT_HEATED 4. BASEMENT_UNHEATED	
		DE_BIMSPEEDHeatLabel	IFCPropertyListValue	List Value: IFCReal/USERDEFINED 1. PRIVATE_HEATED 2. COMMON_HEATED	Identifies the heat label of the object, based on the interior temperature. The value PRIVATE_HEATED corresponds to areas with	This attribute is not intended for checking. It is used as a rule condition for objects belonging to BIMSPEEDCountry=Germany

					temperature equal or more to 19oC (Temp>=19oC). The value COMMON_HEATED corresponds to areas with temperature equal or more to 12oC and less that 19oC (19oC> Temp>=12oC).	
		BG_BIMSPEEDFrameMaterial	IFCPropertyListValue	List Value: IFCReal/USERDEFINED 1. PVC 2. Wood 3. Aluminium	Material of the window frame.	This attribute is not intended for checking. It is used as a rule condition for objects belonging to BIMSPEEDCountry=Bulgaria
		NL_BIMSPEEDGlassLayers	IFCPropertySingleValue	IFCCountMeasure	Number of glass layers	NL_07
		PL_BIMSPEEDRoofWindow	IFCPropertySingleValue	IFCBoolean	Indication whether the element (belonging to country Poland) is a roof window (TRUE) or not (FALSE).	This attribute is not intended for checking. It is used as a rule condition for objects belonging to BIMSPEEDCountry=Poland

		NL_BIMSPEEDRoofWindow	IFCPropertySingleValue	IFCBoolean	Indication whether the element (belonging to country Netherlands) is a roof window (TRUE) or not (FALSE).	This attribute is not intended for checking. It is used as a rule condition for objects belonging to BIMSPEEDCountry=Netherlands
BIMSPEED_Stair	IFCStair	BIMSPEEDRequiredHeadroom	IFCPropertySingleValue	IFCPositiveLengthMeasure / LENGTHUNIT	Required headroom clearance for the passageway according to the applicable building code or additional requirements	ES_42 NL_08
		BIMSPEEDFireExit	IFCPropertySingleValue	IFCBoolean	Indication whether this object is designed to serve as an exit in the case of fire (TRUE) or not (FALSE). Here it defines an exit stair in accordance to the national building code.	ES_44 This attribute is also used as a rule condition.
		ES_BIMSPEEDProtected	IFCPropertySingleValue	IFCBoolean	Indication whether the stair is design as a protected	This attribute is not intended for checking. It is used as a rule condition

					stairway (TRUE) or not (FALSE).	for objects belonging to BIMSPEEDCountry= Spain
		ES_BIMSPEEDSpecial Protected	IFCPropertySingle Value	IFCBoolean	Indication whether the stair is design as a special protected stairway (TRUE) or not (FALSE).	This attribute is not intended for checking. It is used as a rule condition for objects belonging to BIMSPEEDCountry= Spain
		ES_BIMSPEEDFireVesti bule	IFCPropertySingle Value	IFCBoolean	Indication whether the stair includes a fire vestibule (TRUE) or not (FALSE).	ES_46. This attribute is also used as a rule condition for objects belonging to BIMSPEEDCountry= Spain
		PL_BIMSPEEDRiserHei ght	IFCPropertySingle Value	IFCPositiveLengthMe asure / LENGTHUNIT	Vertical distance from tread to tread. The riser height is supposed to be equal for all steps of a stair or stair flight.	PL_35
		NL_BIMSPEEDRiserHei ght	IFCPropertySingle Value	IFCPositiveLengthMe asure / LENGTHUNIT	Vertical distance from tread to tread. The riser height is supposed to be	NL_09

					equal for all steps of a stair or stair flight.	
		NL_BIMSPEEDTreadLength	IFCPropertySingleValue	IFCPositiveLengthMeasure / LENGTHUNIT	Horizontal distance from the front of the thread to the front of the next tread. The tread length is supposed to be equal for all steps of the stair or stair flight at the walking line.	NL_10
BIMSPEED_Door	IFCDoor	BIMSPEEDFireRating	IFCPropertySingleValue	IFCLabel	Fire rating for this object. It is given according to the national fire safety classification.	ES_45
	IFCDoor	BIMSPEEDFireExit	IFCPropertySingleValue	IFCBoolean	Indication whether this object is designed to serve as an exit in the case of fire (TRUE) or not (FALSE). Here it defines an exit door in accordance to the national building code.	ES_44 PL_36 This attribute is also used as a rule condition.

BIMSPEED_FlowTerminal	IFCFlowTerminal	BIMSPEEDHeatingSource	IFCPropertyEnumeratedValue	PEnum_HeatingSource 1. FUEL 2. GAS 3. ELECTRICITY 4. HOTWATER 5. STEAM 6. OTHER 7. NOTKNOWN 8. UNSET	Enumeration defining the heating source used by the space heater.	This attribute is not intended for checking. It is used as a rule condition
		BIMSPEEDThermalEfficiency	IFCPropertySingleValue	IFCPositiveRatioMeasure	Overall Thermal Efficiency is defined as gross energy output of the heat transfer device divided by the energy input.	RO_14, BG_12 – BG_17
		RO_BIMSPEEDOutputCapacity	IFCPropertySingleValue	IFCPowerMeasure / POWERUNIT	Total nominal heat output as listed by the manufacturer.	RO_15