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DEVELOPMENT OF IFC BASED FIRE SAFETY ASSESSMENT TOOLS

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Abstract

Due to the impact that the fire safety design has on the building's layout and on other complementary systems, as installations, it is important during the conceptual design stage to evaluate continuously the safety level in the building. In case that the task is carried out too late, additional changes need to be implemented, involving supplementary work and costs with negative impact on the client.

The aim of this project is to create a set of automatic compliance checking rules for prescriptive design and to develop a web application tool for performance based design that retrieves data from Building Information Models (BIM) to evacuate the safety level in the building during the conceptual design stage. The findings show that the developed tools can be useful in AEC industry. Integrating BIM from conceptual design stage for analyzing the fire safety level can ensure precision in further design decisions

1. Introduction

The purpose of building fire safety regulations and performance design is to prevent loss of human lives and to minimize property damages in case of an unexpected fire.

Building codes are adopting from prescriptive to performance based design, due to the limitations of the prescriptive codes. Performance based codes are flexible [1], allowing the designer to create innovative solutions, using the latest fire protection researches, technologies and advanced simulation models.

Fire safety design has significant impact on the layout, structural, electrical and mechanical systems of buildings, that is why it is important to evaluate the fire safety in an iterative manner during the design stage. If the assessment is carried out too late in the design process sometimes it is necessary to redesign both the layout and different systems in the building. This process is expensive, time consuming, unproductive and can have negative impact on the relation with the client. In order to perform the fire safety analysis, the fire engineers need to have a basic proposal of the building, including information about shape and dimensions of the spaces, openings and materials characteristics. Fire engineers are participating in designing of the fire installation systems. Also they determine the total fire load of spaces by means of fuel packages.

The most efficient and effective way of using the building model (main input in the fire safety design) is to import it using Building Information Modeling in the computer software programs that are used for design checks, fire or evacuation simulations.

"Building Information Modeling (BIM) is a digital representation of physical and functional characteristics of a facility. BIM is shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition."[2].

The Industry Foundation Classes (IFC) developed by buildingSMART, accepted by ISO as an international standard is a general data model that can be implemented, shared and exchanged among software tools used in Architecture, Engineer and Construction - AEC industry. This data model can be used in order to provide an object oriented information of many aspects - layout, material, dimensions and properties.

Interoperability between the stakeholders in building projects was needed [3], [4] and with technologies as BIM and IFC made it possible. In order to achieve a validated design trough rules, normative and procedures it was developed an automated compliance checking system [5].

A number of tools were formed in the industry using IFC open model based on rules If-Then-Else to be capable to check prescriptive requirements, such as Solibri Model Checker [6]. There was investigated a framework which is a practical compliance checking, in order to remove the inefficiency and inflexibility of the present implementation of regulations [7]. In the centre of the framework is the user that is adding all the components as: building model, regulatory data and rules. The output will be a series of warnings with suggestions for design options in order to achieve compliance. This procedure will aid the design process, reducing delays and additional costs.

In order to apply performance based design for fire safety, different calculations and simulations should be performed in order to check the fire-evacuation performance. Results from these simulations can be used to ensure the safety level of a buildings before construction, investigating safety options in existing buildings or what happened in case of fire accidents.

2. Method

The paper is based on a Master thesis in which a literature review has been completed. It was decided as a prerequisite that assessment of fire safety should be based on BIM models in open formats.

In the first part of the project basic assessment of the fire safety will be carried out by customized rulesets in Solibri Model Checker, which is a tool that is able to import building information models in the IFC format and make rule-based checks. These rules will check relevant sections of the building regulation: parameters, limits and thresholds according to Danish codes [8]. In case that the design solution is not validated according to prescriptive codes, warnings and suggestions are reported. In this situation the fire engineer should elaborate a performance based design.

Furthermore, a pilot implementation of a tool has been developed for conceptual stage design for analysing if a building design fulfils performance based design in fire. The tool has been developed in Java and open source BIMserver platform will be used to retrieve data from the IFC model. The tool is based on simplified hand calculation methods for development of the available and required time for evacuation. The main purpose of this application is to access existing IFC model though a server, to retrieve data needed for fire safety and to perform basic calculations.
The developed rule-sets and performance based tool are tested with two different buildings in order to test the function of the developed solutions.

3. Prescriptive based design

In following sections it is covered the method used in this project to check if buildings can pass the rules from prescriptive codes using IFC platform. The computer software programs that were used in the current study are briefly explained in order to understand their functions. Three computer programs are used to achieve the purpose of the project: Revit for design application, SimpleBIM for information exchange and validation, respectively Solibri Model Checker for analysis application.

3.1 Revit

Revit is a designing tool created especially used to facilitate the building design and for engineers to bring ideas from concept to construction using a reliable model-based approach [9]. The software provides IFC export to other building professionals such as: structural or building services engineers.
Important aspects are the quantity and quality of data that are added in Revit in order to use the information further on in different building departments. For example, a fire engineer will not find all the necessary data like: fire compartments or fire rating of the building elements in a Revit model in order to perform directly a check using other analysis software like Solibri Model Checker. To facilitate the consistency of the model a compromise should be made in order to delegate if this information in detail should be added in the model by initial designer or by the fire engineer.

3.1 SimpleBIM

SimpleBIM is an editor program designed to create quality data exchange for construction industry, facilitating the information exchange between different tools: from design to analysis [10]. It can be utilized for certain intended use, for example: fire safety or structural engineering. SimpleBIM can reduce the errors caused by inaccurate or irrelevant information, by excluding all the unnecessary data. For the current project a program feature is used, creating a template to make an accurate and reliable editing with all the necessary requirements in fire safety domain.
The IFC model exported from Revit contains all the objects of the building: walls, doors, windows, foundation etc. To exclude the irrelevant information for fire safety from the IFC model a template it is used, selecting only the relevant objects for prescriptive based design.

In the validation sheet of the template file it is created a list with all the possible values for fire rating for slabs, walls and doors. This list it is used to check the existing information or to facilitate the decision upon what kind of fire rating values can be used for elements (walls, doors, slabs).

Table 1: SimpleBim template - wall fire rating values list.

Object	**Property**	**Values**
Wall	Fire Rating	EI 60 A2-s1,d0
		EI 120 A2-s1,d0
		EI 60 A1-s1,d0
		EI 120 A1-s1,d0
		REI 60 A2-s1,d0
		REI 120 A2-s1,d0
		REI 60 A1-s1,d0
		REI 120 A1-s1,d0
		REI 60
		REI 120
		EI 60
		EI 120
		No rating

Another feature is that different properties can be included for objects (walls, slabs, doors), for example: in case of fire safety windows can be defined as rescue openings using a Boolean function (YES/NOT) in the template sheet.

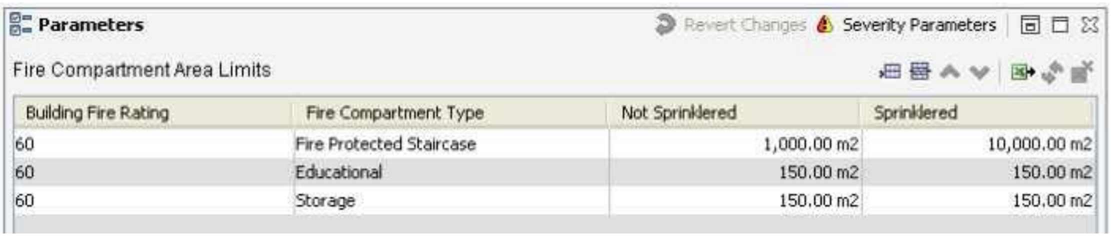
3.3 Solibri Model Checker

Solibri Model Checker is an analysis software that performs integrity and quality checks revealing potential problems, saving time and money in the design phase of construction. The program has the ability to facilitates the compliance with building codes. The application has a library of predefined rules which can be adjusted with own parameters for a specific situation, highlighting the clashing components of the model. The user cannot create new rules, but for a particular compliance checking task it is possible to group a number of built-in rules into a new folder.

A group of rules were created in order to check the compliance of fire safety according to Danish regulation BR10 for initial design. Rules were divided in three parts taking into consideration the checking that will be performed:

- Design of Escape Routes;
- Fire Compartments and Fire Sections;
- Additional Rules.

The ruleset regarding design of Escape Routes included checking of: Door minimum dimension, stair minimum dimension, internal passages width, escape route analysis, and rescue openings. Before the checks will be performed the user can introduce further needed parameters that are specific to the fire safety regulatory compliance. For the building category the user can select between: 1, 2, 3, 4, 5 or 6 taking into consideration the number of persons in the building, knowledge of escape routes, assistance needed to evacuate, day or night usage and building type, see Table 1.
The user can select from the following list the building usage: office, teaching facility, shops, canteen, cinema, restaurant, hotel, hospital, care homes. This information will be used for checking the internal passage width for certain building types.
The check of the doors requires that the width of the doors is greater than or equal 1.3m. Check of the stairs is taking the tread length into account, whereas the check for internal passage is taking the category of the building into account and the internal passageway and furniture are classified in order to check the freeway width. Analysing the escape route is started by isolating the spaces that should be checking, leaving out spaces having specific names. This is done to remove fire stair and other safe spaces from the analysis. The Escape Route Analysis is checking several requirements for fire safety as: maximum travel distance to the escape route, door direction opening and number of doors depending on space type etc. This rule uses classifications that need to be defined by the user: space grouping, exit door, and vertical access. The rule also is taking the total minimum width of doors, and minimum width of passageways into account. The check on rescue openings is check width and height of the rescue opening but not the sum of the width and height as required.
The ruleset on Fire Compartments and Fire Sections checks separately for all selected components: walls, doors and slabs if they have the required fire property and also if that property has the correct value. The rule also checks that spaces must be included in fire compartments, and if space is set to be a fire exit space, it must have fire exit door. The check on fire sections and fire compartment is looking into the input parameters that check if fire sections have walls and doors with correct values. The last check in the ruleset is that fire compartments/sections must be within limits, and for this rule Fire Compartment definition must be made in Solibri, this can be done in several ways using: a classification, all walls and columns, all spaces, selected walls and columns, selected spaces or create an empty compartment. Using this a function in Solibri Model Checker generate a list of compartments where the user has the possibility to choose the building fire rating in that fire compartment/section and the usage from a predefined list. Finally, the area of the sections and compartments must be limited to specific values.


Parameters
Revert Changes Severity Parameters
Fire Compartment Area Limits

Building Fire Rating	Fire Compartment Type	Not Sprinklered	Sprinklered
60	Fire Protected Staircase	1,000.00 m2	10,000.00 m2
60	Educational	150.00 m2	150.00 m2
60	Storage	150.00 m2	150.00 m2

Figure 1: Fire Compartments/section must be within limits.

In the Additional ruleset a check is made on Emergency shelter where the surrounding walls have to be made of concrete and have a thickness of minimum 250 mm.

Remarks about the difficulties in setting the rules in Solibri should be made:
- in the program is not possible to create 3 sub rules depending one of another;
- it was not possible to calculate the semi-perimeter;
- because walls and slabs were defined as a whole - was difficult to define the fire compartments.
- Solibri doesn't make a clear distinction between fire sections and fire compartments.

4. Performance based design

The tool is using hand calculations to estimate the time until conditions become critical in the building in case of fire and the total evacuation time. Steps in developing the web application and its interface will be presented. The achievement of this application is connecting through a server to the IFC file and using its data for a specific subject.
For this purpose was used the open source BIMserver that is capable to turn a computer in a server and to enable the centralization of different project [11]. The aiming of BIMserver is to facilitate efficiently and effectively interoperability between actors from AEC industry. This tool has the possibility to store the IFC file in an underlying database having the advantage to give the users the possibility to query, merge and filter the building model and create IFC files after the needed selection. Another advantage is that multiple-users support allows multiple people to work on their part of model in the same time. They can receive notifications in case that the entire or part of the model was updated or can receive warnings that the model was update by another user in the same time of the editing procedure.
For performance based design it is needed the list of spaces, doors and stairs with their quantities. For each component will be further explain where the necessary information is found in the IFC file. To have a clear view of the IFC file format an IFCWebServer [12] was utilized.

Table 2: Space information position(light grey: stored information, dark grey mark next level in the hierarchy, xx1 - ID number)

Level			
Level 1	className: IfcSpace		
Level 2	longName: “Office” name: “001”	representation: IfcProductDefinitionShape(xx1)	
Level 3	line_id: xx1	representations: IfcShapeRepresentation(xx2)	
Level 4	line_id: xx2	Items(xx3)	
Level 5	line_id: xx3	depth: "3000"	sweptArea: IfcRectangleProfileDef(xx4)
Level 6	line_id: xx4	xDim: 3000 yDim: 4500	

For spaces the following data was drawn out: name (longName), number of space (name), height (depth), length(the largest between xDim or YDim) and width(the smallest between xDim or YDim) the position and the hierarchy of this information can be seen in Figure 34. In level 1 of the hierarchy was searched IfcSpace containing relevant data that were in level 2 as name and number of spaces that were stored together. At the same level was also IfcProductDefinitionShape(xx1) with an id number(xx1). Next was accessed IfcProductDefinitionShape looking for the id number which will connect further with IfcShapeRepresentation(xx2). In the same manner will be accessed IfcExtrudedAreaSolid(xx3) and IfcRectangleProfileDef(xx4) that is storing relevant data: height, length and width. The code used to retrieve information from the IFC file it can be seen in Appendix G. A remark should be made that in case of spaces that don't have a rectangular shape the IFC model doesn't give the length or width value, instead it gives the coordinates of each corner. In this case a mark at the end of the name of spaces was added (*Invalid) and it is need extra input data during the running of the application.
For doors the necessary data was found under IfcDoor level: door type(name) and door width (overalWidth). The data hierarchy is shown in Figure 35.
In case of stairs the necessary data was: name, number of risers, length of tread and height of risers. The data hierarchy is presented below in Figure 36. In case that the above mentioned parameter does not have values defined in the model the user has to add them during the running of the application.
In the first page an introduction of the application is made, providing general information about potential users, what calculations can be performed, used data from the IFC file, methods used and its functions, see Figure 3.

The Evacuation Safety Level function can be used by users that have knowledge on fire safety design. The function is capable to estimate the safety level of the building, performing calculation for ASET - fire in an enclosure or fire in an atrium and for RSET - evacuation time choosing the escape route until the occupants can reach a safe place.

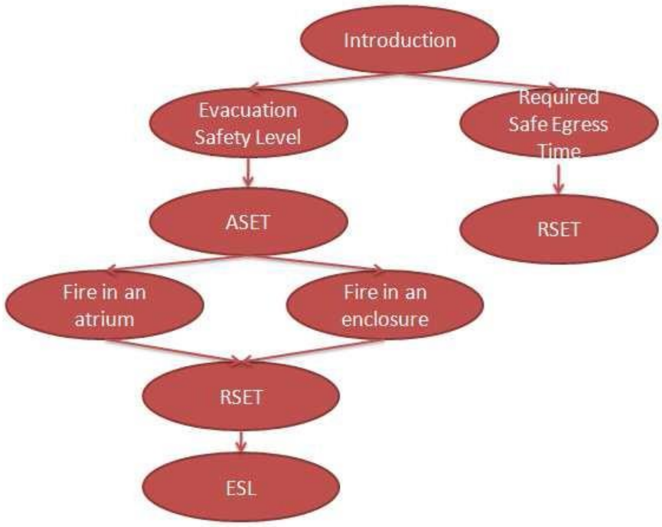


Figure 2: Application structure

The Required Safe Egress Time can be used by the architects that want to calculate for example evacuation time from a space using one or more doors of different dimensions giving results that can be implemented in their initial design.

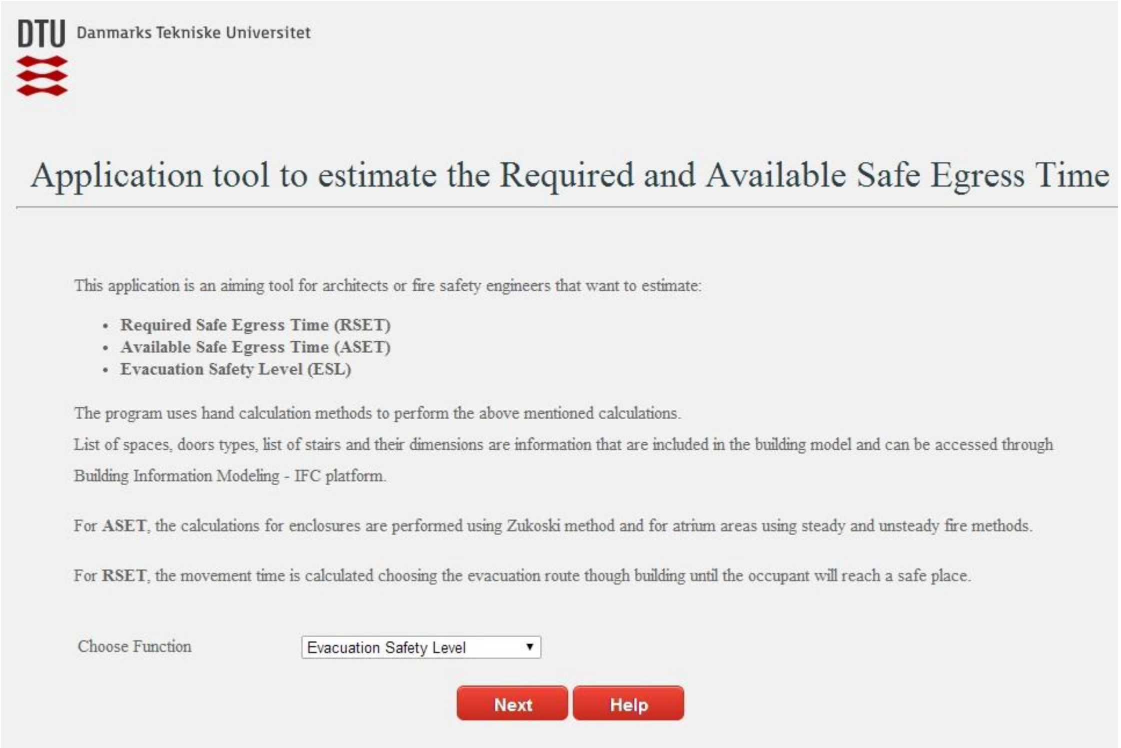
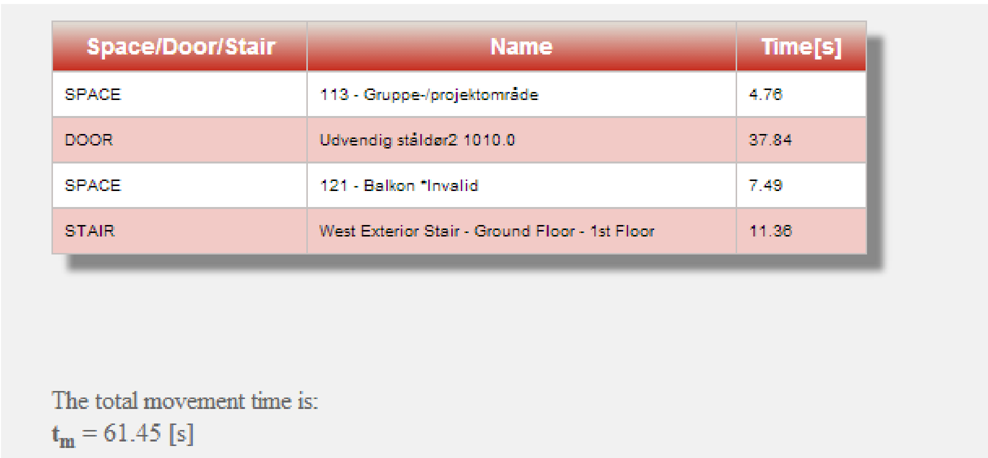


Figure 3: Introduction page



Space/Door/Stair	Name	Time[s]
SPACE	113 - Gruppe-/projektområde	4.76
DOOR	Udvendig ståldør2 1010.0	37.84
SPACE	121 - Balkon *Invalid	7.49
STAIR	West Exterior Stair - Ground Floor - 1st Floor	11.36

The total movement time is:
$t_m = 61.45$ [s]

Figure 4: RSET - total movement time

5. Results

Summing up the implementation and results of ruleset in Solibri for building 118 the following comments can be made:

- the implementation of the IFC platform for the conception design stage can be an useful tool to check automatically the regulatory compliance for fire safety, reducing time and costs;

- the user has the possibility to choose between calculating the distance to the nearest escape route from corner of the room (safe estimation) or from the door.
- to avoid fault warnings that are not significant for checking purpose a checking for functionality of the building should be performed (spaces should have doors, double sided door should be defined as one etc.);
- walls, slabs should be initially drawn in the design software program for each space individually. As mentioned before the fire rating value is not connected with type of material.
- fire engineers should decide if due to the fire load or number of occupants Labs spaces should have more than one door to the escape route;
- the program is not taking into consideration the number of occupants in one room to check the doors opening direction.
- national standardization for space classification should be done.

Taking into consideration that these rulesets is created for initial stage design for escape route analysis and fire sections/compartments, further investigations (ex: required installations for building category 3) must be conducted to along other design teams. This process will be a iterative one. After negotiations regarding the fire safety design with authorities that have jurisdiction in the area and having a positive feedback it can be concluded that Building 118 is designed compiling with prescriptive codes - BR10 respecting all the conditions regarding the escape route dimensions and fire sections/compartments fire rating and space limiting.

Summing up the implementation of the performance based design the results given by the application tool in this current project the following comments are made:

- the current development of the web application can be a useful tool to investigate in the initial stage design the evacuation safety level in the building, implementing the IFC platform.
- further developments should be made in order to create a more user friendly interface.
- for calculating the available safe egress time must be performed more investigations.

6. Conclusion

The implementation of the IFC platform in the conception design stage for fire safety for both prescriptive and performance based design was the main purpose of this project.

For the prescriptive based design was used SimpleBIM for editing and validating the IFC model, adding additional parameters that are used for fire safety and Solibri Model Checker for analysing the model to perform automatic regulatory compliance according to Danish building regulations.

Mapping a IFC model to a specific domain can present limitations because not all the needed properties are defined - fire ratings, heat release rate etc. and it is involving extra procedures in editing and validating the IFC file.

Solibri can cover a part of the requirements that should be implemented into automatic regulatory compliance, however for the full benefit of the digital analysis some national standardization for space classification should be done and also the program should have a user-defined rules features.

For performance based design a web application tool that is using hand calculation methods can be an easy way to implement BIM from the beginning of the design process to decide upon building's layout and installations. For a friendly user interface the user should have less input values as possible so the IFC file should contain, as mentioned before, all the basic quantities of the components to be more efficient in retrieving necessary data from the model (length, width and area).

To sum up in this current development the application tool is capable to take into consideration the both available and requested egress time in order to investigate the safety evacuation level in the building retrieving data from the IFC model.

As a general conclusion is that fire engineers and software developers should gather to enhance fire specific properties for the IFC model though additional property sets or by updating the core of the IFC model.

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