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BIM-based code checking for construction health and safety

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Abstract

Rule-based Code Checking validates the design phase comparing Building Information Models against current codes and regulations translated into parametric rules. The proposed paper fits into a wider project for implementing design verification and validation within a BIM environment. The design of construction site layouts and safety plans is an essential part of an effective integrated process but it is traditionally carried out by means of error-prone and inefficient manual observation and, moreover, building designers and health and safety (H&S) coordinators still lack a collaborative working approach. The digitization of the construction site allows virtual inspections and information-based analysis of construction phases. Moreover, interoperable BIM tools allow the semi-automatic review of design compliance against normative texts, improving accuracy and reliability of the validation process. The research project aims to define an H&S BIM-based design and validation workflow, specifying the minimum level of requirements and mandatory informative content for the submission of construction site layouts and safety plans. The paper is focused on the translation into a parametric rule-set of the Italian construction sites' H&S normative text (D.Lgs. 81/2008). A semantic analysis was used in order to translate it into computable parameters to be implemented into checking rules. Object tables have been created for each construction site element regulated by the D.Lgs. 81/2008. Based on those tables, meant as guideline for the design phase, a BIM library for the construction site has been created and a model checking tool has been used for creating rules to check and validate BIM objects and mutual relations. The customized rule-set includes legal references and information requirements specifications. Such an approach aims at including the design of construction safety plans within digital

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practices, anticipating and supporting the decision-making process, analyzing construction phases and identifying potential issues in a virtual environment.

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Keywords: building information modeling, code checking, construction site layout, interoperability, safety constructability

1. Introduction

According to [1], the 90% of workspace injuries are produced by an unsafe construction site. How to manage such a phenomenon during the building design development is a complex matter. The identification of all potential hazards in a building project, in fact, 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 construction methods decision-making; 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 according to the normative context about construction safety and considering standard practices, the current approach to 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 safety planning and work task execution lacks accuracy due to the massive use of two-dimensional (2D) drawings and, not less relevant, the massive use of software which loses the connection with the real site simulation.

- building designers and Health and Safety coordinator (H&S Coordinator) still lack a collaborative working approach and the choices of the H&S Coordinator do not affect building design. European Union (EU) directives clearly state the importance of the *safety awareness* during the various stages of the design process and, for this reason, remark the H&S Coordinator involvement in the design phase. Nevertheless, in some European countries the involvement of the H&S Coordinator in the design process is still weak, even if national laws (such as the Italian D.Lgs 81/2008) theoretically agree with EU directives [2].

For these reasons, safety planning and design phases provide a crucial opportunity to prevent hazards and to evaluate possible issues related to the future site conditions within the framework of the normative context about construction safety. Overturning the current safety planning approaches, which are primarily text-based, standalone and based on check-sheet tools to assist designers, seems to be one of the main research topics; moreover, the growing implementation of Building Information Modelling (BIM) in the construction industry could be the right support in changing the way construction site safety can be approached. For example, the New York City Department of Building (NYC-DOB) has already started to use BIM processes and tools to validate construction site safety plans; its process of submission, emendation and review is completely digitalized and BIM-based [3,4]. Following such an example, the proposed research project aims to focus on the translation into a parametric rule-set of the aforementioned Italian Construction Health and Safety (H&S) normative text (D.Lgs. 81/2008) in order to define an H&S BIM-based design and validation process that could be easily implemented by Public Clients.

Nomenclature

D.Lgs.	Legislative Decree (normative text)
H&S	Health and Safety
BIModel	Building Information Model
IFC	Industry Foundation Classes

2. Methodology

2.1. BIM-based Rule Checking

BIM-based Rule Checking is a multi-domain validation framework based on parametric rules [5] and various concepts of BIM-based model checking exist [6]. Clash Detection, also known as Clash Prevention or Clash Avoidance, is the most used validation domain and the one with the best effort-benefit ratio because it does not necessarily require information-rich objects [7]. However, a rule-based validation can be also used for assuring the quality of the informative content embedded in BIM objects and to control modelling procedures and internal consistency of BIModels in order to extract reliable data for further BIM-based analyses (i.e. BIM Validation) [8]. Moreover, parametric Rule Checking processes can be also applied to validate the compliance of design proposals against codes and regulations (i.e. BIM-based Code Checking) by comparing the parameters - geometrical and alphanumerical - embedded within the BIModel against normative requirements translated into parametric rule-sets [9,10,11]. BIM authoring platforms usually provide tools for a preliminary Clash Detection. Other Model Checking tools can be used for more advanced application of Rule Checking, allowing the user to customize sets of parametric rules as well as quantity and information take-off definitions (e.g. Solibri Model Checker). Such tools usually apply rules to IFC data schema representing the design solution to be checked and validated [5]: that is one of the reasons why data interoperability between BIM authoring platforms and BIM tools remains a major issue [12].

2.2. The proposed workflow

The presented research illustrates the first results of the digitization of the Italian H&S normative text for construction sites. It mainly focuses on (1) BIM Validation and Code Checking and (2) the creation of a BIM library for the design of site safety plans. The RASE (Requirements, Applicability, Selection and Exception) methodology proposed by [13] was applied for the semantic interpretation of the normative text and the rule-based code checking process proposed by [11] (1. Rule interpretation; 2. Building model preparation; 3. Rule execution; 4. Rule reporting) was used as a basis for structuring the workflow proposed in this paper and following detailed (Figure 1).

step 1. A semantic mark-up methodology was used to convert prescriptive requirements of normative texts into a computable language; this step was necessary to have a clear idea of objects and relationships between objects to be validated, related requirements and informative content.

step 2. Based on rule interpretation, the informative - geometric and alphanumeric - content required by the D.Lgs 81/2008 for objects to be used in construction safety plans has been structured into Object Tables, meant as guidelines for the design phase.

step 3. These tables have represented the starting point for the creation of a BIM library (the *family editor* of Autodesk Revit was used) for the construction site safety plan; each object contains information about the geometry and the necessary level of detail, geometric relations, name attributes, domain specific attributes and instance-specific attributes. A *review category* parameter was added to each BIM objects in order to set up an auto-matching rule within the rule-based model checking tool [3].

step 4. Concurrent the creation of the BIM library, a parametric rule-set was created (the *rule-set manager* of Solibri Model Checker was used). The customized rule-set aims at validating (1) the informative content of the BIM objects used in site safety plans against the Object Tables provided (i.e. BIM object validation); (2) the relationship between two elements of a construction safety plan.

step 5. The rule execution phase is planned to validate:

- how BIM objects have been modelled according to the level of detail required by the normative text (and specified in the object tables);
- the informative content of BIM objects against requirements specified in the object tables:
  - if a required attribute is embedded within a BIM object
  - if the required attribute is filled out
  - if the value of the required attribute is correct;

- the relationships between objects within a construction safety plan (e.g. distance between a wall and a scaffolding).

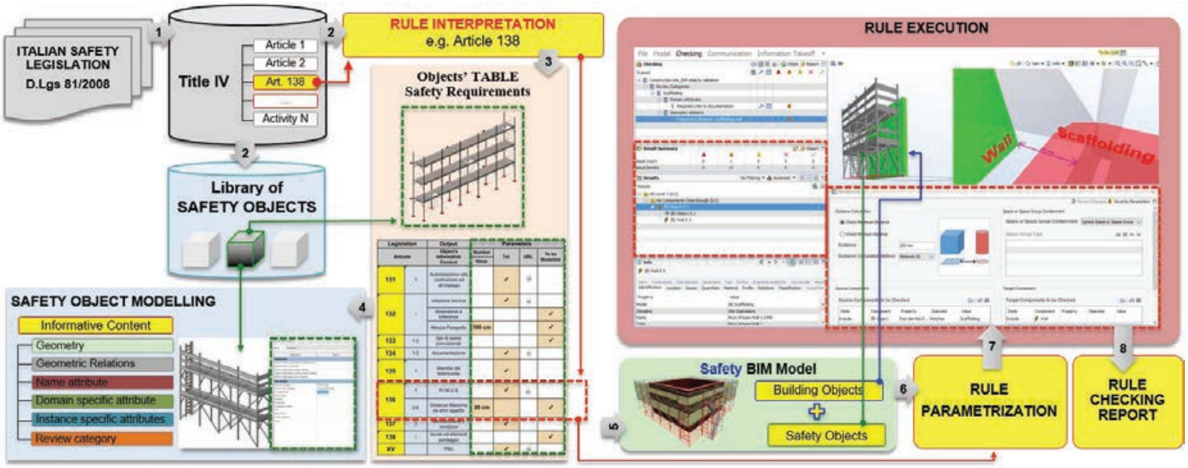

Figure 1 Rule Checking Workflow [14]

2.3. BIM object validation: an example

An example of BIM object validation follows. It is related to the interpretation of *D.Lgs. 81/2008 Title IV Chapter II Section V Scaffoldings Art. 134.1 Documentation*, concerning the required scaffolding documentation (Table 1,2) (Figure 2). During the rule execution phase, it is checked that the BIM object *Scaffolding* contains the required property sets and related 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 BIM object *Scaffolding*. Checking results highlighted that the object contained all the necessary properties, but only one of them (the link to the Pi.M.U.S - guide for the erection, use and dismantling of the scaffolding) had a value and it was acceptable. Other properties intentionally did not have a value, and an issue to be resolved was detected.

Table 1 Example *D.Lgs. 81/2008 Section V Scaffoldings Art. 134.1 Documentation*

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

RULE SOURCE
D.Lgs. 81/2008 Title IV Chapter II Section V Scaffoldings Art. 134.1 Documentation
RULE DESCRIPTION
In construction sites where {*green/*}scaffoldings{*\green*} are used, a copy of the {*red/*}documentation{*\red*} referred to in paragraph 6 of Article 131* as well as a copy of the {*blue/*}guide for the erection, use and dismantling of the scaffolding (Pi.M.U.S.){*\blue*}, in case of works at height, must be kept and exhibited at the request of the supervisory bodies. The contents of Pi.M.U.S. are included in Annex XXII. *Art 131, paragraph 6 {*blue/*}Authorization for the construction and use{*\blue*} {*blue/*}Calculation of the scaffolding according to various conditions of use{*\blue*}; {*blue/*}Instructions for scaffolding load tests{*\blue*}; {*blue/*}Instructions for the erection, use and dismantling of the scaffolding{*\blue*}; {*blue/*}Type-schemes of scaffolding with an indication of the maximum overload capacity, the height of the scaffolding and the deck widths for which there is no obligation of the calculation for every single application{*\blue*}.

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	Authorization for the construction and use	=	*X=**
require	*blue*	Site element. Scaffolding	Calculation of the scaffolding	=	*X=**
require	*blue*	Site element. Scaffolding	Instructions for scaffolding load tests	=	*X=**
require	*blue*	Site element. Scaffolding	Instructions for the erection, use and dismantling of the scaffolding	=	*X=**
require	*blue*	Site element. Scaffolding	Type-schemes of scaffolding	=	*X=**

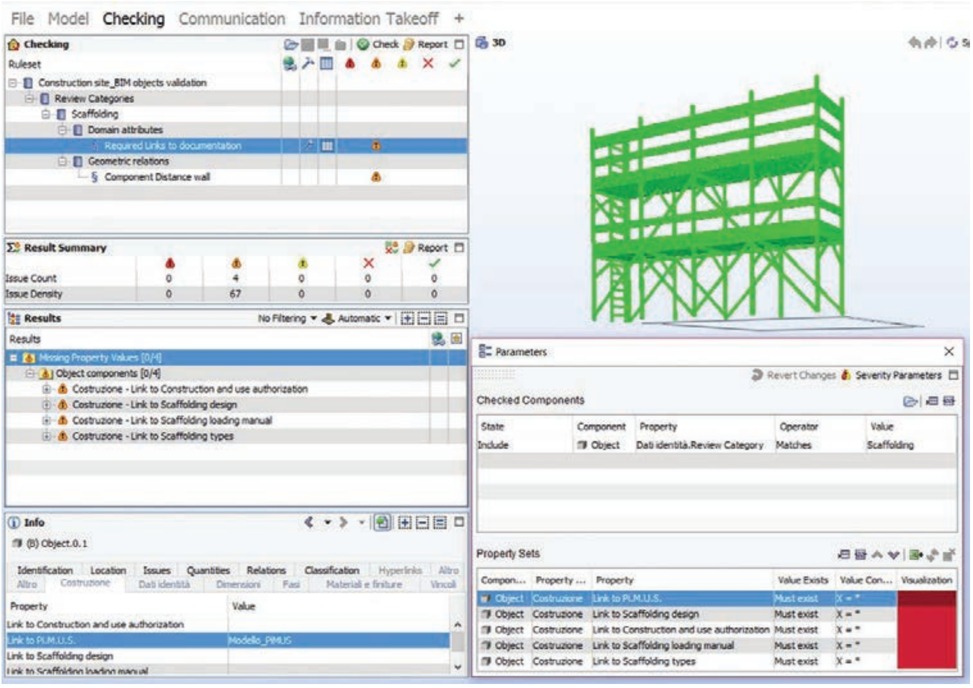

Figure 2 *D.Lgs. 81/2008 Title IV Chapter II Section V Scaffoldings Art. 134.1 Documentation*: the rule checks that the BIM object contains required property sets and properties. It can also check that the properties have (or do not have) a value and the type of the value is acceptable [14].

2.4. Case study

Once the Italian Construction Health and Safety (H&S) normative text (D.Lgs. 81/2008) had been interpreted (step 1 of the methodology), it was translated into a code checking rule-set to semi-automatically verify a construction site safety plan. The rule-set has been divided according to the same sections of the normative text: (I) *General Provisions*,

(II) *Excavations and Foundations*, (III) *Mobile Scaffolds*, (IV) *Fixed Scaffolds*, (V) *Buildings*, (VI) *Demolitions*, (VII) *Health and Safety Plan*. At the same time, from the analysis of the normative text a list of objects for site safety plans and their respective Object Tables have been created (step 2 of the methodology). As schematically depicted in Figure 4, Object Tables have been translated into BIM objects which compose a BIM library. BIM objects, such as f Ramps, Temporal Parapets, Cranes, Signage, Cabins, Site Areas, Fixed Scaffolds, Mobile Scaffolds, Vehicles and Waste Pipes, have been modelled by using the *family editor* of Autodesk Revit (step 3 of the methodology). A *review category* parameter was added to the BIM objects (step 3 of the Methodology) in order to set up an auto-matching rule within the rule-based model checking tool as depicted within the layout models (Figure 3), where filtering colors have been used to distinguished the objects classification.

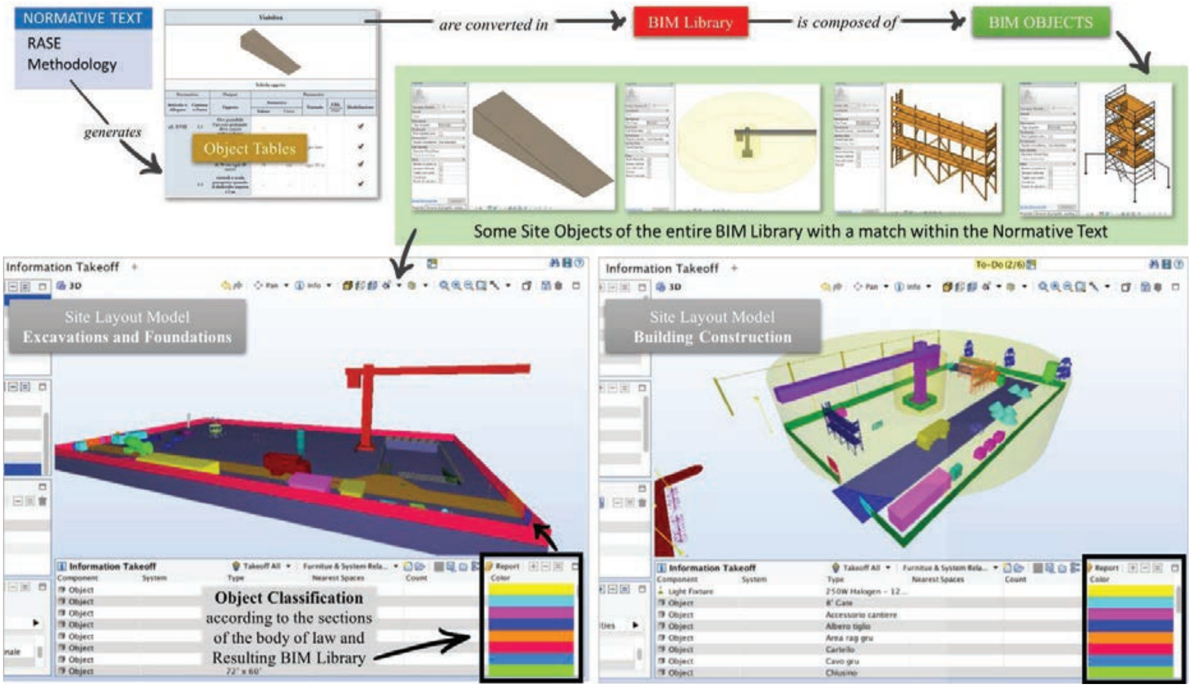

Figure 3 Ad-hoc layouts with *design flaws* to validate the methodology

In order to validate the proposed methodology, two different *ad-hoc* layouts for site safety plans have been created: one that refers to the *Excavations and Foundations* and the other to the effective building construction. Intentionally, they do not refer to a real case study due to the aims of the validation: (1) assess how the validation process functions; (2) whether it functions from a logical and computational point of view. These *ad-hoc* layouts contain errors that should be subsequently checked within the rule-based model checking tool (Solibri Model Checker). It would not be possible to reach the same validation by using a correct model because detecting the intentional errors has been possible to proceed with an iterative alignment between BIM objects and code checking rule-set and, finally, the functioning has been validated. Some explanatory *Opens Issue* which have been checked during the rule execution phase are shown on the right side of the Figure 4, on the middle the main important *Rule Parameters* to be checked and on the left side the identification of the *Design Flaws*.

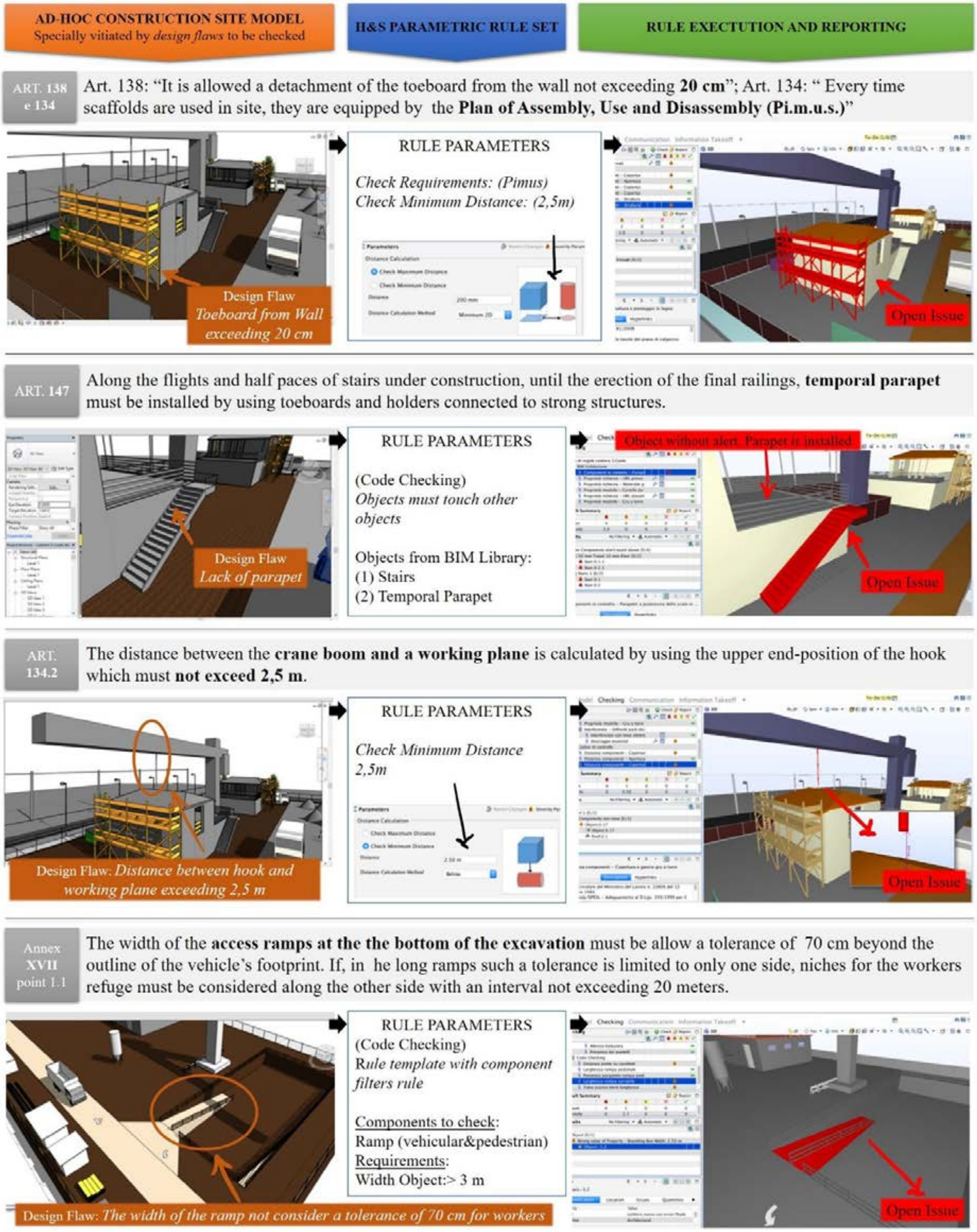

Figure 4 Explanatory open issues detected by applying the created rule-set

3. Results and discussion

The proposed paper contributes to the effective implementation of design activities concerning site safety planning within a digital design process, aiming at supporting Public Clients in their digital transition as far as the construction site is concerned. Site Objects Tables support the interpretation of the normative text and they are meant as a guideline for the design and validation of site safety plans. Their corresponding BIM objects, included within the BIM library, results in an effective site design control which requires H&S coordinators to operate on such parameters.

Future development in this perspective includes the integration of workers' safety information (e.g. safety risks, health risks, best practices) that would create an inclusive process within the proposed methodology of the *design-for-safety* theories and database developed by [15]. Furthermore, the parametric rule-set could be applied in various projects with a significant return of investment and promoting workflow standardization for both the Public Client and the Design and Construction teams.

The limitations of the presented work concern the lack of pilots on actual case studies. Moreover, a reliable data exchange is critical to reach an effective design process, as well as in this research, which strictly depends on the tools (software) included within the process.

Finally, the proposed workflow asks for the use of a shared parameter named "Review Category" in order to auto-match the BIM object to be validated and the code checking rule-set. This is due to IFC-based interoperability issues that do not allow easy mapping and classification of new objects according to the IFC specification. The authors are working in the direction a BIM-based Rule Checking with 4D planning in order to connect the static validation of a construction site configuration with the dynamic analysis of activities and related flow of resources.

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