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BIM-BASED CODE COMPLIANCE CHECKING FOR FIRE SAFETY IN TIMBER BUILDINGS: A COMPARISON OF EXISTING TOOLS

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Abstract: The nature and the complexity of building codes, including the fire regulations, result in mainly manual verification and, therefore, in subjective potential interpretations or errors. In the case of timber construction, the fire safety regulations are moreover a challenge due to the combustibility of the material. Further integration of fire safety is needed during the design process in order to increase the reliability of the designs in terms of fire safety. Building information modelling (BIM) technologies offer today new tools for automating different tasks in the construction process. The different approaches and available tools have been therefore compared in the context of fire protection code compliance. For that matter, criteria applicable to the tools have been identified based on literature review and on the National Building Code of Canada prescriptive provisions, but also based on a practical manipulation of the available tools. The potential of the different tools is therefore assessed based on their integration of the fire protection concepts and on their adaptability to BIM. This contextualized comparison has shown that the fire protection integration in BIM is limited. The tools for performance-based fire protection design are not exploring enough the information contained by the building model that is beyond the geometry. The BIM-based compliance checking tools, in turn, contain insufficient space for fire safety regulations checking as advanced spatial study is required for this purpose. Thus, this paper demonstrates the need for further development in terms of exploiting the building models' semantics in the fire protection context.

Keywords: BIM (Building Information Modeling), Code-checking, Building Code, Fire protection, Timber buildings

1. Introduction

Mass timber buildings gain more and more importance in the construction industry, due among others to the recent development of the cross-laminated timber (CLT) panels in the construction. This offers a new space for the use of wood in the construction of taller buildings. New initiatives take place around the world and feasibility studies are reported with possible designs that go as far as 42 floors (Östman, Brandon, and Frantzich 2017). However, in reality the highest mass timber building as of today is 18 floors high (The Brock Commons in Vancouver) (Fast 2016). Fire protection engineering appeared to be one of the main challenges to address in this case. Therefore, the domain of timber construction must always seek to enhance its fire safety aspect. This can be achieved by optimized fire protection design, which means better management of interfaces with other disciplines (National Fire Protection Association 2007) in the design process. The notion of collaboration implies that building information modeling (BIM) must be taken into consideration, given its ever growing integration in the working processes (Eastman et al. 2011). The BIM approach consists in using "a multidisciplinary object-oriented 3D model of the constructed facility to improve and to document its design and to simulate different aspects of its construction or its operation" (Boton et al. 2018). However several reports show the limited integration of fire safety challenges in the BIM methodology throughout the design process (SFPE 2011), (Norén, Strömgren, and Nystedt 2017)). The work presented in this paper is part of a more comprehensive research which aim is to propose a global approach to enhance the integration of fire protection concepts related to timber buildings earlier in the design phase. This brings up the question of how available tools today manage to cover the needs in terms of fire protection during the design process. The objective of the paper is therefore to first identify the criteria that are essential for evaluating the existing tools and then to execute an objective comparison of the tools according to the needs that are characterized in the first step. It is organized into three main sections. First, the normative context of timber buildings is described in order to understand the needs and the challenges in the building design process. Different tools that are integrating BIM are also listed. Then, criteria are characterized both for fire protection and BIM integration. Their construction is not only based on literature review of fire protection concepts, but they are also taking in account the reality of observed design and modeling practices. Finally, a comparison for all the identified solutions is carried out based on these criteria.

2. Related works

2.1. Timber building in Quebec: the fire safety challenges

In the context of the Quebec construction industry, the fire safety is ensured by two regulatory documents: the National Building Code of Canada (NBCC) (CNRC 2010), that is modified at the provincial level in the "Code de construction du Quebec". Then specifically for Québec was established the technical guide entitled « Mass timber buildings up to 12 floors » (Veilleux, Gagnon, and Dagenais 2015). These regulations prescribe conservative measures to ensure protection of occupants and properties. The regulation context is today identified as one of the main reasons why constructors do not choose mass timber as a construction material (Gosselin et al. 2016). Indeed, tall buildings need to assure very strict fire safety conditions (Östman, Brandon, and Frantzich 2017), that is why it is necessary to prove efficient tools for designing and verification of the fire safety regulations compliance.

Regarding fire safety, the protection of life, property and environment must be considered during the design. Several domains are impacted, including electricity, mechanics, architecture and structure. More specifically, one can distinguish two types of fire safety systems (Buchanan and Abu 2001): active control (sprinklers and other suppression systems) and passive control (fire resistant structure). If the construction material is a combustible material such as wood, it is possible to optimize the construction if more attention is allowed to the aspect of passive protection. The following work will be therefore restricted to the study of passive systems. This concerns two branches of the NFPA (National Fire Protection Association) Fire Safety Concept Tree : "Contain Fire by Construction", which implies the need of integrity of fire separations and their continuity, as well as fire resistance of assemblies (Canadian Wood Council 1996). The second relevant branch in our context is the "Control of Fuel", this means that the ignitability and surface flammability of interior equipment is a crucial aspect of fire growth (Quintiere 2002).

In Canada, compliance to the NBCC can be achieved by complying with the acceptable (prescriptive) provisions found in Division B, or through alternative (performance-based) solutions that will achieve at least the minimum level of performance required by Division B in the areas defined by the objectives and functional statements attributed to the acceptable solutions. (Hurley et al. 2015) define performance-based design as a set of specific fire safety goals and objectives. This means that more complex fire scenarios are developed during the design and accordingly more alternatives are proposed to attain the set goals. This is done by "quantitative assessment" of the behaviour of proposed active and passive protection systems (Buchanan and Abu 2001). More specifically, "accepted engineering tools, methodologies, and performance criteria" (Hurley et al. 2015) are used to obtain the performance of the alternatives. By engineering tools, we mean technologies that support the fire protection design, such as software sprinklers design, hydraulic calculations and computational fluid dynamics (Autodesk CFD). It is observed that some of them are starting to integrate elements of BIM (SFPE 2011).

Even though the performance-based design is used in other code domains, Canadian regulations that are effective today are still very prescriptive oriented. According to the Canadian Wood Council (1996) and more recently Dagenais and Desjardins (2012), more performance-based elements are being added; nevertheless, the prescriptive requirements remain more prevalent. In the prescriptive design, “strict definition of dimensions, construction methods, and other features” (Hurley et al. 2015) are to be respected. However, this verification is still done manually and thus can contribute to some errors. If a climate of trust is to be established in the timber construction industry, the fire safety has to gain more prominent place in the design process. Whether the fire protection is performance based or respects prescriptive requirements, the integration of BIM in the fire protection design needs to be studied as BIM is more and more present in the building process.

2.2. Available approaches and tools integrating BIM for fire protection

Three types of software tools specifically developed for fire protection engineering have been identified. First, solutions for fire suppression system design exist, where the sprinklers disposition and piping design with hydraulics calculations is approached. Second, the simulations of pedestrian dynamics are used for egress routes design. Finally, according to (SFPE 2011), this fluid dynamics simulation tools can evaluate buildings structural ability, demonstrate tenability and validation of smoke control systems. For example CYPECAD with the NIST Fire Dynamics Simulator (FDS) module was developed by the National Institute of Standards and technology (NIST) (CYPE 2012) and similarly, Autodesk has Autodesk CFD software. In terms of BIM integration, these tools use mainly clash detection and retrieval of general geometry for obstacles determination in exit routes and smoke spread determination. However, only fire protection engineers can use these solutions and once the final building model is created and therefore the fire protection concepts are integrated very late in the design process. Furthermore, the semantically rich character of the building information models is not used. For that matter, automated code-checking can be seen as a prospective tool that can provide architect with quick feedback (Eastman 2009). It is an emerging domain of BIM-based technology (Preidel, Daum, and Borrmann 2017) and is defined by Eastman (Eastman 2009) as a software, that “assess a design” without its modification by applying rules and constraints. Growing number of research studies are exploring different approaches for automated code checking, including non-geometrical capacities of the building models and addressing related challenges such as translating the building norms into computer-readable form (Lee et al. 2016), (Hjelseth and Nisbet 2011)), discussing if present object-based models are adapted ((Greenwood et al., 2010), (Malsane et al. 2015)) or studying rule construction practice ((Solihin and Eastman 2015), (Porto et al. 2018)).

Aside from the theoretical research approaches, there are three main commercially available solutions for BIM-based automated code checking: Solibri Model Checker (SMC) by Nemetschek Company ((Taciuc, Karlshøj, and Dederichs 2016, Eastman 2009)), Fornax developed by novaCITYNETS Pte. Ltd. Singapore ((novaCITYNETS 2002), (Solihin et al. 2017)) and EDM Jotne by Jotne IT (Ding 2006). These tools are not built specifically for the fire protection engineering and are mainly concentrating on the accessibility requirements ((Eastman 2009), (Solihin and Eastman 2015)). Similarly to SMC, there are also several solutions for model quality checking on the market that are generally focused on the data quality of the semantically rich model. Among these can be named a model quality checker BIM Assure by Invicara or dRofus by Nemetschek Company for spatial program requirements planification and rooms management.

However all these commercially available solutions are criticized for their lack of flexibility and ‘black-box’ aspect (Preidel, Daum, and Borrmann 2017), (Greenwood et al., 2010)) or they are requiring extensive software development skills ((Kim et al. 2017), (Nawari 2018)). This is not compatible with the ordinary end users: the regulation specialists, which will have to construct the computer-readable rules (Preidel, Daum, and Borrmann 2017). Another approach discussed in the literature for automated code-checking is visual programming. In the present day, the visual programming already exists in the BIM environment for parametric design. We can cite as main providers the Grasshopper for Rhino (Abvent) or Dynamo for Revit (Autodesk) or Marionette for Vectorworks (Nemetschek), that are mainly used in architecture. Furthermore (Preidel, Daum, and Borrmann 2017) define a new visual programing language specifically built for code checking and(Kim et al. 2017) also developed a visual programming approach to the Korean Building Act.

Among all these solutions, none of them addresses properly the link between the rule checking tool and the building model information requirements. Therefore, the possibility of adoption to the Canadian fire protection context needs to be further studied. We are restraining our study to the application on timber building's fire protection.

3. Research approach

In order to carry out a complete and meaningful comparison, criteria of comparison must be identified and the available tools must be listed. First, the regulations cited in section 2.1 have been analysed from the object-oriented perspective in relation to the BIM point of view. The critical elements of fire safety regulation can therefore be identified. To support this work, a practical test of the regulation translation into computer-readable rules is executed on an education building model in order to examine the needs from the design process standpoint. This means that examples rules addressing different aspects of passive fire protection have been selected in order to identify in practice the needs in terms of building information modeling. Then, the available tools have been mapped; this includes not only the code checking software, but also the software used by fire safety engineers during the design process in order to compare the forces and the weaknesses of each approach. Therefore, a more BIM oriented approach will be compared with more fire protection-oriented approach. The comparison is based on different types of accessible documentation for the products. The different applications of such tools have been critically compared to the needs in terms of fire safety. Aside from available peer reviewed literature that could be used for SMC, EDM and Fornax assessment, other sources of information had to be used. The criteria have been practically verified on two available solutions (SMC and Dynamo for visual programming). Then technical guides, and internet description of the functionalities, demonstration videos of working software and reviews of different users, as practically tested, were sources of information for the other tools.

4. A contextualized comparison of existing tools for code checking

4.1. Criteria determination

This section presents the criteria identified for the comparison of existing tools. The criteria related to the fire safety are differentiated from the BIM-related criteria.

4.1.1. Fire safety related needs characterization

In this part, we are not addressing whether the software is able to detect a compliant or a non-compliant element, but whether it is able to identify and work with a certain fire protection concept and access the related information. It is important to mention that in fire safety, several properties that must be checked are non –geometrical (such as properties of materials, fire-resistance rating of assemblies) or demand advanced spatial relationships study (continuity between fire separations). The following criteria were constructed, based on the regulation literature ((CNRC, 2010), (Canadian Wood Council 1996), (FPInnovations), (Buchanan and Abu 2001), (Veilleux, Gagnon, and Dagenais 2015)), as essential for a first fire safety specific compliance checking tool. The study being restricted to the aspect of passive fire protection, the criteria that are presented bellow represent necessary conditions for controlling the design in terms of fire containment and its spread.

Use of results from another defined rule: (Solihin and Eastman 2015) define as derived property an information in the building model that is not presented explicitly, but can be obtained if other necessary data are present. The possibility of creating new derived properties is an essential requirement for a functional and complete rule checking tool (Eastman et al. 2009). This is especially challenging for fire safety regulations as in the Canadian context they are interdependent, which must be translated into the computer-readable rules.

Flame spread rating based on material property: This specific property is an example of why the possibility to derive parameters is necessary. In fact, the flame spread rating is related to the material and therefore there is no use for the explicit input from the modeler's standpoint. The capacity of the tool to deduce the value of this requirement is an important criterion in terms of limiting the fire growth. The results from a software point of view will be equivalent for other constraints, such as smoke development class and other parameters, which can be derived from other information present in the building model.

Fire-resistance rating: Fire-resistance rating requirement must be set independently from the individual element modeling, it depends on the function of space that the fire separation encloses as well as on the adjacent fire separations.

Control of fire dampers position: This criterion is specific in terms of inter-disciplinary integration, as the fire damper is in HVAC scope and the fire separations are in an architecture model. Advanced geometrical requirements are expected here and it must be possible to study relationships between elements. The criterion is met if the solution is able to detect a fire damper and associated fire separations position.

Creation of compartments: The possibility of creating compartments is essential for checking numerous rules for fire protection, because it defines essential list of vertical and horizontal fire separations, with or without a fire-resistance rating. Which in turn are going to be subjected to other constraints (as seen above). It must be possible to create compartments that contain more than just one room.

Continuity of fire separations: All the fire separations must be connected to other fire separations with a coherent prescribed fire-resistance rating to assure integrity throughout the required fire-resistance period. The tool must be able to detect and work with spatial relationships between elements, such adjacent surface intersection or continuous walls that cross several floors.

Fire separations openings control: The checking tool is able to detect relationship between a fire separation element and its opening, through which fire can spread.

Fire load calculation for a compartment: This criterion is part of the performance-based approach only. For this execution is needed among others the weight of every material in the given compartment. This is similar to the material take-off for cost evaluation of a project, except that the different material volumes must be associated with their density and their heat release rate, instead of the cost. Given that a simplified approach of this calculation for the fire load is linear, it is something that a code checking tool should be able to execute. NFPA 557 provides a methodology for determining of fire loads for use in structural fire protection design.

4.1.2.BIM related needs identification

In this part, we examine the criteria from BIM point of view, independently from the fire regulation context. The criteria have been attributed importance when the practical preliminary test has been carried out.

IFC compatibility: The tool must support the interoperability IFC standard in order to participate to the global support of collaboration.

Possibility of direct modification: If a code-checking solution detects a problem of non-compliance and it is possible to directly modify the geometrical and non-geometrical properties, the designer can instantly modify the information based on the feedback received by the tool, which is a more advanced level of automation. The question then is if the direct modification of a parameter is sufficient for the model to be compliant, as there is a reality behind the attributes and there is a reality behand the parameter values that cannot be changed only in the checking tool.

Possibility to directly add missing information: This criterion is similar to the option of direct modification. In this regard, the completed information can either stay located only in the given tool, or the tool can be able to put the information in the building model which enhances the collaboration.

Accessibility: The tool must be accessible for people that want to create new rules, novice programmers or users with virtually no experience in coding must be able to work with the tool. The need for software development skills is to be avoided, among others because a hard-coded tool is harder to keep up to date.

Compliance with norms reporting: Given that the regulations are essentially prescriptive, it is possible to obtain results in form of a true or false evaluation most of the time. We take in consideration that the person performing the compliance check will be an architect and therefore will not be necessary a specialist in the fire protection engineering, the results should be presented in an accessible manner.

Flexibility of rule creation: The user must be free to create rules that he needs, without being restrained by the tool rigidity. This is different from the accessibility of rule manipulation. This criterion is concentrating on the user's liberty to create new rule. If he has the necessary programming knowledge, the tool must to be restrictive in terms of new rule production.

4.2. A comparison of the existing tools

First, each tool's functionality is critically assessed against the above defined criteria. The presented tools are representative of different approaches (cf. 2.2.) during the design phase : SMC with DesignCheck and FORNAX for automated code-checking commercial solutions, dRofus for the spatial programming, BIMAssure for model quality checker and the FDS module with Autodesk CFD are for fire simulations with different functionalities, finally we have Dynamo for the visual programming research approach. The obtained information is then synthetized in an overall comparison presented in Table 1.

Table 1: Software solutions for evaluation

Approaches		Automated checking					Fire safety engineering		Visual programming
Tools		Solibri Model Checker	DesignCheck	FORNAX	dRofus	BIMAssure	CYPECAD MEP - FDS	Autodesk CFD	Dynamo, Grasshopper)
Fire safety	Use of results from another defined rule	✗	-	-	✗	✗	✔	✗	✔
	Flame spread rating based on material property	✔	✔	✔	✗	✔	✔	✗	✔
	Fire resistance rating	✔	✔	✔	✗	✔	✗	✗	✔
	Control of fire dampers position	✗	✔	✔	✗	✗	✔	✗	✔
	Compartment creation	✔ (complicated input)	-	✔	✗	✗	✔	✔	✔
	Continuity of two fire separations	✔	✔	✔	✗	✗	✔	✔	✔
	Fire separations openings control	✔	✔	✔	✔	✗	✔	✔	✔
	Fire load of a compartment	✗	-	-	✗	✗	✔	✗	✔ (Simplified approach)
BIM	IFC compatibility	✔	✔	✔	✔	✔	✔	✔	✔ (Through given BIM software)
	Possibility of direct modification	✗	-	-	✔	✔ (only non-geometrical parameters)	✗	✗	✔
	Possibility to directly add missing information to the model	✗ (only space qualification)	✔	✔	✔	-	✗	✗	✔ (Through given BIM software)
	Accessibility	✔	✗ (software developer)	✗ (software developer)	✔	✔	✔	✔	✗ (basics needed)
	Compliance with fire protection norms reporting (true/false results)	✔	✔	✔	✗ (Comparison of values)	✔	✗	✗	✔
	Flexibility of rule creation	✗	✔	✔	✗	✗	✗	✗	✔

First of all, the code-checking solutions' functionalities are studied. SMC has been practically tested against the defined criteria in 4.1 and it has been observed, in accordance with the literature review, that the manipulation of information in this tool is very restricted (restricted rule creation possibility). First, the results from one rule are not saved so that another rule can further manipulate this derived data and the results of a certain rule cannot be reused in another rule, this also means that flame spread rating cannot be verified here. Then the compartmentation can only be defined based on manually entered parameter or on element type. However, the fire protection function of an element is based on its spatial position and the relationship with other specific elements. These limited spatial operations impact also the fire damper or fire-resistance rating determination. As for BIM integration, the tool is very mature with graphical and user-friendly interface (accessibility). The software can manipulate several IFC models at the same time and all the imported elements are automatically classified by Uniformat, it is also possible to assign specific names to individual rooms directly inside the tool for limited possibility of directly adding missing information.

Then in EDModel Server's DesignCheck, an internal model is developed, which extends the IFC model in order to obtain derived properties (Ding 2006). We conclude that the data derivation functionality makes it possible to create such queries as fire-resistance rating or the flame spread rating verification. Due to the lack of available references, more information in term of fire protection potential could not be deduced from other confirmed functionalities. Regarding the BIM criteria, the software supports interoperability provided by IFC and the tool is operating in ExpressX that is native language of IFC. The API toolkit is fully available (Jotne EPM Technology AS 2018) which makes it very flexible to create rules, but becomes limited in terms of accessibility for users unfamiliar with programming, however the user is then interacting only with an adapted interface of the Express Data Manager. It is also used for all communication with the EDMdatabase of the EDM Server and the model checker associated with EDM is an application that is also invoked through this interface (Jotne EPM Technology AS, 2018) which makes it possible to add missing information based on the compliance assessment.

The last assessed code-checking solution is FORNAX. For the fire protection criteria, the possibility of data transfer between different FORNAX objects is unknown, therefore it cannot be concluded on the use of results from other rules or on the fire load calculation. Then, the system can operate with geometrical objects as inputs (Solihin et al. 2004) and that are then enhanced in the tool, thus derived parameters such as fire-resistance rating and flame spread rating verification should be possible. Solihin et al. (2004) demonstrate data manipulation that suggests that it would be possible to compare and deduce if the position of fire damper is compliant with the apartment's limits. Regarding the BIM criteria, the possibility of direct modification of parameter is unknown; however missing information in the model can be added due to the FORNAX object that enables extension of the IFC imported objects (Greenwood et al. 2010). According to (Solihin et al. 2017), FORNAX provides a toolkit API which insinuates that the creation of rules, including the study of geometry such as compartmentation and closure control, would be flexible. It also means that the accessibility for rule creation is limited to software developers. FORNAX is a very developed compliance code-checking tool, therefore the checking result reports are not only textual, but also graphical: non-compliant elements are also highlighted (Solihin et al. 2004).

Then the quality model checker solutions have been assessed. Based on the user guide (dRofus 2016), we have listed its prospective functionalities possibly applicable for the fire requirements. First, no data derivation as defined by (Solihin and Eastman 2015) is possible, which makes it impossible to study the flame spread rating information or the fire load evaluation. Then, the geometrical properties or space interferences cannot be considered by the tool, which excludes compartmentation, continuity or opening of fire separation control. No rules are created in dRofus, however there is a possibility of comparison of planned data and real data in Revit or Archicad. For this however, all the necessary rooms have to be created in order to compare the data (such as interior finishes) which is an extensive amount of work that is not efficient unless the designer already has integrated the spatial planning in dRofus for other purposes of the project as well. The tool has only shown very satisfying results in terms of BIM integration and accessibility but is not adapted to fire safety related needs.

BIM Assure in its turn creates rules to check model data presence against the project's (Invicara 2018). In the context of fire protection, it is possible to detect if a fire-resistance rating or a flame spread rating is put in, but it is not possible to check if the value is compliant with the regulation requirements. Therefore, a standard quality model checker cannot be used for fire protection compliance checking. Furthermore, it was concluded based on (Khemlani 2016) that the application cannot detect geometry compliance and neither it is able to study relationships between different elements. Thus, the use of compartmentation and of results from another rule is not possible in this tool. In terms of BIM integration, the tool is very advanced among the solutions studied here. In fact, the IFC format is supported (Invicara 2018) which contributes to the independence of the software regarding different users. Furthermore, the non-geometrical properties can be modified. Regarding the creation of rules, it is fully integrated to the software therefore there the accessibility for users is respected, however the flexibility of creation is restricted. Then the results are presented as true or false report in spreadsheet format (Invicara 2018). Finally, the flexibility regarding rule creation is only partially respected as it is restricted to non-geometrical parameters.

Moreover, the CFD solutions are assessed. In CYPECAD with the NIST FDS module, the simulation is very complete, therefore the physical interdependencies are taken in account: when the fire is simulated, it also takes into consideration the presence of sprinklers and therefore it is possible to evaluate if the compartment reaches flashover (CYPE 2012), however it does not take into account the fire ranking, as its capacities are centered around fire dynamics. Different fire safety concepts are available in the tool, including calculation of the fire load based on modeled room finishes and objects. In terms of BIM integration, the module supports IFC format. In fact, the geometry of the building is either manually entered, or the information is imported by IFC in the Cypecad software. Then the properties related to materials (such as conductivity of different layers) that are necessary to carry out the simulation are entered inside the tool (CYPE 2012). The other BIM required criteria are not addressed by this solution.

Then Autodesk CFD is based on similar functioning as NIST FDS simulation, except that it does not contain the special fire dynamics module. Therefore the imported building geometry is only viewed as obstacles for the flame and smoke spread and all the non-geometrical parameters are lost during the CFD simulation (Autodesk CFD 2019) therefore the fire-resistance rating and flame spread rating are not considered. Furthermore, the fire load is not calculated based on the building model, but an equivalent heat source is calculated and placed in the building before the simulation (Munirajulu 2018). In terms of BIM integration, the construction supports IFC interoperability and if a Revit building model has been imported to the Autodesk CFD, the walls can be modified in the software, however no information is available concerning this functionality for IFC models.

Finally**,** Dynamo with Revit has been assessed in the preliminary test to demonstrate its ability to execute code checking-based scripts. In terms of fire protection criteria, all the approaches have been practically tested. The creation of rules is extremely flexible and only limited to the Revit API, even though this requires software development skills. However, the requirements in terms of programming are less important given the graphical interface and the extensive third-party methods development. The building model is accessed through the modeling software for the plug-in or directly imported in the stand-alone Dynamo software, therefore it is IFC compatible. It is possible to create new elements in Dynamo through the visual programming interface given the parametric design character. Then, specific scripts must be developed to detect or add missing information, however it is less intuitive than the quality model checker interfaces in terms of these criteria. The resulting lists are presented in true or false format and the results can be exported in excel sheets (in a similar way to BIM Assure).

To conclude, the Table 1 shows that there is a need for more fire protection and BIM integration. In terms of software solutions, the performance-based and prescriptive approaches are very different. First, the performance-based software runs a series of calculations involving CFD and visualizes the fire and smoke spread (Autodesk CFD 2019). Opposed to this, the automated checking tools will be object-oriented and therefore based on the present elements: all the possible solutions respecting the prescriptive code must be listed. The first approach is not adapted as a decision support tool, because of the complexity of execution, whereas the automated code-checking execution is expected to be very quick. Even though the code-checking will not be as complete as CFD simulation, we can already optimize in some ways the geometry earlier in the process. Therefore, we can view the two approaches as complimentary if their integration in BIM process is improved. Finally, the code checking of a building model for performance-based regulation compliance is more complicated, because the goals are more general. The prescriptive design is very adapted to the automated code-checking features of the building information modelling and is more aligned with the goal of this paper to bring quick fire protection feedback to the designer.

5. Discussion and conclusion

The work presented in this paper aims at comparing the existing tools for automating code checking for fire safety regulations. It can be seen that the tools designed for automated code checking respect more the BIM related criteria and have more advanced code checking capacities. This proposed comparison brings attention to the fact that the existing code-checking solutions fail to answer to the fire protection challenges, showing that this domain has specific needs in terms of modeling and as of now, there is a lack of integration in the BIM driven design process. Furthermore, the focus is not addressed to the whole process. Indeed, we can clearly notice a lack of attention paid to the model preparation aspect and the creation of the rules in coherence with the level of development of the model. This paper has therefore contributed to set foundations for the building model requirements and to practically identify critical challenges in the context of a more global work related to BIM-based fire protection code-checking in timber buildings in Québec.

The main challenges to address can be summarized into the four stages of a rule checking process defined in the framework proposed by Eastman et al. (2009): 1) rule interpretation, 2) building model preparation, 3) rule execution and 4) rule check reporting. This means that especially for fire protection, it is necessary to provide accurate guidelines for building model preparation and avoid demanding extensive information manual input that the modeler does not need to provide. This optimization in term of data supply can be done only if the whole process of code-checking is understood. Unfortunately, there is a lack of research combining all these stages in a comprehensive and consistent method. In the future works, this lack will be addressed, focusing on the challenge of information transfer from one step to another and regarding the specificities of the fire protection compliance. In order to validate this method, the compliance check will be carried out on an actual project in timber construction industry.

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