The Integration of Building Information Modeling with Fire Protection Systems, Software, and Workflows

SFPE Foundation®

March 2024

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March 2024

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About the SFPE Foundation

The Society of Fire Protection Engineers (SFPE) established the SFPE Educational and Scientific Foundation in 1979. The Foundation is a charitable 501c(3) organization incorporated in the state of Massachusetts in the United States of America. It supports a variety of research and educational programs in service of its mission to enhance the scientific understanding of fire and its interaction with the social, natural, and built environments.

Acknowledgments

Executive Summary

Fire causes 5% of injury-related deaths worldwide, while fires in structures and buildings constitute a significant portion of fire accidents. In the US between 2009-2013, there was an average of 14,500 structure fires per year in high-rise buildings causing many casualties and $154 million in loss of property per year [1].

It is for this reason that fire protection engineering design is so vital and important: the ultimate in mission-critical design. As fire protection design technology progresses, so should the software tools that target it. Indeed, many of the design software tools that exist today are quite impressive in their power and feature-set. However, the embrace of this technology by fire engineering[1] (FE) stakeholders is still in its infancy relative to other engineering disciplines such as mechanical, electrical, and plumbing design.

The objectives of this SFPE Foundation research project were to:

- Investigate existing software tools and schemas, and the integration of these schemas into building information modeling (BIM) to fire engineering workflows.

- Interview various stakeholders, including fire engineers, members of the SFPE Foundation, building owners, and BIM and analysis software vendors.

- After careful analysis, select the best tools and workflows and incorporate them into a final user report.

This research project focuses on three overriding themes in relation to fire protection engineering: software tools, data, and interoperability.

Software Tools

There are two categories of software tools for fire engineers:

- BIM authoring tools like Autodesk Revit.

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[1] We use the term "fire engineering" (FE) throughout to refer to both fire protection engineering and fire safety engineering.

- Engineering analysis tools, which can be further classified into several types including:

  o Engineering calculation tools to size equipment, e.g., SprinkCAD.

  o Dynamic simulation tools to actively simulate performance, e.g., PyroSim and Pathfinder.

BIM authoring tools allow architects and engineers to create 3D models of buildings. As it relates to fire engineering, BIM can be used to enhance fire engineering design by providing a more comprehensive view of the building and its systems. BIM can include information about the location of fire protection equipment, such as sprinklers, alarms, and extinguishers, as well as data about the building's layout, materials, and construction.

Fire engineering analysis software is specifically designed for analyzing and simulating fire protection and safety systems within buildings. It helps fire engineers and professionals design, assess, and optimize fire detection, suppression, and evacuation systems to ensure the safety of occupants in case of a fire and/or smoke event.

Data

Data plays an important role in fire engineering, helping to design effective fire prevention and suppression systems, assess fire risks, and ensure the safety of buildings and occupants. Data is used as follows:

- Computational tools use data to model fire behavior.

- Data from real-world fire tests and experiments are essential for understanding how materials and structures respond to fire.

- Fire engineers must adhere to building codes and standards that are based on data-driven research and testing.

In our interviews with FE stakeholders, we asked about their FE-related data needs and challenges they encountered. Data in this research project can be broken down into these categories:

- Building codes

- Construction material information

- BIM objects and families

Integration (Interoperability)

Interoperability allows for the sharing of data between different software tools developed by different vendors. Interoperability is essential for BIM to realize its potential as a transforming technology versus 3D CAD tools that are limited in their use as holistic building design tools. For example, interoperability enables integration between BIM authoring and stand-alone FE software analysis tools since FE software tools utilize much of the information stored in the BIM.

Conclusions

We arrive at several conclusions regarding the above three themes:

- **Software:** We suggest improvements to BIM authoring tools by vendors such as Autodesk. In addition, we suggest that simulation tools take advantage of application programming interfaces (APIs) provided by these larger software vendors.

- **Data:** We provide suggestions to equipment manufacturers to design more usable Revit families and to FEs to better utilize these families.

- **Interoperability:** We suggest updates to the IFC schema and recommend using add-ins such as Evac4BIM.

Finally, we discuss a bit about the future of FE software including AI and Digital Twin technology.

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Table of Abbreviations

Acronym	Term
AEC	Architecture, Engineering, and Construction
AI	Artificial Intelligence
AIA	American Institute of Architects
API	Application Program Interface
APS	Autodesk Platform Services
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BIM	Building Information Model/Modeling
BOCA	Building Officials Code Administrators International
BOCA/NBC	BOCA National Building Code
CAD	Computer-Aided Design
CFD	Computational Fluid Dynamics
CIBSE	Chartered Institution of Building Services Engineers
DT	Digital Twin
FDS	Fire Dynamics Simulator
FE	Fire Engineering
gbXML	Green Building XML
HVAC	Heating, Ventilation, and Air Conditioning
IBC	International Building Code
ICBO	International Conference of Building Officials
ICC	International Code Council
IDM	Information Delivery Manual
IDS	Information Delivery Specification
IFC	Industry Foundation Classes
IoT	Internet of Things
LOD	Level of Detail
MEP	Mechanical, Electrical, and Plumbing
NFPA	National Fire Protection Association
NIST	National Institute of Standards and Technology
OMA	Occupant Movement Analysis
RFP	Request For Proposals
SBC	Standard Building Code
SBCII	Southern Building Code Congress International
SFPE	Society of Fire Protection Engineers
UBC	Uniform Building Code

1. Introduction

1.1 Background

The *Fire Engineering Practitioner Tools: Survey and Analysis of Needs* [2] report highlights many gaps with respect to the knowledgebase of building information modeling (BIM) and fire engineering applications. Most recently, this report found that "there is a sizeable gap in the use of advanced building information models by the general design/engineering sectors in buildings compared with those used by fire engineers," and that we are "not able to easily share data between tools."

To address some of these gaps, the SFPE Foundation requested proposals for a research project that investigates the current usage of BIM in the practice of fire engineering workflows, and the gaps related to BIM integration in the fire engineering sector. A requirement of the RFP included research into how BIM transcends all aspects of fire engineering, including fire models, human behavior, fire protection systems, structural fire engineering, and risk assessment, among other areas, and demonstrate how addressing specific issues related to BIM integration would benefit fire engineers. The RFP also requested a conclusion into laying out a strategy for the profession as it relates to BIM integration, including priority areas for tool development, recommending data exchange protocols and formats, research, training, certification, or related needs.

BIM software has evolved over several decades, transforming the architecture, engineering, and construction industries. While computer-aided design (CAD) took off in the 1980s with the advent of AutoCAD, it wasn't until the 2000s that BIM really emerged. Autodesk's Revit, released in 2000, was a paradigm shift, offering parametric 3D modeling and data-rich information integration [3].

In the field of fire engineering, BIM integration has emerged as a way for fire engineers (FEs) to design and implement fire safety measures in buildings. As buildings and infrastructure become more complex and the demand for efficient fire safety solutions grows, the synergy between BIM and fire engineering software becomes more important. The integration of BIM in fire engineering enables comprehensive 3D modeling of building elements and systems to design

robust fire protection systems and serve as a data repository for software tools that identify potential fire hazards, simulate fire scenarios, and optimize evacuation plans. This research project aimed to explore the opportunities and challenges associated with the seamless integration of BIM technologies within the realm of fire engineering workflows. Furthermore, the research project delved into the issues and bottlenecks that may impede the seamless integration of BIM technology, addressing issues of interoperability, software integration, and data.

This research project set out to develop a deeper understanding of the potential benefits of BIM integration in fire engineering, as well as practical strategies for overcoming obstacles to its implementation. As the fire engineering community pushes the boundaries of technology and innovation, this project represents a crucial step towards enhancing the safety and resilience of our built environment.

1.2 Project Impact

Software governs all aspects of our lives both at home and at work, including the buildings that we encounter. Software specific to building design has greatly improved over the past two decades. For example, it allows engineers to design safe and sustainable buildings more accurately by using technology that predicts yearly energy usage and calculates peak cooling and heating loads. For FE design, a wide range of software exists. However, according to the *Fire Engineering Practitioner Tools: Survey and Analysis of Needs* report [2], there is a disconnect between many of the software tools. This project builds upon the progress made so far and proposes ways to make the BIM-to-FE analysis workflow more seamless and more accessible to fire protection professionals. This project also includes research on how digital twin (DT) technology could be applied to FE analysis. DT technology could revolutionize FE analysis by allowing professionals to model and even view events in a building in real-time.

This research project will benefit fire engineers by allowing them to more accurately and more easily model fire protection systems and human behavior in buildings. However, its impact goes beyond fire engineering. It will also benefit BIM and building analysis software providers by providing roadmaps to enhanced modeling and data exchange capabilities that allow software

tools to pass building data to and from FE analysis tools. Finally, it will benefit building owners by providing them with a more accurate building model for purposes of budgeting, implementing fire safety measures, and much more.

2. Methodology

2.1 Tasks Overview

The scope of work as proposed by Carmel Software in response to the RFP included the following tasks:

- **Task 1:** *Review the current state of BIM and fire protection analysis software design tools and schemas.* This task called for an assessment of existing BIM and fire protection analysis software tools and modeling schemas. Our approach to performing this task was to identify all relevant tools and schemas with some track record of industry adoption associated not just with fire protection design, but with fire evacuation modeling, building code compliance, and more. Based on an initial survey of all these existing software tools and schemas, a subset was identified for deeper inquiry. This task also included speaking with and interviewing various stakeholder groups about the research. We talked with 41 stakeholders including fire protection engineers, business owners, software developers and product managers, and university researchers.

- **Task 2:** *Identify the enhancements needed within both BIM, interoperability data schemas, and FE software tools to facilitate better use of these workflows.* The objective of Task 2 involved identifying enhancements needed to BIM authoring, interoperability schemas, and FE software tools to help facilitate a more seamless user experience. The goal of this task was to map out all the enhancements required to update these tools to make them easier to use.

- **Task 3:** *Document a user guide on integrating BIM with FE.* The objective of this task was to create a user guide that compiles all our findings based on our research and interviews from Tasks 1 and 2. It instructs end-users on the best workflows for integrating BIM to FSE software analysis and instructs software vendors on what is required by them to better integrate with BIM authoring tools. It also offers suggestions to update IFCs and gbXML to better accommodate these workflows. This document is geared toward fire

engineers, code officials, software vendors, and related professionals. It is available on the SFPE Foundation website.[2]

- **Task 4:** *Develop a final report and include data deliverables.* The objective of the final task was to create this final project report and technical paper geared toward the SFPE Foundation. It lays out a strategy for the profession as it relates to BIM integration, including priority areas for tool development, recommending data exchange protocols and formats, research, training, certification, and related needs.

2.2 Workflow Study

One of the requirements of this research project by the SFPE Foundation was to hire a university student to assist in portions of the research, all in the name of promoting this industry to future engineers. Jacob Mondora is currently a sophomore at Northwestern University studying computer engineering and data science.

To contribute to Task 2, Jacob carried out research into the workflows between BIM and fire engineering analysis software tools including Revit, Pathfinder, PyroSim, Evac4BIM, and FDS (Fire Dynamics Simulator). Some of his work included recreating his freshman college dorm building in Revit, exporting the model as an Industry Foundation Classes (IFC) file, and importing it into PyroSim and Pathfinder to determine optimal egress and fire/smoke analysis. He then performed extensive analysis to study the interoperability between the software tools and to optimize fire safety and efficiency (i.e., door placement, occupant evacuations, etc.). Furthermore, he downloaded and installed the Evac4BIM Revit add-in. A full report of his findings is in Appendix A of this report.

2.3 Stakeholder Interviews (Task 1)

The foundation for this research project involved interviewing many stakeholders in the fire engineering community. This is where we would find the challenges encountered in BIM software workflows and possible solutions to these challenges. We contacted over 250 stakeholders via email, 41 of which agreed to be interviewed. Of the 41 interviewees, 11 were under the age of 35.

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[2] https://www.sfpe.org/foundation

We found the interview exercise to be so effective that we continued to interview stakeholders throughout the entire lifecycle of this research project (above and beyond Task 1).

Most interviews were typically 30 to 45 minutes over Zoom. We took a semi-structured approach to the interviews. While a core set of questions were asked, the conversations themselves were quite fluid. Sometimes, multiple stakeholders from the same firm were on the same call to offer different perspectives. Table I lists the core set of questions that all interviewees were asked. Table II lists all of the interview participants and their affiliation. Most of our findings that are described throughout the rest of this final report come from information and advice from these interviewees.

TABLE I
SEMI-STRUCTURED INTERVIEW SCHEDULE

Questions
1. *What is your role at your firm? How many years have you been there?*
2. *How do you use BIM and analysis software tools in your daily work?*
3. *What are the challenges that you encounter when using these tools?*
4. *Do you have suggestions for improving these software workflows?*
5. *Any other comments or suggestions?*

TABLE II
INTERVIEWED STAKEHOLDERS

Interviewee	Affiliation
John Alford	Atkins Global
Carl Baldassarra	Wiss, Janney, Elstner Associates, Inc.
Dennis Banschbach	Banschbach & Assoc., LLC
Mike Beach	Brown-Forman
Shawn Block	Jensen Hughes
Barrett Boone	Jacobs Engineering
Dave Branson	Compliance Services Group
Jacob Dentici	FEI Fire
Bryan Echelberger	Veritas Fire
Mark Ferraresi	Jensen Hughes
Matt Foley	SLS Fire
Fred Frank	Bentley Systems
John Frank	AXA Insurance
Scott Grainger	Grainger Consulting
Austin Grant	Performance Based Fire Protection Engineering
Patrick Hughes	CodeComply
Al Johnston	Hydratek
Kieran Kelly	Fisher Engineering
Bill Kerbein	Wiss, Janney, Elstner Associates, Inc.
Matt Killebrew	Killebrew and Killebrew, Inc.
Bryan Klein	Thunderhead Engineering
Daniel LeClair	TLC Engineering
Mark Mergenschroer	Autodesk
Tyler Mobley	Mobley Fire Protection
David Pitts	VSC Fire and Security, Inc.
Chris Pruitt	Coffman
Patrick Reilly	Telgian Engineering & Consulting
Brian Rzewnicki	Cybor Fire Protection Co.
Steven Scandaliato	Scandaliato Design
Ankit Sharma	Case Western Reserve University
Robert Smith	Johnson Controls
Robert Solomon	SLS Fire
David Stacy	Performance Based Fire Protection Engineering
Glynis Thompson	SFPE Foundation
Peter Thompson	University of Canterbury
David Tomecek	Jensen Hughes
Jack Trexler	HGI Fire
Beth Tubbs	International Code Council
Michael Wojcik	Jensen Hughes
Doug Yester	Merrick
Gilead Ziemba	Fire Protection Consulting Group, LLC

2.4 Workflow Assessments (Task 2)

Per our proposal, the objective of Task 2 was to identify enhancements needed to BIM authoring, FSE software tools, data, and interoperability schemas, to help facilitate a more seamless user experience. The goal was to map out all the enhancements required to update these tools to make them easier to use.

One of the questions that we asked all the stakeholders was concerning the issues they face in using BIM and engineering analysis software tools. Almost all of them expressed one or more challenges, and as we interviewed more stakeholders, we identified three themes: software, data, and interoperability. In the following three sections, we provide the results from these interviews. We first discuss software (BIM and analysis tools) to help the reader better understand what types of software fire engineers use, how they use the software, and the issues they encounter. We next discuss data and what it means to FEs. Finally, we discuss interoperability and how it ties everything together.

Each section begins with background information for each of the three themes, including overall descriptions, examples, and the challenges encountered. In section 6, we make recommendations for workflow enhancements based on the information provided in sections 3, 4, and 5.

3. Software

Fire engineering software can be broken down into two main categories: BIM/CAD and engineering analysis software.

BIM software is primarily used for collaborative design, modeling, and management of building projects. It allows architects, engineers, contractors, and other stakeholders to create 3D digital representations of a building's design. BIM software can be used for architectural, structural, MEP (mechanical, electrical, and plumbing), and fire engineering design.

Fire engineering analysis software, on the other hand, is specifically designed for analyzing and simulating fire-related aspects of a building's design. It helps fire protection engineers and safety experts assess fire risks, plan fire protection systems, and model fire scenarios. There are plenty of FE software tools that aid in fire protection design, code compliance, sprinkler design, structural engineering, evacuation modeling, and much more.

3.1 How Existing FE Software Tools Are Used

Through our interviews with stakeholders, we have concluded that there are five ways that FEs take advantage of BIM and engineering analysis tools to design fire protection systems:

- **Collaboration:** BIM allows for collaboration among stakeholders in the design and construction process. Furthermore, FEs can work with other professionals to incorporate fire safety and fire protection systems into building design.

- **3D Modeling:** BIM software provides 3D modeling capabilities, which allows for visualization of fire protection systems in the context of an entire building.

- **Simulations:** BIM and engineering analysis tools can be used to create simulations of fire scenarios and test the performance of fire protection systems under a wide variety of conditions.

- **Clash Detection:** BIM can be used to detect clashes between fire protection systems and other building elements, including MEP and structural.

- **Maintenance and Operations:** BIM can be used to manage and maintain the fire protection systems after construction. Fire protection engineers can use BIM to create a database of fire protection equipment and systems, including their locations, maintenance schedules, and replacement dates. This can help to ensure that the systems are properly maintained and functioning as intended.

3.2 Fire Engineering Analysis Software

As previously mentioned, one of the categories of fire engineering software is engineering analysis. FE analysis tools can be further broken down into several types. Table III outlines the seven types and provides examples of each type of tool.

TABLE III
TYPES OF FIRE ENGINEERING ANALYSIS SOFTWARE

Type	Software Tool(s)
Egress modeling	Bentley Legion, MassMotion, Pathfinder
Fire and/or smoke development spread	Ansys Fluent, CONTAM, FDS, PyroSim, Ventus
Data pre-post processing and visualization	Bluebeam, NavisWorks, Revit, BricsCAD
Hydraulic flow calculations	AutoSprink, HydraCAD, SprinkCAD
Detection and suppression system design	AutoSprink, HydraCAD, SprinkCAD
Risk analysis	B-Risk, Excel
Response to elevated temperatures	Ansys Fluent

3.2.3 Overview of FE Analysis Software Tools

Fire engineering analysis software is specifically designed for analyzing and simulating fire protection and safety systems within buildings. It helps fire engineers and professionals design, assess, and optimize fire detection, suppression, and evacuation systems to ensure the safety of occupants in case of a fire and/or smoke event. In talking with FE stakeholders and doing research, we have encountered the following software tools that are being used across the entire FE industry:

1. **Ansys Fluent:** A computational fluid dynamics (CFD) software tool that models smoke migration behavior in a building. It includes various physics models such as turbulence modeling, combustion, and conjugate heat transfer.[3]

2. **AutoCAD:** A widely used computer-aided design (CAD) software developed by Autodesk. Launched in 1982, it has become a cornerstone tool for architects, engineers, and designers across various industries. AutoCAD enables users to create precise 2D and 3D drawings and models, facilitating the design and documentation of architectural plans, mechanical components, electrical circuits, and more.

3. **AutoSprink:** An AutoCAD and Revit add-in that performs hydraulic calculations of existing piping systems.[4]

4. **Bentley Legion:** A software tool developed by Bentley Systems that models human egress behavior in a building.[5]

5. **Bluebeam:** A PDF collaboration tool that is used by many FE professionals to view piping and sprinkler plans.[6]

6. **BricsCAD BIM:** BricsCAD BIM is built on the BricsCAD system, so users can leverage the 2D drafting tools as they ease into 3D workflows. This BIM authoring tool has been mentioned by many FEs as a BIM-tool of choice.[7]

7. **CONTAM:** A software tool developed by the National Institute of Standards and Technology (NIST) for multi-zone indoor air quality and ventilation analysis including smoke control systems.[8] It helps with:

   a) *Airflows*: infiltration, exfiltration, and room-to-room airflows in building systems driven by mechanical means, wind pressures acting on the exterior of the building,

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[3] https://www.ansys.com/products/fluids/ansys-fluent
[4] https://autosprink.com
[5] https://www.bentley.com
[6] https://www.bluebeam.com
[7] https://www.bricsys.com/en-us
[8] https://www.nist.gov/services-resources/software/contam

and buoyancy effects induced by the indoor and outdoor air temperature difference.

b) *Contaminant Concentrations*: the dispersal of airborne contaminants transported by these airflows; transformed by a variety of processes including chemical and radiochemical transformation, adsorption and desorption to building materials, filtration, and deposition to building surfaces, etc.; and generated by a variety of source mechanisms.

c) *Personal Exposure*: the predictions of exposure of occupants to airborne contaminants for eventual risk assessment.

8. **FDS (Fire Dynamics Simulator):** A CFD model of fire driven fluid flow developed by NIST. This software solves numerically a form of the Navier-Stokes equations appropriate for low-speed, thermally-driven flow, with an emphasis on smoke and heat transport from fires.[9]

9. **HydraCAD:** Another Revit and AutoCAD add-in for piping layout and sprinkler design and calculations.[10]

10. **MassMotion:** A software tool developed by Arup, an architectural/engineering firm, that models human egress behavior in a building.[11]

11. **Autodesk Navisworks:** A widely used software tool from Autodesk that allows users to open and combine 3D models, navigate around them in real-time, and perform clash-detections amongst various engineering disciplines.[12]

12. **Pathfinder:** Pathfinder, from Thunderhead Engineering, is a widely used desktop software tool that models human egress behavior in a building due to a fire event. It is an agent-based (i.e., occupant-based) evacuation simulation model and is used

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[9] https://pages.nist.gov/fds-smv
[10] https://www.hydratecinc.com
[11] https://www.arup.com/services/digital/massmotion
[12] https://www.autodesk.com/products/navisworks

internationally by engineering consultants and academic institutions. It uses a 3D triangulated mesh to represent the model geometry.[13]

Figure 1. 3D Rendering of occupancy egress in Pathfinder. Credit: Thunderhead Engineering. Reprinted with permission.

13. **PyroSim:** Another software tool from Thunderhead Engineering used to simulate fire and smoke behavior in a building. PyroSim is a visual front-end to NIST's Fire Dynamic Simulator (#8 above). It allows for smoke, temperature, velocity, toxicity, and other outputs of the FDS analysis to be viewed, and for videos to be created in real-time.[14]

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[13] https://www.thunderheadeng.com/pathfinder
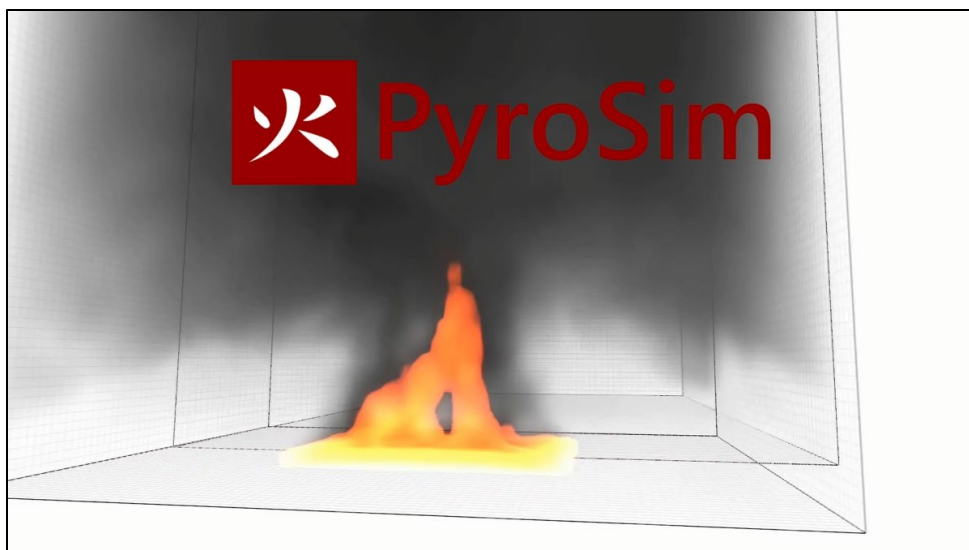[14] https://www.thunderheadeng.com/pyrosim

Figure 2. Image of fire and smoke behavior in PyroSim. Credit: Thunderhead Engineering. Reprinted with permission.

14. **Revit:** A BIM authoring software tool developed by Autodesk. It serves as both analysis software and BIM authoring software.

15. **SprinkCAD:** An add-in to Revit, Autodesk's Building Information Modeling (BIM) authoring tool. This add-in works inside Revit (as an additional ribbon) and adds fire suppression piping and sprinkler design and calculation capabilities within Revit.[15]

16. **Ventus:** A new software tool available from Thunderhead Engineering that provides a 3D visual front-end and post-processor for the NIST ContamX simulator (#7 above), to perform pressurization studies for smoke control solutions.[16]

The above list is just a subset of all the possible software tools used by fire protection engineers. Wade et al. surveyed 156 users worldwide in 2021 and reported over 60 commonly used software tools in fire engineering (both BIM and analysis, see Fig. 3) [2].

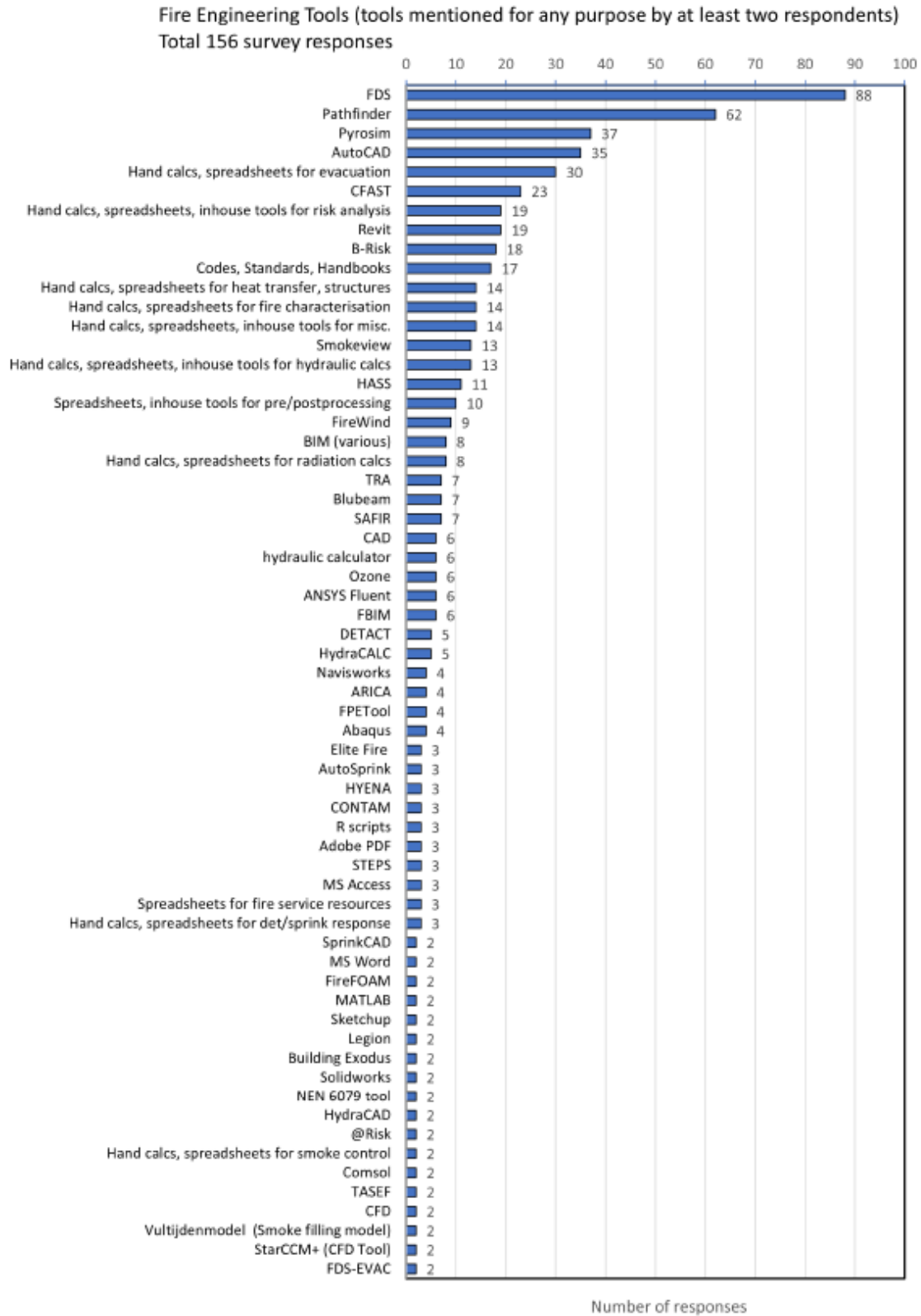[15] https://sprinkcad.com
[16] https://www.thunderheadeng.com/ventus

Fire Engineering Tools (tools mentioned for any purpose by at least two respondents)
Total 156 survey responses

Figure 3. List of Popular Fire Engineering Software Tools.
Credit: Wade, et al. [2]. Copyright SFPE Foundation.

3.2.4 More In-Depth Overview of Occupant Movement Software

It is worth discussing in more detail one type of popular fire engineering software: occupant movement software tools like Thunderhead Engineering's Pathfinder. It is a tool to model human egress behavior in a building due to a fire and/or smoke event. It helps architects and engineers to design buildings and layout doors, elevators, and other elements to accommodate fast and efficient egress of building occupants. A tool like Pathfinder supports two simulation modes:

- **Steering Mode:** Agents (or occupants) proceed independently to their goal, while avoiding other occupants and obstacles. Door flow rates are not specified but result from the interaction of occupants with each other and with boundaries.

- **SFPE Mode:** Agents use behaviors that follow SFPE guidelines, with density-dependent walking speeds and flow limits to doors. By default, each occupant uses a combination of parameters to select their current path to an exit. This is a more realistic modeling scenario.

A tool like Pathfinder provides support for the import of BIM formats such as buildingSMART's Industry Foundation Classes (IFC) format, as well as DWG, FBX, DAE, and OBJ. It uses a 3D triangulated mesh to represent the model geometry. Fig. 4 is a screenshot of a Pathfinder egress model. The blue cylinders represent occupants on various floors of the 3D virtual model.
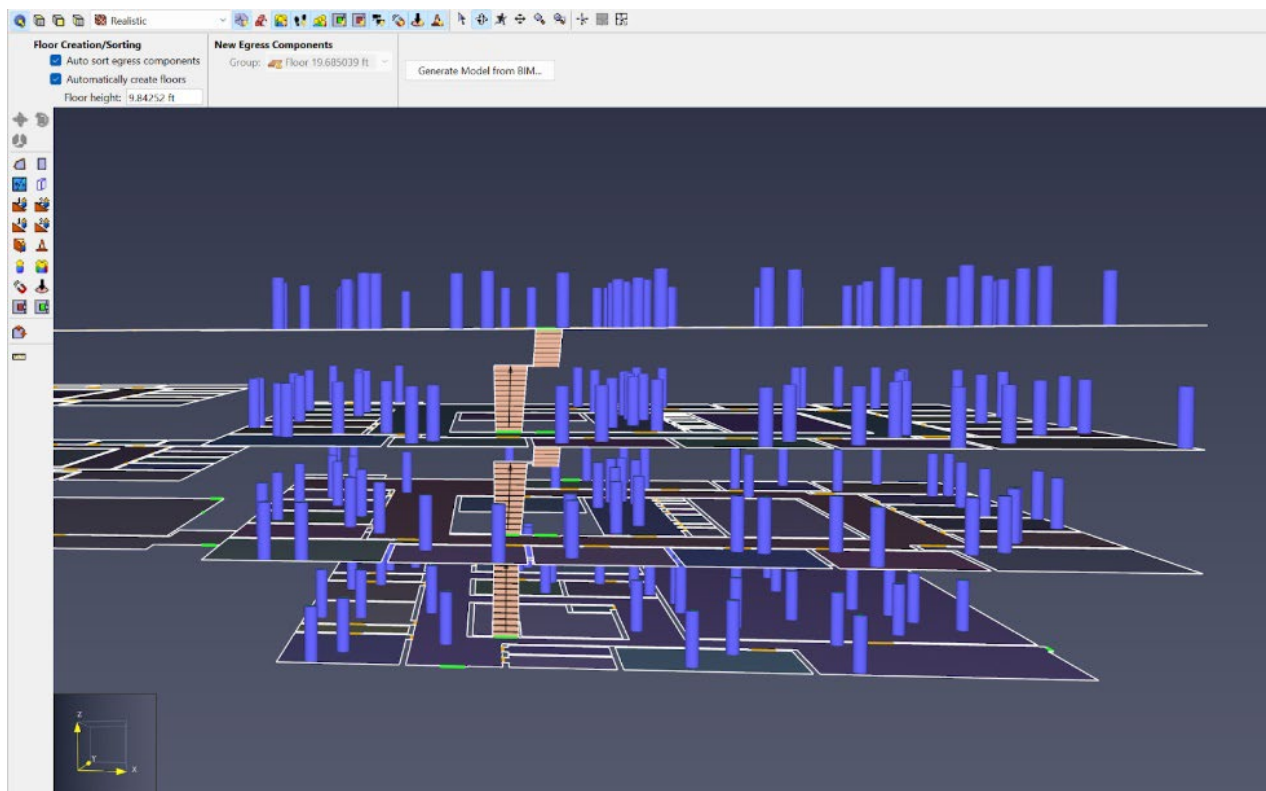
Figure 4. Schematic view of building occupants represented by blue cylinders in Pathfinder. Credit: Thunderhead Engineering. Reprinted with permission.

Some key features of evacuation modeling software include:

- **Simulation of Occupant Behavior:** Evacuation modeling software simulates how occupants within a building respond to a fire emergency. It considers factors such as human behavior, mobility, and response to alarms.

- **Visualization of Evacuation Paths:** The software provides visual representations of evacuation paths, indicating the routes people are likely to take during an emergency. This includes identifying primary and alternative escape routes, exit locations, and assembly points.

- **Impact of Fire and Smoke:** Evacuation models consider the location and progression of the fire, as well as the spread of smoke.

- **Evaluate Evacuation Times:** Evacuation modeling software calculates and analyzes evacuation times based on simulated scenarios.

3.2.5 Software Add-Ins

Software add-ins differ from stand-alone software tools discussed in the section above. A software add-in is a piece of software that can be added to an existing software application to enhance or extend its functionality. Add-ins are typically designed to work within the framework of a specific host application and extend the capabilities of the host software.

Key characteristics of software plugins include:

- **Customization:** Add-ins offer users the flexibility to personalize the software by adding features that might not be part of the core software package.

- **Functionality Expansion:** Add-ins introduce new functions, tools, or integrations, enabling the host software to perform tasks that it couldn't do on its own.

An example of a popular add-in is a browser extension (i.e., to Chrome or Firefox) like an ad-blocker that prevents ads from popping up and displaying on web pages.

3.2.5.1 The Evac4BIM Add-In

A fire engineering-centric add-in exists for Revit called Evac4BIM [4]. This add-in was developed by Nazim Yakhou at Lund University [5] as a research project. Its main goal is to simplify the workflow of transferring a BIM in Revit into a tool that imports BIM like Pathfinder or PyroSim. The current stand-alone workflow of exporting IFCs, discussed in Chapter 5, is full of issues including models that are not "watertight." The Evac4BIM add-in helps correct some of these issues.
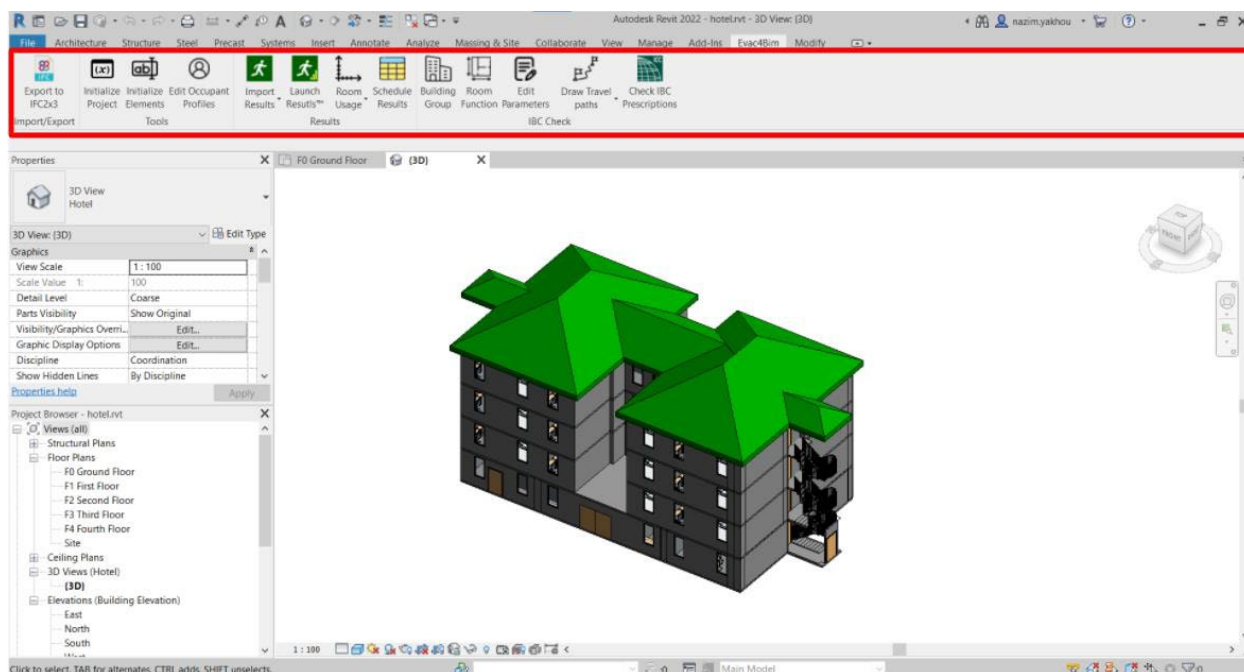
Figure 5. The Evac4BIM Revit Add-In is a ribbon on the toolbar. Here it is outlined in red. Credit: Nazim Yakhou, Lund University. Reprinted with permission.

Fire engineering professionals do not reap the benefits of traditional BIM software that other disciplines enjoy (such as HVAC, plumbing, and electrical), primarily due to a lack of support for fire engineering in IFCs. As a result, many issues arise when trying to use fire-simulation and BIM software together, such as:

- Delays for design evaluation

- Fragmentation of design and review processes

- Inconsistent documentation and ambiguity in roles/responsibilities

- Data loss

In response to these issues, Yakhou developed the Evac4BIM add-in for Revit. The advantages of using this add-in are:

- Solves the current disconnect between BIM and FE to create a consistent workflow.

- "Round-tripping" of data is possible (i.e., send data from Revit to Pathfinder and back into Revit). Data regarding occupants, simulation data, and more from Pathfinder is easily imported by Revit.

- Data regarding the structure dimensions, features, rooms, stairs, occupant data, etc., is immediately read by Pathfinder.

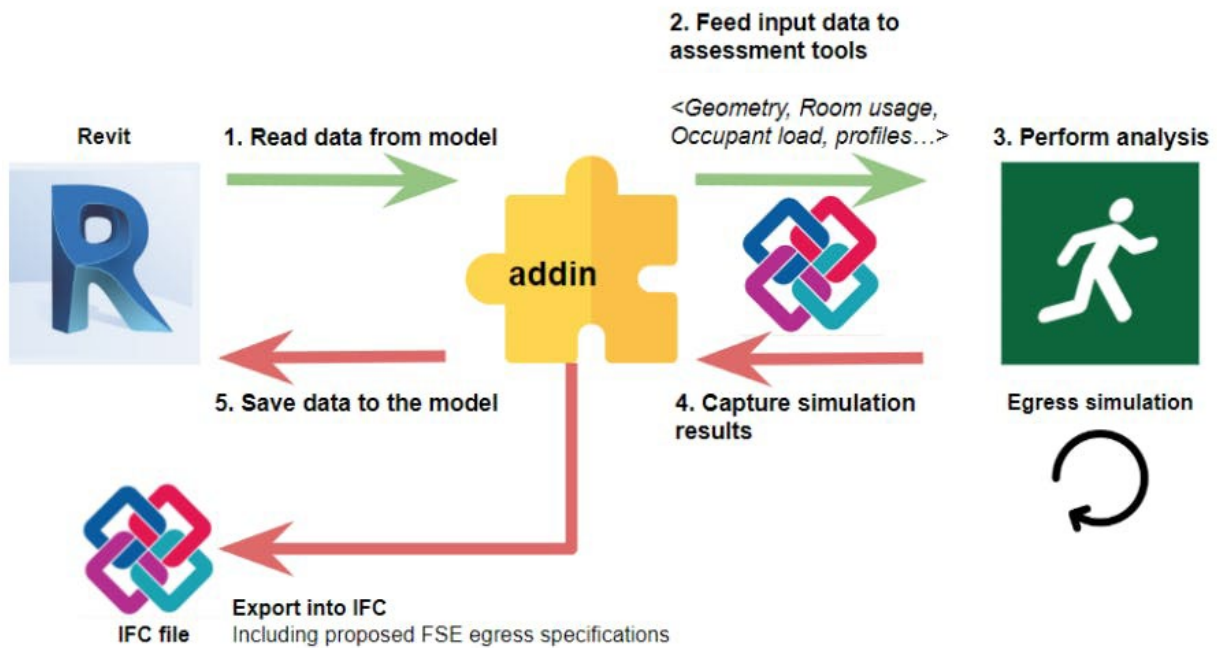Fig. 6 is a visualization of the Evac4BIM add-in workflow.

Figure 6. Evac4BIM Framework workflow. Credit: Nazim Yakhou, Lund University. Reprinted with permission.

According to the creators of the Evac4BIM add-in, future goals include:

- Expanding the scope of data exchange with simulation tools.

- Expanding Pathfinder import to support and process additional input properties from IFC files.

- Supporting additional evacuation simulation tools beyond Pathfinder.

3.3 BIM Authoring Software

3.3.1 Overview of BIM Authoring Software Tools

BIM is a digital, collaborative, and 3D modeling process used in the construction and architecture industries to create and manage detailed representations of building projects. BIM software enables architects, engineers, contractors, and other stakeholders to work together by creating a centralized and dynamic database of building information. This information encompasses not only the geometric aspects of the infrastructure, but also data related to its design, construction, and operation. BIM allows for the visualization, simulation, and analysis of a building's entire lifecycle, aiding in better decision-making, improved project coordination, cost estimation, and efficient resource management, ultimately resulting in more streamlined and sustainable building projects.
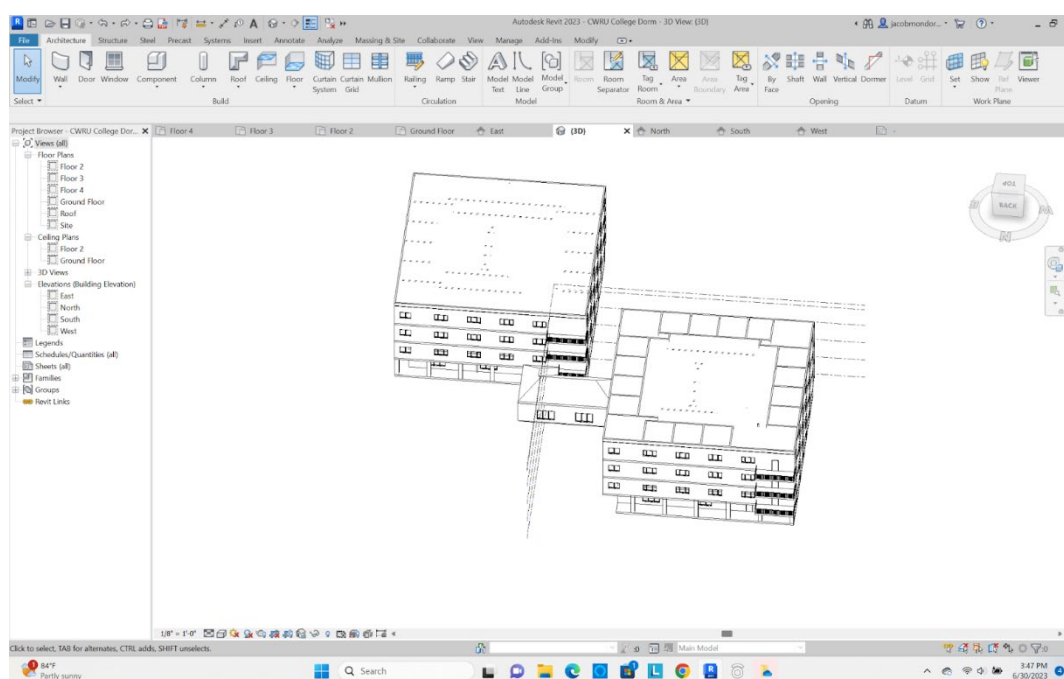

Figure 7. Sample Autodesk Revit model.

BIM can be used to enhance fire engineering design by providing a more comprehensive view of the building and its systems. The BIM can include information about the location of fire protection equipment such as sprinklers, alarms, and extinguishers, as well as data about the

building's layout, materials, and construction. This information can be used to simulate fire scenarios and evaluate the effectiveness of fire protection systems.

BIM can also facilitate collaboration amongst stakeholders in the building design process. By using a shared BIM, architects, engineers, contractors, and owners can coordinate their efforts and ensure that fire protection features are integrated seamlessly into the overall design.

BIM offers many advantages over generic CAD software tools such as AutoCAD:

- **Information Rich Data:** This includes object-oriented, data-rich, and intelligent digital representation of a facility or infrastructure.

- **Collaboration:** Project stakeholders from different disciplines all using the same model.

- **Single Integrated Model:** Offers a single repository of all knowledge and information about a building throughout the entire building lifecycle, all the way from conceptual design to operations and maintenance.

- **Reduce Waste and Lower Construction Costs:** Enables effective handling of waste recovery and materials.

- **Improved Visualization:** The same data can be viewed in many ways.

However, there are also disadvantages of using BIM relative to CAD:

- **Learning Curve:** BIM software tends to have a steeper learning curve compared to traditional CAD software.

- **Software Costs:** BIM software can be more expensive than basic CAD software.

- **Project Size:** BIM is particularly beneficial for large and complex projects, but it can be overly complex for smaller designs. For smaller projects, traditional CAD is probably more efficient.

- **Time-Consuming:** BIM can be time-consuming to create and maintain, especially during the initial stages of a project.

- **Over-Engineering:** BIM can sometimes lead to over-engineering, as it offers a high level of detail and accuracy.

- **Resistance to Change:** Some professionals in the industry may resist the transition to BIM due to familiarity with CAD.

Despite the disadvantages of BIM, authoring tools like Revit are simply too entrenched in the workflows of architectural and engineering firms to go away.

3.3.2 Limitations of Fire Engineering Design in BIM

Based on our talks with industry stakeholders and other research, we've compiled a list of limitations and challenges that FPEs encounter when using BIM software.

- **Lack of Accurate Fire Modeling:** BIM software can model the building's geometry, but it does not accurately represent the behavior of fire and smoke within the building. Stand-alone software tools are required for this type of analysis.

- **Human Error:** BIM relies on human input, and errors in data entry or modeling can compromise the accuracy of fire engineering design.

- **Increased Cost and Time:** Many stakeholders complain that BIM software is overly complex and adds to the cost and timelines of projects.

- **Sizeable Gap Between AEC Domains:** There is a sizeable gap in the use of advanced building information models by the general design/engineering sectors in buildings compared with those used by fire engineers.

- **Lack of BIM Expertise:** There are many difficulties securing staff and other project team members with requisite expertise in BIM. In fact, many stakeholders mentioned that many larger projects should have a dedicated BIM manager if one is available.

As mentioned previously, of the 250 FE stakeholders that we contacted, 41 responded to our calls. We assume that the stakeholders who did respond were more inclined to embrace BIM, while those who did not respond were either not interested or simply did not use BIM. Even with this selective group of BIM enthusiasts, we still heard plenty of criticism of BIM authoring tools.

There seems to be a great divide between stakeholders that we talked to who embrace BIM and others who see it as too complicated. Several stakeholders even suggested that they do not see a huge demand to use BIM in fire engineering. Instead, they see more people using Bluebeam to analyze sprinkler systems in drawings.

For example, one stakeholder from a large fire protection manufacturer mentioned that many designers who have used AutoCAD for many years face a steep learning curve to master a tool like Revit since it is a much more complicated tool to learn. In fact, almost all the FEs 35 and younger embrace BIM more easily since they often are trained on it in school.

Another reason for the low use of BIM tools by fire engineers seems to be due to the lack of fire-related BIM add-ins and the inability for many fire software applications to directly communicate with BIM tools like Revit. Some of the comments related to this were:

- "The biggest gap is linking hydraulic calculations to Revit. Almost no sprinkler designers use Revit because there is no link."

- "Revit tools for fire protection significantly lag behind the rest of the industry."

- "The ultimate would be the ability to model egress and fire development in the same model."

- "A linked model which incorporates fire models and egress models together would be useful for more complex projects especially involving travel through smoke."

- "Refined interfaces linking egress and fire modeling with consequence assessments (FED/FIC etc.)."

3.3.3 FE Feature-Specific Limitations of Revit

Other FE feature-specific limitations of Revit include:

- Revit is not good at sloped piping (which happens to be an integral part of sprinkler design). Sloped piping is important for FEs for a couple of reasons:

  - Gravity drainage to ensure water flows from source.

  - Pressure maintenance: Maintain water pressure throughout the system. Prevents stagnated water.

  - Freeze protection: Allows for effective drainage of water where there is risk of freezing.

  - Corrosion prevention.

- Center-to-center piping is not native to Revit. Ideally, users could align all piping with the touch of a button.

- Without constant training and usage, many casual users quickly lose their knowledge of Revit and its functions due to its complexity. The learning curve for Revit only becomes steeper among those who have previously used AutoCAD.

- Built-in piping layout functionality in Revit is not necessarily geared towards fire engineers.

- Revit files are not backward compatible. With some projects taking 5-10 years to complete, this causes compatibility issues since Revit comes out with a new version every year. Architects are often not diligent about (or simply do not want to pay for) upgrading models every year.

- Autodesk frequently renames software tools, requires an annual license subscription, and develops an abundance of software tools that do the same things, causing confusion.

- Revit doesn't come with built-in brace and hanger families.

- Revit thinks sprinklers are plumbing fixtures. Sprinklers do not belong in the drainage category like conventional plumbing fixtures.

- If a designer hosts sprinkler families directly in a ceiling object, and if the architect eventually deletes the ceiling, the sprinklers also disappear. This is not an acceptable workflow according to some stakeholders.

All things considered, the main issue is that Revit is not accommodating towards fire engineers. And while there are ways to work around this, such as purchasing third party tools and families, this causes inconvenience for fire engineers. With the right improvements in place, BIM could play a much smoother role in the fire protection design process.

3.3.4 Features in Revit That are Not Widely Known

As mentioned previously, a big issue with BIM and Revit adoption is lack of training and usage. Revit is a very complex software tool that requires daily or weekly usage to maintain proficiency. However, there are several features in Revit that are not widely known to users that can readily be used by fire engineers.

- **Travel Distance Calculator:** This Revit feature optimizes the shortest distance between points A and B (i.e., for optimal egress). It can also assign view filters to path lines for easy assessment of length and time and can go around obstacles and through doors.
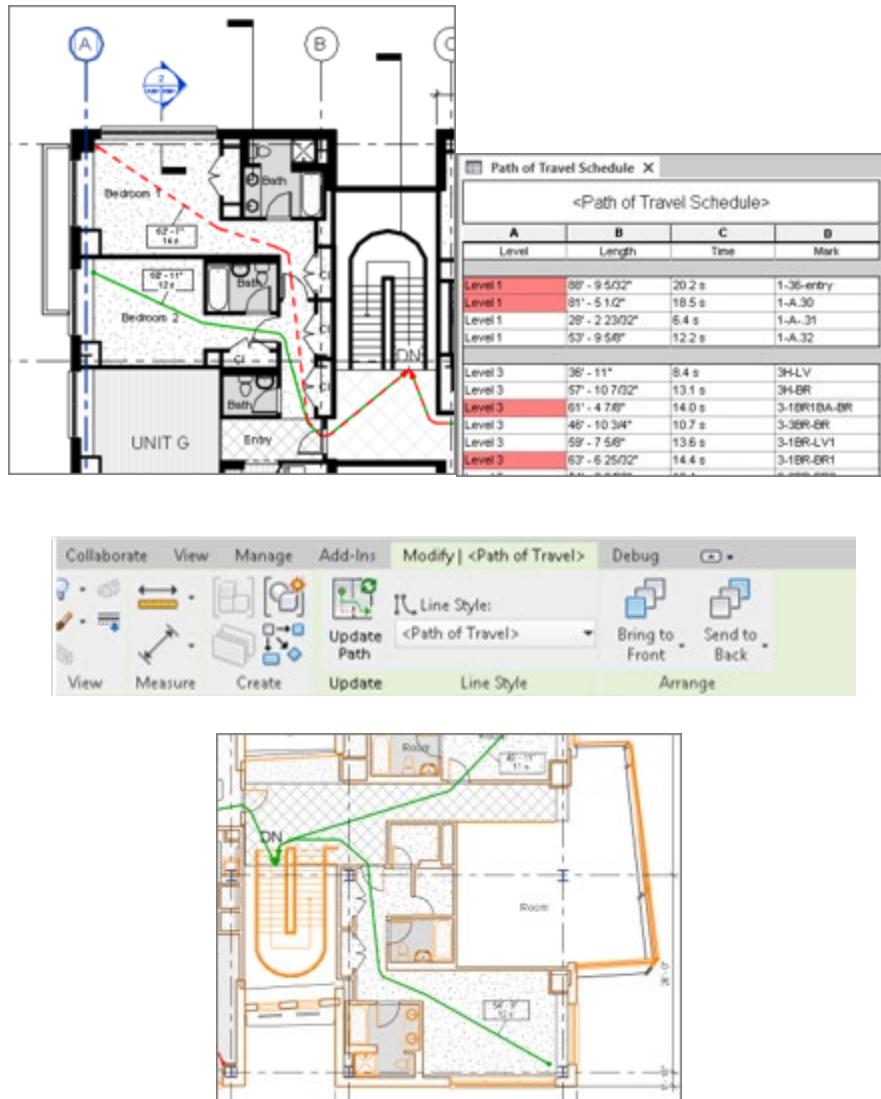
Figure 8. Travel Distance functionality screen shots in Revit. Credit: Peter Thompson, University of Canterbury. Reprinted with permission.

Revit also allows the user to schedule and tag paths and distances.

- **Occupancy Numbers:** In Revit, there are ways to set occupancy loads in a space, display them in a table, and add them to the room labels. This is a great way for FEs to visualize occupant densities and design systems accordingly.
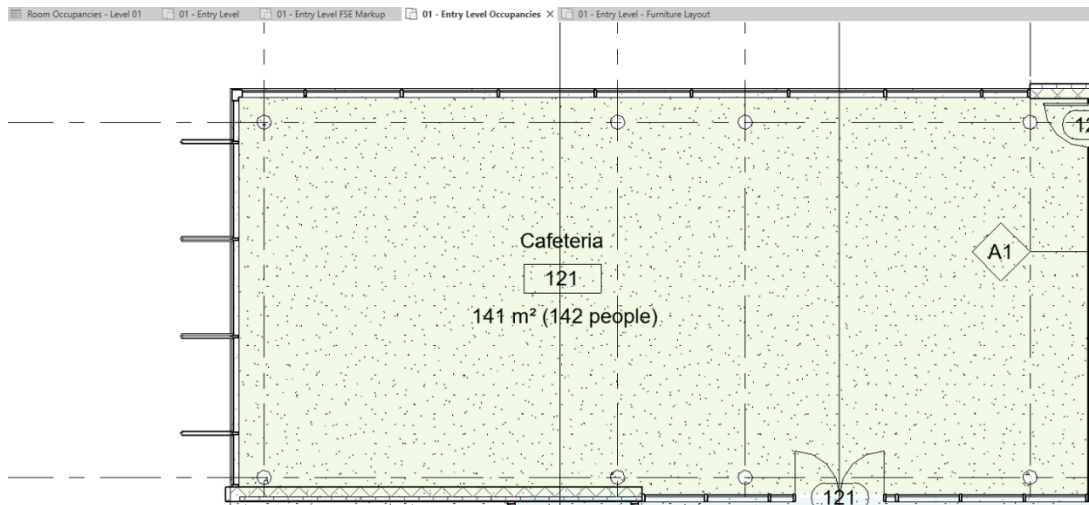
28

Figure 9. Occupancy schedule displaying number of people in a room in Revit. Credit: Peter Thompson, University of Canterbury. Reprinted with permission.

- **Automatic Calculation of Door Widths:** In Revit, users can automatically set the width of doors to accommodate fire codes that are dependent on the number of occupants.
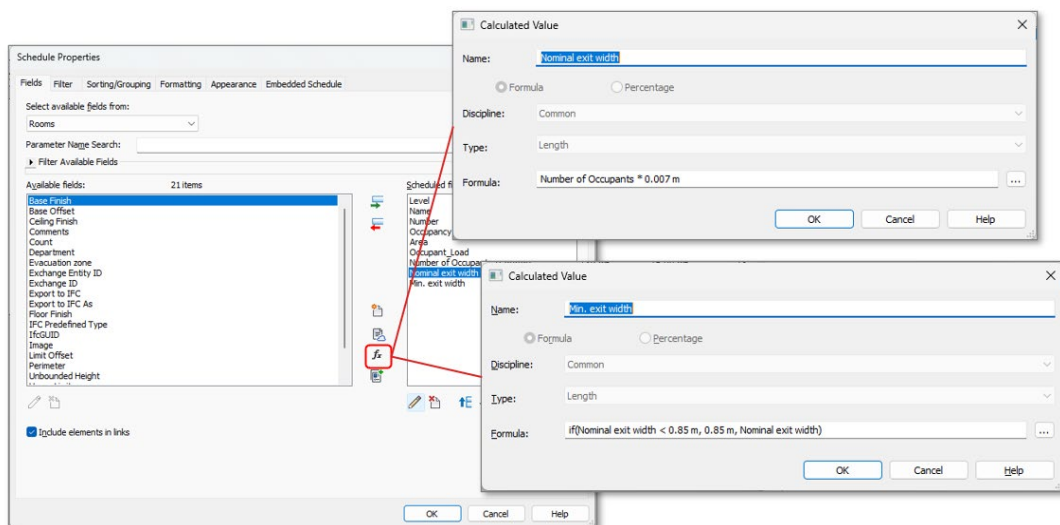

Figure 10. Pop-up screens display door width calc parameters in Revit. Credit: Peter Thompson, University of Canterbury. Reprinted with permission.

- **Fire Resistance Ratings:** In Revit, the user can color code plan views to represent different fire resistance ratings. In Fig. 11, 60 minutes rated walls are highlighted in purple.
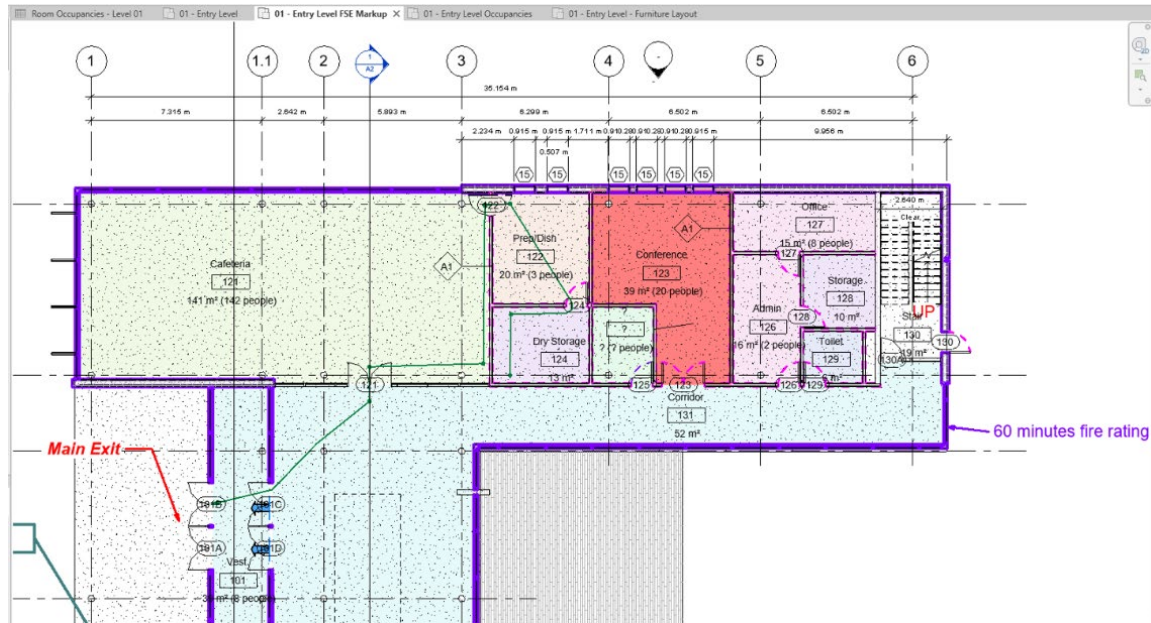

Figure 11. Color scheme showing 60 minutes rated walls highlighted in purple in Revit. Credit: Peter Thompson, University of Canterbury. Reprinted with permission.

- **Annotating Sprinkler Inlets, Valve Rooms, and More:** The annotating functions in Revit (Fig. 12) are well known, but many FEs do not realize how they can easily be applied to fire protection system elements and devices.
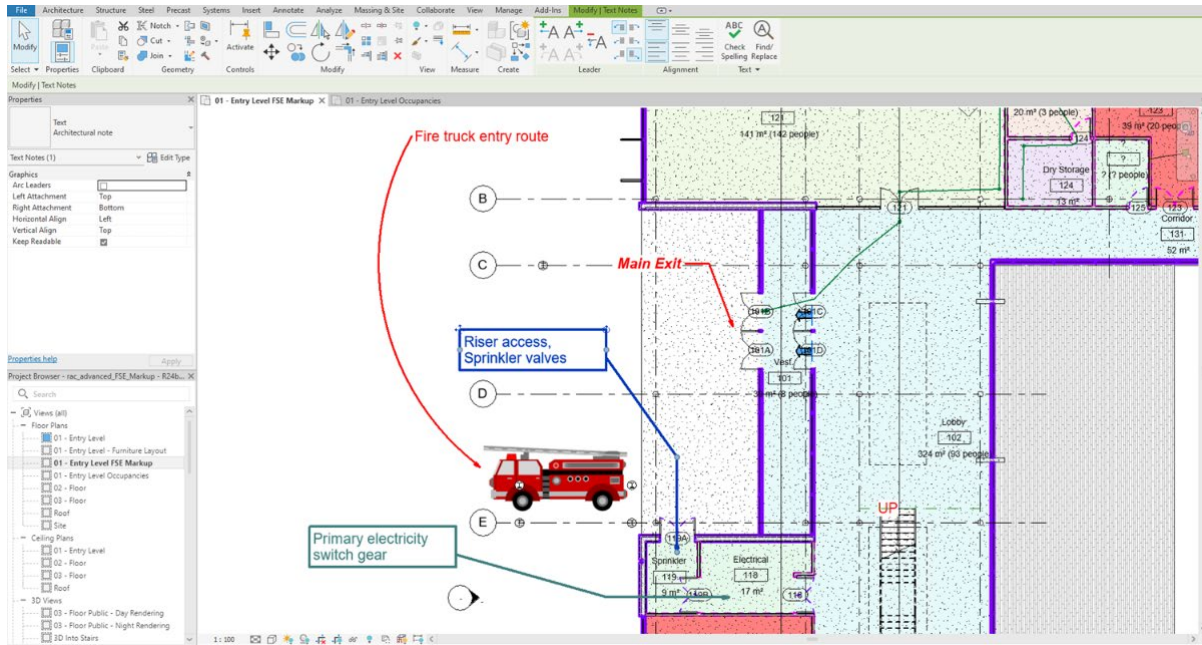
Figure 12. Example of fire protection annotations in Revit. Credit: Peter Thompson, University of Canterbury. Reprinted with permission.

4. Data

The second theme discussed in this research report is data. Data plays an important role in fire engineering, helping to design effective fire prevention and suppression systems, assess fire risks, and ensure the safety of buildings and occupants. Data is used as follows:

- Computational tools use data to model fire behavior, including how fires start, spread, and evolve in different scenarios.

- Data from real-world fire tests and experiments are essential for understanding how materials and structures respond to fire.

- Historical fire incident data is used to identify trends, causes, and common fire hazards.

- Fire engineers must adhere to building codes and standards that are based on data-driven research and testing.

In our interviews with FE stakeholders, we asked about their FE-related data needs and challenges that they encounter. Their responses can be broken down into the following categories:

- Building codes

- Construction material information

- BIM objects and families

4.1 Building Codes

The design, installation, and operation of fire detection, alarm, and suppression systems are governed by a blend of standard engineering techniques, local and state codes, and fire insurance requirements. It is necessary for FEs to review all applicable codes and meet the most stringent of these overlapping requirements. Design of buildings and installation of fire protection systems are governed by local building codes. A municipality can develop its own building code, but it usually adopts the International Building Code (IBC) published by the International Code Council (ICC) [6].

The IBC combines legacy building codes including:

- BOCA National Building Code (BOCA/NBC) by the Building Officials Code Administrators International (BOCA)

- Uniform Building Code (UBC) by the International Conference of Building Officials (ICBO)

- Standard Building Code (SBC) by the Southern Building Code Congress International (SBCCI)

Most of these model building codes have been heavily influenced by, or have adopted sections largely unchanged from, the National Fire Protection Association (NFPA) publications such as the *NFPA Fire Prevention Code* (*NFPA 1*), *Life Safety Code* (*NFPA 101*), and the *Uniform Fire Code*.

Local fire codes can vary from city to city, depending on which building code has been adopted. Regulations concerning sprinklers and other protective devices are subject to change, administrative view, and interpretation by local building and fire officials.

While a couple of stakeholders that were interviewed talked about building codes and software, this research project does not focus too much on this topic. Instead, we focus on data in the BIM since this is what most stakeholders expressed interest in talking about.

4.2 BIM Objects and Families

The biggest "data" related issue for FEs by far deals with BIM objects and Revit families. The "I" in BIM means that BIM authoring tools can store all information about a building including wall and window construction types, occupant density, lighting density, HVAC equipment, duct work, electrical wiring, plumbing, and sprinkler piping. In fact, the entire essence of BIM is the ability to extract this data from the model and get it into other software tools to perform a wide variety of building analysis including FE design.

A BIM (or Revit) family is a collection of parametric 3D model elements that represent real-world objects. These objects can range from simple components like doors, windows, and furniture to more complex elements like HVAC rooftop units, electrical cable tray, and fire protection sprinkler heads. In fact, there are two main types of families in Revit: "Component Families" and "System Families." Component Families are standalone objects like furniture or

lighting fixtures, while System Families are essential building elements like walls, floors, and roofs. System families are built into Revit and available in the architectural ribbon.

The concept of families in Revit is central to its parametric modeling capabilities. Each family contains a set of parameters that can be modified to create variations of the object while maintaining its underlying behavior and constraints. This means that when the user changes a parameter value, the entire family adjusts accordingly, ensuring consistency and efficiency in the design process. Families are created using the Revit Family Editor, a tool within the Revit software suite. The Family Editor allows users to define and customize the geometry, dimensions, properties, and behaviors of the family.

Revit families are used in HVAC, plumbing, electrical, and fire engineering. For example, companies like Viking Pump have created pump Revit families, while other companies have created simple signage Revit families for specifying exits and evacuation routes.

4.2.1 Issues with BIM Families

Many stakeholders that we interviewed expressed frustration with the state of Revit families for fire engineering. This is because many manufacturers do not create well-designed families, meaning:

- The Revit families are over-designed and way too "heavy" and detailed. Such families often bog the 3D Revit model down so that it is way too slow to manipulate and view.

- Revit families are often not flexible enough or do not contain the correct connections and metadata.

4.2.2 Over-Designed Revit Families

One FE stakeholder mentioned that fire pump Revit families are difficult to create since there are so many dimensions associated with pumps. Therefore, many manufacturers' Revit families are too heavy and slow down the Revit model. This also occurs with sprinkler head families that are overdesigned.
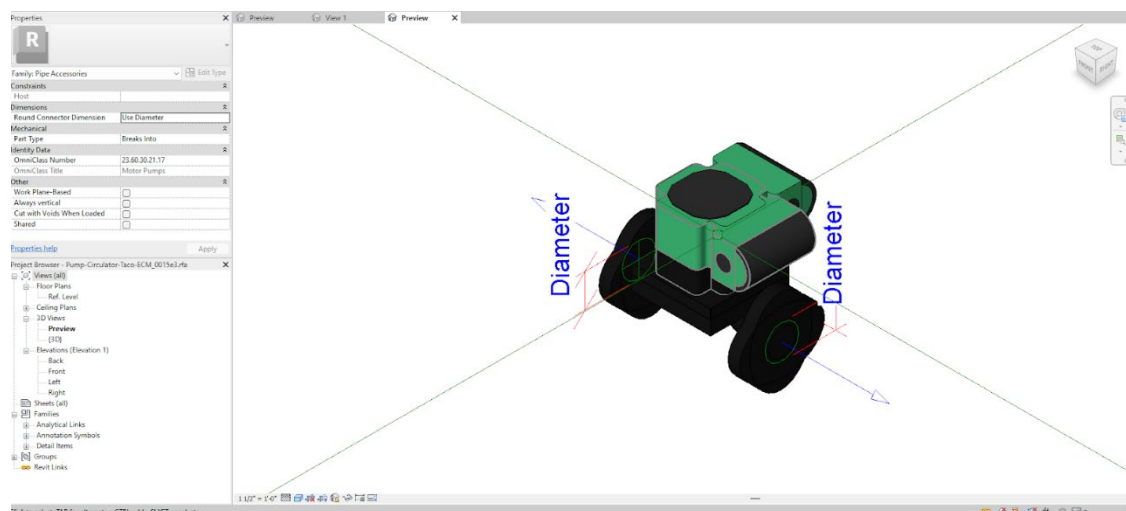
Figure 13. Sample Revit family.

A stakeholder from a large software vendor mentioned that Revit families for fire protection have improved over the past five years but are still overdesigned and too heavy, thereby weighing down the model. Manufacturers do not need to represent their equipment models perfectly if the geometry is approximate and the metadata is correct. However, they need to make sure the inlet and outlet center-line elevations are correct.

Several FE stakeholders mentioned that fire alarm families are also not well designed. They admit that fire alarms are difficult to design as 3D Revit families. They are much easier to utilize as 2D models even though this is not ideal in a 3D Revit model. A big reason for this is that in the NFPA 170 Standard, *Standard for Fire Safety and Emergency Symbols* [7], fire safety and emergency symbols are often designed as 2D families.

Another engineering stakeholder suggests that the industry needs to overcome the excuse that they are not using BIM for fire alarm analysis because NFPA 72, *National Fire Alarm and Signaling Code* [8], likes to see 2D symbols. The industry needs to encourage the NFPA to take on the task of developing a 3D database of fire alarm and signaling code symbols. A case in point: lots of federal organizations, including the U.S. Department of Energy, require BIM deliverables.

Many of the built-in families that come with Revit out-of-the-box are not suitable for fire protection design including pipe braces and hangers. Another engineering stakeholder mentioned that the piping families coming from Revit are very clunky unless a designer wants to

design a very generic piping system. The pipe fittings that come with Revit do not follow industry standards and the dimensions do not make sense.

Another issue with Revit families is keeping sprinkler head templates updated. One stakeholder uses 15 different types of sprinkler heads, and it is very time consuming to maintain and update them.

5. Interoperability

Interoperability allows for the sharing of data between software tools developed by different vendors. Interoperability is essential for BIM to realize its potential as a transforming technology versus 3D CAD tools that are limited in their use as holistic building design tools. For example, it enables integration between BIM authoring and stand-alone FE analysis software since FE software tools utilize much of the information stored in the BIM. The advantages of interoperability are two-fold:

- It reduces user input errors since parameters required by FE tools are automatically imported into the software.

- It allows for more "what-if" analysis since it is much easier to re-enter new and updated data from the BIM into the FE design tool.

Today, robust open data exchange standards exist to support various BIM and building design workflows including:

- **Industry Foundation Classes (IFCs)** [9] are a standardized, semantic, digital description of the built environment, including buildings and civil infrastructure. It is an open, international standard data model meant to be vendor-neutral, and usable across a wide range of hardware devices, software platforms, and interfaces for many different use cases.

- **Green Building XML (gbXML)** [10] is a built asset data model schema primarily focused on the capture and exchange of information between model-centric applications for the purpose of building energy performance simulation and analysis. gbXML's focus enables it to more comprehensively and thoroughly describe and capture information needed for a variety of building performance related workflows throughout a building lifecycle.

Think of these schemas as just another file format the software tools save as. The difference is, many analysis software applications can read these file formats so they can import much of the information entered into the BIM authoring tool. These schemas also provide a standardized way of representing building information that can be used by different software applications,

which can significantly reduce the time and effort required to exchange data between different tools. For example, some egress modeling software tools import native AutoCAD drawings (via DWG or DXF formats) or IFC files exported from BIM authoring software tools. This allows users to easily import geometry into the egress modeling tool versus manually creating this geometry in that tool.

5.1 IFCs

IFC files contain detailed information about building elements, materials, spatial relationships, and other attributes necessary for a comprehensive representation of a construction project. This information is organized in a structured manner, making it easier for different software applications to interpret and work with the data.

Key features of Industry Foundation Classes (IFCs):

- **Interoperability:** IFCs allow various software applications to communicate effectively and share BIM data without requiring the same proprietary file format.

- **Open and Neutral:** IFCs are an open standard that can be used by any software vendor, ensuring no vendor lock-in and encouraging collaboration within the industry.

- **Comprehensive Data Representation:** IFC files can encompass a wide range of information, not just geometric information about the building.

- **Versioned and Evolving:** The IFC standard is continually evolving to meet the changing needs of the AEC industry.

- **International Standard:** IFC is recognized as an ISO standard (ISO 16739:2013) for the exchange of building and construction data.

5.2 gbXML

gbXML (Green Building XML) is an established data format used in the architecture, engineering, and construction (AEC) industry to exchange information related to building and energy performance analysis, particularly for green building design and evaluation. It is an XML-based file format specifically designed to facilitate the exchange of data between different software

applications that are involved in building performance analysis, energy simulation, and sustainability assessments. In fact, SFPE recently adopted a position statement on sustainability and fire protection engineering design [11]. Therefore, gbXML could be a potential schema for facilitating BIM and performance simulation workflows for FEs.

5.3 APIs

Interoperability can also be facilitated with APIs (application programming interfaces) such as Autodesk Platform Services (APS).

APIs were discussed previously and define a standardized set of rules and protocols that enable software components and tools to communicate with each other. This common language ensures that different tools can understand and interpret the data being exchanged, basically the essence of interoperability.

APIs have the following characteristics:

- **Service Abstraction:** APIs abstract the underlying implementation details of a service or software component. This means that the internal workings of the tools can be modified or upgraded without affecting their ability to communicate with each other.

- **Modular Development:** APIs allow developers to build software in a modular fashion. Different components can be developed independently, as long as they adhere to the agreed-upon API specifications.

- **Cross-Platform Compatibility:** APIs enable interoperability across different platforms and operating systems. If a tool supports the API, it can interact with other tools regardless of the underlying technology stack.

- **Facilitates Third-Party Integration:** APIs allow third-party developers to create applications or services that can interact with existing tools.

- **Real-time Communication:** Many APIs support real-time communication, enabling instant data exchange between applications.

The advantage of APIs over data schemas is that APIs involve a cleaner workflow for end users. With data schemas, the user needs to "Save As" from the BIM authoring tool then "Import" into the consuming analysis tool. With APIs, this process occurs automatically without user intervention. The disadvantage of APIs versus data schemas is that it takes much more work on the part of the software vendor to implement and program this functionality. An ROI analysis is needed.

5.4 Interoperability Issues

In terms of fire engineering, the main interoperability workflows involve saving IFCs from Revit and importing them into analysis software tools such as Pathfinder and PyroSim.

The problem users encounter when importing a BIM is that it is difficult to get complete and accurate geometries of all elements in a building including the walls, roofs, floors, windows, and more. Often, the walls and other elements will not connect correctly, so there are gaps. In other words, it is not watertight. These gaps cause faulty boundary condition parameters that can adversely affect the results. Therefore, users often must redraw the model in the consuming analysis tool or manually re-enter geometric information. This is more of a problem with the way the BIM authoring tool exports the information to IFCs as opposed to an issue with the schema itself. I have seen the same issue in the building energy performance analysis realm. Faulty BIM imported into building energy analysis software tools also produces inaccurate results.

According to some stakeholders, it would be ideal to be able to "roundtrip" the data from the BIM authoring tool to the analysis software tool and back. In other words, populate the IFC with geometry and occupancy information from the BIM tool, send it to a tool such as Pathfinder to perform simulation and analysis, and reimport results such as alarm time and peak occupancy back into Revit to be displayed throughout the model.

According to a team at the University of Greenwich in the UK, the IFC schema needs to be updated to better accommodate fire engineering workflows. A proposed update to the IFC schema is discussed below.

5.4.1 Evac4BIM Add-In

One example of work being done to improve interoperability and the IFC export from Revit is the Evac4BIM add-in which was discussed previously. Its main goal is to simplify the workflow of transferring a BIM from Revit into a consuming tool like Pathfinder or PyroSim.

While the idea behind Evac4BIM is noble, in reality it is a research project and not a truly commercial software tool, so it requires a lot of work to get it installed and working.

Jacob Mondora, the college intern who also worked on this SFPE Foundation research project (discussed in the Appendix) was tasked with getting the add-in to work properly. He experienced quite a few difficulties during the process. Despite thoroughly troubleshooting and extracting the necessary ZIP files to the correct location, he continued to receive pop-ups from Revit regarding missing features, errors, and more.

After contacting the creator of the add-in, Nazim Yakhou from Lund University, he was finally able to get the Evac4BIM ribbon to appear in Revit. However, he continued to get an error pop-up whenever he tried to use any of the functions, including initializing the project.

Finally, he realized that the issue was that Evac4BIM was not supported / compatible with Revit 2023 - it only was compatible with versions 2021 and 2022 of Revit.

Once he downloaded Revit 2022, Evac4BIM seemed to work in practice. However, there were problems when exporting the project file into Pathfinder:

- Despite naming the IFC files he wanted to export, it would automatically be saved as the project file name and overrode existing IFC files of the same name for the same project. This caused a lot of confusion, as it looked like the IFC export feature was not working correctly.

- Despite initializing the project and parameters successfully, none of the parameters would load into Pathfinder.

  o In other words, every time he went to load an exported IFC file from Evac4BIM, it would be the same as loading any other IFC file exported from Revit's default IFC exporter.

o He contacted the tool creator about this, who believed that the most probable option was that Thunderhead dropped support for the IFC schema of the Evac4BIM add-in.

As the reader can infer, the Evac4BIM tool has lots of potential to ease the flow of information flow between BIM and analysis tools but being so difficult to install and use hampers wide-spread usage of such an add-in.

6. Overall Recommendations for Workflow Enhancements

One of the primary goals of this research project is to provide suggestions for the improvement of BIM authoring tools, data schemas, interoperability, and FE software workflows to enhance the fire design and fire protection process. We have identified several common themes that are discussed in the sections below.

6.1 Software Findings and Suggested Improvements

6.1.1 BIM Software and Autodesk Revit

Based on research and conversations with FE stakeholders, the following is a list of suggested improvements to BIM authoring tools, specifically Autodesk Revit. This list also includes suggestions for companies on how to better utilize BIM:

- **FPE Ribbon:** Autodesk needs to create a dedicated Revit ribbon solely for fire protection engineering. This will reduce the need for FEs to license additional (and often times expensive) software. It will also show FE stakeholders that Autodesk is serious about helping develop tools for the fire protection industry.

- **IFC Exporting Capabilities:** Interoperability schemas like IFCs are discussed in much more detail below. Autodesk should improve its IFC exporting capabilities so that more watertight models (models without gaps or holes) can be exported.

- **Data and Databases:** Offer a comprehensive database of fire-rated materials and building systems, including detailed information about their fire resistance properties, such as:
    - Wall / floor materials
    - Sprinkler systems
    - Fire alarm systems
    - Exit lighting

- **Advanced Visualization & Modeling Tools:**
    - The addition of visualization tools inside Revit to accurately represent fire and smoke behavior would be welcome. This may be a pipe dream, though, since great stand-alone software tools already exist like Pathfinder and PyroSim.

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- o Allow integration with real-time sensor data to provide accurate information about fire and smoke conditions within the building during simulations. This is often referred to as a digital twin.

- **In-House BIM Manager:** If possible, A/E organizations should hire an in-house BIM manager who uses BIM authoring tools every day. This will allow for coordination of all the different trades to give better priority to fire design engineering, including better accommodating the fire engineering designs.

- **Educational Resources:**
  - o Include a repository of case studies and or best practices that showcase successful fire engineering projects accomplished using Revit.
  - o Provide comprehensive training materials, such as tutorials, that are specifically focused on using Revit for fire engineering. For example, Meyer Fire University[17] includes a subscription service for training videos on many aspects of fire protection design.
  - o Many resources exist on the Internet where users can learn how to use BIM authoring tools including:
    - ▪ YouTube training videos[18]
    - ▪ Autodesk University[19] recorded videos and transcripts
    - ▪ Resources from the many authorized Autodesk partners[20]

- **General Revit Recommendations for Autodesk:**
  - o Provide more visual cues and feedback within Revit to assist users with navigating the modeling process.
  - o Increase the time in between new releases of Revit, so that new users can fully get used to working in the current environment without constant changes and updates.

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[17] https://www.meyerfire.com
[18] Like this series for beginners: https://www.youtube.com/@CADinblack
[19] https://www.autodesk.com/autodesk-university/
[20] https://www.autodesk.com/partners/locate-a-resell

> o Continue to improve upon Revit's customizable workspace or offer a user interface that more closely resembles the AutoCAD environment.

6.1.2 FPE FE Analysis Software - Take Advantage of APIs

Software vendors should implement APIs (Application Programming Interfaces) into their software tools to allow for better customization. APIs are basically ways to allow software tools to be customized by end users to better accommodate workflows. They can be valuable for fire engineering software tools in many ways, enabling integration, data sharing, and enhancing functionality including:

- **Data Exchange:** Fire engineering often relies on data from various sources, such as architectural plans, building materials, and fire simulation data. APIs can be used to import and export data from these sources.

- **Simulation and Modeling:** APIs can connect BIM software to external simulation engines or cloud services for more accurate modeling.

- **Device Integration:** Fire protection systems often include various sensors and devices like smoke detectors, fire alarms, and sprinkler systems. APIs can be used to interface with these devices, allowing for real-time monitoring and control within the fire protection software (e.g., digital twins).

- **Collaboration:** APIs can be used to facilitate collaboration by connecting software with project management tools.

- **Machine Learning and AI:** APIs can be used to integrate machine learning and AI services. These technologies can help in predictive analytics for fire risk assessment, anomaly detection in fire protection systems, and optimization of fire safety strategies.

Why doesn't every software tool inherently include APIs? Because it is time consuming for software vendors to program API functionality into their software tools. Software vendors need to calculate a return-on-investment in terms of whether developing an API will bring in enough revenue to offset the work to implement them into their tools.

Fortunately, larger software firms are recognizing the importance of APIs. For example, Autodesk Platform Services (APS) [12] allows users to create applications that tie directly into

many of Autodesk's tools such as Revit and AutoCAD, thereby sharing information. In fact, at the time of this writing (Fall 2023), Autodesk just released the AEC Data Model API [13]. The AEC Data Model API allows developers to read, write, and extend subsets of models through cloud-based workflows. All these without the need to write custom add-ins for desktop authoring applications like Revit.
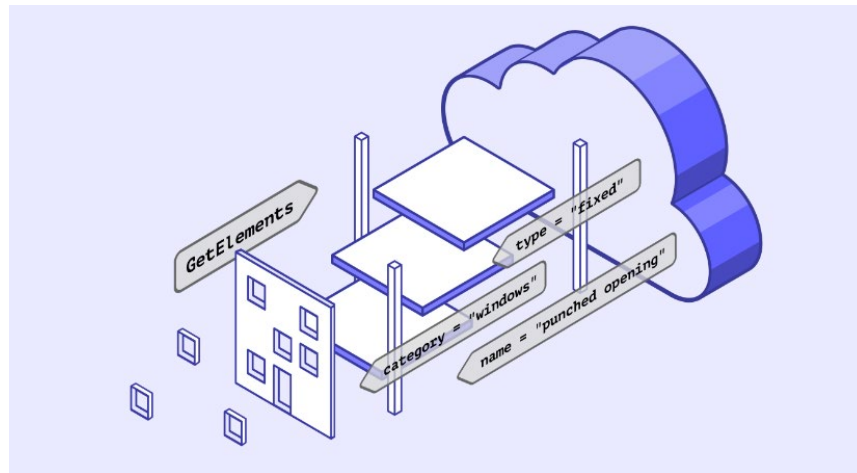

Figure 14. Representation of AEC Data Model workflow from cloud to desktop tool. Image courtesy of Autodesk. Reprinted with permission.

According to Autodesk [13], the AEC Data Model is built on three design principles:

- "**Extensibility:** This data model [allows users] to add their own classifications to reflect their workflows by adding custom data using basic and common data currencies.

- **Flexibility:** Flexibility is achieved through the different ways in which data can be related and categorized. For instance, a glass wall in a conference room may be regarded as both a window and a wall, such that it can be included both in the window schedule and as a room in the building's specifications.

- **Federation:** In addition to Properties, the AEC Data Model can store other data models, such as Analytical and Structural Models, Issues, Drawings, and Requests for Information."

APIs play a pivotal role in fostering interoperability since they serve as bridges that enable different software tools and platforms to seamlessly communicate and collaborate,

allowing developers to integrate diverse functionalities without delving into the intricacies of each underlying system. The work that Autodesk is doing is taking the burden of API development off the smaller software vendors by creating this AEC Data Model. This is all in the name of making it easier for end users like FEs to use these fire engineering workflows.

6.2 Data Findings and Suggested Improvements

It is imperative that fire engineering manufacturers design more usable families including ones that are not super heavy and detailed. Revit families do not need to represent every bolt and screw on a pump. Instead, Revit families need to represent the important information such as inlet/outlet locations, centerlines, and sizes.

The following are suggestions to manufacturers to improve the creation and design of Revit families:

- **Standardize:** All equipment manufacturers should use the same conventions and standards when designing their Revit families. This will make it easier for designers and engineers to compare and select equipment from different manufacturers. There are guidelines from Autodesk ("Best Practices for Modeling Revit Families" [14]), ASHRAE (i.e., ASHRAE RP-1801 [15]) and CIBSE that provide standard parameters that should be used for many different types of HVAC and related equipment.

- **Parametric Flexibility:** Revit families should ideally be highly parametric, allowing users to modify various parameters to match specific project requirements.

- **Simple Geometry and Smaller File Size:** Revit families should be simple and light.

- **Sufficient LOD (Level of Detail):** Revit families should have different levels of detail to accommodate various project stages. Some equipment manufacturers may provide families with limited LOD options, which can result in overly detailed or simplified representations, depending on the project phase.

- **Maintain a Consistent Naming Convention:** Use consistent and descriptive names for parameters, types, and families to make it easier to identify and locate elements in the project.

- **Create and Manage Parameters:**

  o Add relevant parameters to families to enable flexibility in controlling dimensions and properties.

  o Use shared parameters for information that will be scheduled or tagged.

  o Group parameters logically within the family and use prefixes or suffixes to indicate their purpose.

- **Establish Reference Planes:** Utilize reference planes for aligning and controlling the geometry of the family and allowing piping to easily line up with pump inlets and outlets.

- **Use Constraints:** Apply constraints to ensure that the family adapts correctly to the project environment, allowing for parametric changes.

- **Maintain 2D and 3D Geometry:** Incorporate both 2D and 3D geometry to ensure that families look accurate in floor plans, elevations, sections, and 3D views.

- **Use Nested Families:** Utilize nested families to organize complex components or to improve the parametric control of a family.

- **Recommended Features for Fire Engineering Families:**

  o *Realistic but not over-realistic visualizations.* Develop families with good-quality visual representations that are not overdesigned.

  o *Compliance checks.* Add in parameters that automatically check fire safety components for compliance with codes and standards, helping users ensure their designs adhere to current regulations.

- o *Information integration.* Embed additional information within families like manufacturer data, testing certifications, and links to relevant standards and regulations for reference.

The following is a list of suggestions for fire engineers utilizing Revit families in their projects:

- **Use the Right Family Template:** Choose the appropriate family template based on the category of the element that is being created (e.g., wall, door, window, furniture, etc.).

- **Customize Families When Needed:** Users may not find a perfect match for a particular element in the manufacturer's content library. In such cases, Revit users can customize families or create simpler versions to match project-specific requirements.

- **Regularly Update Families:** Ensure that families are up to date. As designs evolve, families will need to be modified or replaced.

- **Learn to Properly Use Revit Families:** There are two types of Revit families: instantiated and referenced.

  - o *Instantiated families* are those that are actively placed or used within a Revit project. When the user places a door, window, furniture, or any other building element in a project, the family is instantiated.

  - o Many users do not realize that families can be referenced as opposed to instantiated. *Referenced families* are those that are linked into a Revit project but not directly placed or used within the project. They exist in an external file, often referred to as a "family file," and users link them into the project file as a reference. This takes up much less memory than instantiated families.

6.3 Interoperability Findings and Suggested Improvements

6.3.1 IFC Schema Update

According to a team at the University of Greenwich, Lund University, and University of Canterbury headed by Asim Sidiqqui and Peter Lawrence, and assisted by Peter Thompson, the

IFC schema needs to be updated to better accommodate fire protection engineering workflows [16]. Therefore, they are proposing Occupant Movement Analysis (OMA) and Fire Safety Engineering in the IFC Information Delivery Specification (IDS) [17].

The IDS defines a subset of the IFC schema that is needed to satisfy one or many data exchange requirements of the building industry. The method used and propagated by buildingSMART to define such exchange requirements is the information delivery manual (IDM). An IFC IDM defines a legal subset of the IFC schema (being complete) and provides implementation guidance (or implementation agreements) for the IFC concepts (classes, attributes, relationships, property sets, quantity definitions, etc.) used within this subset. It represents the software requirement specification for the implementation of an IFC interface to satisfy the exchange requirements.

In the first phase of the project, process maps of the three identified use cases have been produced. Also, broad categories of the required data exchange have been identified. The next phase of this project is currently underway (Fall 2023), and it will include the identification of specific data properties for each data category based on a review of multiple pedestrian modeling tools.

The data exchange specification development work on enhancing support for OMA in the IFC Model will offer several potential benefits for the stakeholder (e.g., regulators, fire engineers, owners/clients, construction companies/builders, consultancy firms, etc.) producing a more robust plan. Some of the key benefits are summarized below:

- **Audit Trail:** Information relating to the OMA process, including records of inputs, outputs, and assumptions.

- **Compliance Checking:** Access to full information on OMA data and potentially facilitate automated compliance checking.

- **Decision Making:** Preserves and tracks the information relating to the association between the OMA and the building's design, throughout the design process and life cycle.

- **Automation:** Development of enhanced software tools to manage the OMA processes and smart building capabilities.

- **Safety:** Ensure all stakeholders understand the logic relating to the OMA related design aspects.

- **Cost Savings:** Identify OMA issues sooner to avoid costly changes later in the project.

- **Time Saving:** Streamline the process of data sharing between stakeholders.

6.3.2 Evac4BIM Add-In

The Evac4BIM add-in discussed in multiple places in this report is a potential solution to the interoperability issues discussed above. However, as mentioned previously, this add-in is currently a university research project, so it requires a lot of work to get it installed and running properly. Handing this add-in over to a commercial software company to improve its installation process and fix its bugs is the recommended path forward.

6.4 Additional Findings and Suggested Improvements

One of the goals of this research project is to suggest improvements to the BIM and FE software workflows used by fire engineers. In each of the sections above (software, data, and interoperability), we discuss possible solutions for each of these themes. However, according to some stakeholders that were interviewed, there needs to be a more holistic view of BIM and FE software workflow improvements.

6.4.1 Better Coordination with Architects

One suggestion is that SFPE needs to improve their engagement with architects. The reasons for this are multifold:

- Architects play a crucial role in building design and construction.

- Engaging architects early in the design process allows fire protection engineers to influence decisions related to building layout, materials, and structural elements.

- Architects are responsible for ensuring that buildings adhere to local building codes and regulations, including those related to fire safety.

- Architects often participate in code development committees and organizations.

Marketing toward architects is a strategic move for SFPE because architects are key stakeholders in the building design process. One idea is to form a partnership with the American Institute of Architects (AIA) to make the industry more aware of fire engineering design. By establishing strong connections with architects, SFPE can promote a holistic approach to fire protection and contribute to safer, more fire-resistant buildings. Going a step further, together SFPE and AIA, coordinating with enterprise level architects, could attempt to influence development of dedicated fire engineering tabs or other features in the major BIM tools like Revit. A similar strategy was successful in the past when multiple professional architect organizations based in Europe sent an open letter to Autodesk [18,19].

6.4.2 Better Coordination with Other Trades

One stakeholder mentioned that designing fire protection systems in BIM is difficult since stakeholders need to coordinate not only with mechanical, electrical, and plumbing (MEP) but also with structural elements. Also, fire protection systems are usually designed after the MEP and structural are designed so this causes many coordination issues that MEP engineers do not have to worry about. He believes that fire protection design should occur sooner in the lifecycle of the design process.

7. The Future of FE Software

7.1 Artificial Intelligence

In our talks with stakeholders, we also saw the future of FE software. For example, CodeComply[21] from SLS Fire is working on a software tool that runs in BlueBeam and uses AI to allow users to identify code deficiencies and verify compliant designs. It automatically generates a list of non-compliant items and allows users to verify compliance throughout the building.

Figure 15. Building floorplan in Bluebeam with CodeComply.AI. Credit: CodeComply.AI. Reprinted with permission.

CodeComply.Ai currently supports various editions of the IBC and the NFPA 101 Standard, "Life Safety Code" [20]. Compliance solutions include:

- **Occupant Load:** The total number of people that are expected to occupy an area.

- **Egress Capacity:** The total number of people that the exits can accommodate.

- **Exit Separation:** The minimum distance required between two exits to ensure that at least one exit is always available.

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[21] https://www.codecomply.ai

- **Travel Distance:** The maximum allowable distance that a person can travel from their location in a building to the nearest exit.

- **Common Path:** The maximum allowable distance that a person can travel before access to two distinct paths leading to separate exits are available.

7.2 Robotic Total Station

The author was made aware of a technology called a robotic total station that could be utilized by fire engineers in addition to the traditional MEP trades. This is a highly advanced surveying instrument used in the field of land surveying, civil engineering, construction, and various other applications where accurate measurements and data collection are crucial. In construction, it is used to establish precise reference points and layout markings on construction sites. One stakeholder mentioned that most of the trades are using robotic total station technology, but fire protection contractors are not.

Figure 16. U.S. Air Force Senior Airman Michael, an engineer technician, uses a robotic total station at Kadena Air Base, Japan. Credit: Naoto Anazawa. Public Domain.

Fire engineers could use the data derived from a robotic total station to plan the installation of fire sprinklers, alarms, and other fire protection equipment. This would ensure that the systems are installed in the right locations and with proper clearances.

In addition, a robotic total station could be used to survey evacuation routes and analyze the accessibility of exits during a fire emergency. Engineers could use this information to optimize evacuation routes.

7.3 BIM-Controlled Signage

Yenumula et al. [21] propose a BIM-controlled signage system to solve the problem of multiple exit signs leading to different directions and causing confusion. With the help of heat sensors that detect the fire prone areas in the building, the proposed system identifies the best route and activates the corresponding sign blinkers with high intensity. Think of this as a digital twin working in real-time leading occupants to safety as smoke and fire engulf a building.
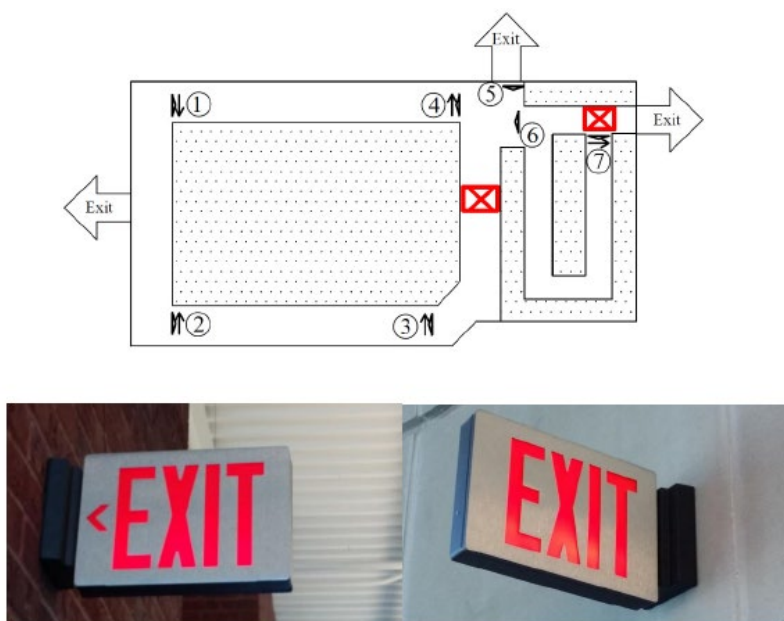

Figure 17. Schematic of a BIM-controlled signage system. The floor being evacuated has 7 exit signs, some of which are directional (left exit sign) and some of which are un-directional (right exit sign). Signs would activate or deactivate according to the conditions of the fire scenario, e.g., location of the fire. Credit: Yenumula et al. CC BY-NC-ND.

Basically, the challenge is that the absence of facility management and inappropriate guidance poses a threat to building occupants. While a building might meet fire safety codes, it all comes down to the behavior of occupants during a smoke and fire event.

Because occupants are under stress, the signage system must be very easy and intuitive to understand and follow. Basically, BIM-controlled signage works as follows:

1. Once a fire is detected using Internet of Things (IoT) sensors connected to the BIM digital twin, it will detect the location of the fire and smoke and reflect it in the indoor route network.

2. This indoor route network is extracted from the BIM and includes information about the signage.

3. The indoor route network will then control the signs and direct occupants to the closest exit, acting almost as a virtual guide toward safety.

7.4 Digital Twins

The term "digital twins" (DT) has been used sporadically throughout this report. Digital twin software is a technology that creates virtual representations (in Revit, for example) of physical buildings and infrastructure. It combines real-time data from physical entities with advanced simulation and analysis capabilities to mirror their behavior and performance in a digital space. Some key aspects are:

- **Virtual Replication:** Digital twin software generates a detailed digital counterpart or twin of a building. This twin replicates the physical entity's behavior and characteristics.

- **Real-Time Data Integration:** It integrates real-time data from various sources using sensors, IoT devices, or other data collection mechanisms. This data is used to update and refine the digital twin.

- **Monitoring and Control:** Digital twin software allows for remote monitoring and control of physical assets or processes through their digital representations.

When applied to fire protection engineering design, digital twins can be quite useful. It can be used for:

- **Design Optimization:** It can help assess the structural integrity of a building during a fire assuming the proper sensors are incorporated. It can also optimize escape route designs like those discussed above.

- **Risk Assessment:** By integrating sensors with a digital twin, it can enable the development of early warning systems in the event of a fire and smoke.

- **Performance Monitoring:** Post-construction, digital twins can monitor the building's fire safety systems and provide real-time feedback on the status of the sensors and monitors.

Digital twin software is constantly changing and improving. Leading the way are companies like Autodesk with their Autodesk Tandem [22] virtual twin platform.

8. Conclusion

This research project on building information modeling (BIM) integration with fire engineering software represents an effort to understand the power of digital technology for enhancing fire safety in buildings. While BIM authoring tools can help with the basic design and communication side of fire engineering, dynamic simulation software helps engineers gain the ability to simulate fire scenarios, assess fire risks, and optimize fire protection systems in a more efficient and accurate manner. This integration between BIM and simulation software provides a comprehensive understanding of a building's fire safety features, leading to enhanced protection and more effective decision-making. One of the key benefits of this integration is its ability to facilitate collaboration among multidisciplinary teams working on a construction project.

In theory, these workflows sound seamless and efficient. In reality, these workflows are fraught with many problems that discourage FEs from using BIM. These issues and problems were discussed in each of the sections talking about software, data, and interoperability. At the end of this report, suggestions for improving workflows were highlighted.

In conclusion, BIM integration with fire engineering software represents a potentially transformative leap in the field of fire safety. It allows engineers and professionals to leverage advanced digital tools for designing, analyzing, and optimizing fire protection systems, all within the context of a holistic BIM environment. This integration offers enhanced collaboration and accuracy, ensuring that buildings are not only aesthetically pleasing and structurally sound but also equipped with the most efficient and reliable fire protection solutions available. By implementing the recommendations in this report, FEs will be able to enhance their daily workflows when using BIM authoring and simulation software tools.

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Appendix

College Dormitory Fire Safety Analysis

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Abstract

During the summer of 2023, I assisted Carmel Software Company on the research project, *BIM Integration Research Project,* through the SFPE foundation. The primary goals of this research project included understanding the "enhancements needed within BIM, interoperability data schemas, and fire engineering software tools to facilitate better use of these workflows." My work specifically involved learning a wide range of complex fire engineering software applications, including Fire Dynamics Simulator (FDS) & PyroSim/Pathfinder by Thunderhead Engineering, and how these software applications interact with (or fail to interact with) BIM (building information modeling) software, specifically Revit. To apply my knowledge of these software applications, I created two sample college dormitories using Revit that I used to perform my own fire safety simulations/analysis.

Objectives

- Create two sample dormitories similar in structure & dimensions, but varying in number of exits, stairways, and doorways.

- Export an IFC file from this Revit project into Pathfinder software to perform analysis and simulation.

- In Pathfinder, observe occupant movement throughout the two buildings during evacuation, and compare occupant exit times, occupant densities (especially surrounding doorways and exits), and occupant routes.

  o Does an extra staircase significantly reduce occupant evacuation times?

o   Does the addition of extra doors and exits placed on the ground floor of these structures significantly reduce occupant density during evacuations, or is it the placement of exits that is more important?

Procedure
Revit

Most of the time spent on this project involved the creation of the structure in the Revit software. As someone new to BIM and Revit, I quickly realized that careful planning was essential to having a successful structural model that could be used for simulation later. To adequately account for all extraneous variables that could affect fire spread, occupant evacuation times, and more, I wanted to make sure that these two dorms were very similar in dimensions and features (other than the number of exits and staircases present). Therefore, we can assume that the differences in evacuation data and fire spread can be attributed to the building features in question.

Both buildings have four floors that are exactly twelve feet tall. The ground floors of both buildings each have a select number of dorm rooms on one side of the floor. I created a series of rooms on both ground floors that are representative of bathrooms, common areas, laundry rooms, storage rooms, and more. The two ground floors within the buildings are connected via an exterior building, which allows occupants to travel between the two buildings without needing to go outside. Both ground floors are 85 x 85 feet, and the top three floors of both structures are 99 x 99 feet, which gives occupants a 7-foot shaded "walkway" on all sides of both buildings. The top three floors of each building are identical.

The exterior of each floor is surrounded by exactly eighteen dorm rooms and a common room, which leads out to a small balcony. Although the dimensions are not identical for each room, most non-corner rooms tend to measure approximately 16 x 15 feet. Corner rooms on each floor of both buildings are larger, measuring about 20 x 20 feet. In the center of the top three floors for each building, there is a restroom area with two exits on each side, a kitchenette space, and miscellaneous/storage area. First-floor dorm rooms have two exits (one to their corresponding hallway and one leading to a shared "bathroom"), whereas dorm rooms located on all other floors only have an exit leading to the main hallways. I purposely designed wider

hallways (~7-10 feet wide) so that occupant crowding would not occur due to crammed halls (which would confound with the other variables).

Lastly, it is important to note the key differences between the two structures. As shown, one dormitory has two staircases (and therefore an additional exit per floor), as well as six different ground floor exits. This compares to the second dormitory, which only contains one staircase, and three ground floor exits. Shown below in Fig. A1 are the ground floor and top floor plans on the two structures in Revit. Doorways, walls, and staircases are all indicated in these floor plans.
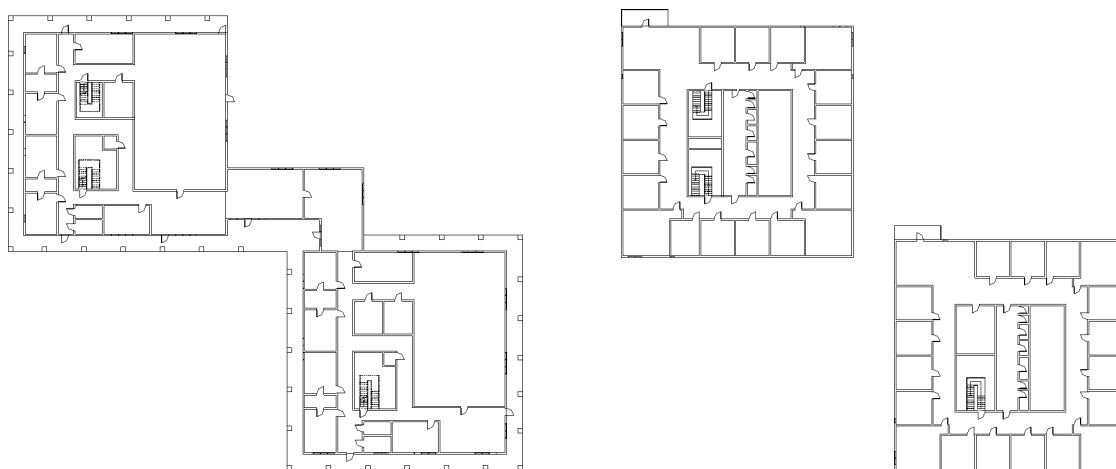
Figure A1. Floor plans for model connected dormitories
in Revit., ground floor (left) and top floor (right).

Fig. A2 shows two different 3-D views of the two structures in Revit.
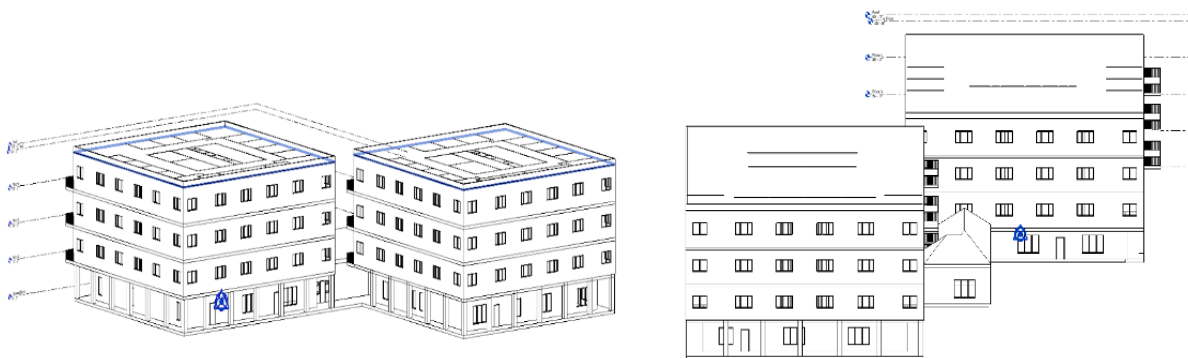
Figure A2. 3-D views of model dormitories in Revit.

Pathfinder

One very helpful feature of Pathfinder is that it allows for many model visualization options for users. Standard, Solid, and WireFrame are some of the viewing options that I used throughout this project to analyze my Revit model (Fig. A3).

Figure A3. Model viewing options in Pathfinder. L-R: Standard, Solid, and WireFrame.

After exporting the IFC file of the model from Revit into the Pathfinder software, I spent most of the time preparing the model for simulations and fixing any errors in the model that I came across. First, I had to extract each room manually (hallways, dorms, stair landings, etc.), as Pathfinder was unable to do so on its own. (However, it can recognize each floor of the structure.) After hiding the imported geometry, I then needed to specify where the door exits were (despite already doing so in Revit) and manually replace the doors in Pathfinder, or else occupants would become "stuck" during the simulations. Finally, I replaced each staircase so that occupants would be able to move down them during the simulations. It is important to note that while these were simple tasks, they still proved to be tedious, since they required constantly hiding surrounding elements in view (walls, windows, etc.) to see the model correctly. Shown below in Fig. A4 is the model with and without the imported geometry. The different shapes and figures on each floor represent separate rooms, and each highlighted green and orange line represents doorways.
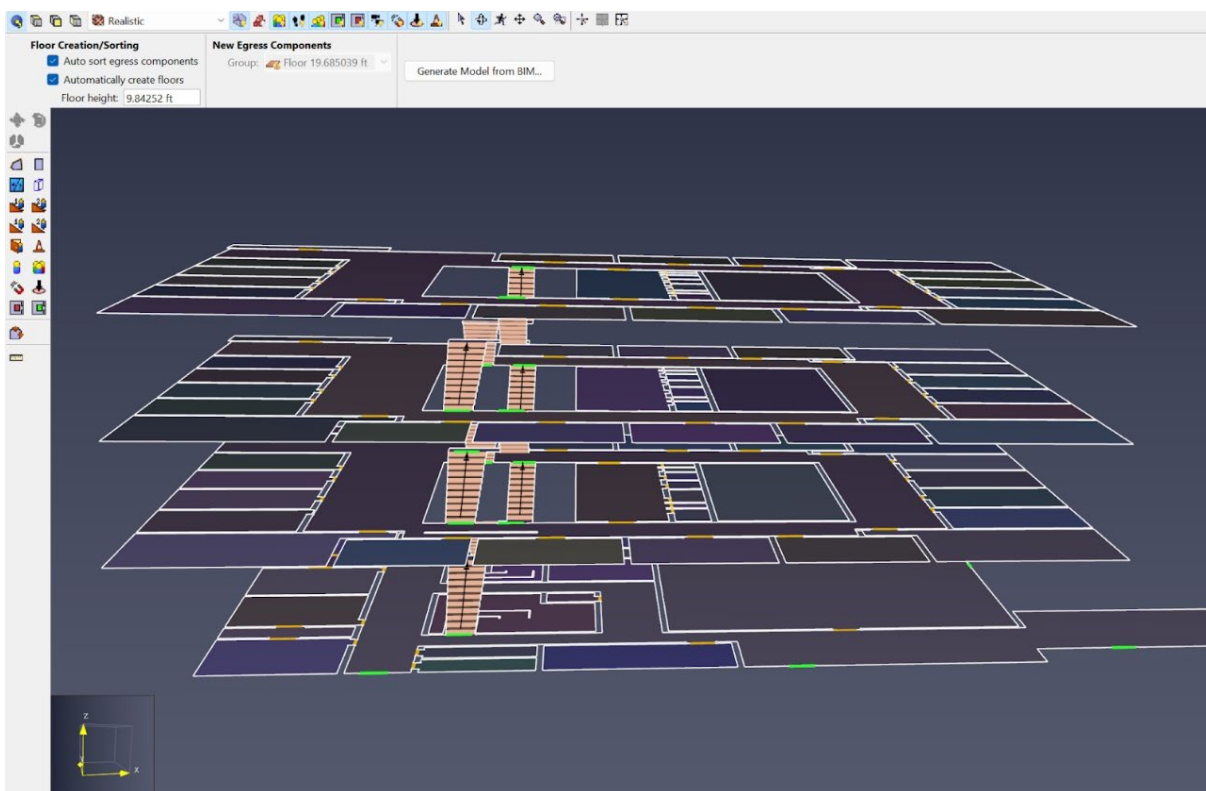
Figure A4. Pathfinder model with and without the imported geometry. The different shapes and figures on each floor represent separate rooms, and each highlighted green and orange line represents doorways.

Next, it was time to place occupants throughout the dorm structure. To ensure accuracy in the simulations run for each dorm, I specifically assigned each dorm room two occupants, each hallway five occupants, and each bathroom seven occupants for all floors except the ground floor. On each ground floor, I put two to five occupants in each room (except for areas representative of storage closets) and twenty occupants spread out throughout the common rooms and hallway system. Note that within each room, all occupants were randomly distributed. I also assigned a special behavior to all occupants, so that all would only be able to exit the structure through the appropriate ground doors. (This step was necessary due to some "gaps" in the model when exported into Pathfinder, such as the floorless surface under the staircase system that Pathfinder deemed a suitable exit for occupants.)

Once the occupants were placed, I then had to deal with the errors that were occurring in my model during the simulation. Because Pathfinder did not specify what the errors were in my

model, it took some trial and error to determine what needed to be fixed. Using the Wireframe viewing option in Pathfinder, I was able to observe that many occupants were becoming stuck in the stairs, due to the placement of Pathfinder doors that didn't exactly align with the staircases in the model. After completing the processes of setting up the simulations and fixing errors in the model for both dorm structures, I was then ready to run separate simulations of occupant evacuations for each dorm. Fig. A5 shows the model ready for simulation (the blue cylindrical figures represent occupants).
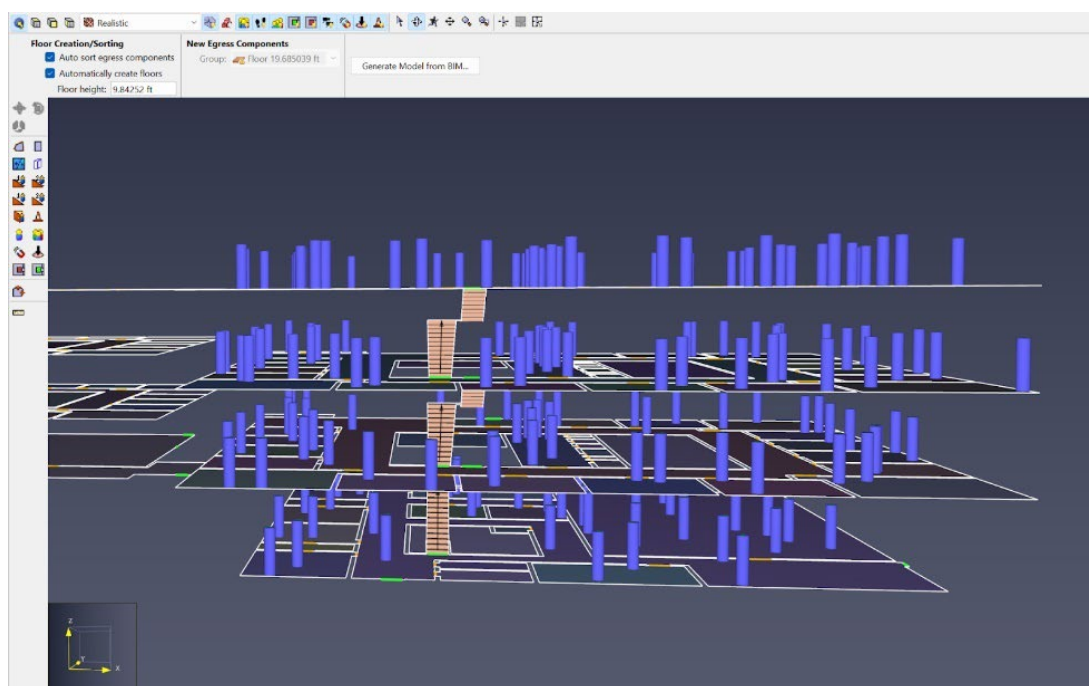
Figure A5. Pathfinder model suitable for simulation. Blue cylindrical figures represent occupants.

Fig. A6 is an image from during the simulation. I set the view to Wireframe Render so that I could carefully observe occupants & their paths while fleeing the building. The simulation view is very similar to the interface, making them easy to run once one understands the fundamentals of using Pathfinder.
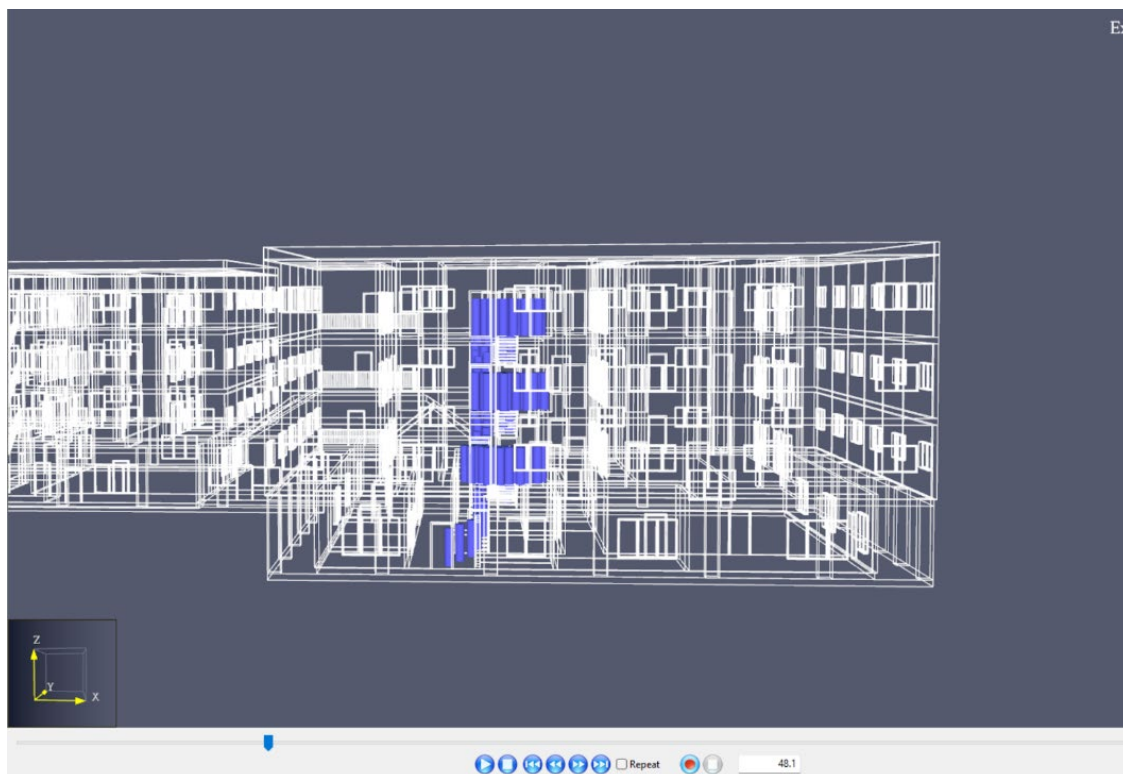
Figure A6. Wireframe render of model during simulation. Occupants (blue cylindrical figures) are exiting the building.

Analysis and Results

After creating the model and preparing it for simulation, it was finally time to analyze the results, and determine whether the addition of stairs and exits would improve occupant evacuation time and efficiency. To reiterate the differences once again between the two dormitories, I have included two images below. Fig. A7 indicates the stairway systems by red circles, showing that dormitory A has two staircases, while dormitory B relies on only one staircase to connect each floor.

Figure 7A. Red circles indicate stairway systems on ground floors of model dormitories.

Fig. A8 shows the difference in the number of exits to the outside on the ground floor. Dormitory A has a total of six exits (indicated by the black circles), while Dormitory B only contains three exits (indicated by the red circles). Before performing the simulation, I suspected that the number of exits would be irrelevant in evacuation times compared to their distances from the staircase(s). This proved to be the case, as we will see shortly.
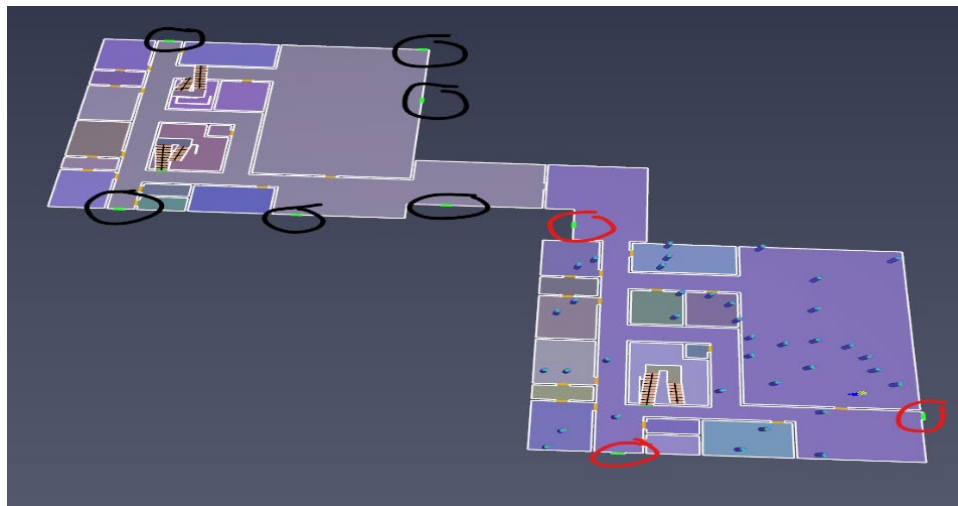
Figure A8. Dormitory A has six exits (circled in black), while Dormitory B only has three exits (circled in red).

Now, let's look at the evacuation data and how it differs between the two dormitories. Dormitory A contained exactly 188 occupants. When the simulation was run, it took just over

130.0 seconds (2 minutes, 10 seconds) for all occupants to evacuate the building. Furthermore, we can see that starting at around 20 seconds into the evacuation, the slope of Fig. A9 (showing time versus number of occupants) became mostly linear and slightly decreased (closer to zero).
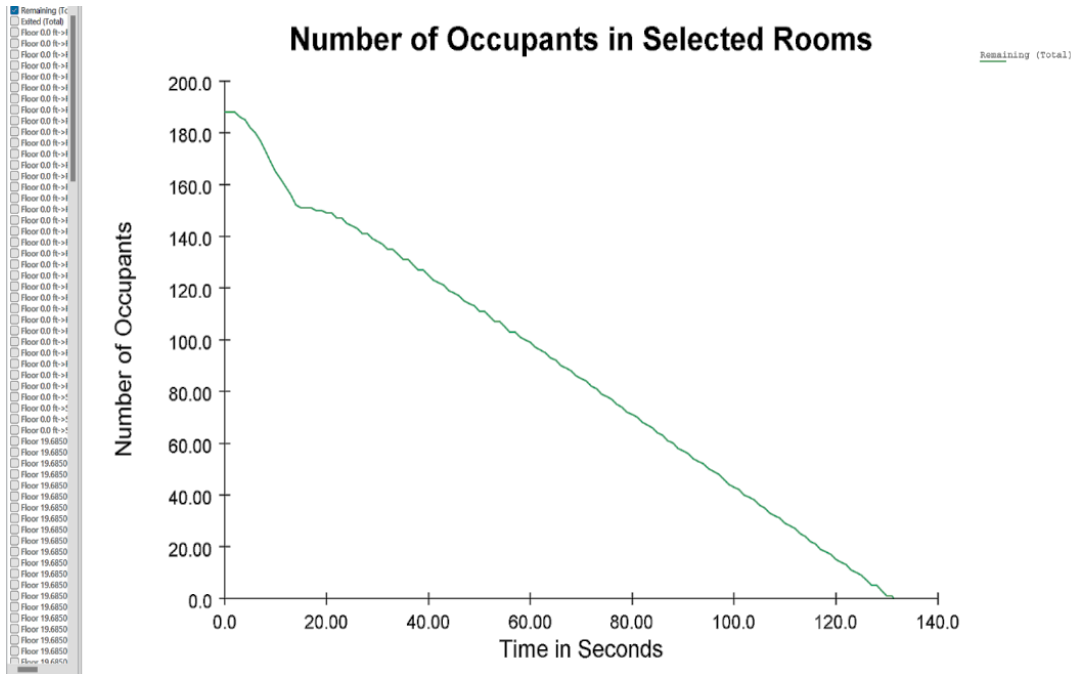

Figure A9. Pathfinder simulation occupant evacuation times for Dormitory A.

This is probably because the occupants exiting first were from the ground floor, and therefore had a much quicker axis to multiple exits. Due to crowding in the doorways, as shown in Fig. A10, the occupants evacuating from the top three floors exited uniformly, rather than in clumps. Still, the crowding seemed to not cause a huge delay in evacuation times, as the density of occupants only reached 3 per square meter in very select areas surrounding the staircase doorways.
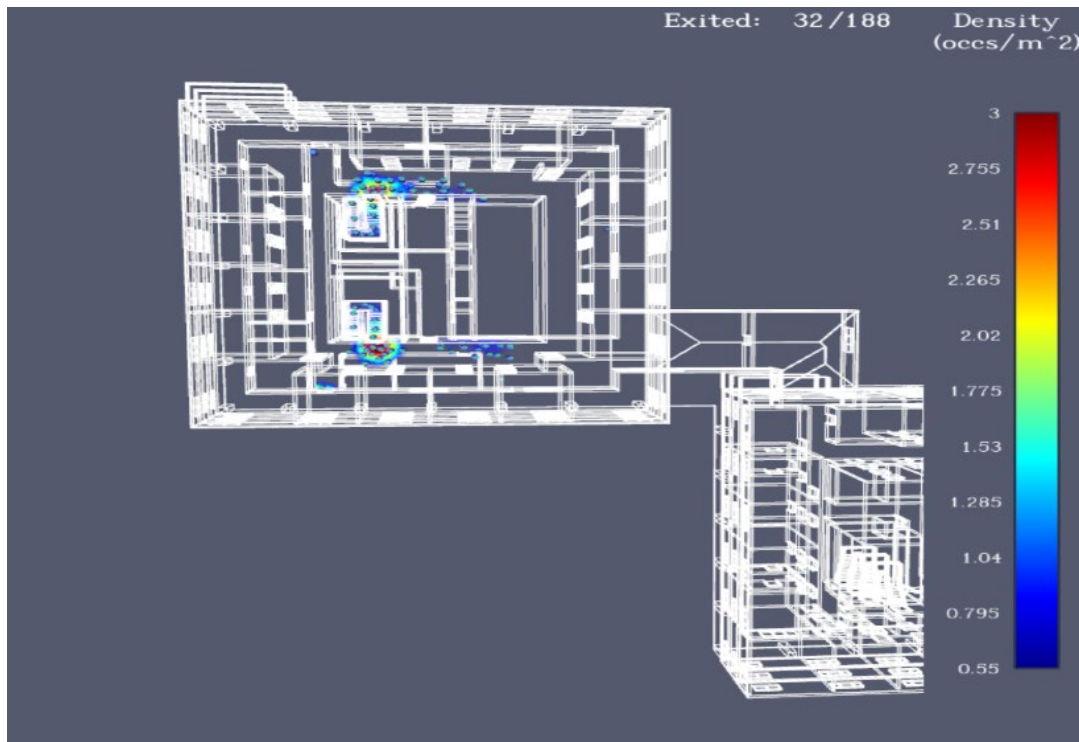
Figure A10. Pathfinder simulation occupant density heatmap for Dormitory A.

Now, let's analyze the door usage during the evacuation of Dormitory A. We only care about the six exits that connect the ground floor to the outside of the building. Based on the data, Doors 18, 192, 21, and 22 were only used by occupants on the ground floor, as there was no traffic recorded after forty seconds. However, doors 17 and 19 continued to experience traffic until the end of the simulation, which is expected, since these two doors are closest to the two sets of staircases. Therefore, we can conclude that exits close by to staircases in this building were essential in reducing evacuation times for occupants on the top three floors.
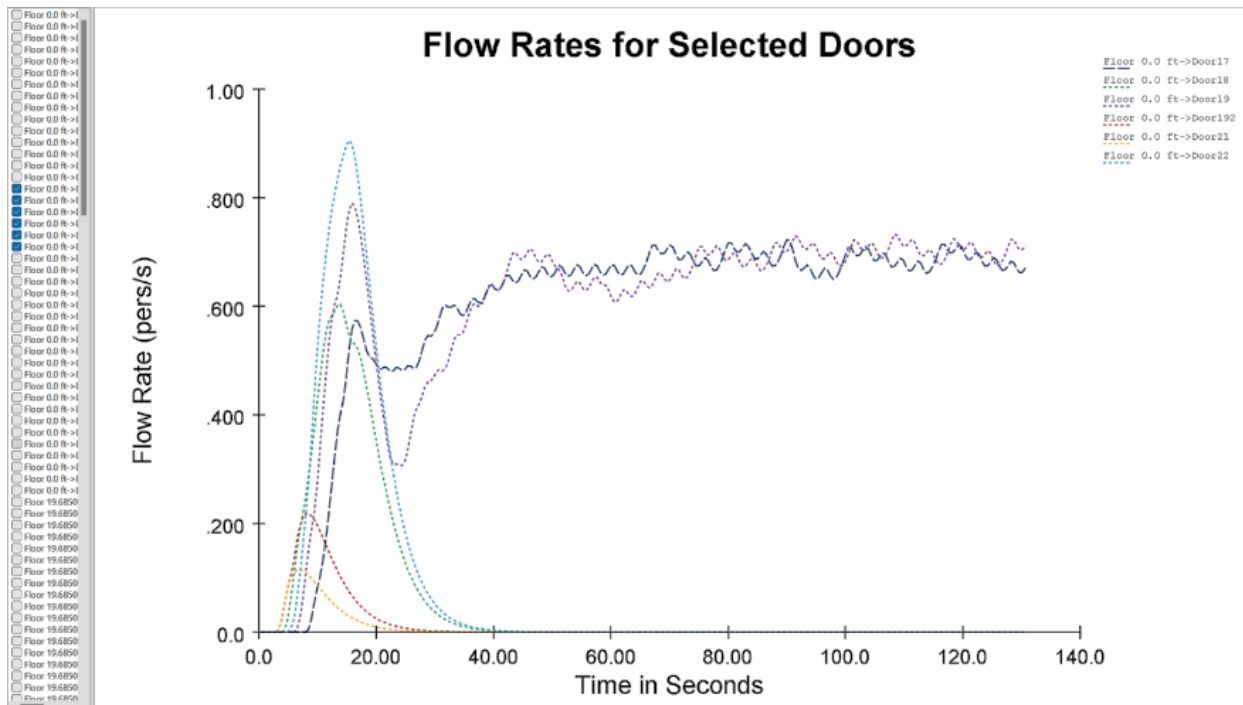
Figure A11. Pathfinder simulation selected doors flow
rate for Dormitory A.

After running the simulations on Dormitory A, I then ran separate simulations on Dormitory B and compared the results. As shown below in Figs. A12 and A13, the lack of a second staircase system in Dorm B significantly increased evacuation times and hindered evacuation efficiency. Compared to Dorm A, it took almost twice as long (approximately 240 seconds, or 4 minutes) for all occupants in Dorm B to successfully exit the building. Furthermore, the ground floor occupants were still subjected to slower evacuation times (~25 versus 10 seconds) due to fewer exits located on the ground floor (3 versus 6 exits).
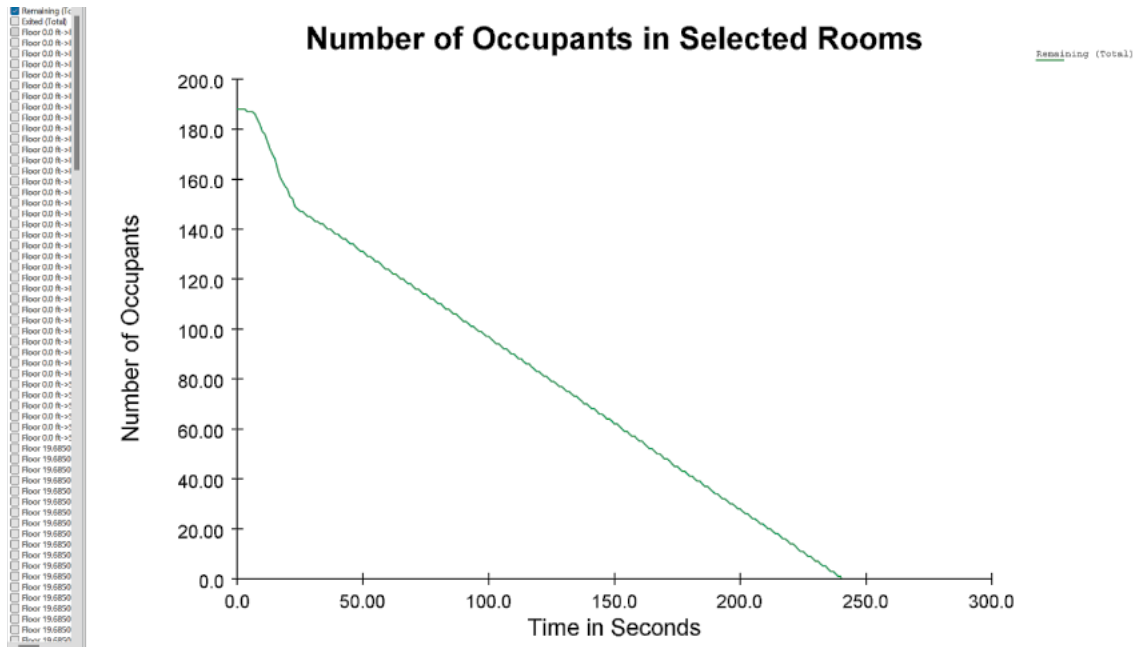
71

Figure A12. Pathfinder simulation occupant evacuation times for Dormitory B.

Fig. A13 shows the density heatmap for Dormitory B around the single staircase during evacuation. Compared to Fig. A10, there is intense crowding on and near the stairs (3 occupants per square meter).
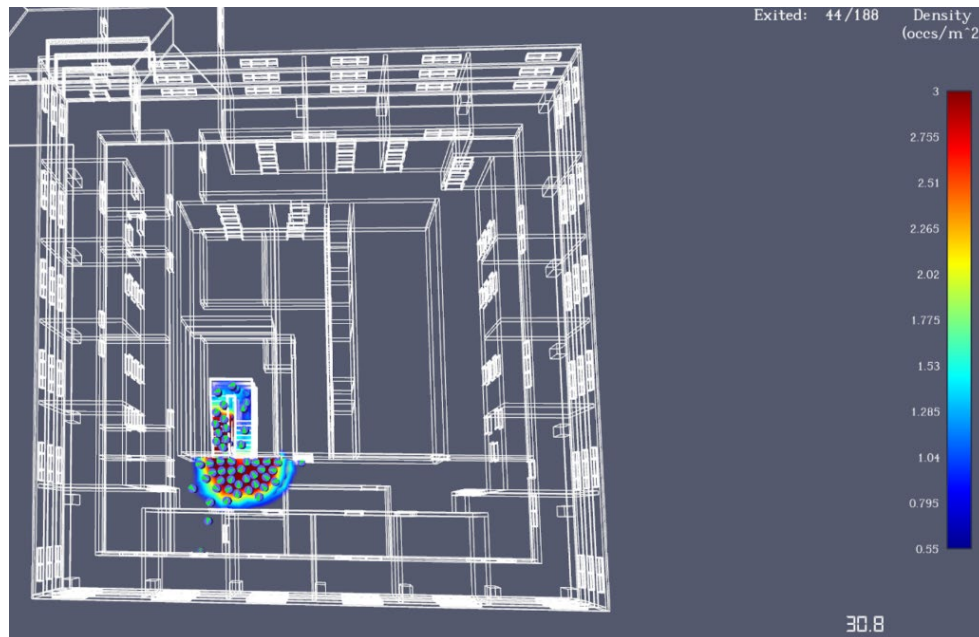

Figure A13. Pathfinder simulation occupant density heatmap for Dormitory B.

Finally, let's take a look at the flow rates for the three ground floor exits within Dormitory B. Based on the graph in Fig. A14, it is clear that Exit 2A was used by top floor occupants, as it was in close proximity to the staircase. The ground floor occupants, on the other hand, seemed to split up, with some using Exit 2B and others using Exit 2C. Compared to the information shown in Fig. A11, we can see that the ground floor occupant evacuation times were surprisingly only slightly shorter due to the shortened number of exits. Instead, it seemed that the placement of exits should be prioritized over the amount of exits in structures like these models. Note that the top floor occupants also did not seem to be affected by exit placement since there was an exit in Dorm B near the single staircase.
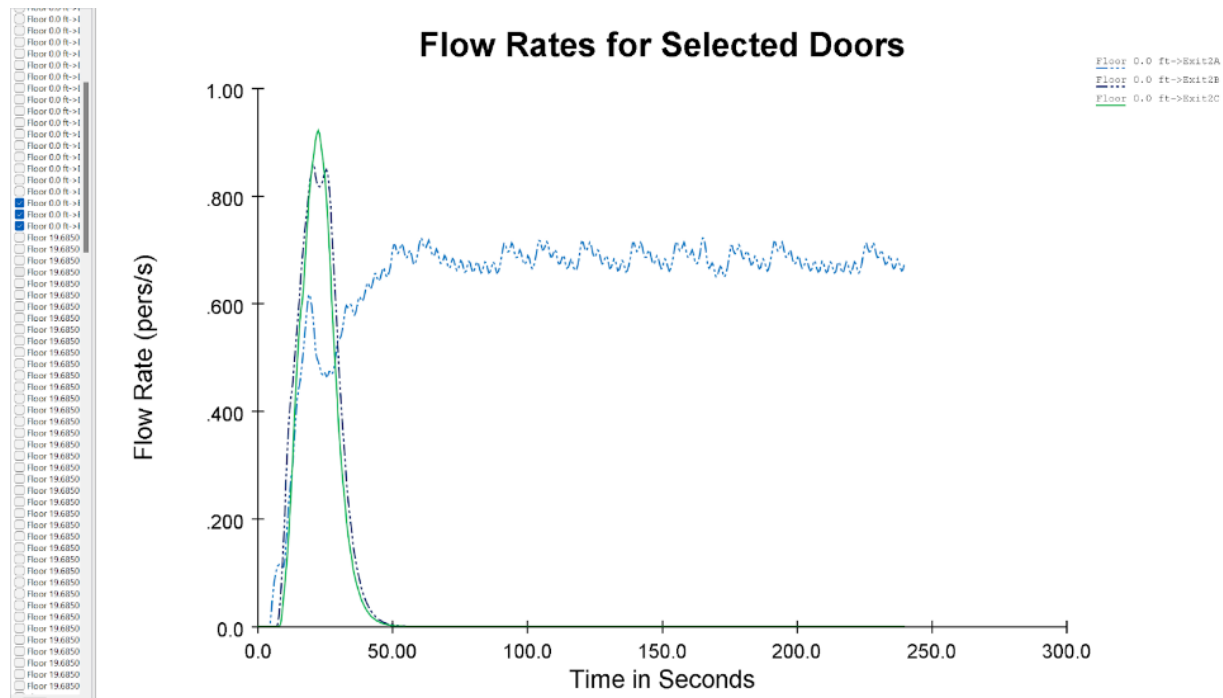

Figure A14. Pathfinder simulation flow rates for selected doors for Dormitory B.

In short, by using BIM software (Revit) and fire safety simulation software (Pathfinder), we can conclude that the number of staircases and placement of exits must be optimized to maximize the safety of building occupants in the event of a fire emergency. To ensure the safety of ground floor occupants, many exits should be placed uniformly throughout the exterior of the building. For top floor occupants, there should be multiple (depending on the building size) staircases that closely connect to exits on the ground floor.

Additional Comments

In addition to using these workflows to understand the fire engineering process and gain hands-on experience, this project also served to document and understand the limitations, obstacles, and challenges I experienced during my work to help Carmel Software provide insightful recommendations for improving BIM and other software for fire engineering.

First, I believe it would have been easier to expand upon the findings of this research project if there was a way to export simulation data and occupant information back and forth between Revit and Pathfinder. While Evac4BIM is an emerging Revit add-in made for such purposes, it is not yet ready for broad use, and a built-in Revit feature would be much more convenient.

Second, software that could combine the capabilities of both Pathfinder and PyroSim (which is a fire simulation software by Thunderhead Engineering) would make it much easier to create realistic evacuation scenarios. For example, my simulations assumed that all available exits and stairways were safe for occupant evacuation. If I was able to simulate a fire in a specific room or area during evacuation, this would alter the paths of nearby occupants, changing the data.

Finally, I felt that there was a great deal of tedious and repetitive work required to prepare the model in Pathfinder for simulations. It took a significant amount of time to manually mark floors, staircases, and exits from the imported geometry. If Pathfinder was able to do this automatically, it would have saved up to a couple hours of time in this process. Despite raising these concerns, however, I believe that BIM software (especially Revit) is a valuable tool that should be taken advantage of in the discipline of fire engineering.