

BACK TO 4.0:

RETHINKING

THE DIGITAL CONSTRUCTION INDUSTRY

A cura di

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“ Construction Health and Safety Code Checking: a BIM-based Validation Process ”

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Topic: Models for design and Construction

Abstract

Rule-based Code Checking validates the design phase comparing a Building Information Model (BIM) against current codes and regulations translated into parametric rules. The proposed paper fits into a larger research project about the parametrization of Italian normative texts related to building design requirements in order to proceed with a rule-based validation within a BIM Environment. The paper is focused on the translation into a parametric rule-set of the Italian Construction Health and Safety (H&S) normative text (D.Lgs. 81/2008), concerning construction sites. The research project aims to define an H&S BIM-based design and validation process, including the mandatory informative content for the submission of construction site layouts and safety plans into an interoperable BIM Environment. A BIM library for the construction site has been created, including construction vehicles, safety and site elements. An IFC-based Model Checking tool has been used for BIM Validation and Code Checking; the customized rule-set includes legal references and information requirements specifications. The rule execution phase has started checking site layouts in case of a series of safety hazards defined by the normative text. Such an approach could effectively anticipate and support the decision-making process related to design and validation of construction site layouts and safety plans, analyzing construction phases and identifying potential issues in a virtual environment. The aim is to propose a guideline for the modelling, management and validation of Building Information Models in the field of Construction Health and Safety.

1. Introduction

Safety at work is a complex phenomenon, and the subject of safety attitudes and safety performance in the construction industry is even more so. In the construction industry the risk of a fatality is five times more likely than in a manufacturing based industry, whilst the risk of a major injury is two and a half time higher. For that reason, safety in construction remains a major issue. The identification of all potential hazards in a building project is generally considered the key component of planning for safety, as well as the decision on choosing corresponding safety measures. The problem arises when safety planning is done separately from project execution planning and choices of the construction methods; moreover critical issues may arise when safety planning involves different actors without a collaborative design approach.

Considering how designers, practitioners and clients are involved and integrated in the Normative Context about Construction Safety and considering the standard practises, the current state of safety planning in construction can be summarized as follow:

- *Traditional safety planning is carried out by means of manual observations which result to be labor-intensive, error-prone, and often highly inefficient.* The link between planning for safety and work task execution lacks accuracy due to the massive use of two-dimensional drawings (2D) and, not less relevant, the massive use of software which loose the connection with the real site simulation.
- *Building designers and Health and Safety Coordinator (H&S Coordinator) still lack a collaborative working approach and H&S Coordinator's choices do not affect building design.* EU directives clearly state the importance of the “safety awareness” during various stages of design and, for this reason, remark the Health ad Safety Coordinator involvement in the design phase. Despite of it, in some European countries (i.e. Italy with D.Lgs 81/2008) the involvement of Safety Coordinator in design process is weak, even if national laws theoretically agree with EU directives (Aulin and Capone 2010).

For these reasons, the planning and design phases provide a crucial opportunity to prevent hazards and to verify the future site conditions according to the National Safety Legislation. Overturning the current safety planning approaches which are primarily text-based, standalone, check-sheet type tools with responsive tools and resources to assist designers, seems to be one of the best research directions and the growing implementation of Building Information Modelling (BIM) in the AEC/FM industry should be the right support in changing the way safety can be approached.

The proposed research project aims to focus on the translation into a parametric rule-set of the Italian Construction Health and Safety (H&S) normative text (D.Lgs. 81/2008), concerning construction sites, in order to define an H&S BIM-based design and validation process.

2. BIM-based Rule Checking

BIM-based Rule Checking is a multi-domain design validation framework based on parametric rules within a BIM environment (Zhang et al., 2013). It consists in a control system through which the user is able to perform a check, whose results may be “*pass*”, “*fail*”, “*warning*” and “*unknown*”, in case of incomplete or missing data (Hjelset and Nisbet, 2010). Rule Checking validation is a key process in order to ensure quality and internal consistency of a Building Information Model (Kulusjärvi, 2012). Moreover, in an open BIM environment, based on the use of an interoperable and neutral data format, the validation phase is essential to formalize information exchange procedures (Dave et al., 2013), increasing transparency and interoperability of the process as a whole.

A parametric Rule Checking system can be implemented in two different ways. The former is the use of applications and plug-ins in BIM authoring platforms, which usually contain tools to perform a preliminary check of the interferences or a partial BIM validation of geometric aspects. On the other hand, at present, BIM design tools do not provide more advanced Model Checking capabilities based, for example, on customizable rule-sets. Model checking BIM tools are required, which apply rules to Industry Foundation Classes (IFC) building model data (Zhang et al., 2013): that is one of the reasons why data interoperability remains a major issue.

Clash Detection is the Model Checking use with the best effort-benefit ratio, since it does not necessarily require information-rich objects. Anyway, in an entirely digitalized building process the focus is on BIM Data Validation and semi-automated Code Checking.

BIM Validation is the application of parametric rules analyzes quality and internal consistency of a Building Information Model. This check guarantees the production of a high quality Building Information Model from which it is possible to extract reliable data for further BIM-based analyses (Kulusjärvi, 2012). This rule-set checks geometric and non-geometric attributes embedded in a BIM model in order to validate property values and modelling procedures. For example, BIM Validation rules allow the analysis of the informative content associated to a parametric object and the validation of the correspondent Level of Development (LOD) based on what previously specified in Employer Information Requirements (EIR) and BIM Execution Plan (BEP) (Ciribini et al., 2015).

BIM-based semi-automated Code Checking is a specific case of Rule Checking that validates three-dimensional (3D) and object-oriented design (Solihin et al., 2015) through various validation domains, comparing the parameters of the Building Information Model against current codes and regulations (Hjelset and Nisbet, 2010). As already said, manual validation of design solutions is a subjective, error prone, expensive and time-consuming activity (Zhang et al., 2013) that may lead to

ambiguity, inconsistency in assessments and delays over the entire building and construction process (Malsane et al., 2015). BIM-based Code Checking can provide reliable validation results: in standard design and validation processes, just the 5-10% of the informative content of a project is systematically checked against the 40-60% of the validated design by means of semi-automatic BIM-based Model Checking tools (Kulusjärvi, 2012).

The Rule-based Code Checking process is composed of four major stages (Eastman et al., 2009):

- *rule interpretation*: rules are logically structured for their implementation and application in rule checking tools;
- *building model preparation*: the model is integrated with the necessary informative content required for comparing it with the set of rules;
- *rule execution*: the checking phase is carried out;
- *rule reporting*: checking results are reported to be shared and resolved.

Constraints for building design are typically defined in written text and table having legal status. Rule interpretation is a key step to convert human-oriented languages into a computable one. A well-developed technique consists of extracting rules from codes and regulations through a semantic-based translation. It has been proved that a direct semantic interpretation of texts based on four mark-up operators can provide trustworthy rules and results (Hjelseth, 2009). For example, semantic operators that can be used on normative texts are: Requirements, Applicability, Selection and Exception. These tags are the foundation for the RASE methodology, a semantic mark-up method to efficiently convert prescriptive requirements of normative texts into a computable language, and their translation in well-defined rules to be implemented into BIM/IFC-based Model Checking tools. Once logically structured, regulations can be grouped into rulesets representing a validation domain.

Alongside the rule interpretation phase, the Building Information Model has to be prepared, implementing a semantic uniformed way of mapping objects in order to allow the receiving Rule Checking tool to read a semantically rich model. BIM objects' informative content should include information about geometry, geometric relations, name attributes, domain specific attributes and instance-specific attributes.

3. Methodology

The proposed paper is focused on the translation into a parametric rule-set of the Italian Construction Health and Safety (H&S) normative text (D.Lgs. 81/2008), concerning construction sites, in order to define an H&S BIM-based design and validation process. The research project aims to propose a guideline to model, manage and validate Building Information Models in the field of Construction Health and

Safety. At present, the phases of rule interpretation and building model preparation have been investigated. The rule execution phase has started, checking sample site layouts in case of a series of safety hazards defined by the normative text.

Rule interpretation has been the first step of the Rule Checking process. The normative text has been analyzed by applying the RASE semantic mark-up methodology in order to translate qualitative statements and quantitative requirements, transforming the latter in parametric rules. On the one hand, this analysis of the normative text has been useful to develop a parametric rule-set to validate BIM-based safety plans; on the other hand, from the analysis of the normative requirements, the necessary informative content for each BIM object has been identified and structured into a BIM object table.

These tables have represented the starting point for the creation of a BIM library for the construction site, of which geometrical attributes, geometric relations and alphanumeric properties could be validated by the parametric rule-set. Each object contains information about the review category, geometry, geometric relations, name attributes, domain specific attributes and instance-specific attributes. An IFC-based Model Checking tool has been used for the rule execution phase of BIM Validation and Code Checking in order to check the compliance of the Building Information Model against normative requirements digitally transformed (Fig. 1).

4. First Applications

The creation of a BIM library is currently ongoing. An example of the rule interpretation and execution phases is following described.

A scaffolding has been modelled in the BIM object editor of Autodesk Revit. Geometric and non-geometric attributes have been added to validate the object in the Model Checking tool, Solibri Model Checker, in accordance to the information requirements defined in the normative text. A *review category* attribute has been used to automate the mapping phase between rules and objects in the validation tool. In the proposed example, the scaffolding is validated against two types of rule. The first example is the interpretation of *D.Lgs. 81/2008 Titolo IV Capo II Sezione V Ponteggi fissi Art. 134.1 Documentazione*, about the required scaffolding documentation (Fig. 2) (Table 1) (Table 2). During the rule execution phase, it is checked that the scaffolding BIM object actually contains the required property sets and properties. It is also checked that the properties have (or do not have) a value and the type of the value is acceptable. In this case, the parametric rule was used to check that the required documentation had been attached to the scaffolding BIM object. Checking results highlighted that the object contained all the necessary properties, but only one of them (the link to the Pi.M.U.S) had a value and it was acceptable. Other properties did not have a value, and an issue to be resolved was detected (Fig. 3).

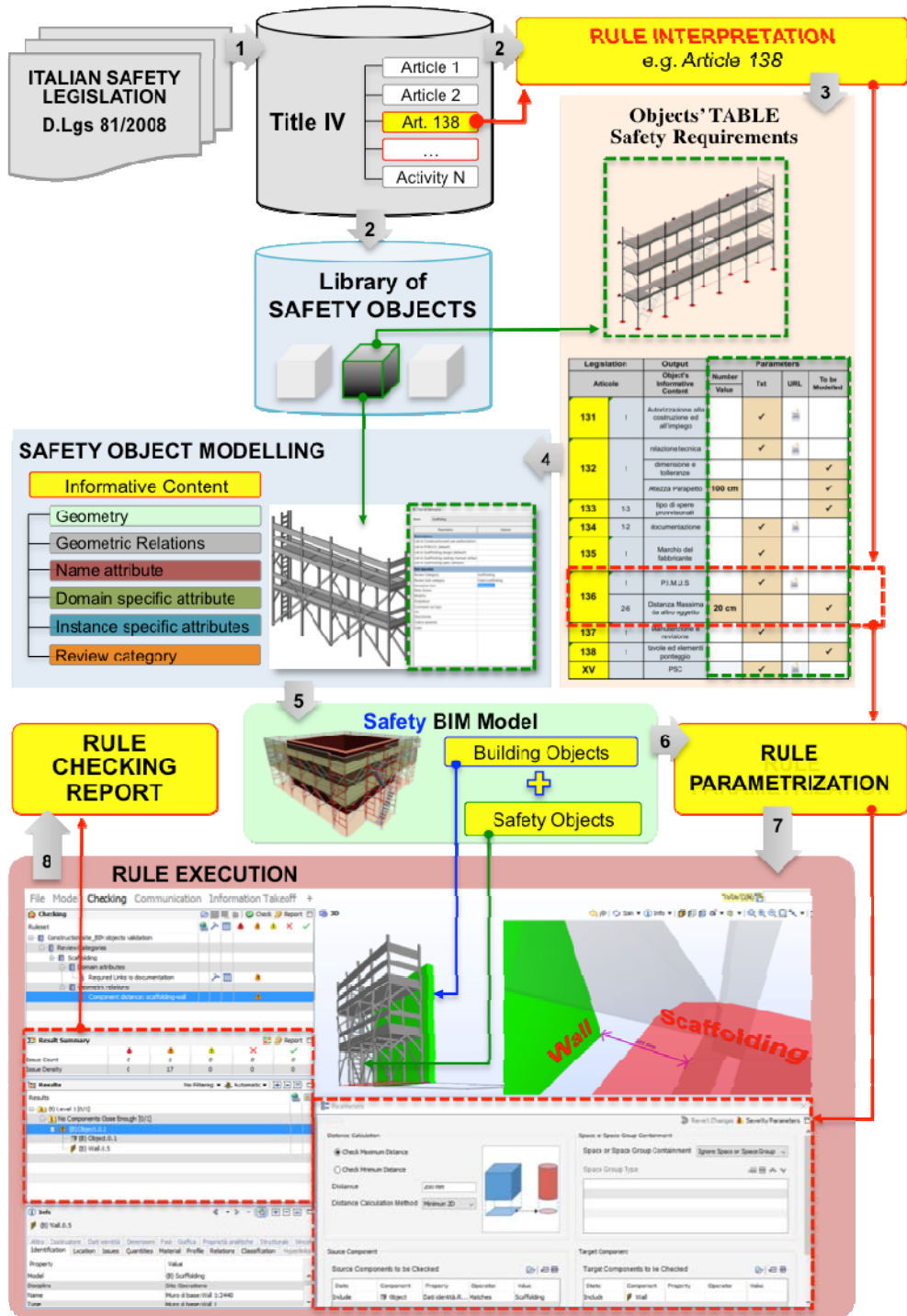


Fig. 1 The BIM-based Rule Checking Process

Requirement {blue}	Applies {green}	Select {red}	Exception {orange}
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Fig. 2 The four operators for rule development (Hjelseth, 2010)

Table 1 Example clause (based on D.Lgs. 81/2008 Sezione V Ponteggi fissi Art. 134.1 Documentazione).

Rule source	D.Lgs. 81/2008 Titolo IV Capo II Sezione V Ponteggi fissi Art. 134.1 Documentazione
Rule description	<p>Nei cantieri in cui vengono usati {green/}ponteggi{green} deve essere tenuta ed esibita, a richiesta degli organi di vigilanza, copia della {red/}documentazione{red} di cui al comma 6 dell'articolo 131* e {blue/}copia del piano di montaggio, uso e smontaggio (Pi.M.U.S.) {blue}, in caso di lavori in quota, i cui contenuti sono riportati nell'allegato XXII del presente Titolo.</p> <p>*Art 131, comma 6 {blue/}Autorizzazione alla costruzione e all'impiego{blue}; {blue/}Calcolo del ponteggio secondo varie condizioni di impiego{blue}; {blue/}Istruzioni per le prove di carico del ponteggio{blue}; {blue/}Istruzioni per il montaggio, impiego e smontaggio del ponteggio{blue}; {blue/}Schemi-tipo di ponteggio con l'indicazione dei massimi ammessi di sovraccarico, di altezza dei ponteggi e di larghezza degli impalcati per i quali non sussiste l'obbligo del calcolo per ogni singola applicazione{blue}.</p>

Table 2 Overview of mark-up for the required scaffolding's documentation.

Mark-up operator	Mark-up colour	Identification of construction object	Property of object	Logic relation	Value
apply	green	Site element. Scaffolding	(existence)	=	(true)
select	red	documentation	(existence)	=	(true)
require	blue	Site element. Scaffolding	Pi.M.U.S	=	X=*
require	blue	Site element. Scaffolding	Autorizzazione alla costruzione e all'impiego	=	X=*
require	blue	Site element. Scaffolding	Calcolo del ponteggio	=	X=*
require	blue	Site element. Scaffolding	Istruzioni per le prove di carico del ponteggio	=	X=*
require	blue	Site element. Scaffolding	Istruzioni per il montaggio, impiego e smontaggio del ponteggio	=	X=*
require	blue	Site element. Scaffolding	Schemi-tipo di ponteggio	=	X=*

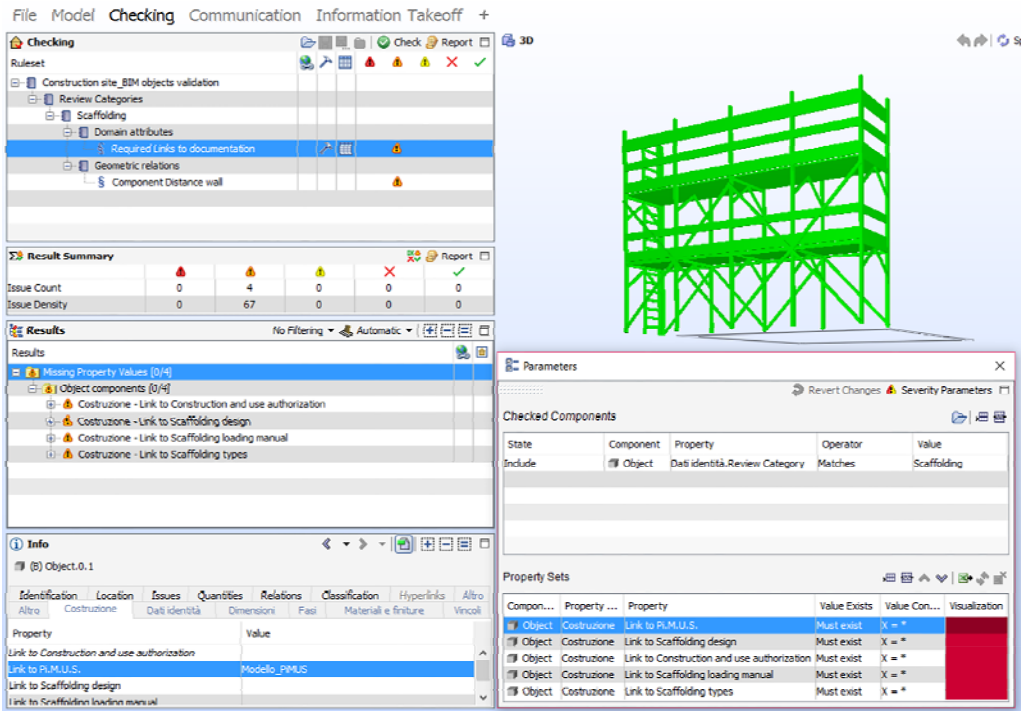


Fig. 3 D.Lgs. 81/2008 Titolo IV Capo II Sezione V Ponteggi fissi Art. 134.1 Documentazione: the rule checks that the BIM object contains required property sets and properties. It can also checks that the properties have (or do not have) a value and the type of the value is acceptable.

The geometric relation between a scaffolding and a wall was also checked, according to what required in D.Lgs.. 81/2008 Titolo IV Capo II Sezione V Ponteggi fissi Art. 138.2 Norme particolari (Table 3) (Table 4). In this case, a parametric rule was customized to check the components distance between the site element and the building element, once they had been opportunely classified and mapped in order to automate the rule execution and guarantee reliable results (Fig. 4).

Table 3 Example clause (based on D.Lgs. 81/2008 Sezione V Ponteggi fissi Art. 138.2 Norme particolari).

Rule source	D.Lgs. 81/2008 Titolo IV Capo II Sezione V Ponteggi fissi Art. 138.2 Norme particolari
Rule description	Nell'uso di <i>ponteggi</i> <i>fissi</i> È consentito un <i>distacco</i> delle tavole del piano di calpestio dalla muratura <i>non superiore a 20 centimetri</i> .

Table 4 Overview of mark-up for a scaffolding-wall geometry relation.

Mark-up operator	Mark-up colour	Identification of construction object	Property of object	Logic relation	Value
apply	green	Site element. Scaffolding	(existence)	=	(true)
select	red	Site element. Scaffolding	type	=	fixed
require	blue	Building element. Wall	(existence)	=	(true)
require	blue	Building element. Wall Site element. Scaffolding	distance	≤	20 cm

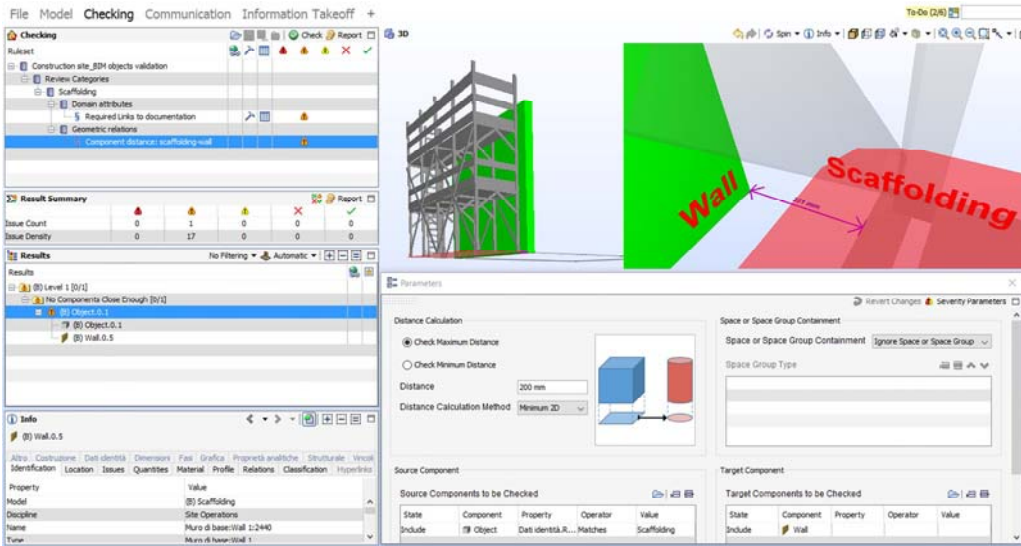


Fig. 4 D.Lgs. 81/2008 Titolo IV Capo II Sezione V Ponteggi fissi Art. 138.2 Norme particolari This rule checks components distance between each other.

5. Conclusion

The proposed research project has outlined a framework for a rule-based checking system for safety planning and simulation by integrating BIM and safety issues. As shown in this paper, even if the current BIM practice mostly uses a parametric rule-based checking approach in order to validate architectural design, it has emerged that the site safety digitalization is a fundamental component for the design chain and its validation needs to be carried out in parallel with the others.

From a Safety Management perspective, the benefits are outlined below:

- safety risks will be identified early in the process before issues arise in the field;
- three-Dimensional, real-time images and models enhance the communication between field inspectors and office supervisors in order to help them to resolve detected issues immediately.

The connection between a rule-based checking system and a 4D BIM-based modelling is the next research challenge aiming to validate the site safety design for each phase that composes the building schedule.

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