Journal of Building Engineering 63 (2023) 105557

Contents lists available at ScienceDirect

Journal of Building Engineering

journal homepage: www.elsevier.com/locate/jobe

The integration of building information modelling and fire evacuation models

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ARTICLE INFO

Keywords:
BIM
Evacuation simulation
Fire safety
Egress
Building information modelling

ABSTRACT

This paper presents a framework for integrating fire evacuation models into Building Information Modelling (BIM). The framework is intended to enhance coordination between stakeholders from diverse disciplines involved in the domain of fire evacuation design. It supports a full in/out data loop linking BIM and evacuation design tools, which enables professionals and authorities to review building design models coupled with evacuation data and perform comprehensive assessments more efficiently. The development of the framework is discussed along with the associated data exchange from a fire safety engineering perspective. Additionally, the benefits of two-way data flow between BIM and fire evacuation design tools are demonstrated by implementing a prototype system for coupling Revit, a popular BIM platform, and Pathfinder, a widely used evacuation simulator. This open source tool is named Evac4BIM and has been systematically tested to demonstrate its applicability in building design.

1. Introduction

Building Information Modelling (BIM) is growing as a useful methodology across the Architectural, Engineering and Construction (AEC) industry and is seeing a rapid expansion in uptake across the globe. In fact, it is becoming a mandated requirement for government-funded projects in many countries [1]. One of the many benefits of BIM is coordination between stakeholders from multiple disciplines. However, the field of fire evacuation design is lagging behind because of its lack of integration into this digital workflow [2,3]. As performance-based design requires Fire Safety Engineering (FSE) tools (such as evacuation models), the lack of integration of model and analysis data increases the design team workload, especially when assessing design iterations and repeated analytical model rebuilds. This may affect the workflow and hinder the possible collaboration of parties undertaking projects. Fragmentation of the design and review processes may also occur, where the data supporting the FSE assessment is split over different stakeholders rather than being consolidated centrally. This can potentially result in inconsistent documentation and ambiguity in roles and responsibilities and ultimately lead to safety issues.

Recently, both the International Fire Safety Standards coalition (IFSS - a worldwide group of over 80 fire safety organisations) and the Hackitt report (a document in response to the Grenfell Tower fire [4]), established the need for improved sharing of information

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https://doi.org/10.1016/j.jobe.2022.105557
Received 13 September 2022; Received in revised form 8 November 2022; Accepted 13 November 2022
Available online 19 November 2022
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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. In the Hackitt report, this digital record was conceptualised as the "Golden Thread of Information".

However, current open BIM workflows have limitations that can impede the implementation of the "golden thread of information" from the FSE perspective making it difficult to achieve this objective [5]. These limitations include the inability to capture, display and store data generated by FSE assessment tools (such as fire evacuation simulators [6,7]). Furthermore, the lack of FSE 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 evacuation component dimensions, simulation output, etc.) which could impede their cooperation. Furthermore, an asset manager overseeing multiple building projects may have difficulties consolidating data if it is not stored in a standard format. This is especially true in the context of fire evacuation design where ambiguous terminologies may be adopted [8].

Previous studies in the domain of fire evacuation and BIM focused on attempting real-time data exchange [9], tracking people inside a building [10], developing risk indices [11], or parsing BIM data for fire safety management [12]. From analysing the literature, several recurring gaps were identified. Often, the data exchange is one-way (from BIM to evacuation modelling tools) and the results from fire evacuation models are not brought back into the BIM model. This practically means that no comprehensive loop of exchange of information is currently available. In order to address this limitation, this work aimed at developing an open source framework to enable a full two-way data loop with a specific focus on fire 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 [13], to Pathfinder [14], a popular evacuation modelling tool [15]. This prototype add-in was released as an open source project called Evac4BIM. This work is closely related to the ongoing Model View Definition for Occupant Movement Analysis project under the administration of BIM Standards organisation buildingSMART.[1] It should be noted indeed that the approach adopted in this work (i.e., two-way data sharing through an add-in) is one of the approaches that the involved domain experts recommend. Also, in addition to the ongoing Occupant Movement Analysis project (focused on the evacuation and circulation modelling aspects), another buildingSMART project (mostly focused on the fire modelling aspects) is currently seeking participation of interested parties.[2] Ultimately, the aim of these activities is to facilitate the creation of a full data loop between the BIM-authoring tools (e.g., Revit) and evacuation models allowing the exchange of inputs and calculation results between them and to facilitate achieving the "golden thread of information".

2. The two-way data exchange of BIM and fire evacuation models

The focus of this study is to establish a full data exchange loop, linking BIM software to fire evacuation simulators resulting in an effective two-way data exchange including not only geometry but also semantic information required for these assessments (see Fig. 1). This means that the results can be captured and stored in the BIM model.

Fire safety engineers require a set of information from the designers in order to perform their assessments. The need for smooth digital information sharing between stakeholders during all phases of a project led to the creation of an open data exchange standard known as the Industry Foundation Classes (IFC) [16]. Industry Foundation Classes (IFC) is a data model and an industry standard for describing building data that ensures BIM information can be accessed by all stakeholders regardless of the software they are using. The buildingSMART consortium is responsible for developing and maintaining the IFC standard [17]. The current major version is IFC4 which was released in 2013 and presented in the ISO 16739:2013 Standard [18]. The open data structure and the neutrality of the format have convinced a large sector of the design and engineering professions to use IFC [19]. A key concept in IFC is Model View Definitions. A Model View Definition helps determine which information is necessary and which is optional for a particular application or discipline (e.g., FSE). For instance, a fire safety engineer may be interested in the evacuation time of a space or usage of an exit, but not a structural engineer or a building energy analyst. In this regard, the Model View Definition specifies what parts of the overall BIM model are filtered out and also which data is required for a specific purpose [19]. Given its standardized format, this work uses the base IFC standard, with a proposed Model View Definition as a starting point for the development of the new framework for the domain of fire evacuation design.

A list of data properties needs to be identified to allow the two-way coupling of BIM tools and fire evacuation simulations. Multiple sources were adopted for this purpose. A PhD thesis [16] and its associated publication [5] presented both a conceptual strategy for enhanced data sharing between FSE and BIM, including fire evacuation as well as an initial draft Model View Definition comprising data requirements for FSE. However, even though a prototype was developed to show two way data flow, it was achieved using an external database, i.e., it was not integrated with a BIM authoring tool by implementing additional data properties within it. To ensure the IFC schema is comprehensive, documentation of a list of microscopic evacuation simulators commonly used in the FSE domain was also reviewed, including Pathfinder [14], buildingEXODUS [20], MassMotion [21] and STEPS [22] along with the ongoing occupant movement analysis project by buildingSMART [23]. The latter includes additional models as well as the previously mentioned simulators, namely crowd:it [24], ASERI [25] and SimCrowds [26].

The choice to review microscopic models was driven by the fact that they currently represent the most commonly used modelling approaches in the domain of performance-based design of fire evacuation [15]. In addition, these models have already implemented one-way "import-only" integrations with IFC format, thus presenting a set of relevant information to develop a two-way integration.

[1] https://www.buildingsmart.org/the-occupant-movement-analysis-project-team-have-achieved-an-important-milestone-on-their-project-they-have-documented-the-process-maps-of-the-first-phase-onto-the-use-case-management-tool/.

[2] https://www.buildingsmart.org/standards/calls-for-participation/fire-safety-engineering/.

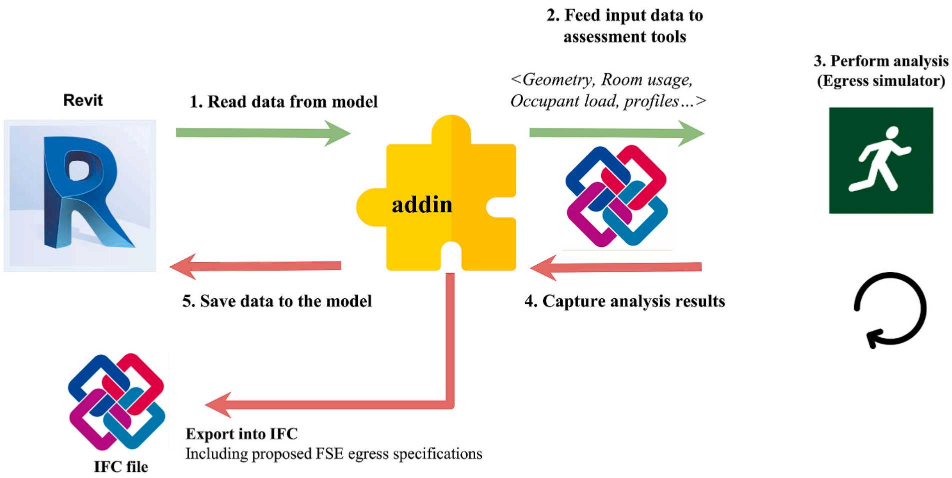

Fig. 1. Two-way data exchange loop linking BIM tools and evacuation models.

The level of space and occupant detail in microscopic evacuation models reflects the breadth and depth of information required for the intended two-way data integration. In fact, microscopic models represent evacuees as individual agents, thus allowing the assessment of a set of key individual and aggregate properties which can be linked to BIM tools. In addition, the space representation in such models is generally continuous [7], meaning that the geometrical layout information provided presents a consistent level of granularity with those available in BIM tools.

3. Data requirements for performance-based fire evacuation design

Based on the methods presented, a list of relevant input and output data properties was developed (see Tables 1 and 2) to define a framework for the usage of evacuation data within BIM tools. As mentioned, these inputs and outputs were first drafted after the review of the evacuation models and the previous documentation available in this domain [16,23].

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 simulated people start moving
Number of people	Number of simulated people in a space/room
Occupant load	Density of simulated people for a space/room [m^2/pers]
Peak number of people	Maximum number of simulated people allowed in a space
Building occupancy day/night	Evolution of occupancy number over the day
Component status	State of a component (available/unavailable)
Door flow rate	Flow rate through a door component [pers/sec]
People profiles	A set of profiles describing the characteristics of simulated people: unimpeded speed, size, and impairment.
Admitted profiles	List of simulated people 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 simulated people assigned to each space at simulation start
Evacuation time	Time from start until simulated people reach a safe place
Overall evacuation time	Time from start until all simulated people reach a safe place (often indicated as Required Safe Egress Time, RSET, in performance-based design)
Occupant history	The evolution of simulated people count in a space, building or stairway over time
Travel distances	Total distance travelled by any simulated person (min, max and average)
First occupant in	Time of the first simulated person crossing a component
Last occupant out	Time of the last simulated person crossing a component
Total use	Total number of simulated people crossing a component
Door flow rate history	The evolution of flow rate through a door over time
Average flow rate	Average flow rate though a door [pers/seconds]

In addition, ISO 20414:2020 [27] was used as a key reference, since it documents the verification and validation of evacuation models for fire safety engineering applications. It also includes a dedicated section concerning the key components present in evacuation models (basic, fire-related, building-specific and behavioural components), along with their typical outputs.

Although not exhaustive, the list eventually produced is deemed to capture the key inputs and outputs included in current evacuation modelling tools used in the FSE context [6]. In fact, it should be noted that although only a subset of evacuation models on the market were reviewed, the list provided is meant to be generally applicable for most microscopic evacuation modelling tools available. This is supported by the fact that the three most widely used evacuation models were reviewed (those combined represent over half of the evacuation modelling market based on the survey by Lovreglio et al. [15]) and that this work was conducted in conjunction with the activities on occupant movement analysis by the buildingSMART group working in this domain. This was also ensured by checking reviews of existing evacuation models on the market [15,28,29].

The input parameters for evacuation simulation were based on the so-called engineering evacuation time-line [6]. It should be noted that different nomenclatures and time-lines exist in the literature, thus the one adopted in this work was chosen in line with key references in the field, such as the Society of Fire Protection Engineering Handbook [30–32] and relevant fire engineering performance-based design codes and standards [27,33,34]. In the adopted timeline, evacuation time is assumed to be constituted of different elements, namely alarm time (time for detection and notification), pre-evacuation time (time between notification and purposive movement towards safety) and movement time [35]. While alarm/pre-evacuation times are generally set as user inputs by evacuation models, movement time is calculated based on a set of variables (e.g., walking speed, route choice, fundamental speed/density or flow/density relationships [36], and flow constraints). A set of additional parameters was then defined based on typical inputs required in evacuation models. These are in line with recommendations provided for setting up occupant behavioural scenarios [37]. They include inputs related to the number of people in the building, characteristics of egress components (availability, flow rates on the components) and people profiles. The profiles include properties such as unimpeded walking speeds, body size of the occupants and possible special characteristics of the simulated occupants (e.g., people with disabilities [38,39], profiles ability to pass through a given component). The complete list of inputs is presented in Appendix 1 and it is deemed to allow users to have a complete input set for the performance of an evacuation simulation.

Mirroring the process employed for the definition of evacuation simulation inputs, a list of property sets was identified for output parameters. The goal was to identify key outputs needed for the use of evacuation models in the context of performance-based design in fire safety engineering. Also in this case, this work was performed both scrutinizing the outputs produced by commonly adopted evacuation models [15], the occupant movement analysis project by buildingSMART [23] and reviewing relevant fire engineering codes and standards [32,33]. The identified output parameters include basic information regarding the evacuation simulator in use (name, version, vendor) and a short description of the simulation performed. In addition, key outputs related to the evacuation process are reported, including the time for each simulated occupant to reach a safe place, the overall evacuation time (i.e., time of the slowest occupant to reach a safe place). More detailed outputs are also considered, such as tracking occupant history (the evolution of person count over time in a given space in the building or a given egress component) and travel distances (minimum, maximum and average). While those outputs are not always used in performance-based design for fire safety engineering applications, they were deemed useful for specific applications (such as estimation of congestion levels in high density scenarios or scenarios possibly including long travel paths). Space usage was also deemed to be a relevant issue to be analysed in an evacuation scenario. For this reason, first and last occupants in and out of a given egress component of the building were added as relevant outputs. This information could for instance be useful for calculating flow rates throughout the whole building. This is especially relevant for those components for which flow rate cannot directly be obtained. Following this same principle, the total number of people crossing a given component was also added to the list of outputs. Door flow rate history and average flow rates were instead directly added to the output parameter list. This was done since they can be commonly obtained as outputs by evacuation simulators. The output list was designed by considering a compromise between data resolution (e.g., availability of key data for possible analyses to be performed) and quantity of information provided. The approach deployed allows the selection of the output parameters for both a simpler analysis (e.g., assessment of required safe egress time which is typically performed in performance-based design), as well as more complex analysis of the evacuation process. It is then up to the user to decide which levels of data detail to use and how to employ them in fire safety engineering design.

When defining the list of output parameters, particular attention has been given to the fact that evacuation models make use of pseudo-random sampling from distributions [40]. This means that results should not consider merely individual simulation results, but also take into account the variability of results across different repeated runs. This is in line with existing methods recommended for the estimation of convergence in evacuation simulations [41–43]. For this reason, each output parameter considers both results from individual runs but also from aggregated repeated runs (i.e., key statistical information concerning distribution of results, such as average, standard deviation, minimum and maximum values).

4. The Evac4BIM prototype

The proposed framework representing the two-way data loop has been implemented in a prototype by following a previously established three steps strategy [5]. The prototype was developed with two popular tools in their respective domains: the Revit [13] model as BIM authoring tool, and the Pathfinder [44] model as evacuation simulator.

Step 1: Implementation of enhanced IFC Model Specification

The identified data requirements for fire evacuation design were compared to existing IFC specifications so that new entities could be defined and incorporated. This list of entities formed a proposed, expanded IFC schema covering the data requirements for fire evacuation and supporting the current efforts for the implementation of the FSE Model View Definition led by buildingSMART. This included expanding the existing list [16] to cover additional properties, and also refine it by mapping new items into property sets (see Appendix 1) and proposing a nomenclature with property names and units.

Step 2: Enhancing BIM tools to support the framework

An add-in called Evac4BIM was developed to extend the current capabilities of Revit and support importing, exporting, storing, and processing data requirements for fire evacuation (through IFC) expanding upon Autodesk's open-source IFC export library [45]. Evac4BIM also enabled interoperability between the BIM package and evacuation modelling tools. Thus, Revit becomes the central platform connecting stakeholders from various disciplines (e.g., architectural design and fire safety) storing fire evacuation data directly within the BIM model.

Step 3: Enhancing fire evacuation modelling tools to support BIM

Evacuation modelling tools are an essential component of the proposed data loop. These tools require input data to perform their analysis and generate output data that is stored in the BIM model. Thanks to a collaboration with Thunderhead Engineering (the developers of the Pathfinder model), a demo version of the software was implemented with the capability of reading and processing the newly proposed IFC schema, which included input data for the simulation (along with geometrical information). This made it possible for the add-in described in Step 2 to capture, process, display and store simulation results from Pathfinder into the Revit/BIM model.

The online repository of the tool is made available in open source to any interested party: https://github.com/YakNazim/Evac4Bim. More information can be found in the full report associated with this work [46].

4.1. Code structure and implementation

Based on the definitions of the list of property sets for the enriched IFC schema, a set of standalone commands were added to the User Interface in Revit. The purpose of the standalone commands is to execute the tasks needed for sourcing the key inputs needed, performing the evacuation simulations and producing the required outputs. This involves the ability to read files, define new shared parameters, lookup and edit parameters, etc. This was achieved thanks to the methods offered by the Revit Application Programming Interface (API). The list of key standalone commands (classes) available in Evac4BIM is presented in Table 3.

An IFC exporter was then forked from the open-source Revit IFC exporter [45]. It generates enriched IFC files supporting the fire evacuation data requirements of the draft Model View Definition for FSE. The typical working sequence of the standalone commands involve a command querying building elements from the model (such as doors, rooms, stairs, etc.) and then parsing their properties (for instance, door width). It can then perform tasks and, optionally, write results back into the model. The whole reading/writing process between the add-in commands and the main Revit environment is handled by API transactions.

The Pathfinder evacuation software is able to generate JSON files containing simulation results, stored as simple data structures and objects in JavaScript Object Notation (JSON) format [47]. This JSON file is imported into Revit by the add-in, and its content is "deserialized" (i.e., the data is decoded into a native format. In this case, it is converted into a class with properties and fields). Next,

Table 3
List of key standalone commands from the add-in source code.

Class	Description
CmdBuildingGroup.cs	This class allows the user to define the building group of the model. Then, it initialises variables which depend on the building group such as maximum travel distance and width per occupant.
CmdCreateSchedules.cs	This class creates schedules in the Revit user interface to display simulation results that were imported.
CmdEditOccupantProfiles.cs	This class enables the user to edit/store occupant profiles in the model.
CmdEditRoomFunction.cs	This class allows the user to define the function of a room. Then, it initialises variables which depend on the room function such as the occupant load factor.
CmdExport.cs	This class provides a shortcut for calling the IFC exporter. The IFC exporter must be loaded into Revit - at start-up - through a separate add-in. This class calls the exporter with pre-defined parameters. It will intercept the export and fill empty fields with default values.
CmdGenerateInputFile.cs	This class allows users to export an extended pathfinder input file. The original input file (containing the geometry) is selected by the user then additional properties - extracted from the model - are appended to the input file.
CmdImportParameter.cs	This class imports simulation results and stores them in shared parameters.
CmdLaunchResults.cs	This class enables the user to launch Pathfinder results from the Revit user interface.
CmdLoadParameters.cs	This class loads shared parameters in the Revit project. The shared parameters are parsed from a CSV file which contains name, type and applicable category.
CmdMakePaths	This class generates travel paths from rooms to a specified exit. It can also store the horizontal travel distance.
CmdSelectPreferredExit	This class allows users to assign an exit to a selected room.
CmdSelectPreferredStair	This class allows users to assign a stairway to different rooms.
CmdAssignLinkedComponent	This class allows users to link individual stairs to a multi-storey system in order to compute the vertical travel distance.
CmdPlotCharts.cs	This class plots various charts from imported simulation results.
CmdRenameItems.cs	This class sets the parameter "IfcName" for elements such as doors and rooms. The name includes the id of the element in the Revit model. The name is stored in the IFC model and used to query the elements when importing results.
CmdResultAnimation	This project includes classes implementing the animation of simulation results via a modeless dialog.

the properties of the "deserialized" object are copied into a generic interface for storing egress simulation data. This class is meant to establish a level of abstraction so that it can store data from any evacuation simulator. The class diagram properties include lists of building elements such as rooms, stairs, and doors, which in turn store associated simulation results (e.g., a door has an id, an average flow rate, etc). Once simulation results are imported, it is possible to plot graphs of time-dependent values such as the number of people in a room over time.

A more detailed presentation of the code structure and its implementation is presented in Appendix 2.

4.2. Revit add-in

After the data processing code was structured and implemented, a graphical user interface was designed in order to be available within Revit as an add-in. This was developed using the Revit API [13] and it displays UI ribbon and menu items, hosted within the main Revit interface (see Fig. 2). This includes the possibility to export IFC files, initialise projects, initialise elements and edit occupant profiles. In addition, it can import results (as individual runs or multiple runs), launch the Pathfinder result viewer and display key outputs such as room usage, total usage, stair usage, door flow rate and simulation results in Revit schedules.

Evac4BIM allows exporting data as combined IFC files that can be used by Pathfinder to automatically set the input of an evacuation simulation including both the geometric layout and key features related to occupant profiles (see Fig. 3). Evac4BIM also allows the user to import the Pathfinder output files, thus making it possible to load results directly from the extended Revit interface, and store them as an extension to the Revit data model.

Evac4BIM also includes a custom visualizer which allows displaying visually key outputs from the evacuation simulation in Revit. This includes dynamically displaying numerical outputs and using colour-coding, e.g., representing flow rates and the number of occupants/density in a given space at given time-steps, with representative colour, like a space-level heat-map.

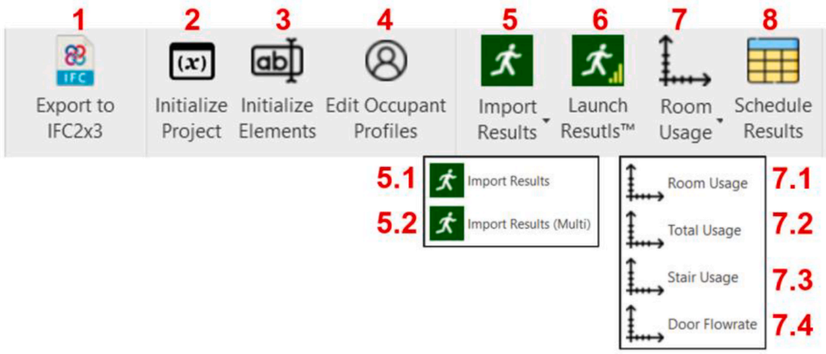

Fig. 2. Commands of the Evac4BIM Revit add-in available in the Graphical user interface.

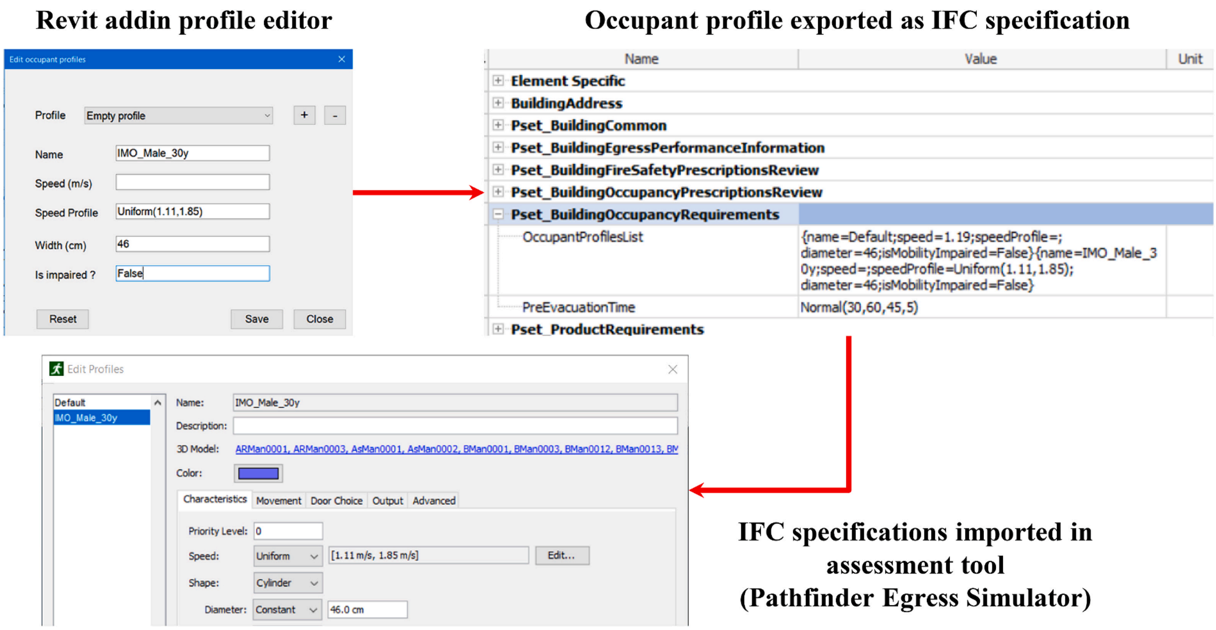

Fig. 3. Process of exporting data from the Revit add-in for calibrating input in an evacuation simulator using the IFC files.

4.3. Importing IFC files into pathfinder

After the core features for Evac4BIM were developed, the next step was to ensure that the evacuation model in use (Pathfinder) was able to read and use the IFC files generated. Pathfinder needed to be able to parse and interpret the custom IFC files which include information both about the geometric layout as well as key additional inputs (e.g., occupant profiles). It should be noted that the existing commercial version of Pathfinder (2021.4) at the time this work was conducted was able to read only geometrical data from IFC files. A collaboration with the developer of the software (Thunderhead Engineering) was initiated to make it possible for the evacuation model to read and process the data generated by Evac4BIM (e.g., including occupant profile data). A key set of properties present in the IFC schema were included in this automated process of parsing data through Pathfinder. Those were selected to represent the typical inputs required to perform an evacuation simulation for FSE applications [6,48]. Those include number of occupants in a given space, the area per occupant (in m^2 per pers), the maximum number of occupants allowed in a given space, the name of the space, the door/exit state (if open or closed), the maximum flow rate through a given component (in pers/s), the pre-evacuation time (s) and the set of profiles describing the characteristics of the occupants such as walking speed (m/s), body size (m), etc.

This means that Evac4BIM became able to generate IFC files which could be used to automate and facilitate the process of input calibration of evacuation models directly from and through a BIM environment (e.g., Revit).

5. Testing and case study

In this section, the outcome of the testing performed with the Evac4BIM add-in is presented. This consists of a fictitious case study of a hotel, with an intentionally realistic geometry. The sequence for testing the add-in was intended to cover all its features, including:

1. Initialization of the case study model (i.e., to import all required parameters etc.) using the built-in commands.
2. Performing necessary modifications to prepare the model (e.g., switch door directions outward, name rooms, assign room functions)
3. Exporting the Revit model into an IFC file combining geometry and input parameters for the Pathfinder simulation. After that, the evacuation simulation was executed.
4. Importing Pathfinder simulation results.
5. Exporting all data into a final IFC model which combines geometry and assessment results.

This sequence was applied for each case study. 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 4.

Regarding IFC export, it is necessary to ensure that the integrity of data points is preserved with regards to:

- Units (for numerical properties)
- Values (i.e., the values were not altered during the export process)
- Mapping to IFC schema (i.e., each property was exported under the right category/property set and with the correct name).

The first two criteria are assessed manually, by cross-checking the exported IFC file with the values written in the Revit model. The third criterion is checked using Solibri software. Solibri is a BIM quality assurance software solution that analyses BIM models for validation, compliance control, design process coordination, design review, analysis, code checking and clash detection [49]. One interesting feature of Solibri is the validation of IFC files to ensure they follow the correct structure specified in a ruleset [50].

The ruleset defines a list of IFC properties, along with their name, unit, object they apply to, and the category/property set they fall under. Next, the IFC files generated by Revit and comprising the additional properties will be loaded into Solibri and checked against it. Lastly, the simulation results that were imported into Revit are checked to ensure they were not altered. Here again, the assessment is performed manually by comparing results stored in Revit to those produced by Pathfinder at the end of the simulation (Pathfinder can export simulation results into comma-separated values files).

5.1. Case study

The case study investigates a fictitious hotel building which consists of 4 storeys (3 levels above ground). The storeys are connected via a central staircase which opens out onto the main lobby. In addition, there are two emergency stairways on each side of the

Table 4
Validation criteria for testing the add-in.

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

building discharging the upper storeys outside of the hotel (see Fig. 4). The upper floors mainly consist of sleeping rooms whereas the ground floor comprises facilities such as a kitchen, dining rooms, a day care, a lounge, and a conference room, in addition to the main reception at the lobby. The building is assumed to be equipped with a sprinkler system and automatic detection and alarm.

5.2. Testing and evaluation

Input data was sent from the Revit model to Pathfinder via IFC data. The IFC file comprises, in addition to the geometry, additional specifications, such as occupant profiles, pre-evacuation times, state of door, etc. Some of these specifications were edited from within Revit with a set of dedicated commands that have been developed for this purpose (see an example of add-in command for Pathfinder input specification within Revit in Fig. 5).

The IFC file was then imported into Pathfinder, which parsed the geometry as well as the additional input parameters and visualized it within the model, as shown in Fig. 6. The prototype Revit add-in was employed for this purpose. The resulting Pathfinder model was then simulated.

After running the simulation, the results were imported back into the Revit model to close the data loop via the dedicated command provided by the add-in. The results were stored in the Revit model and could be displayed to the user directly within Revit.

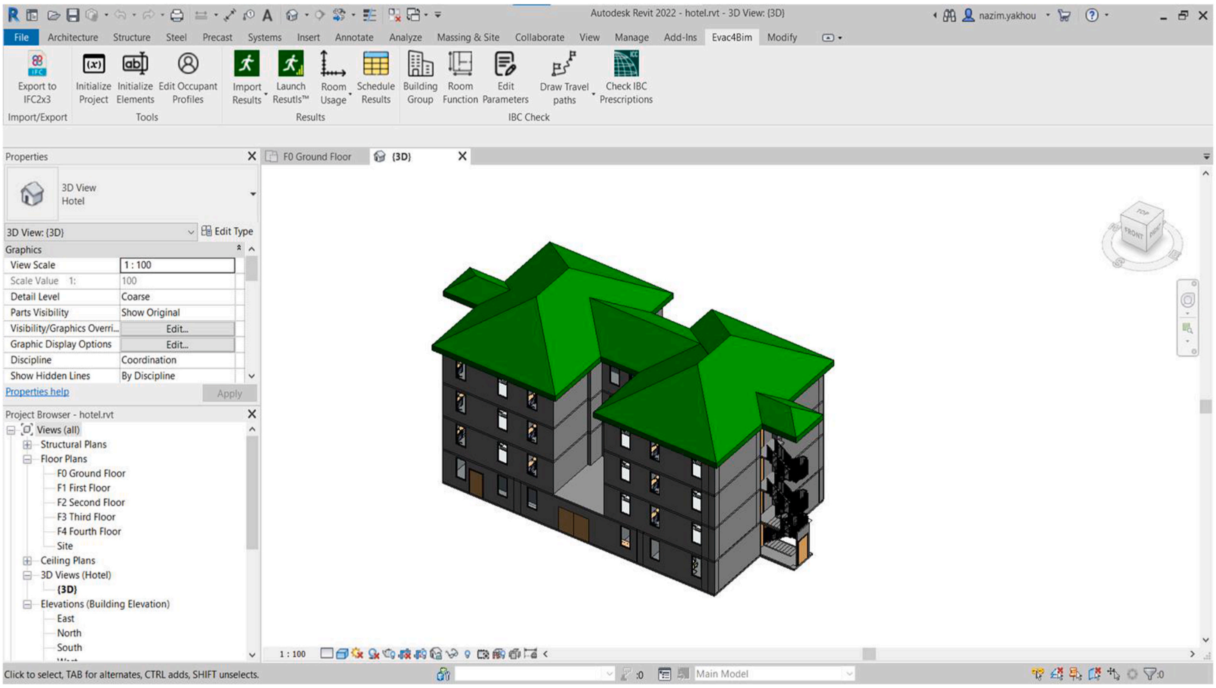

Fig. 4. Overview of the Hotel building used for the case study.

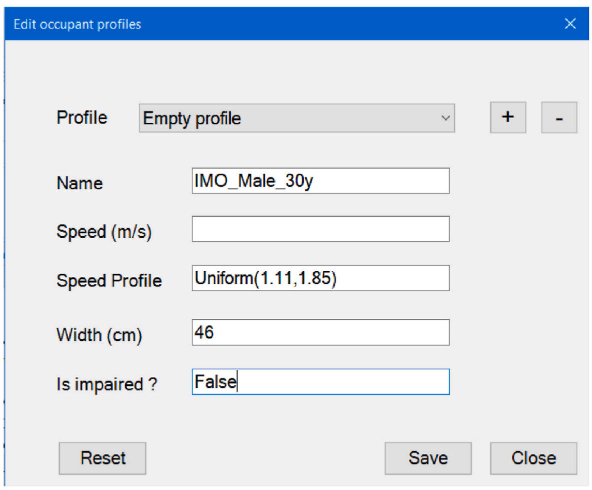

Fig. 5. Add-in command for Pathfinder input specification.

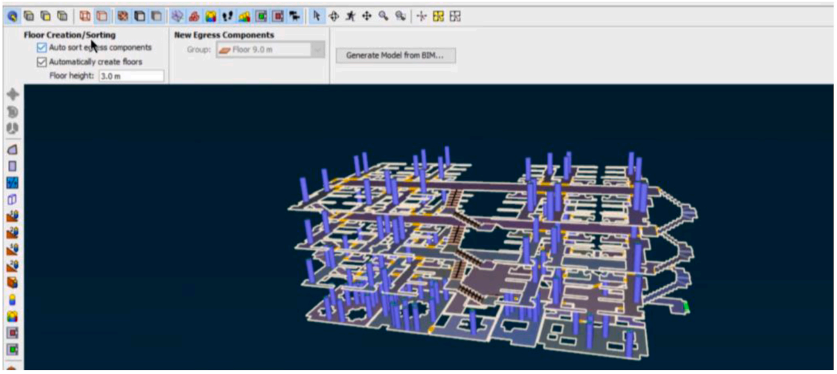

Fig. 6. Preview of the model imported in Pathfinder.

To ensure the results were not altered, a cross comparison between the results stored in the model and those produced by Pathfinder was performed at the end of the simulation. As evacuation models generally make use of a probabilistic approach in which pseudo-random sampling from distributions is adopted [41], the procedure was also repeated for the case of multiple repeated runs. Therefore, the add-in succeeded in enabling two-way communication with the simulation by passing the necessary data to perform the analysis, capturing the results in the BIM model, and displaying them to the user (both in case of individual runs and multiple repeated runs of the same scenario).

Finally, the last step was performed to ensure that the integrity of data (input and output from assessment tools) was preserved when exporting into IFC. First, the values in the generated IFC file were checked manually to verify that they matched those stored in the Revit model. Key results were evaluated for consistency such as number of occupants who exited, number of occupants in total, etc. Fig. 7 shows examples of visualized outputs in REVIT after being ported from Pathfinder, while Fig. 8 shows the consistency in the exported IFC properties and properties in the REVIT model (e.g., egress capacity, occupancy number limits, area per occupant space, etc.).

This was followed by a systematic validation performed in Solibri to ensure the IFC files had the correct structure (i.e., the property was exported under the right category/property set and with the correct name, see Fig. 9).

In the end, both evaluations were positive. As a result, the add-in succeeded in exporting data points required for fire evacuation design according to the specifications, in terms of preservation of values and units, and correct mapping of properties (i.e., correct names, correct categories, etc.).

6. Discussion

This paper discusses the benefits of improved integration of fire evacuation simulation tools and BIM. The existing challenges and limitations concerning the integration of fire evacuation simulation tools in the context of BIM have been identified. An assessment of the current situation demonstrated that the data exchange between BIM and evacuation modelling tools is traditionally one-way and limited to geometrical information (i.e., a calibration of evacuation model inputs linked to occupant characteristics is not possible), with no explicit provision for capturing the results generated by evacuation modelling tools. This leads to data loss and fragmentation of review processes. This also practically means that a BIM user may not easily access evacuation model results unless they are familiar with evacuation modelling tools. This issue can be overcome with a two-way data exchange, so that key relevant information can be made available directly within BIM (e.g., in REVIT).

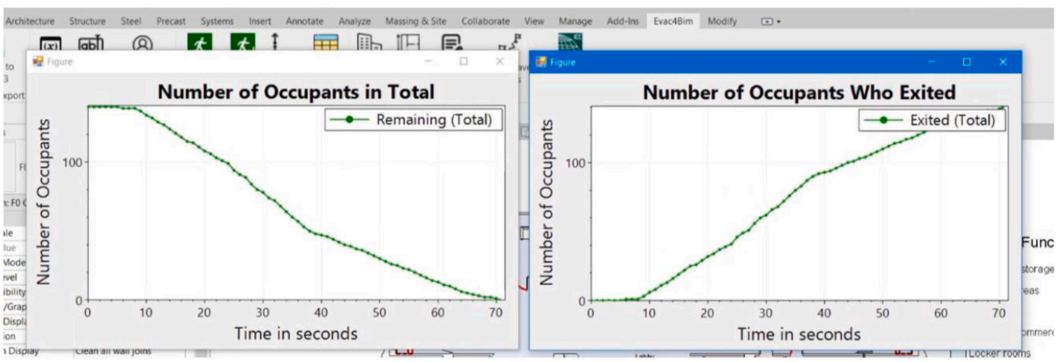

Fig. 7. Pathfinder results displayed in REVIT by the add-in.

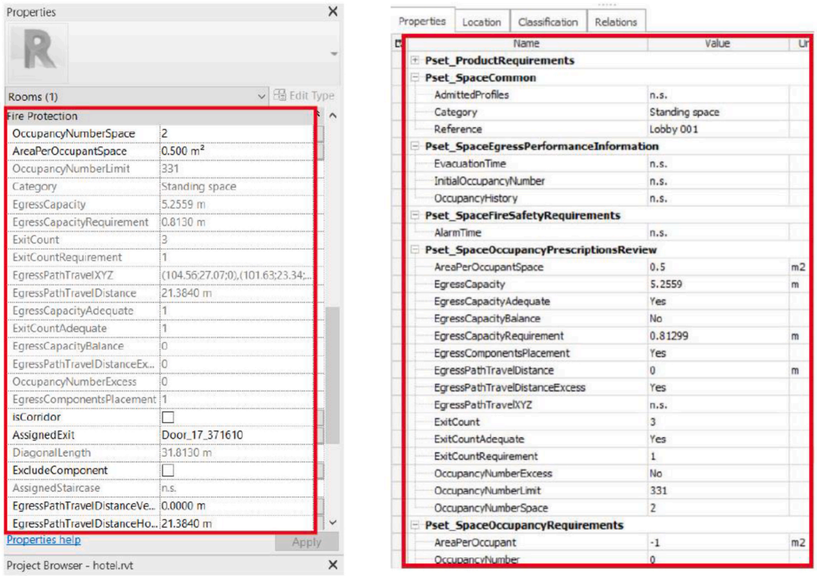

Fig. 8. Comparison of exported IFC properties and properties in the REVIT model.

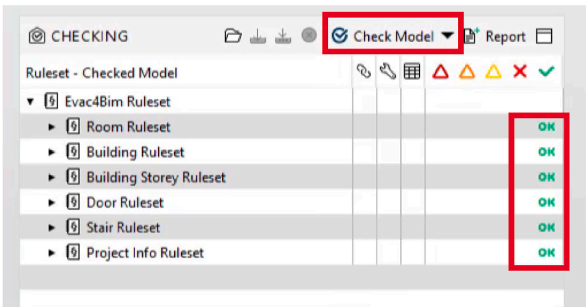

Fig. 9. Preview of the validation performed in Solibri.

In order to address these issues, a framework was proposed to enable the creation of a two-way data loop, linking BIM software to evacuation modelling tools. This was then prototyped and tested by adopting two popular tools, namely Revit (as the BIM platform) and Pathfinder (as the evacuation simulator). The current approach is in contrast with existing one-way data exchange, mostly focused on geometry export from BIM into evacuation models [5]. The approach presented demonstrated an effective two-way data exchange including key input data necessary to conduct fire evacuation design. It should be noted that the prototype Revit add-in (Evac4BIM) was developed by selecting a set of key inputs and outputs needed for the automation of the evacuation design and assessments. Nevertheless, several other inputs (especially linked to the calibration of complex behavioural itineraries) or outputs (e.g., linked to the level of service [51]) may be implemented in the future. The added value of this work includes filling existing gaps that were identified in the literature. The use of a standard format for data storage enables smoother data interoperability between multiple software. In addition, the implementation of an updated IFC data schema made it possible to include specific semantic data related to fire evacuation. The use of a Revit add-in also makes it possible to remove the need for directly working within external software packages or databases, enabling BIM as a central hub for managing all aspects of building design, assessment and management.

Development work in support of this framework was carried out and included the identification of suitable information for performance-based fire evacuation design and assessments. This was achieved by augmenting the building information model pathways with both input and output FSE occupant movement data. Reliability of input/output data was ensured by adopting a systematic approach of reviewing the list of properties (input/output) available in a set of widely used microscopic evacuation models. This ensured that key data were included in the input/output specification. In addition, the integrity of data was checked systematically both manually as well as in an automated way using the Solibri software. This ensured that IFC files followed the correct structure in a given ruleset and that no data loss occurred.

This work was based on pre-existing draft definitions [16,23] but extended, prototyped and tested. The prototype Revit add-in Evac4BIM was tested according to a predefined protocol and the results were presented and discussed. The Evac4BIM prototype and the proposed IFC schema will be used as a reference in buildingSMART's occupant movement analysis project and are deemed to stimulate further development work associated with an update to the IFC standard for occupant movement and FSE. This is facilitated by the fact that the framework and tool are made freely available, and its repository is open source.

Coupling models and engineering tools via a vendor-neutral format (IFC) also allows for establishing a fully open data loop between the components of the fire evacuation design workflow, which can be easily inspected, improved and extended. The data requirements for performance-based design studies of occupant evacuation in the context of FSE were analysed and used to inform the development work. This relates to input properties for evacuation modelling tools and the output results they generate.

The possibility to display evacuation modelling outputs directly within Revit through Evac4BIM has the benefit to avoid the need for sharing and storing large results files which are generally created by evacuation models. This is deemed to avoid fragmentation of results since the data necessary for the visualization of high-level heatmaps within Revit is stored in the BIM model as lightweight text. This also leads to the advantage of making evacuation model results available to stakeholders who may be familiar with BIM environments (e.g., Revit) while not being fully familiar with evacuation modelling tools. Evac4BIM can also capture the results from probabilistic simulations and automatically post process them. This is very important since most evacuation models make use of pseudo-random sampling from distributions and currently do not allow automatic analysis of the result statistics generated [40]. Evac4BIM allows the automated obtainment within the Revit environment of key descriptive statistics of evacuation model results (e.g., average, standard deviation, minimum and maximum of the distribution of results).

In the Evac4BIM prototype, this work focused on the Pathfinder evacuation model. Nevertheless, future research and development can focus on any of the commercial or research evacuation modelling software available on the market which present a comparable modelling approach (i.e., microscopic models [7]).

The development of the new IFC schema covering the data requirements for fire evacuation represents a fundamental step to standardize names, units, and mapping in the context of evacuation design using BIM tools. In addition, the presented framework and suggested workflow could be extended in the future to similar processes (e.g., coupling fire modelling tools and BIM). On a related note, the work performed for validating the tool can become a useful testing protocol for any further work of this kind (either expanding the data exchange capabilities in the domain of fire evacuation or translating this approach to other domains).

An important note is that the work has been developed as an open source project and it has therefore been published in a public online repository which is accessible to all interested parties. This has several known benefits in the context of software development to aid building design automation. Firstly, it is deemed to increase the opportunities for future developments of this and similar tools, as the tool and its underlying assumptions are fully available to researchers and developers. Secondly, it increases the credibility of the tool, as its transparency makes it possible for any interested party to review the work done and assess its accuracy. Thirdly, it stimulates the creation of a community of users and developers, which in turn may lead to a better assessment of bugs, future improvements, and aim at a roadmap for developments.

Future research can focus on enabling the possibility to develop configuration files directly in the Revit user interface via specific commands. This could allow users to develop ad hoc features desired for specific projects. The fire evacuation domain is only a specific sub-domain of FSE. It is desirable that future efforts would focus on applying similar methodologies and approaches used for this domain to other FSE domains. Similarly, the current work has mostly focused on fire evacuation applications. In contrast, pedestrian modelling may be used in other contexts, such as pedestrian planning for comfort and safety in large events [51,52]. Those applications may require an updated IFC data schema.

7. Conclusion

This work presented a framework for the two-way integration of BIM and fire evacuation modelling tools. The framework has been implemented and tested through an open source Revit add-in prototype called Evac4BIM that was coupled with a widely used evacuation simulator called Pathfinder. This research is deemed to stimulate further developments in the area of automation of building design including FSE through open source software using open data standards.

Author statement

Nazim Yakhou was involved in conceptualization, methodology, software development, validation, formal analysis visualization, and writing the original draft. Peter Thompson was involved in conceptualization, supervision and methodology. Asim Siddiqui was involved in conceptualization and supervision. Jimmy Abualdenien was involved in conceptualization and supervision. Enrico Ronchi was involved in conceptualization and writing the original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The source code of the Evac4BIM tool is available publicly

Acknowledgements

The authors thank Thunderhead Engineering for their technical support and input on working with the Pathfinder software but most importantly, for developing a demo version which supports the newly proposed IFC schema. The authors also acknowledge and thank the Autodesk team developing and maintaining the open source “Revit IFC” project.

Appendix 1. List of Property Sets for the proposed IFC schema

Property Set Name	Property Name	IFC Type	Description	Format
Pset_SimulationID	EvacuationModelName	IfcText	Name of the evacuation model used for the simulation	e.g., "Pathfinder"
	EvacuationModelVersion	IfcText	Version of the evacuation model	e.g., "2021.2.0525"
	EvacuationModelVendor	IfcText	Developer/vendor	e.g., "www.thunderheadeng.com/pathfinder"
	EvacuationSimulationBrief	IfcText	Comment/description of the simulation	
Pset_SpaceFireSafetyRequirements	AlarmTime	IfcTimeMeasure	Time to Detection + Notification in a space/room [seconds]	e.g., "120"
Pset_SpaceEvacuationPerformanceInformation	InitialOccupancyNumber	IfcTimeMeasure	Initial number of people assigned to a room/space before simulation starts [pers]	Single run > e.g., "5" Multiple runs > "n.a"
	EvacuationTime	IfcTimeMeasure	Time from start of simulation until people exit a space/room [seconds]	Single run > e.g., "60" Multiple runs > "avg = 41.53, min = 41.35,max = 41.7, std = 0.18"
	OccupancyHistory	IfcCountMeasure	Array representing the evolution of person count in a space/room over time, throughout the simulation	Single run > "time, value; time, value; " e.g., "0,0; 1,0; 2,0; 3,3; " Multiple runs > "n.a"
Pset_SpaceOccupancyRequirements	OccupancyNumber	IfcCountMeasure	Required number of people to populate the space/room [pers]	e.g., "10"
	AreaPerOccupant	IfcAreaMeasure	Required density of people for the space/room [m^2/pers]	e.g., "1"
	OccupancyNumberPeak	IfcCountMeasure	Maximum number of people allowed in the space/room	e.g., "10"
Pset_SpaceCommon	AdmittedProfiles	IfcPropertyTableValue	List of person profiles that are allowed in a component	"occupantProfile1, occupantProfile5"
	Category	IfcLabel	Category of space usage or utilization of the area. It is defined according to the IBC code § 1004.5	String value
Pset_SpaceOccupancyPrescriptionsReview	OccupancyNumberSpace	IfcCountMeasure	Actual number of people in the space/room	e.g., "10"
	OccupancyNumberLimit	IfcCountMeasure	Maximum number of people allowed in the space/room	e.g., "10"
	AreaPerPeoplepace	IfcAreaMeasure	Required density of people for the space/room [m^2/pers]	e.g., "1"
	EvacuationCapacity	IfcLengthMeasure	Actual combined width of exits serving a space/room [mm]	e.g., "1600"
	EvacuationCapacityRequirement	IfcLengthMeasure	Exit width required by IBC code (§1005.3.2) for a space/room [mm]	e.g., "1600"
	ExitCount	IfcCountMeasure	Actual number of exits serving a space/room	e.g., "2"
	ExitCountRequirement	IfcCountMeasure	Number of exits required by IBC code (§1006.2) for a space/room	e.g., "2"
	EvacuationPathTravelDistance	IfcLengthMeasure	Actual distance to room/space to an exit [mm]	e.g., "20000"
	EvacuationCapacityAdequate	IfcBoolean	Indication whether the combined width of exits serving a space/room is sufficient compared to the number of people	String value "TRUE","FALSE"

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Property Set Name	Property Name	IFC Type	Description	Format
	ExitCountAdequate	IfcBoolean	Indication whether the of exits serving a space/room is sufficient compared to the number of people	"TRUE","FALSE"
	EvacuationCapacityBalance	IfcBoolean	Indication whether the evacuation capacity is well distributed over the available exits (IBC (§1005.5)	"TRUE","FALSE"
	EvacuationPathTravelDistanceExcess	IfcBoolean	Indication whether the maximum allowed travel distance is exceeded (EvacuationPathTravelDistanceLimit)	"TRUE","FALSE"
	OccupancyNumberExcess	IfcBoolean	Indication whether the number of people exceeds the limit set by the IBC code (OccupancyNumberLimit)	"TRUE","FALSE"
	EvacuationPathTravelXYZ	IfcText	Coordinates of the vertices defining the curve line of the travel path	
	EvacuationComponentsPlacement	IfcBoolean	Indication whether the exits are placed correctly according to IBC code (§1007.1.1)	"TRUE","FALSE"
Pset_BuildingEvacuationPerformanceInformation	EvacuationTimeOverall	IfcTimeMeasure	Time from start of simulation until all people exit the building [seconds]	Single run > e.g., "60" Multiple runs > "avg = 41.53, min = 41.35,max = 41.7, std = 0.18"
	MinTravelDistance	IfcLengthMeasure	Minimum distance travelled by any person [meters]	Single run > e.g., "60" Multiple runs > "avg = 10.39, min = 8.69,max = 11.51, std = 1.49"
	MaxTravelDistance	IfcLengthMeasure	Maximum distance travelled by any person [meters]	Single run > e.g., "60" Multiple runs > "avg = 10.39, min = 8.69,max = 11.51, std = 1.49"
	AverageTravelDistance	IfcLengthMeasure	Average distance travelled by people [meters]	Single run > e.g., "60" Multiple runs > "avg = 10.39, min = 8.69,max = 11.51, std = 1.49"
	MinEvacuationTime	IfcTimeMeasure	Minimum evacuation time recorded for any person [seconds]	Single run > e.g., "60" Multiple runs > "avg = 25.07, min = 24.8,max = 25.37, std = 0.29"
	AverageEvacuationTime	IfcTimeMeasure	Average evacuation time recorded for people [seconds]	Single run > e.g., "60" Multiple runs > "avg = 25.07, min = 24.8,max = 25.37, std = 0.29"
	OccupancyHistoryOverall	IfcCountMeasure	Array representing the evolution of person count for the whole building over time, throughout the simulation (total remaining/ total exited vs time)	"time, remining,exited; time, remaining2,exited; "
Pset_BuildingCommon	OccupancyDistributionDayNight	IfcPropertyTableValue	Array describing the evolution of occupancy over the day by applying a multiplication factor at various times of the day.	"<HH, fraction>; <HH, fraction > … " e.g: Office building at full capacity between 8am and 5pm with reduced occupancy at lunch break "0,0; 8,0; 9,1; 12,0.5; 14,1; 17.5,0"
	OccupancyType	IfcLabel	Occupancy type for this building. It is defined according to the IBC code § 302.1	String value

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Property Set Name	Property Name	IFC Type	Description	Format
	EmergencyCommunication	IfcLabel	Indication whether the building equipped with an emergency communication system (true) or not (false).	"TRUE","FALSE"
	SprinklerProtection	IfcLabel	Indication whether the building is sprinkler protected (yes) or not (No).	"TRUE","FALSE"
Pset_ BuildingOccupancyRequirements	PreEvacuationTime	IfcTimeMeasure	Delay between the time evacuation is notified and the time people start moving [pers]	Discrete value > "30" Distribution: "Uniform(Min,Max) " "Normal(Min,Max,Mean, Std dev)" "LogNormal(Min,Max, Location, Scale)"
	OccupantProfilesList	IfcPropertyTableValue	A set of profiles describing the desired characteristics for people: speed, width …	{name; speed; speedProfile; diameter; isMobilityImpaired}{ … } e.g. "{name = Fruin2; speed = ; speedProfile = Normal(0.6,1.8, 1.2,0.2); diameter = 45.58; isMobilityImpaired = False}"
Pset_BuildingOccupancyPrescriptionsReview	OccupancyNumberBuilding	IfcCountMeasure	Actual overall number of people in the building	e.g., "100"
	StairCountContinuity	IfcBoolean	Indication whether the number of stairs used for evacuation is maintained at each storey (IBC (§1005.4)	"TRUE","FALSE"
	StairCapacityContinuity	IfcBoolean	Indication whether the capacity of the stair system used for evacuation is maintained at each storey (IBC (§1005.4)	"TRUE","FALSE"
	StairCapacityPerOccupant	IfcLengthMeasure	Required stair width per occupant unit [mm/pers]	e.g., "3.8"
	EvacuationCapacityPerOccupant	IfcLengthMeasure	Required exit width per occupant unit [mm/pers]	e.g., "3.8"
	OccupancyNumberLimitSingleExitSpace	IfcCountMeasure	Maximum allowed number of people in a space/room having a single exit IBC (§1006.2.1)	e.g., "50"
	EvacuationPathTravelDistanceLimitLowOccupancy	IfcLengthMeasure	Maximum allowed travel distance in a space/room having a single exit and less than 30 people (§1006.2.1)	e.g., "78000"
	EvacuationPathTravelDistanceLimitHighOccupancy	IfcLengthMeasure	Maximum allowed travel distance in a space/room having a single exit and more than 30 people - Or equipped with sprinkler protection (§1006.2.1)	e.g., "80000"
	EvacuationPathTravelDistanceLimit	IfcLengthMeasure	Maximum allowed distance to room/space to an exit [mm] (§1017.2)	e.g., "75000"
Pset_BuildingFireSafetyPrescriptionsReview	SprinklerProtectionRequirement	IfcBoolean	Indication whether a sprinkler system is required by the IBC code (§1017.2)	"TRUE","FALSE"
	SprinklerProtectionLacking	IfcBoolean	Indication whether a sprinkler system is required by the IBC code (§1017.2) but is not provided	"TRUE","FALSE"
Pset_DoorEvacuationPerformanceInformation	FirstOccupantInTime	IfcTimeMeasure	Time to first person crossing the component [seconds]	Single run > e.g., "60" Multiple runs > "avg = 41.53, min = 41.35,max = 41.7, std = 0.18"
	LastOccupantOutTime	IfcTimeMeasure	Time to last person crossing the component [seconds]	Single run > e.g., "60" Multiple runs > "avg = 41.53, min = 41.35,max = 41.7, std = 0.18"

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Property Set Name	Property Name	IFC Type	Description	Format
	AverageOccupantFlowrate	IfcReal	Average flow rate though component [pers/seconds]	Single run > e.g., "60" Multiple runs > "avg = 0.12, min = 0.12,max = 0.13, std = 0.01"
	TotalUse	IfcCountMeasure	Total number of people crossing the component	Single run > e.g., "10" Multiple runs > "avg = 10,min = 5, max = 15,std = 5"
	DoorFlowrateHistory	IfcCountMeasure	Array representing the evolution of flow rate through component over time, throughout the simulation	Single run > "time, value1; time, value2; " e.g., "0,0; 1,0; 2, 0; 3,0; 4,0; 5,0; " Multiple runs > "n.a."
	OccupancyHistory	IfcPropertyTableValue	Array representing the evolution of person count in a space/room over time, throughout the simulation	Single run simulation > "time, value1; time, value2; " e.g., "0,0; 1,0; 2,0; 3,3; 4,5; 5,8; 6,13; 7" Multiple runs > "n.a"
Pset_DoorCommon	isAccessible	IfcBoolean	Door state (open/closed)	e.g., "true"
	RequiredDoorFlowrate	IfcReal	Required flow rate through component [pers/sec]	e.g., "1"
	FireExit	IfcBoolean	Indication whether the component is a fire exit	"TRUE","FALSE"
	DischargeExit	IfcBoolean	Indication whether the component serves as a storey/building discharge exit	"TRUE","FALSE"
	DimensionAdequate	IfcBoolean	Indication whether the door has adequate dimensions according to IBC code (§1010.1.1)	"TRUE","FALSE"
Pset_StairEvacuationPerformanceInformation	FirstOccupantInTime	IfcTimeMeasure	Time to first person crossing the component [seconds]	Single run > e.g., "60" Multiple runs > "avg = 41.53, min = 41.35,max = 41.7, std = 0.18"
	LastOccupantOutTime	IfcTimeMeasure	Time to last person crossing the component [seconds]	Single run > e.g., "60" Multiple runs > "avg = 41.53, min = 41.35,max = 41.7, std = 0.18"
	AverageOccupantFlowrate	IfcReal	Average flow rate though component [pers/seconds]	Single run > e.g., "60" Multiple runs > "avg = 0.12, min = 0.12,max = 0.13, std = 0.01"
	OccupancyHistory	IfcPropertyTableValue	Array representing the evolution of person count in a space/room over time, throughout the simulation	Single run simulation > "time, value1; time, value2; " e.g., "0,0; 1,0; 2,0; 3,3; 4,5; " Multiple runs > "n.a"
Pset_StairCommon	AdmittedProfiles	IfcPropertyTableValue	List of person profiles that are allowed in a component	"occupantProfile1, occupantProfile5"
Pset_StairPrescriptionsReview	RiserHeightAdequate	IfcBoolean	Indication whether the stair has an adequate riser height (§ 1011.5.2)	"TRUE","FALSE"
	TreadLengthAdequate	IfcBoolean	Indication whether the stair has an adequate tread length (§ 1011.5.2)	"TRUE","FALSE"
	FireEvacuationStair	IfcLabel	Indication whether the stair can serve for fire evacuation	"TRUE","FALSE"
Pset_BuildingStoreyCommon	EntranceLevel	IfcLabel	Indication whether this building storey is an entrance level to the building (yes), or (no) if otherwise	"TRUE","FALSE"
Pset_BuildingStoreyOccupancyPrescriptionsReview	OccupancyNumberStorey	IfcCountMeasure	Actual overall number of people in the storey	e.g., "10"
	EvacuationCapacityStorey	IfcLengthMeasure	Actual combined width of exits serving a storey [mm]	e.g., "1600"

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Property Set Name	Property Name	IFC Type	Description	Format
	EvacuationCapacityRequirementStorey	IfcLengthMeasure	Exit width required by IBC code (§1005.3.2) for the storey [mm]	e.g., "1600"
	ExitCountStorey	IfcCountMeasure	Actual number of exits serving a space/room	e.g., "2"
	ExitCountRequirementStorey	IfcCountMeasure	Number of exits required by IBC code (§1006.3.2) for the storey	e.g., "2"
	EvacuationCapacityAdequateStorey	IfcBoolean	Indication whether the combined width of exits serving the storey is sufficient compared to the number of people	"TRUE","FALSE"
	ExitCountAdequateStorey	IfcBoolean	Indication whether the number of exits serving the storey is sufficient compared to the number of people	"TRUE","FALSE"
	EvacuationCapacityBalanceStorey	IfcBoolean	Indication whether the evacuation capacity is well distributed over the available exits (IBC (§1005.5)	"TRUE","FALSE"
	StairCount	IfcCountMeasure	Actual number of stairs serving the storey	e.g., "2"
	StairCapacity	IfcLengthMeasure	Actual combined width of stairs serving the storey	e.g., "1600"
	StairCountRequirement	IfcCountMeasure	Required number of stairs for the storey according to IBC code (§1006.3.2)	e.g., "2"
	StairCapacityRequirement	IfcLengthMeasure	Required stair capacity for the storey according to IBC code (§1011.2)	e.g., "1600"
	StairCountAdequate	IfcBoolean	Indication whether the number of stairs serving the storey is sufficient compared to the number of people	"TRUE","FALSE"
	StairCapacityAdequate	IfcBoolean	Indication whether the combined width of stairs serving the storey is sufficient compared to the number of people	"TRUE","FALSE"
	StairCapacityBalance	IfcBoolean	Indication whether the evacuation capacity is well distributed over the available stairs on the storey (IBC (§1005.5)	"TRUE","FALSE"

Appendix 2. Code Structure and Implementation

This appendix 2 presents the structure of the Evac4Bim code and its implementation.

Code Structure

The main entry point to the program is the **Evac4Bim.MainApp** class. This class sets up the User Interface in Revit and includes calls to different "standalone" commands. The standalone commands can execute several tasks such as reading files, defining new shared parameters, lookup and edit parameters, etc. Each command consists of a class inheriting the **IExternalCommand** interface and implementing the Execute method which is called by Revit after the user runs it. The main argument of the Execute command is an **ExternalCommandData** object which gives access to the current Revit document, the user interface and the project. An IFC exporter was forked from the open-source Revit IFC exporter. It generates enriched IFC files supporting the fire evacuation data requirements of the draft Model View Definition for FSE. The main entry point for IFC exporter is **Revit. IFC.Export.Exporter** namespace. In order to enable exporting additional property sets not supported natively by Revit, a delegate method is defined. The implementation of the derived class can be found under **Revit. IFC.Export.Exporter.CustomExporter.cs.**

Code implementation

The typical working sequence of the standalone commands is presented in Figure A2.1 When the user runs a command (by clicking the corresponding button in the user interface), its **Execute** member method is called. The command would query building elements from the model and then parse their properties via the **LookupParameter** method. It can then perform tasks and then, optionally, write results back into the model.

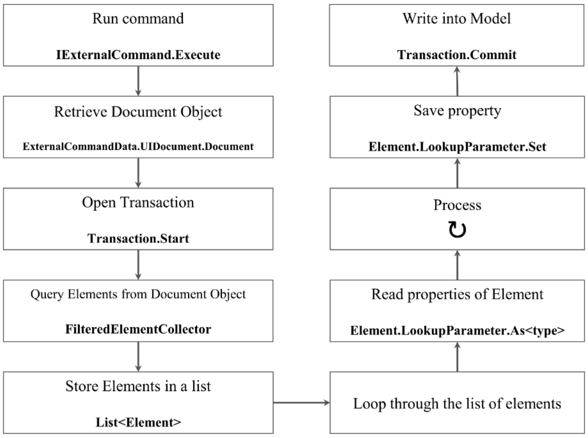

Fig. A2.1. Typical read-write sequence of an API command in Revit

The working sequence of the **ImportParameter** command is shown in Figure A2.2. This command is responsible for importing and storing Pathfinder simulation results into the Revit model.

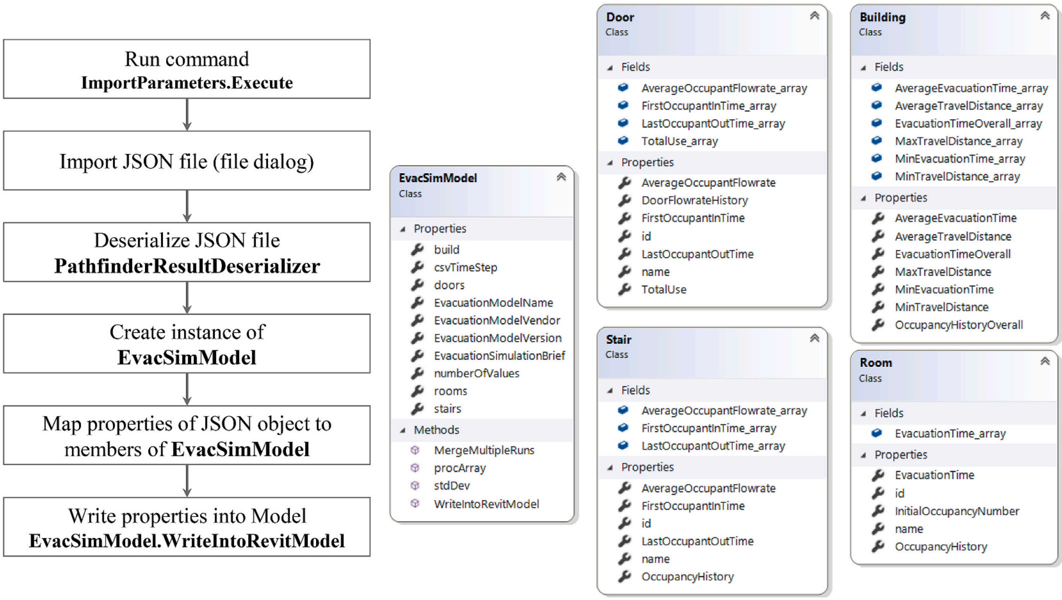

Fig. A2.2. Working sequence of the ImportParameter command from the Revit add-in.

Pathfinder is able to generate a JSON file, which stores simple data structures and objects in JavaScript Object Notation (JSON) format. This JSON file is imported, and its content is "deserialized" (i.e., the data is decoded into a native format. In this case, it is converted into a class with properties and fields). Next, the properties of the "deserialized" object are copied into an instance of **EvacSimModel.** The class **EvacSimModel** is a generic interface for storing egress simulation data. This class is meant to establish a level of abstraction so that it can store data from any evacuation simulator.

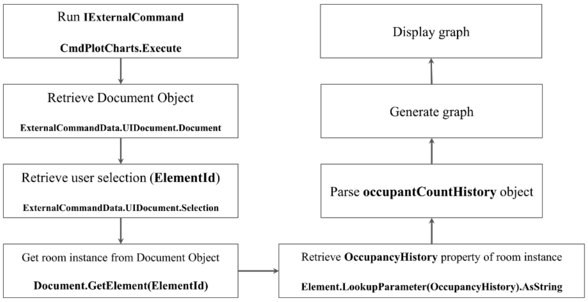

Fig. A2.3. Working sequence of the **CmdPlotChart** command form the Revit add-in.

The class diagram properties include lists of building elements such as rooms, stairs, and doors, which in turn store associated simulation results. Once simulation results are imported, it is possible to plot graphs of time-dependent values such as the number of people in a room over time. This is done by running the **CmdPlotChart** command. Figure A2.3 shows its working sequence.

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