Development Of The 'Evac4BIM' Add-In for Revit

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ABSTRACT

BIM models are usually imported into evacuation simulators to define basic geometry. This is usually a one-way process where much of the rich data found in BIM models is lost. Moreover, few, if any, occupant movement and fire safety parameters can be specified in BIM, and this prevents evacuation calculations from being easily iterated. In this regard, work has been done to develop a Revit add-in that is capable of using .ifc files for two-way communications between evacuation models and Revit. This means that .ifc files can be used to generate inputs for evacuation models (i.e., not only geometry, but also other parameters related to occupant profiles, occupant loads, etc.) but also to store evacuation simulation results. Pathfinder has been used to demonstrate this new workflow, in collaboration with Thunderhead Engineering developers who have implemented this feature in their software.

INTRODUCTION

Background And Motivation

Building Information Modeling (BIM) has evolved as a useful methodology in the Architectural, Engineering and Construction field and is seeing a rapid expansion in uptake across the globe.

One of the many benefits of BIM is the enhanced coordination between stakeholders from multiple disciplines. However, the field of Fire Safety Engineering (FSE) is lagging behind other AEC sectors due to its lack of integration into this digital workflow (Chevin, 2020). The lack of integration increases the efforts needed to evaluate designs, hinders collaboration of parties undertaking projects, and causes a fragmentation of design and review processes. This in turn may result in inconsistent documentation and ambiguity in roles and responsibilities.

Recently, both the International Fire Safety Standards (IFSS, 2021) - a worldwide coalition of over 80 fire safety organizations - and the Hackitt report - a document in response to the Grenfell Tower fire - established the need for better sharing of information related to fire safety. This is seen as a means to prevent life and property loss by keeping track of design and maintenance data of a building throughout its life cycle. This digital record was conceptualized as the “Golden Thread of Information” (Hackitt, 2018).

However, the current BIM workflow can obstruct the implementation of this “golden thread of information” for fire safety engineering (Siddiqui et al., 2021). This is due to the inability to capture, display and store data generated by FSE assessment tools - such as evacuation simulations - (Ronchi, 2021). Furthermore, the lack of data exchange protocols can be a source of conflict, data loss and frustration among stakeholders. For instance, an architect and a fire consultant may use different formats (nomenclature, units, etc.) to store and process FSE related data in their undertaking (such as dimensions, simulation output, etc.) and this can impede their cooperation. This is especially true in the context of fire evacuation where ambiguous terminologies may be adopted (Haghani et al., 2019).

Related Work

Existing studies in the domain of fire evacuation and BIM focused on attempting real-time data exchange (Al-Sadoon & Scherer, 2021), tracking occupants inside a building (Wehbe & Shahrour, 2021), developing risk indices (Mirahadi et al., 2019), or parsing BIM data for fire safety management (Wang et al., 2015). From analyzing the literature, several recurring gaps were identified.

Often, the data exchange is one-way (from BIM to evacuation tools) and the results from fire evacuation simulations are not looped back into the BIM model. This practically means that no comprehensive loop of exchange of information is currently available.

An effort was made (Al-Sadoon & Scherer, 2021) to capture some output from fire and evacuation simulations in real time and send it back to the BIM model. However, the data exchange process itself was not integrated in the BIM workflow since a separate software package had to be used for the coupling of Revit and simulation software. This adds an extra layer of complexity and may result in data loss and miscoordination.

Recently, a PhD thesis (Siddiqui, 2019) presented a conceptual strategy for enhanced data sharing between FSE and BIM, covering both fire modelling and occupant evacuation. This was an attempt to enable two-way data communication by developing a database in which results from fire and evacuation simulations can be stored along with geometry extracted from an Industry Foundation Classes (.ifc) file, and initial draft comprising data requirements for FSE was produced. IFC is a data model and an industry standard for describing building data. It ensures BIM information can be accessed by all stakeholders regardless of the software they are using (buildingSMART, 2022).

In the end, previous research did not develop a comprehensive solution for the integration of fire evacuation into BIM. More effort is needed to extract parameters from BIM, capture assessment results and improve synergy with assessment tools. It also important to define a standard exchange format and integrate the data sharing process into BIM platforms. This is because the external integration process, often seen in past projects, involves many time-consuming steps, is prone to errors and contradicts the trend of evolving BIM towards centralization (Bew & Richards, 2008).

Research Objectives

In the previous section, the need for a framework that enhances the FSE workflow and improves its integration with BIM was highlighted. In order to address this gap, this work aimed at developing a framework for smoothly integrating FSE into BIM-authoring tools, with a specific focus on evacuation.

This aim was achieved by first identifying and evaluating a set of key properties and inputs/outputs related to evacuation simulation tools. Subsequently, this was exemplified by developing and implementing an add-in prototype able to couple REVIT, a commonly used BIM software platform (Autodesk, 2022b) to Pathfinder (Thunderhead Engineering, 2022), one of the most popular evacuation modelling tools (Lovreglio et al., 2020).

Therefore, the potential for exchange and collaboration between stakeholders is leveraged by embedding evacuation simulation data into a shared BIM model. This will enable professionals and authorities to review building design models coupled with analysis results allowing them to perform more efficient and comprehensive assessments.

Ultimately, this enables the creation of a full data loop between the BIM platform (Revit) and evacuation assessment tools allowing to pass input parameter and calculation results between them and achieving the “golden thread of information” for asset management, auditing, and forensics.

METHODOLOGY

In order to tackle the objectives of this study, a methodology consisting of 4 main steps was implemented.

First, a literature review was carried out to gather information on BIM and FSE workflows. At the highest level, the points of data loss in the current workflow were investigated, resulting from the lack of support for comprehensive data exchange between BIM and evacuation simulators. This led to the identification of key properties - inputs and outputs - that are typically imported to/from evacuation simulation tools.

Next, a framework was proposed to establish a data loop, linking between Revit BIM and evacuation simulators. In this framework, input properties are transferred from the BIM model to the assessment tool and the results are captured and sent back to the BIM model.

The Industry Foundation Class (IFC) was retained as a vendor-neutral format for data exchange between these nodes. For this purpose, a data schema was drafted in line with the specifications of the IFC standard to store the data points previously identified in a proper format.

To implement the proposed framework and subsequent IFC data schema in Revit, an add-in was developed using the Revit Application Programming Interface (API) (Autodesk, 2022a). It can extract data automatically from any BIM model (e.g., door / staircase widths, corridor length, occupancy…), add user input, and store output from evacuation assessment tools. The add-in also enables the possibility to visualize simulation results within the Revit interface (through graphs, schedules, and annotations).

Finally, this add-in was tested to ensure the integrity of the data that is being exchanged.

IMPLEMENTATION

Proposed framework for the integration of Fire Evacuation into BIM

The focus of this study is to establish a full data loop, linking BIM software to evacuation simulation tools and resulting in an effective two-way data exchange comprising not only geometry but also semantic information required for these simulations. Then, the results can be captured and stored in the BIM model. This data loop is illustrated in Figure 1 below.

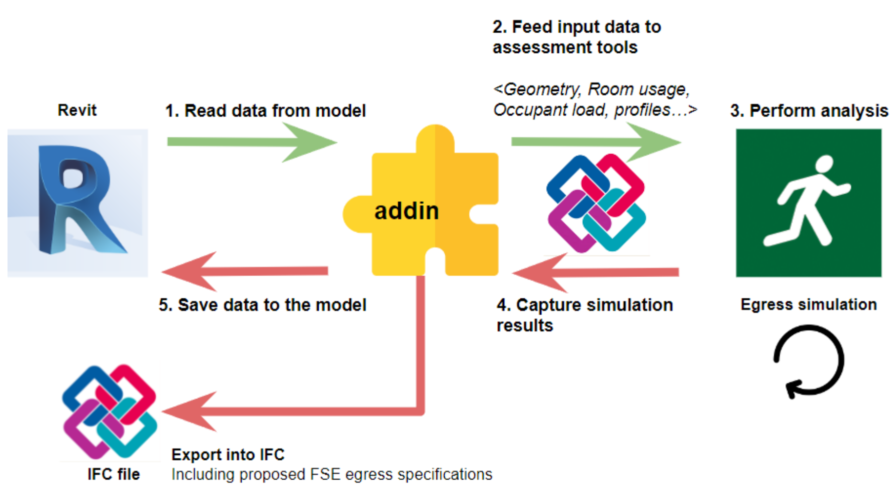

Figure 1 - Data loop linking Revit to assessment tools

In this framework, IFC will serve as a vector for transferring data in a standard format. It is therefore essential that the IFC Model is enhanced to support the required semantic information input/output data).

The development effort in support of this framework comprises three essential steps which implement the strategy proposed by (Siddiqui et al., 2021) in their “Strategy for data sharing”.

The first step was to implement a data schema by enhancing the IFC Model specifications. This was achieved by identifying the data requirements for evacuation simulations which were compared to existing IFC Specifications so that new entities could be incorporated.

The next step was to enhance Revit BIM to support the proposed framework. An add-in was developed in order to extend the current capabilities of Revit and support importing, exporting, storing, and processing data points for fire evacuation (through IFC) and enable interoperability between the BIM package and evacuation simulators.

The final step was to enhance evacuation simulators to support this new framework. This was demonstrated by Thunderhead Engineering (the developers of Pathfinder) who, in consultation with the authors, released a demo version of the software (version number 2022-1-0404) with the capability of reading and processing the newly proposed IFC schema, featuring not only the geometrical information, but also semantic data related to the simulation.

<u>Analysis of data requirements for fire evacuation simulations</u>

The data requirements for evacuation simulations were analyzed. This relates to the input properties for evacuation tools and the output they generate.

For this purpose, a list of data properties was compiled from multiple sources, such as Pathfinder’s user manual which lists properties of the evacuation model and output results. Additional properties were gathered from the literature (Abualdenien et al., 2021; Siddiqui, 2019). The findings are presented in Table 1 and Table 2 below.

Table 1 : Identified input parameters for evacuation simulation

Property name	**Description**
Alarm time	Time to Detection + Notification
Pre evacuation time	Delay between the time evacuation is notified and the time agents start moving
Number of occupants	Desired number of agents in a space/room
Occupant load	Desired density of agents for a space/room [m^2/pers]
Peak number of occupants	Maximum number of occupants allowed in a space
Building occupancy day/night	Evolution of occupancy number over the day
Component status	State of a component (open/closed)
Required door flow rate	Required flow rate through a door component [pers/sec]
Occupant profiles	A set of profiles describing the characteristics of agents : speed, diameter, and impairment.
Admitted profiles	List of agent profiles that are allowed to pass through a component

Table 2: Identified output parameters from evacuation simulation

Property name	Description
Evacuation Model Info	Name/version/vendor of the evacuation model used for the simulation
Simulation Brief	Description of the simulation
Initial Occupant Number	Initial number of agents assigned to each space at simulation start
Evacuation Time	Time from start of simulation until agents exit a space/room (RSET)
Overall Evacuation Time	Time from start of simulation until all agents exit the building
Occupant History	The evolution of agent count in a space, building or stairway over time
Travel distances	Total distance travelled by any agent (min, max and average)
First occupant in	Time to first agent crossing a component
Last occupant out	Time to last agent crossing a component
Total use	Total number of agents crossing a component
Door Flow rate History	The evolution of flow rate through a door over time
Average occ. flow rate	Average flow rate though a door [pers/seconds]

However, the Industry Foundation Classes (IFC) does not yet support the data requirements for FSE evacuation assessments. This makes data extraction and transfer difficult. There are currently no built-in parameters in the IFC standard for handling these newly established data points.

Therefore, a critical step was to map the properties identified previously into the IFC model (Borrmann et al., 2018). In order to achieve this, the properties were given a valid name (for identification), and a type (which relates to the type of data carried by this parameter: area, length, time…). Properties were then grouped into thematic property sets. An illustration is given in Figure 2.

Property	Description
Evacuation Time	Time from start of simulation until agents exit a space/room
Travel Distance	Average distance travelled by agents

Proposed IFC name	Proposed IFC type	Proposed IFC Property set
EvacuationTime	IfcTimeMeasure	Pset_SpaceEvacuationPerformanceInformation
TravelDistance	IfcLengthMeasure	Pset_BuildingEvacuationPerformanceInformation

Figure 2: Example of a property converted into IFC property

The names of IFC properties were chosen based on a careful analysis of the nomenclature related to fire evacuation from relevant standards and literature (Gwynne, 2010; ISO, 2017, 2020).

Following this methodology, the selected parameters from Tables 1 and 2 above were analyzed, and a complete list of new IFC properties was established. In total, 87 properties were defined, spread over 18 property sets (of which 7 already exists in IFC specifications and were expanded with additional parameters. The complete list of IFC properties is presented in a separate report (Yakhou, 2022a) and could not be reproduced here for the sake of brevity.

Implementation of the prototype Revit add-in

The add-in program runs within the Revit environment and can access, read, display, edit and save any information available in the Revit model, Figure 3.

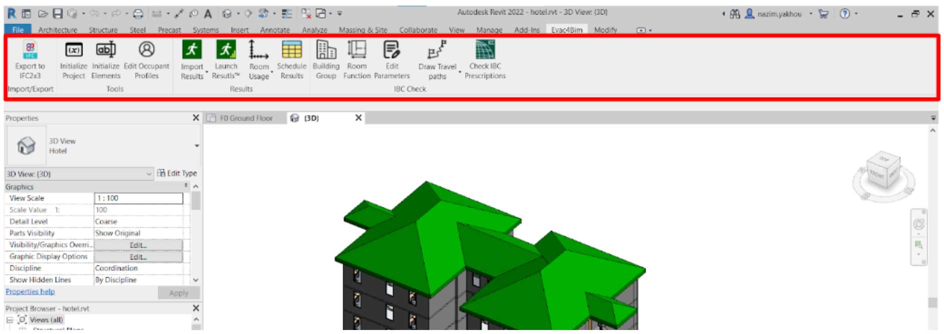

Figure 3: Illustration of the add-in integration in Revit's main interface

Table 3 summarizes the commands that can be accessed in the add-in from the main Revit interface, also shown in Figure 4.

Figure 4: Available commands in the Revit add-in

The add-in was developed using the Revit Application Programming Interface (API) (Autodesk, 2022b). The logical implementation is not included in this report so that it can be read without a background in computer coding.

Table 3 – Summary of commands available in the Revit add-in

Command n°	Role
1	Export model into IFC (including specifications related to fire evacuation)
2	Initialize project (initialize project settings)
3	Initialize element properties
4	Edit occupant profiles (speed, shape…)
5.1	Import simulation results from pathfinder (single run)
5.2	Import simulation results from pathfinder (multiple run simulation)
6	Launch the pathfinder result viewer
7.1	Display room usage graph (number of occupants vs time)
7.2	Display total usage graph (number of occupants in building vs time)
7.3	Display stair usage graph (number of occupants in a stair vs time)
7.4	Display door flow rate graph (door flow rate vs time)
8	Display simulation results in schedules

The add-in can be used to generate input files for the evacuation simulator (in this case, Pathfinder). In addition to the geometry, the add-in allows the user to provide additional semantic information

(For instance, occupant profiles, number of occupants, room function/usage, etc.) using different commands, Figure 5.

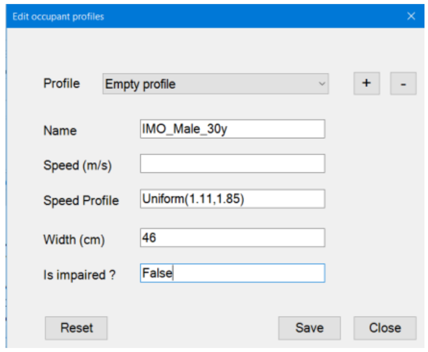

Figure 5 – User input for evacuation assessment tools in the Revit add-in

Then, this data is exported into a combined .ifc file which can then be parsed within Pathfinder, Figure 6.

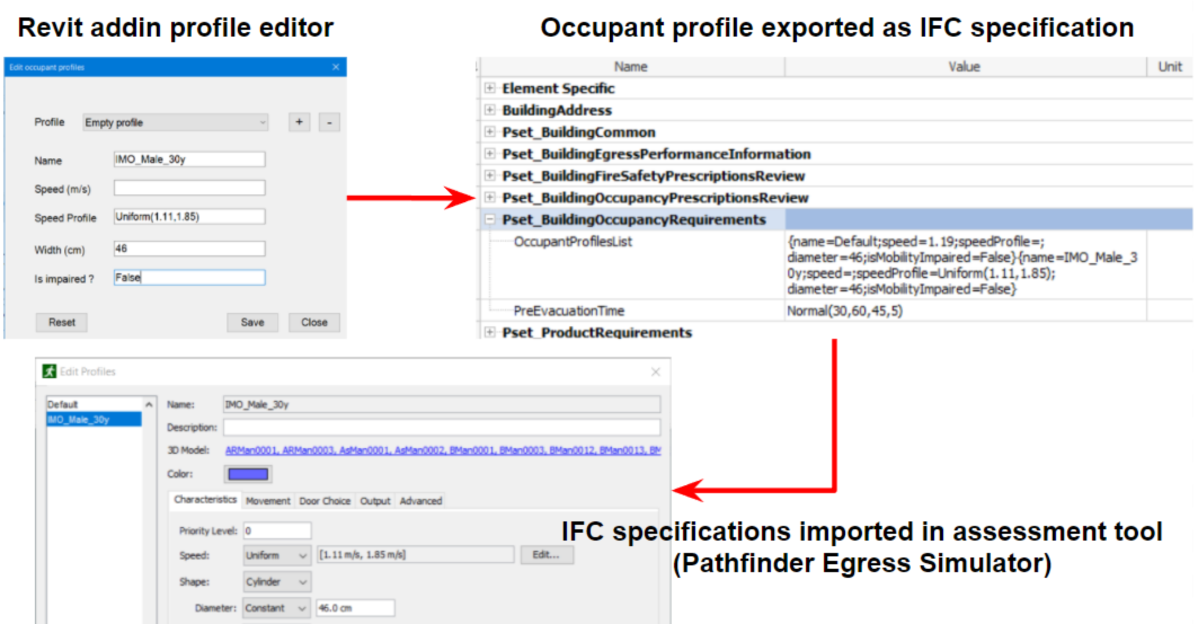

Figure 6 – Exporting input for evacuation assessment

After running the evacuation simulation, the results can be loaded into Revit using the dedicated command. The results are saved and can be displayed to the user, Figure 7.

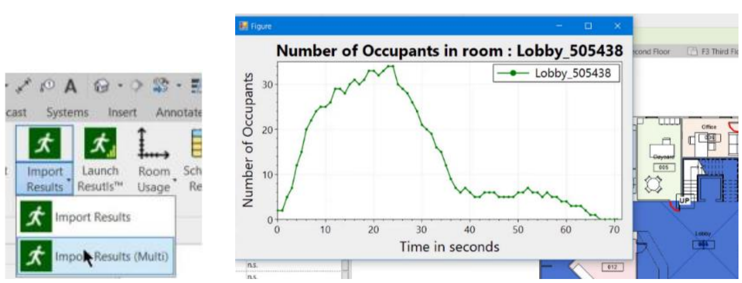

Figure 7 – Evacuation assessment results displayed in Revit by the add-in

Additionally, the add-in can animate some of the fire evacuation results which are stored as time distributions, as shown in Figure 8.

Figure 8 – Illustration of results animation in the prototype add-in

The properties that are displayed include, at various time steps: door flow rate, number of occupants remaining in a room and the density of a room (shown as a color scheme). This timed feedback helps visualize the level of performance achieved by the building design in terms of fire evacuation for informed decision making. Additionally, this partially eliminates the need for sharing and storing large contour files (generated by Pathfinder) and fragmenting assessment results, since the data necessary for these animations is stored in the BIM model as lightweight text. Moreover, stakeholders who need to evaluate fire evacuation performance but are not familiar with simulation software can access this useful information directly in Revit or using a BIM/IFC viewer.

It should be noted that the add-in can also capture the results from probabilistic (multi-run) simulations and postprocess them, since pseudo-random sampling from distributions is generally adopted by evacuation models (Ronchi et al., 2014). Results are stored in the model as an enumeration of key statistical properties: average, standard deviation, minimum and maximum.

Pathfinder IFC import

At this stage, it was necessary to expand the scope of Pathfinder so that it can parse and interpret .ifc files which include the newly defined properties from the earlier steps.

Thanks to a collaboration with Thunderhead Engineering (the developers of Pathfinder), a version of the software (number 2022-1-0404) was implemented, which can read and process the newly proposed IFC schema. This enables the passing of input parameters, required to setup the evacuation simulation, into Pathfinder, which can in turn read those properties and include them in its internal model. For this prototype version, a selection of IFC properties was extracted from the IFC schema introduced earlier. The selected properties were mapped to corresponding Pathfinder properties as presented in Table 4.

Table 4 – List of selected IFC properties for implementation in Pathfinder

IFC Property	Description	Pathfinder property
OccupancyNumber	Required number of agents to populate a space/room [pers]	Populate space with occupants
AreaPerOccupant	Required density of agents for a space/room [m^2/pers]	
OccupancyNumberPeak	Maximum number of agents allowed in the space/room	Room Capacity
ifcName	Name of the space/room/door element	Room Name
isAccessible	Door state (open/closed)	Door State
RequiredDoorFlowrate	Required flow rate through component [pers/sec]	Door Flowrate
PreEvacuationTime	Delay between the time evacuation is notified and the time agents start moving [seconds]	Behaviors - Initial delay
OccupantProfilesList	A set of profiles describing the desired characteristics for agents: speed, width...	Create new profiles

For reference, Pathfinder is now capable of importing spaces from the BIM model as rooms and populate them with agents based on the specified number of occupants or occupant density (m^2/pers), as shown in Figure 9.

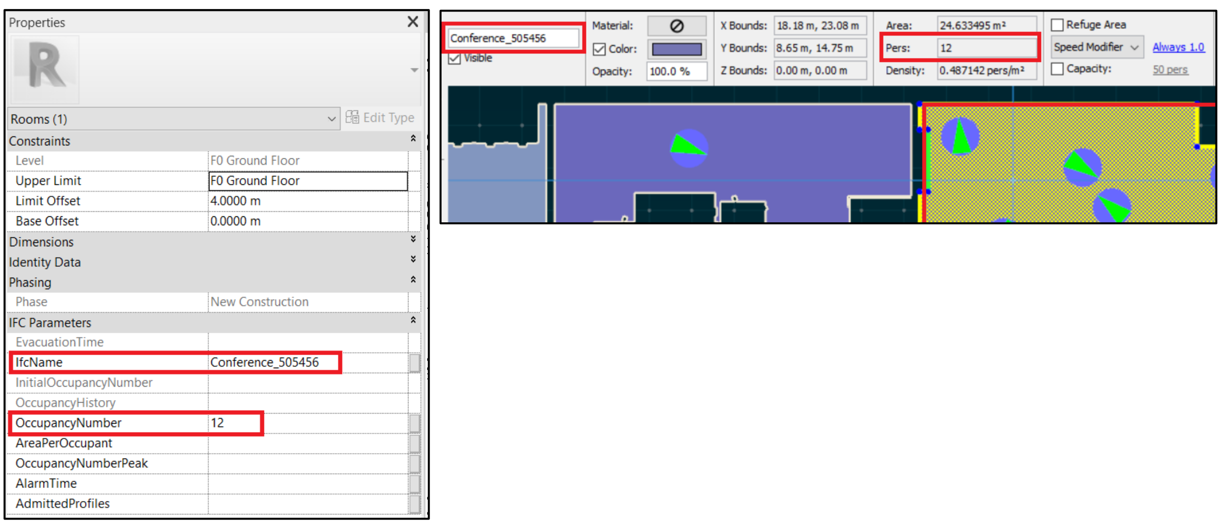

Figure 9 – Parsing room names and occupants number from Revit into Pathfinder

Left: original room model in Revit - Right: Imported room model in Pathfinder

Similarly, door properties such as state (open/closed) and flow rate (pers/sec) can be passed into the evacuation simulator, as shown in Figure 10.

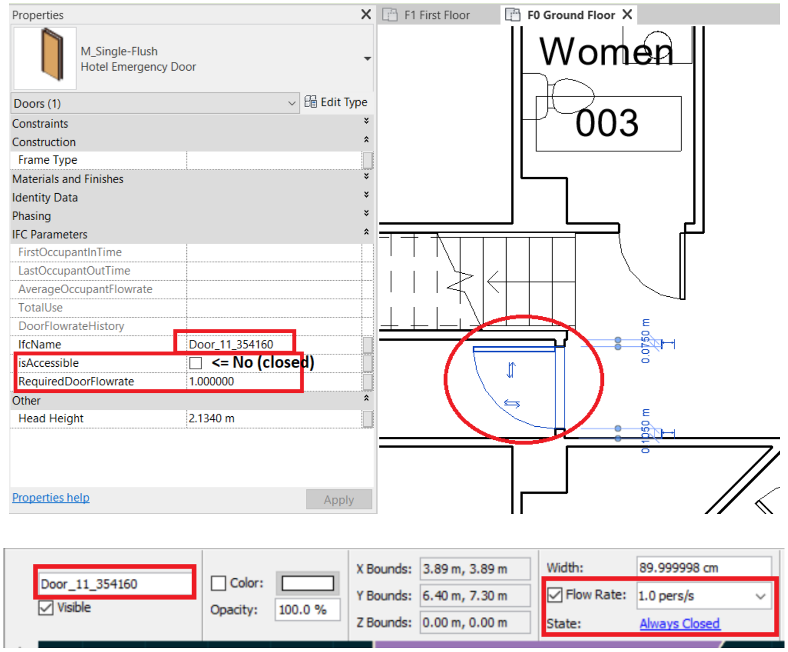

Figure 10 – Parsing door properties from Revit into Pathfinder

Top: Door model in Revit - Bottom: Imported door model in Pathfinder

Additionally, occupant profiles and behavior (pre-movement time) can also be exported into the Pathfinder simulation.

RESULTS AND DISUCSSION

Testing and validation

The sequence for testing the add-in covered all its features including : the provision of semantic data by the user, exporting the Revit model into an .ifc file - combining geometry and input parameters, importing this "enriched" .ifc file in Pathfinder and running the simulation, and finally, recording simulation results in the Revit model.

For this purpose, two test case studies were selected. The first model (a school building) is a sample project provided by the developers of Revit. The second model is a fictitious (a hotel building) is a courtesy of Dr Enrico Ronchi.

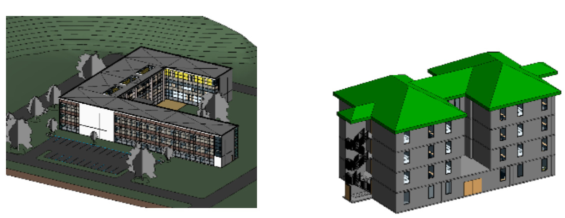

Figure 11 – Illustration of the BIM models used for the validation of the Revit add-in

The outcome of each step was checked to ensure the correctness of the results. The validation criteria for both case studies are shown in Table 5.

Table 5 – Validation criteria for testing the add-in

Function	Criterion	Outcome
Evacuation simulation	Required input data is passed to Pathfinder	Effective 2-way data exchange between Revit and Pathfinder
	Output data is captured in Revit	
IFC export	Values and units are preserved	Data integrity is preserved during the exchange process Effective coupling of Revit and Pathfinder
	Parameters are exported with the correct name	
	Parameters are mapped correctly in the IFC schema	
Data access	Required data points for fire evacuation are stored correctly in the Revit BIM model	Golden thread of information Integration of fire evacuation in the BIM workflow Collaboration and informed decision making
	The data points can be accessed and displayed to the user dynamically in the Revit interface	

The first criterion was assessed manually, by cross-checking the exported .ifc file with the values written in the Revit model. The second criterion was checked using Solibri, a BIM quality assurance software employed for the validation of .ifc files, to ensure they follow a specific structure and format (Solibri, 2022). The list of IFC specifications defined previously was used as a template and the .ifc files generated by Revit - comprising the additional properties - were loaded into Solibri and validated against it, Figure 12.

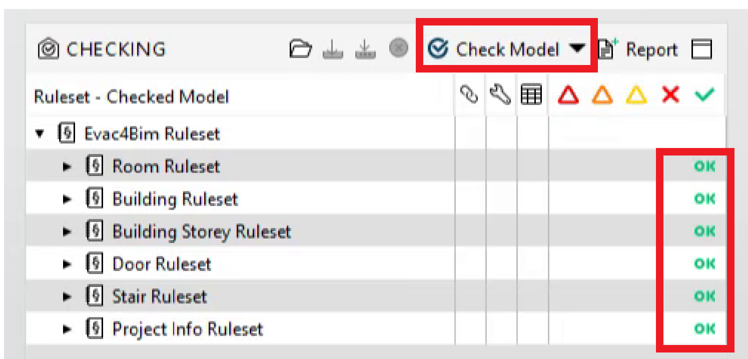

Figure 12 – Illustration of the validation in Solibri

In the end, both evaluations were positive, and the add-in succeeded in exporting data points required for fire evacuation simulations according to the criteria set by the author, in terms of preservation of values and units, and correct mapping of properties (i.e correct names, correct categories, etc.).

Discussion

An important outcome of this work was the identification of data requirements for prescriptive and performance fire evacuation assessments.

This led to the definition of an IFC schema covering the data requirements for fire evacuation. The proposed IFC schema can contribute to the drafting of the MVD for Fire Safety Engineering which is in development by buildingSMART (buildingSMART, 2020). It also offers a broad definition which allows future developments to add support for alternative software packages.

Another contribution of this research is that it demonstrated the feasibility of two-way data exchange between a BIM platform (Revit) and fire safety assessment tools (evacuation simulator).

Moreover, it enabled prototyping the golden thread of information by embedding fire evacuation information in the BIM model.

Finally, it was demonstrated that the fire safety engineering workflow can effectively be implemented in a BIM environment (in this case Revit) and this offers a better insight of evacuation performance and enables informed decision making by recording the information and providing a visual feedback of assessment results accessible to all stakeholders.

Added value to previous research

This research successfully filled some of the gaps that were identified in previous projects.

First, it effectively established a data loop enabling two-way data exchange from a BIM platform (Revit) to fire evacuation assessment tool (Pathfinder).

For this purpose, an updated IFC data schema was implemented, and it features semantic data related to fire evacuation on top of the geometry. Storing the data in a standard format using IFC enables seamless data transfer.

Moreover, the integration of this framework directly into Revit – through the prototype add-in - removes the need for external software packages or databases, preventing the fragmentation of the information.

Finally, the visual feedback and animation of time-dependent properties in Revit's interface allows for a better understanding of evacuation performance and informed decision making.

Future Work

The development work presented in this thesis research can be expanded and elaborated in different ways and the following items are suggested:

- Expanding the scope of data exchange with simulations tools
- Extraction of contour files generated by Pathfinder (e.g Level of service, density)
- Expanding Pathfinder to support/parse additional input properties from IFC.
- Exporting simulation results into IFC directly from within Pathfinder, according to the proposed IFC schema
- Supporting additional evacuation simulation tools available on the market.
- Better support for complex datasets in IFC (such as lists, enumerations, and arrays)

CONCLUSION

This research highlighted the need for better integration of fire evacuation simulation tools and BIM. The key challenges and limitations facing the integration of fire evacuation simulation tools in the context of BIM were identified and an assessment of the current situation demonstrated that the data exchange between BIM and simulation tools is traditionally one-way and limited to geometrical information, with no explicit provision for the capture of results generated by these tools. This leads to data loss and fragmentation of review processes.

In order to address these issues, a framework prototype was proposed which enabled the creation of a "round trip" data loop, linking BIM software (in this case Revit) to evacuation simulation tools and resulting in an effective two-way data exchange comprising not only geometry but also input properties necessary to conduct these simulations.

The results from such evaluations can also be captured and sent back to the BIM model to be stored along with geometrical information

Development work in support of this framework was carried out and included the identification of suitable data points and parameters for performance fire evacuation assessments as well as output data. This work was based on pre-existing draft definitions (Abualdenien et al., 2021; Siddiqui, 2019) developed into usable items.

Furthermore, a prototype add-in was developed using the Revit Application Programming Interface to demonstrate data sharing between BIM and fire evacuation simulators. The prototype add-in was then tested according to a predefined sequence.

It is hoped that this prototype will become the template for further developmental work associated with an update to the IFC standard for occupant movement and fire safety engineering.

OPEN-SOURCE PROJECT REPOSITORY

The source code and the assemblies were released on a public online repository (Yakhou, 2022b) which is accessible to all interested parties. Therefore, it is possible for anyone to test the tool on their own. It also makes the project transparent and open for future development.

ACKNOWLEDGEMENTS

Jimmy Abualdenien (TU München) and Dr. Asim Siddiqui (University of Greenwich) for their guidance and their research on the Fire Safety Engineering Model View Definitions for BIM.

Thunderhead Engineering for their technical support and input on working with the Pathfinder and for implementing the newly proposed IFC schema in their software.

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