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A BIM-Based conceptual fire safety management framework for building with integration of fire dynamic simulator

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ABSTRACT

Building fires often result in loss of property and life. Despite existing building fire safety designs, the increasing frequency of fire incidents highlights the need for improvements in fire safety management. This paper presents a conceptual framework for Building Information Modelling (BIM)-based fire safety management, integrating Fire Dynamics Simulator (FDS) for a three-storey building. The primary objectives are to develop a building BIM model with fire safety compliance checks, conduct a fire simulation using FDS to integrate the results into the BIM model, and test the feasibility of the framework. The framework's main components are modelling, analysis, data integration, and user education. The BIM model developed using Revit was assessed for fire safety compliance using Dynamo. FDS simulations were concurrently carried out for fire risk assessment in critical scenarios, followed by evacuation route planning. Fire safety results were then integrated into the BIM model. The framework illustrates an effective BIM-based fire safety management platform that incorporates FDS simulation, with fire safety information accessible to building occupants.

Keywords: Building information modelling, fire safety management, fire dynamics simulator

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1. INTRODUCTION

Fire safety in buildings is a significant concern in the construction industry. According to the Fire and Rescue Department of Malaysia (2024), 9352 building fire incidents occurred in 2023, resulting in an estimated loss of RM 2.61 billion. Given the growing threat of building fires, which resulted in considerable losses of life and property, prioritising the development of effective strategies for managing fire safety and risks has always been a key focus in building design (Mi et al., 2020).

However, the conventional fire safety approach is heavily focused on preventive fire protection of buildings, often lacking integration with the building design process. This approach, thus, has limited effectiveness in addressing the various factors that influence fire safety. While fires may not necessarily be caused by inadequate design of fire protection systems, other factors may play a role, such as insufficient law enforcement, faulty fire safety equipment, inadequate management, poor maintenance, and a lack of awareness about fire safety among construction parties and building occupants (Rahardjo and Prihanton, 2020). Kodur et al. (2020) highlighted that poor adherence to fire safety regulations and the lack of education among building users are the leading causes of the high building fire rates.

Fire safety management of buildings, which conventionally involves checking building design compliance with fire safety regulations, is typically performed manually. However, these methods are susceptible to risks of human error. As noted by Hsu et al. (2023), manual building inspections are susceptible to errors resulting from human factors such as observational skills and personal judgment. Thus, this called for a better Building Information Modelling (BIM) approach to ensure the fire safety of buildings. Effective fire safety management can swiftly and efficiently determine, prevent, and control fire hazards in buildings and construction sites (Yang et al., 2022; Zhang et al., 2024).

The application of BIM can enhance the effectiveness of fire safety management and reduce errors caused by human factors. Fire simulation has also been used in most studies on building fire safety (Sun and Turkan, 2020). Although realistic performance tests with real human subjects during a fire can significantly enhance the effectiveness of fire safety studies, conducting such tests on humans is considered unethical; therefore, fire simulation is primarily used.

BIM has been applied in numerous fire safety management studies to efficiently manage the fire safety of buildings. Escape plans in a BIM model, incorporating the location of fire safety equipment and keypoint-based symbol detection, were utilised in the research of Schönfelder et al. (2024). Ding et al. (2024) developed fire evacuation system simulations for large buildings by applying BIM. The building's geometrical information was provided by the BIM model, which was used as input for the computational algorithm. Li et al. (2020) utilised BIM to emulate a fire risk environment for indoor crowd evacuation, considering the effects of fire and changes in the evacuation path. Likewise, Sun and Turkan (2020) employed BIM to propose a fire safety management framework, simulating the escalation of fire and examining critical factors in fire evacuation. Mirahadi and McCabe (2021) utilised BIM to develop a model for managing real-time evacuation, with the aim of identifying building fire hazards and predicting building fire conditions during emergency evacuations.

Although extensive research has been conducted on the application of BIM and its integration with other simulation tools for enhanced fire safety management, most research focuses on the evacuation aspect of fire safety rather than adopting a more comprehensive approach. Sun and Turkan (2020) highlighted that the full potential of BIM utilisation for fire safety had not been reached owing to challenges such as data interoperability, research scope, and software technical limitations.

Fire Dynamics Simulator (FDS) is widely used in fire engineering to simulate the behaviour of heat, smoke, and toxic gas emissions in buildings. Since its inception in 2000, FDS has become one of the most widely used fire simulation tools (McGrattan et al., 2025). Developed by the National Institute of Standards and Technology (NIST), FDS is a computational fluid dynamics (CFD) model designed to simulate fire. It operates by solving a set of simplified Navier-Stokes equations, adapted for low-speed, thermally driven flows that characterise fire, with an emphasis on heat and smoke transport.

FDS divides the simulated environment into a three-dimensional rectangular grid and models the turbulent movement of smoke and heat. These equations, which are partial differential equations, describe the fluid-like movement of heat and smoke during a fire, enabling accurate modelling and simulation of complex fire conditions. Users define the geometry, material properties, fire source (typically represented via a heat release rate), and environmental conditions such as ventilation and ambient temperature. FDS then calculates the transport of heat, smoke, and gases through convection, radiation, and conduction, and predicts parameters such as temperature, velocity, smoke concentration, and toxic gas levels over time. The results are output as data files and visualised using Smokeview, allowing users to analyze fire behaviour, assess visibility and safety conditions, and support design or forensic investigations.

The earliest documented application of FDS was the simulation of fire dynamics in a two-story duplex during the 1999 Iowa Fire, detailed in a technical paper by Madrzykowski, et al. (2002). Early application of FDS includes academic validation of building fires, such as the validation of FDS version 3.01 against an ISO-9705 compartment fire test by Zou and Chow (2005). The use of FDS for performance-based design in commercial buildings was later explored by Zalok and Hadjisophocleous (2011). The FDS application also transitioned into a forensic investigation tool for building fires, as demonstrated by the reconstruction of a high-casualty fire in an inn using FDS by Chi (2013). Lin et al. (2012) used FDS simulation to investigate the “Cardon basement fire” that occurred in Taipei (1993).

More advanced applications of FDS include testing the effectiveness of firefighting tactics for wind-driven high-rise fires (Panindre et al., 2017) and fire simulations involving specific building materials, such as the analysis of fire spread behaviour in wooden structures under varying fire conditions by Zhao et al. (2023). Recent applications of FDS include fire incident reconstruction using FDS in a traditional wooden building in Chiayi, Taiwan, for accident verification (Lai et al., 2024) and exploration of the fire hazard zone of a 40-foot energy storage system by Huang and Chi (2024).

This study thus proposes a BIM-based conceptual fire safety framework that integrates FDS to enhance fire safety management. This framework encompasses multiple aspects of fire safety in a building, including BIM modelling, compliance with fire safety requirements, fire simulation, evacuation planning, and user education. A typical three-storey office building model in Malaysia was used to test the conceptual framework, with detailed elaboration provided in subsequent sections of this paper. This study offers insights into fire safety management that are beneficial to the construction industry.

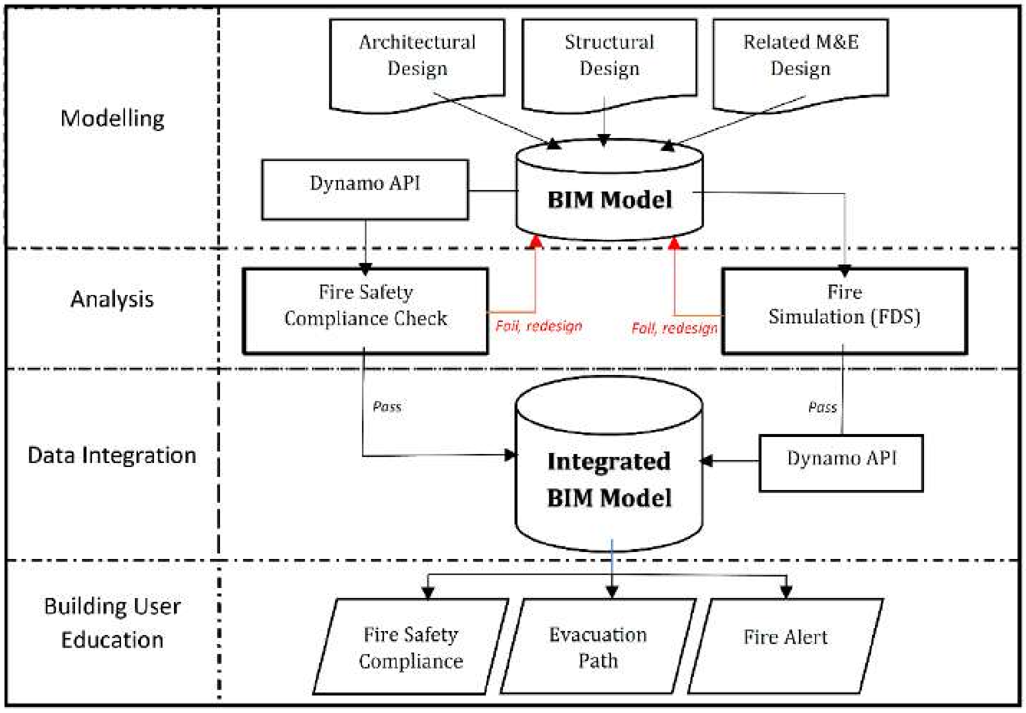

Fig. 1. BIM-based Conceptual Fire Safety Management Framework for a building

2. METHODOLOGY (FRAMEWORK)

2.1 Fire Safety Framework

This conceptual fire safety framework is an extension of the fire risk management framework (Leong et al., 2025). It consists of four key components to manage building fire risks and ensure fire safety in buildings: Modelling, Analysis, Data Integration, and User Education, as illustrated in Fig. 1.

Initially, a BIM model is created in Revit based on available design drawings and information in the 'Modelling' component. Building design compliance with fire safety regulations is subsequently assessed using the Dynamo Application Programming Interface (API) on the BIM model during the 'Fire Safety Compliance Check' process. Concurrently, the BIM model was exported to FDS for fire simulation and fire analysis in the 'Fire Simulation' process. Both processes fall under the 'Analysis' component of the framework. The results from the 'Fire Safety Compliance Check' and 'Fire Simulation' processes are integrated back into the BIM model via the Dynamo API in the 'Data Integration' component. The updated BIM model, now incorporated with fire safety information, is utilised to assess fire safety compliance levels, plan evacuation routes, and provide emergency alerts to building occupants in the event of a fire. Each component will be discussed in detail in Sections 2.2 through 2.5.

2.2 Modelling

An accurate BIM model is generated using Revit, based on architectural, structural, and mechanical and electrical (M&E) designs in the 'Modelling' component. However, only the basic geometric layout and building component information are required to be modelled for building requirement checks and export to FDS software, as shown in Fig. 2.

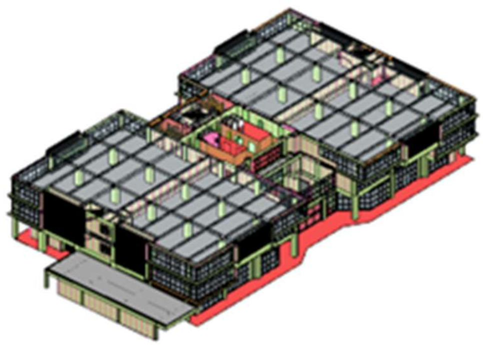

Fig. 2. BIM model of the building

2.3. Analysis

In the 'Analysis' component of the framework, there are two processes: 'Fire Safety Compliance Check' and 'Fire Simulation'. The 'Fire Safety Compliance Check' verifies the compliance of building designs with fire safety requirements, while the 'Fire Simulation' performs fire simulations and analysis.

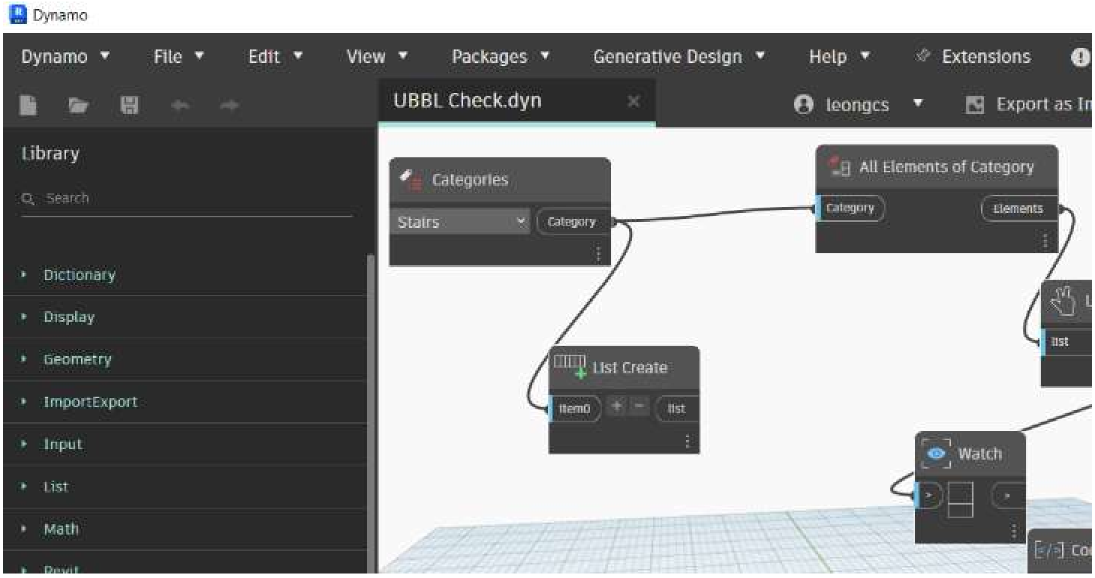

Fig. 3. Dynamo API used for Compliance Check

2.3.1 Fire Safety Compliance Check

Conventionally, building inspections for compliance with regulatory and safety requirements are conducted only after construction is completed. This approach could be problematic, as detecting non-compliance late in the process may result in costly construction changes and delays in obtaining the Certificate of Fitness. In contrast, the proposed framework enables the early detection of regulatory compliance within the BIM model through the application of Dynamo API, an advanced graphical programming interface plugin for Revit that enhances its capabilities beyond standard functions, as shown in Fig. 3.

Dynamo analyses the fire safety compliance of the BIM model based on script inputs that specify the required conditions, issuing warnings when non-compliance is detected. Non-compliance warnings are crucial for designers to identify design mistakes or overlooked requirements, thereby preventing human errors that are costly to address during the post-construction period. At the design stage of a building, these warnings also help guide design decisions to ensure fire safety compliance.

2.3.2 Fire Simulation

FDS is used in the 'Fire Simulation' process to simulate building fires through Computational Fluid Dynamics (CFD). As FDS does not have a Graphical User Interface (GUI), Pyrosim, a GUI interface for FDS, is employed to facilitate FDS simulations. Zhang et al. (2024) utilised Pyrosim to efficiently model and simulate fire dynamics for buildings in their research. The geometrical and material information from the BIM model is exported to Pyrosim in the International Foundation Class format for FDS analysis. As a result, FDS simulation generates time-series data, such as changes in visibility level, gas species concentrations, and room temperature over time. These time-series data are essential for evaluating the tenability of a building for occupants during a fire event and help determine the available time for evacuation. A safe evacuation of occupants depends on having enough time (available safe egress time) before the fire reaches a critical state, at which point evacuation becomes impossible. The available time for evacuation must be greater than the required evacuation time (required safe egress time) before building conditions reach hazardous levels (Qin et al., 2020). According to the Society of Fire Protection Engineering (SFPE), the recommended temperature threshold for safe evacuation in FDS modelling is 60°C (Morgan, 2016). Additionally, the smoke produced by fire reduces occupant visibility, which slows evacuation and complicates escape (Li et al., 2020). SFPE recommends maintaining visibility of at least 2 meters for safe evacuation (Morgan, 2016). SFPE also specified the toxicity threshold for gaseous by-products, particularly carbon monoxide (CO), to be established at a concentration of 1400 ppm or 1.4 kg/m^3 (Morgan, 2016). Therefore, the safe evacuation thresholds are visibility of at least 2 meters, room temperature below 60°C, and CO concentration below 1400 ppm.

2.4 Data Integration

The 'Data Integration' stage is where the important part of the 'Analysis' Stage results obtained from both the 'Fire Safety Compliance Check' and 'Fire Simulation' processes are imported back into the BIM model. A BIM model must contain sufficient information about a building or its construction for the BIM management process to function effectively. In this context, fire safety management of a building can be carried out more effectively when all fire

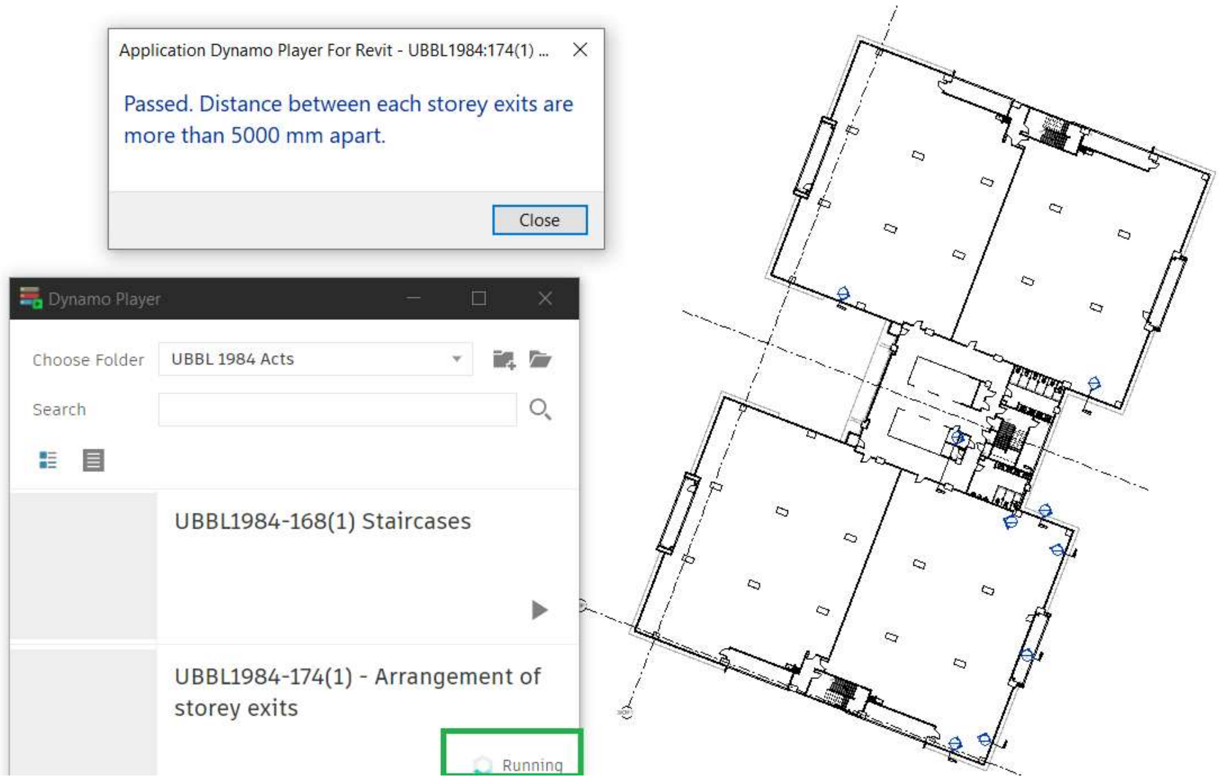

Fig. 4. Results for UBBL1984: Act171(1) requirement

safety data is consolidated within the BIM model, allowing for further planning and decision making directly within the model itself. Integration between Revit and other software, such as Pyrosim, can be highly challenging; however, in this proposed framework, part of the fire simulation results can be imported into the BIM model with the aid of Dynamo. The necessary information for the next framework component can be directly extracted from the BIM model.

2.5 User Education

Information regarding evacuation routes, fire safety compliance, and fire alerts is crucial for building occupants to ensure their safety during a fire. The available time for evacuation can be obtained from the BIM model, which is now integrated with the results of the FDS analysis. As for evacuation route planning, the optimal path is the path that is both the safest and shortest. Revit's 'Path of Travel' function in the BIM model accurately identifies the shortest travel distance required while avoiding all potential obstructions. This function navigates around obstacles, such as furniture or other building components, to ensure the optimal evacuation route is calculated. The distance for the evacuation travel path can be extracted from the Revit schedule and used to estimate the required time for evacuation (egress). The BIM model now includes information on evacuation routes as part of the building's fire safety design and management, and it can yield the required safe egress time.

For fire alerts, the BIM model serves as input for microcontrollers, such as Raspberry Pi and Arduino, which send emergency alerts to registered occupants' smartphones. The programmable microcontroller Arduino is user-friendly and has been successfully applied in the BIM-based research by Habib et al. (2019). Furthermore, fire safety information, such as evacuation routes and building regulatory compliance, can be shared through floor plans on widely accessible cloud platforms like Dropbox or Google Drive. Oh (2024) highlighted the importance of these cloud drives for sharing construction files and effectively managing them to enhance collaboration within the construction industry. Hence, the proposed framework in this study can deliver fire safety information on building floor plans, provide evacuation route plans and visualise fire simulation outcomes.

3. RESULTS AND DISCUSSION

The conceptual framework was tested using a 3-storey building, 12.8 m in height, modelled in Revit with a Level of Detail (LOD) of 300. Similar research on fire safety also uses a BIM model with an LOD of 300 to export the building geometry to other software for analysis (Sun and Turqan, 2020; Wehbe and Shahrour, 2021). The details of the tests are discussed in the following sections.

3.1 Compliance Check

The compliance check functionality was tested using the building model with Uniform Building By-law 1984: Act

168(1) and Act 174(1) requirements (Legal Research Board, 2015). UBBL 1984: Act 168(1) mandates that all upper floors of a building must have a minimum of two escape staircases, ensuring that if one staircase becomes unusable, the other can serve as the alternative escape staircase. The design model's compliance with this requirement was verified using Dynamo scripts, and notifications were generated showing that three staircases were detected, thus fulfilling the requirement of Act 168(1). For UBBL 1984: Act 174(1), which stipulates that "Every compartment shall be provided with at least two storey exits located as far as practical from each other and shall not be less than 5 meters apart measured between the nearest edges of the opening", compliance was also verified using Dynamo scripts. The task of calculating the distance between each storey exit, which is typically a laborious task for manual inspection, was efficiently automated using the compliance checker as shown in Fig. 4. Compliance with other requirements may similarly be achieved through the deployment of customised Dynamo scripts.

3.2 Fire Simulation

Pyrosim imports the 3D geometrical data of the building BIM model for FDS analysis as shown in Fig. 5. Fire simulation parameters were then set in Pyrosim, such as analysis meshing, vent boundaries, and fire with heat release rate (HRR) of 500 kW/m², which aligns with the UK standard BS 7974-1:2019 (Wilkinson, 2019), specifying that HRR for office buildings ranges from 150-650 kW/m². The duration of the fire simulation was set to 20 min to observe changes in tenability conditions within the building. Upon completion, the simulation yields the results required to assess the tenability threshold of the building. These results included critical conditions under which building occupants can safely evacuate, such as the room temperature, visibility, and the concentration of toxic gases over time, specifically carbon monoxide (CO). Previous research on fire simulation also uses these three parameters to decide the critical conditions under which building occupants can evacuate safely (Sun and Turqan, 2020; Wehbe and Shahrour, 2021; Sabbaghzadeh et al., 2022).

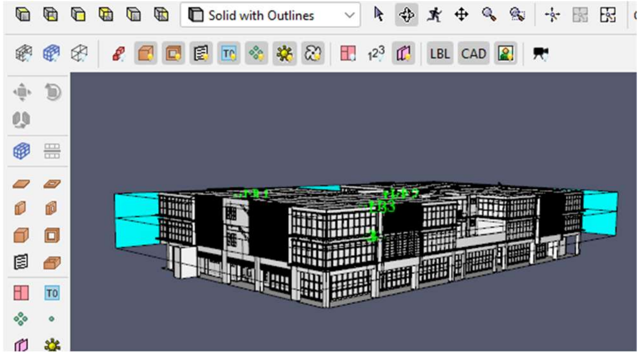

Fig. 5. BIM model exported to Pyrosim

These time-series results, as shown in Fig. 6(a) – Fig. 6(c), are essential for determining the available time for evacuation before building conditions become too hazardous for occupants to escape. According to SFPE (Morgan, 2016), as mentioned in the methodology, tenable conditions are defined as a temperature below 60°C, a CO concentration below 1400 ppm, and a visibility of at least 3 meters. Based on the fire simulation, the visibility threshold was breached approximately 331 s into the fire at the fire source floor level, as shown in Fig. 6(b). Thus, it is determined that the available evacuation time for the test building model is 331 s.

In Pyrosim, the fire and smoke spreading simulation can also be visualised using the built-in software: Smokeview, as shown in Fig. 7. This 3D visualisation, although not incorporated into the BIM model, can be saved in movie file format and used by designers to understand the most likely scenario of how the fire will occur, which may help inform the design process.

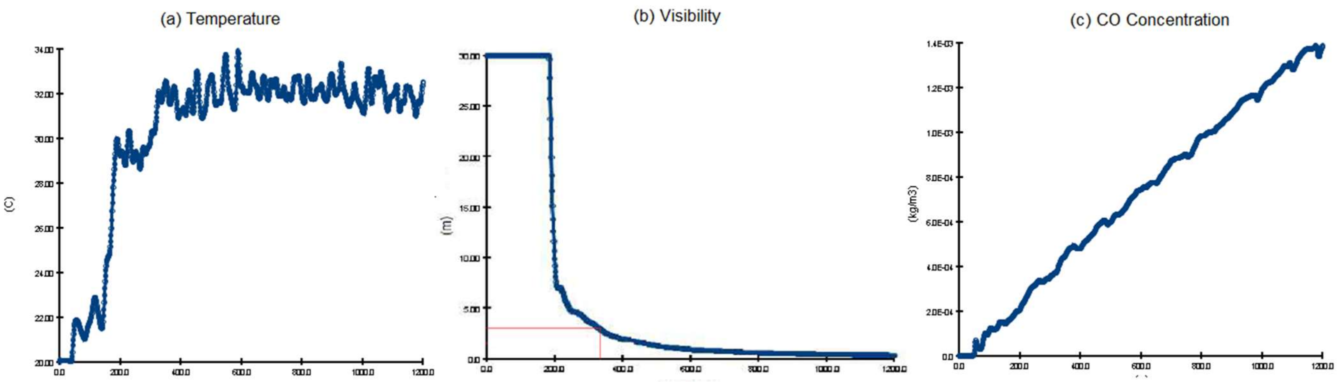

Fig. 6. Results for (a) Temperature (left). (b) Visibility (mid). (c) CO Concentration (right)

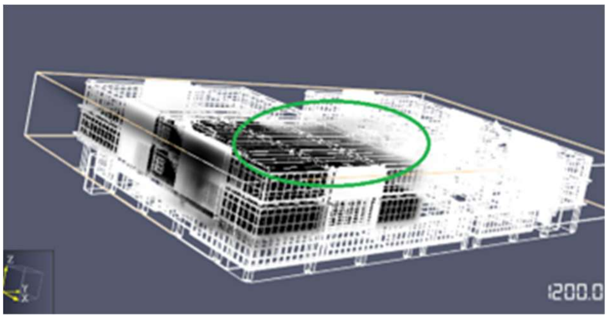

Fig. 7. Visualisation of smoke propagation in Smokeview

3.3 Evacuation Path / Evacuation Route Planning

Using Revit's 'Path of Travel' function, two evacuation route examples (A and B) were created on the 1st floor of the building's left wing in the BIM model, as shown in Fig. 8.

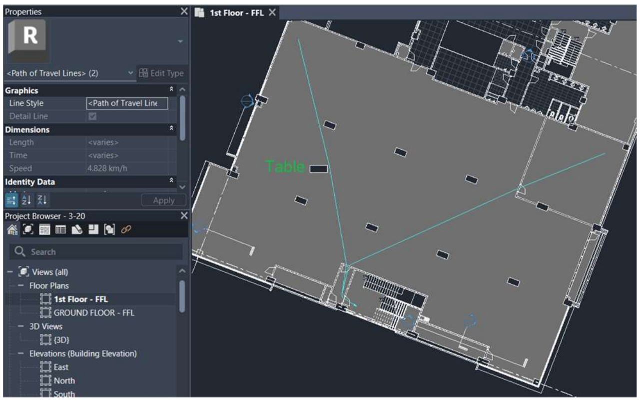

Fig. 8. Path of Travel

The paths were configured to extend from the furthest corners of the left wing to the nearest staircase exit. For testing purposes, a table was intentionally placed along the evacuation path A, which leads to the staircase. The evacuation route was successfully reconfigured to an alternate shortest path as analysed by 'Path of Travel' while avoiding the furniture obstacle. The travel distance data was then generated in the Revit Schedule, as shown in Fig. 9.

Path of Travel Schedule

<Path of Travel Schedule>

A	B	C	D	E
Mark	Length	Level	Speed	Time
A	29579	1st Floor - FFL	4.8 km/h	22.1 s
B	34653	1st Floor - FFL	4.8 km/h	25.8 s

Fig. 9. Path of Travel schedule

The time required to reach the staircase exit was calculated using the 'Path of Travel' function. Based on the length of the generated path, the time required to reach the staircase was calculated to be less than 30 s. Given that this floor level's available safe egress time is 331 s (approximately 5.5 min), it was concluded that safe evacuation of occupants in the event of a fire is possible, as the available safe egress time exceeds the required safe egress time.

3.4 Contribution of Study

The proposed conceptual BIM-based framework enables comprehensive building fire safety management through the integration of FDS, positioning BIM as the central platform for all fire safety management activities and analysis. Unlike previous research, which mainly focused on the evacuation aspect, the framework covers various aspects of fire safety for buildings. BIM enables the integration of multidisciplinary data, as demonstrated in the modelling component where architectural, structural, mechanical, electrical, and plumbing information (under M&E) is consolidated into a single model. This integration facilitates coordinated building design alongside fire safety planning. In contrast to conventional practices, where fire safety information is scattered across different drawings, reports, or manuals, BIM integrates all information within a single model, enhancing accessibility and enabling a holistic approach to fire safety design and management.

The BIM model is checked for design compliance with fire safety regulations using Dynamo API in Revit, and a warning is generated if non-compliance is detected. Dynamo scripts are written to perform the required fire safety regulation check in compliance with the local fire authority requirements. Early detection of regulatory non-compliance in the early stages of building design is significant as it will save costs on construction reworks, as highlighted in Section 2.3.1. Early detection of non-compliance also helps reduce delays caused by rework. While the 'Fire Safety Design Compliance Check' may function independently of the 'Fire Simulation', as part of the BIM-based fire safety framework, the compliance check helps identify non-conforming fire safety designs at the early stage of design, thereby reducing the overall fire risk associated with the building design.

In the 'Fire Simulation' process, this framework integrates the FDS analysis result back into the BIM model. Previous research that similarly uses FDS for fire simulation has never done this. Sun and Turqan (2020) highlighted that the FDS analysis data cannot be integrated back into the BIM model due to technical limitations of data interoperability between software. While FDS can be performed independently, integrating its simulation results, such as heat increase, smoke movement and toxic gas emissions over time, information into a BIM model provides the building designer with a comprehensive overview of fire safety information, supporting optimal fire safety planning. This integration also facilitates the calculation of available evacuation time, which can then be incorporated into the building's fire safety design. The Hackitt report, which addresses the failures and poor practices in the UK construction industry following the tragic Grenfell Tower fire incident, recommends that all building information, including fire safety data, should be recorded and preserved throughout the building's entire lifecycle - an approach that can be achieved using BIM (Hackitt, 2018). Siddiqui et al. (2021) also further highlighted that one of the challenges to the flow of information between fire engineering and BIM is that fire simulation results are not explicitly captured within BIM model files. They emphasised that a two-way data exchange between BIM and fire safety engineering is essential for preserving comprehensive building life cycle information – referred to as the "golden thread of information" in the Hackitt report.

Davidson and Gales (2021) noted the need for fire simulation tools to be fully interoperable with BIM platforms, as external integration processes involve time-consuming steps and thus are prone to error. They further emphasised that for BIM to realise its full potential in fire safety, interoperability between BIM and fire simulation software is essential. Dynamo API was used in this research to overcome the technical limitation of bridging the data interoperability between BIM and FDS by integrating the FDS results back into the BIM model. The inclusion of fire safety results into the BIM model with the help of Dynamo API in this current study will enable the BIM model to be more comprehensive with fire safety information of building design and ease the retrieval of fire safety information for fire safety management by building facility managers and sharing safety information to building occupants to aid in evacuation planning.

Thus, this study demonstrates the importance of a comprehensive BIM-based fire safety management framework with integration of FDS. As Boying et al. (2024) highlight, BIM utilisation is essential for the early identification of fire risk in building design, as opposed to conventional prescriptive fire safety design. Fire safety does not end at the design stage; integrated BIM models are also useful for fire safety management by building facility managers throughout the entire life cycle of a building. This is particularly effective when the BIM model is enriched with accessible fire safety information, all of which is consolidated within a single, integrated model. The proposed fire safety framework transforms passive building documentation into an intelligent and actionable system that supports fire safety across the building's lifecycle by integrating all relevant fire safety information into a holistic BIM model.

As shown in Fig. 10, the time when the visibility threshold is exceeded can be easily retrieved from the FDS results integrated into the BIM model's Revit schedule, matching the results obtained from the manual interpretation of the FDS time-series graph results in Fig. 6(b).

Thus, this study demonstrates the importance of a comprehensive BIM-based fire safety management framework with integration of FDS. As Boying et al. (2024) highlight, BIM utilisation is essential for the early identification of fire risk in building design, as opposed to conventional prescriptive fire safety design. Fire safety does not end at the design stage; integrated BIM models are also useful for fire safety management by building facility managers throughout the entire life cycle of a building. This is particularly effective when the BIM model is enriched with accessible fire safety information, all of which is consolidated within a single, integrated model. The proposed fire safety framework transforms passive building documentation into an intelligent and actionable system that supports fire safety across the building's lifecycle by integrating all relevant fire safety information into a holistic BIM model.

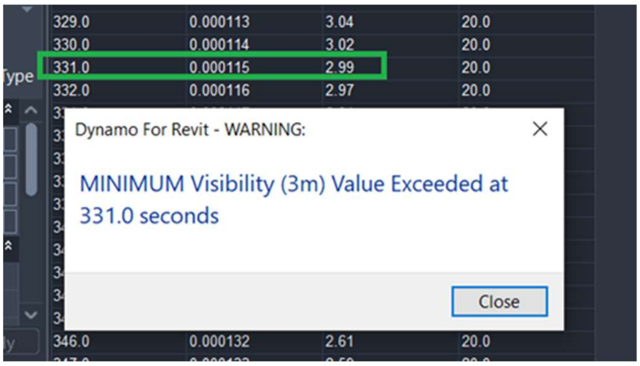

Fig. 10. Time for minimum visibility reached, as retrieved from the BIM model

3.5 Generalisability of Framework

Fire breakout differs according to building types and various circumstances. As such, the solution for fire safety management in a building should be equally flexible and dynamic. The proposed conceptual framework consists of four components, each of which can be customised to suit the building under study.

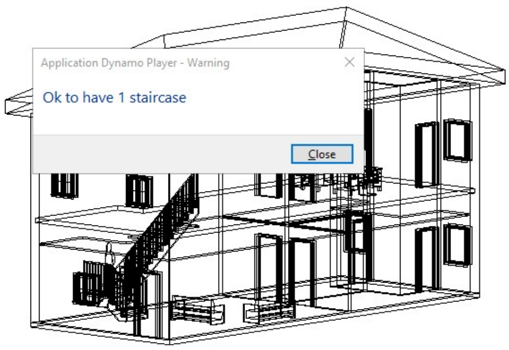

Fig. 11. 'Compliance Check' for a double-storey house

For 'Compliance Check' under the Analysis component, the different fire safety requirements for building design can be customised by altering the Dynamo script, allowing for the check on all types of fire safety requirements compliance. The 'Compliance Check' was successfully tested on a double-storey house to assess compliance with the Uniform Building By-law 1984: Act 194 (Legal Research Board, 2015), which stipulates that a single staircase is allowed for buildings with the topmost floor not exceeding 12 m in height. The 'Compliance Check' result is shown in Fig. 11.

For 'Fire simulation' under the 'Analysis' component, the fire parameters, such as HRR of fire simulation in FDS, can be adjusted to suit the fire intensity or fire load based on the building type and function. The HRR of 500 kW/m² for the 3-storey building is adjusted to a smaller value of 150 kW/m2 based on the same standard, BS 7974-1:2019 (Wilkinson, 2019) for the FDS analysis of the double-storey. building shown in Fig. 11, and the visibility threshold of 3 m is exceeded at 600 s as shown in Fig. 12 due to the smaller HRR value.

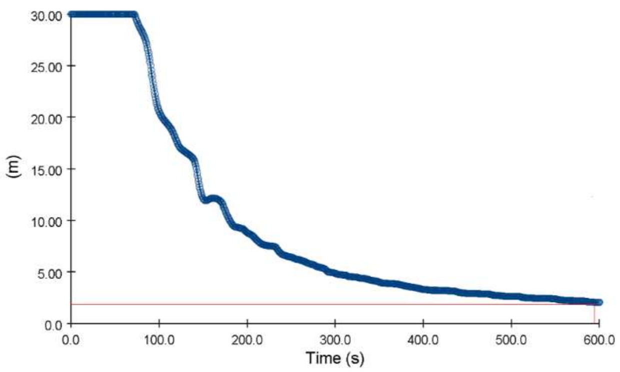

Fig. 12. Visibility value during fire for the double-storey house

These examples demonstrate part of the framework's adaptability to different types of building fires and fire safety standards. Similarly, the function 'Path of travel' in the 'Evacuation Path' process, which uses the Simulex engine, will adjust automatically based on the shortest route while navigating around obstacles or manually set routes depending on the building design being studied.

4. CONCLUSION

The feasibility test of the BIM-based fire safety management conceptual framework for buildings with integration of FDS, was successfully demonstrated. The conceptual framework consists of four main components: Modelling, Analysis, Integration, and User Education. Revit was used to create the BIM model for the test building, which served as the core for all the framework's components. In the 'Analysis' component – 'Compliance Check', building design compliance with fire safety requirements was assessed through the BIM model using Dynamo API. The 'Analysis' component – 'Fire Simulation'-simulated a fire scenario based on the imported BIM model, providing results on fire behaviour and the available safe egress time before the building became untenable for occupants. These outputs were subsequently utilised in the evacuation planning component, which identified the optimal evacuation path based on available time and the shortest route using the 'Path of Travel' function of Revit. Sharing these results contributed to the 'User Education' component, which informs and educates users on fire safety. The framework testing yielded positive results, demonstrating a successful BIM-based fire safety management framework integrated with FDS that comprehensively manages a building's fire safety. Future research could explore additional aspects of fire risk management, such as incorporating various types of fire sources, unique building types, software inter-compatibilities for fire analysis, and alternative ways to raise fire safety awareness among building users in Malaysia.

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.

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