Sharing Fire Engineering Simulation Data Using the IFC Building Information Model

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Keywords: *Fire engineering, Simulation, Interoperability, Building information modelling*

EXTENDED ABSTRACT

Fire engineers use computer-based fire simulation models to determine the spread of fire and smoke; the response of a structure to high temperatures and the movement of people exiting from a building. The standardised Industry Foundation Classes (IFC) Building Product Model can be used to begin to achieve interoperability between electronic building descriptions created in commercially available Building Information Modelling (BIM) applications and fire simulation models.

Two mainstream BIM applications, ArchiCAD and Revit, have been used to generate IFC compliant files that are translated by a parsing software tool into input files for two fire simulation models widely used by fire engineers, BRANZFIRE and FDS. The specific needs of fire simulation software means that a software tool has been developed to parse the IFC Model from the STEP physical file format to generate a subset of fire simulation related entities. This intermediate data is used by dedicated software interfaces developed to create specific input data for different fire simulation models (Figure 1).

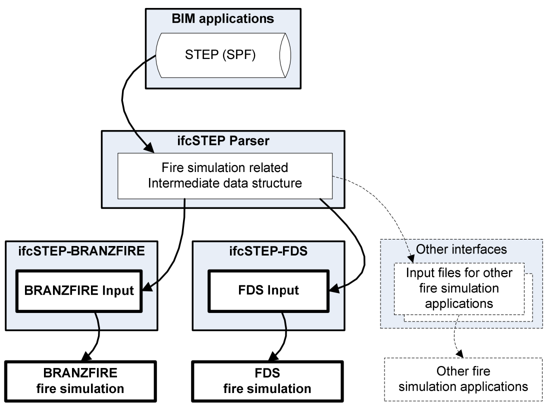


Figure 1. Data exchange process.

The two fire simulation models employ distinctive conceptual representations of a building and differ in the way in which they carry out their computations. These differences significantly determine the requirements of the translation process from the IFC Model.

The translation of geometrical and topological building information requires the identification of spaces, boundaries (walls and slabs) and openings (windows and doors) and their relationship to one another. Trial buildings have been used to test the ability to correctly interpret the IFC files and to determine where difficulties occur. A specific trial building is described here as an illustration of the capability of the current parsing tool.

There are a number of challenges when using this approach for data sharing. There are limitations inherent in the IFC Model in describing buildings and fire engineering specific information where the structure of entities may not be compatible with the requirements of a particular fire simulation model. The representation of building spaces and elements can differ significantly with the various categories of models. This requires an ability to interpret and translate IFC Model entities to these alternate representations which adds to the complexity of the exchange process. Finally there are issues with the implementation of the IFC schema in commercial BIM applications and the capacity for users to populate IFC Model entities.

The ability to quickly and accurately share building information created in BIM applications with fire simulation models has the potential to assist fire engineers during their design process. The IFC Model can be used to fulfil this role but there are a considerable number of obstacles that need to be tackled before then.

1. INTRODUCTION

Fire engineers are involved in many aspects of a building's construction, fit-out and renovation with the objectives of providing means of escape to occupants, preventing the spread of fire to neighbouring property, providing protection to fire service personnel during fire-fighting and limiting the effects of fire on the environment. These objectives are met through the consideration of issues such as exit route design, fire and smoke spread mechanisms and structural stability.

In order to carry out designs, fire engineers are likely to conduct computer simulations particularly where the building is complex. Much of the initial simulation effort is spent obtaining and transferring the basic building description into the specific fire/evacuation simulation model. Very few of the currently available models can import building information in an electronic form and even those that do are limited by the information available such as provided in a DXF file.

There are many aspects of a building that are common to the fire engineering, architecture, structural engineering and building services domains. Fire engineers need to have the basic geometry and topology of a building which includes information on the size and shape of rooms, openings and hidden voids, the exits from a space and where those exits lead.

In addition, fire engineers need to determine the fires that could likely occur through an assessment of the fuels in the building. This analysis requires the fire properties of lining materials, the contents of the spaces in terms of total fuel load, the arrangement of fuel packages and the relative flammability of those packages. Fuel packages might include furniture and fittings plus wall, floor and ceiling coverings. The specification and design of fire safety systems such as alarm, suppression and smoke management systems requires details of system components plus electrical wiring layouts, plumbing and pipe work, ducting networks etc.

Information regarding the site of the building may also be necessary. Weather may be a factor and temperatures, wind velocities, humidity may all be required in order to specify the performance of the fire safety systems. Finally fire engineers need to obtain details of the occupancy characteristics of the building. This may include information such as the primary use of the spaces, numbers of people, times when the building will be occupied and by whom, the physical and mental state of the occupants.

2. IFC BUILDING PRODUCT MODEL

The IFC Building Product Model is a general product model that provides an object-oriented description of many aspects of a building and related services enabling interoperability between different vendors of Architectural, Engineering and Construction / Facilities Management (AEC/FM) software. The IFC Model aims to support the exchange of information throughout the design, construction and operation stages of a building life cycle.

Development of the IFC Model began around 1996 and has continued through several versions up to the present IFC2x Edition 3 release as specified by the International Alliance for Interoperability (2006). Early versions of the IFC Model only had a limited set of fire engineering related properties but IFC 2x Edition 2 release has a considerable amount of material that is useful to fire engineers and was sufficient for the work described in this paper.

The IFC model is highly complex containing over 650 entities and over 300 supplementary data types to represent building storeys, spaces, walls, slabs, doors, windows and openings etc. Since the IFC Model is a general product model rather than being domain specific (Ito, 1995) it is not intended to define properties for every building element that may exist or contain entity that may be required by a specialist domain such as fire engineering. Mapping a general product model to a highly domain specific application can present limitations as demonstrated by Karola et al. (2002). A 'property set definition' mechanism overcomes some of the limitations by allowing extensions to be made outside of the main IFC Model specification. As the IFC Model matures it is expected that new entities and property sets will be added as well as refining those that already exist.

IFC Model data is exchanged using STEP (Standard for Exchange of Product Data) Part 21 physical files (ISO 10303 2002) or through an XML encoding that has been specified by the International Alliance for Interoperability (Nisbet et al., 2005).

The IFC Model is ideally suited to meet the requirements set out by Mowrer et al. (1988) for room fire modelling. The object-oriented structure of the IFC Model and the ability to associate properties to objects were two of the key points identified by Mowrer et al. (1988). The IFC Model can be used to allow fire engineers to extract relevant building-related entities in order to assess designs using fire simulation models. Currently two fire simulation models commonly used by fire engineers in New Zealand have been selected for the data exchange process.

3. BIM APPLICATIONS

Early work investigating the sharing of electronic building information with fire simulation software (Spearpoint, 2003) used Microsoft Visio Professional 2002 and a tool developed as part of the BLIS projects (BLIS, 2004) to create building descriptions and export them as IFC files using the XML encoding specification. However it appears that no further development has taken place on MS Visio to keep up with new releases of the IFC Model.

In this work IFC 2x Edition 2 conforming STEP files were generated using two commercially available Building Information Modelling (BIM) applications: ArchiCAD 9 from Graphisoft and Revit Building 9 from Autodesk. Both are integrated architectural design tools that represent buildings using a 'virtual building' model stored in a central database. Building elements such as slabs, walls, doors etc are used to construct a 3-dimensional model of a building. Building elements are intelligent objects that have their own associated properties and behaviour. The object-oriented approach means that the building model is more than the 2-dimensional line representation of a building that is common with traditional computer-aided design (CAD) systems. The tools can be used to view a building model not only as plans, elevations and sections but also can generate perspective and virtual reality presentations of the building.

4. FIRE MODELLING SOFTWARE

4.1. BRANZFIRE

Zone models are a common category of fire simulation software available to the fire engineer. The atmosphere within a space (or 'compartment') is normally split into two vertically and horizontally uniform zones; the hot upper gas layer due to the fire and the cool layer below. Although zone fire simulation tools all follow the same basic philosophy regarding the way in which the fire environment is represented, individual software tools may have facilities that are not present in others. BRANZFIRE (Wade, 2003) is a widely available multi-compartment zone model which can simulate the movement of smoke between up to ten spaces inter-connected by openings (or 'vents'). Fires are specified by the modeller or by using a built-in fire spread model in the case of room linings. The model also has the ability to incorporate sprinkler and smoke detector activation, the breaking of window glass and the effects of mechanical fans. Although the data exchange of the IFC Model to the BRANZFIRE fire simulation model (version 2003.1) is specifically explored in this work, the issues are representative of those faced integrating many of the available zone fire simulation software family.

4.2. Fire Dynamics Simulator

Fire Dynamics Simulator (FDS) developed by McGrattan (2005) and co-workers is one of the most well-known Computational Fluid Dynamics (CFD) codes used by fire engineers. It uses the Large-Eddy Simulation (LES) numerical technique to solve large-scale hydrodynamic turbulence, a condition that typically occurs in fires. FDS also employs sub-models to deal with specific fire related phenomena such as heat transfer, detector activation and sprinkler sprays. The FDS input file specifies the building geometry, material types, computational scope, grid resolution, boundary conditions, fire source parameters, fire safety and mechanical systems specifications, as well as specification on the types of outputs. The computational domain is user defined and made up of one or more rectangular meshes, each with its own three-dimensional rectilinear grid. Building enclosure elements and solid objects are specified as a series of orthogonal rectangular blocks representing flow obstructions, whereas doors and windows are viewed as voids allowing fluid and particles to flow through. The simulation outputs from FDS can be visualised in an interactive or animated 3-dimensional graphical environment using a companion software application, SmokeView. Version 4 of FDS is used for this work.

5. GEOMETRICAL CONVERSION

5.1. Spaces

BRANZFIRE and FDS have quite different underlying philosophies regarding the way in which they represent fire scenarios and therefore also have distinct differences in the way in which the geometrical information is specified. These differences pose a number of challenges when exchanging with the IFC Model.

Zone models such as BRANZFIRE represent buildings as a collection of compartments with specified dimensions. This representation does not require the exact position of openings relative to their parent walls. Instead only the two compartments (or to the outside) that are connected are specified by a given opening and the dimensions of that opening. Conversely FDS does not use the concept of compartments per se but simply uses solid boundaries to enclose computational volumes. Thus in FDS, boundaries are positioned using their exact placement to create computational enclosures and openings are placed with boundaries relative to their parent wall. The result of these differences means that specifically identified spaces are essential for BRANZFIRE but optional for FDS. In contrast, exact positions of space boundary elements are not required for BRANZFIRE but must be determined for FDS.

Furthermore, BRANZFIRE can only deal with spaces that have a rectangular footprint whereas FDS is more flexible but walls need to be orthogonal due to limitations of the IFC parser algorithms. Both of these limitations require some manual or automatic interpretation of building geometries that do not conform to these requirements.

5.2. Walls and slabs

Walls and slabs form the primary space boundaries in a building. The IFC Model has two wall entity types: a simplified 'standard' type and a more complex generic type, and three methods of solid model representation described below:

- Clipping representation is the geometric representation as the result of a Boolean subtraction on Constructive Solid Geometry (CSG) solid objects.
- Swept Solid representation is the geometric representation of solid models created with profile sweeping using either linear extrusion or revolution techniques.
- Boundary Representation (BREP) describes a solid that is defined by its boundaries rather than by profiles and extrusions. In the IFC model, BREP geometry is the fallback position for any geometry than cannot reasonably be represented using parametric solids.

The combination of the two wall entities and three representations adds to the complexity of the exchange of walls from the two BIM applications to the two fire simulation models. The current work focuses on the CSG and Swept Solid representations. Furthermore, details regarding the definition of wall placement differ in the STEP files generated by ArchiCAD and Revit in that the facing of a wall from ArchiCAD is used to define its position by default whereas it is not in Revit.

Slabs are treated in a similar way as walls in terms of the parser. In Revit and ArchiCAD, floor and roof flat slabs can be used interchangeably. Whether a slab forms the floor or the ceiling of a compartment is not immediately apparent from the IFC file. The user of a BIM application may be able to specify the relationship of a slab to a space or define a property that specifies the use of the slab. In Revit a roof differs to a floor slab in that it can have user-defined slopes in any of its sides to form a combination of gable or valley shapes.

In practice roof object is used as being the uppermost 'slab' and so the vertical position of the slab relative to a space or a wall may be used to determine its function in enclosing a space. Whether a slab forms a floor or ceiling is relevant, for example, where a fire engineer wants to assess the properties of a slab exposed to a fire in which the slab is a composite of different material layers.

The current work only considers single storey buildings and for the FDS exchange the lower and upper boundaries of the computational domain are conveniently specified as being inert surfaces, eliminating the need to map floor and ceiling slab entities. In order to be able to map slab entities, the parser needs to be able to process BREP solid representations as all slabs are exchanged as these from Revit.

In general, boundary materials can be defined in the BIM applications however their mapping to the fire simulation models is not direct. The IFC Model does not control the semantics used for naming materials and there needs to be a specific mapping created where a fire simulation model includes a database of materials with its own naming conventions as is the case with BRANZFIRE and FDS version 4. The current parser extracts materials specified in the BIM and populates the fire simulation model input files with identified materials but without any mapping to the model's internal database.

5.3. Openings

Door and window openings are exchanged as opening element entities. The relationships between the openings and the voids in the wall or the openings and the filling elements such as a door or a window are described in the IFC Model by voiding or filling entities respectively. The local placement of door and window openings is exchanged as the horizontal and vertical offset distances from the placement origin of the wall. This can be obtained from the STEP file where the horizontal offset distance is found from the placement origin of the wall to either the near or far edge of the opening depending on the facing of the opening.

It was found that the representation of openings in ArchiCAD and Revit differed in that the reference point for the entity was not defined in the same manner. The Revit STEP file defines the x-coordinate local placement as the edge of the opening element entity whereas ArchiCAD uses the centre of the opening element entity. Similarly, the sill of a window-type opening differed in that Revit uses the local placement of the opening element entity whereas ArchiCAD places the sill with respect to the parent wall z-coordinate placement.

The connection of neighbouring spaces by an opening is relatively simple to define in FDS since it just creates a void in a solid boundary. A more complex approach is needed for BRANZFIRE in which the relationship between an opening, its parent wall and the spaces that the wall bounds need to be determined. The IFC Model encodes these relationships although it is not a trivial task to extract and interpret these relationships.

6. TRIAL BUILDINGS

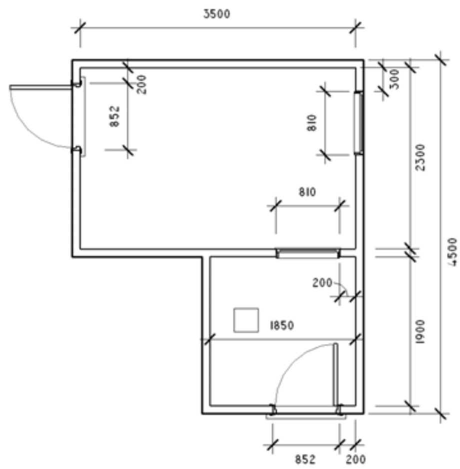
The complexity of the exchange required a series of trial buildings to be created in the two BIM applications and the exported STEP files then processed for the FDS and BRANZFIRE simulation models.

The trial buildings test the ability to correctly interpret the building geometry (i.e. wall and opening dimensions and positions) and the building topology (i.e. the connections between spaces and to the outside).

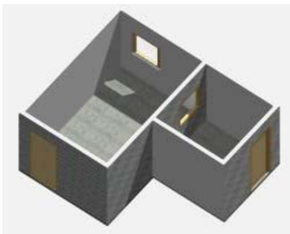
A simple trial building (Figure 2) is discussed here to illustrate process of transferring the geometrical data. The building consisted of two different size rooms, the larger having approximately twice the floor area of the smaller. Two doorways to the outside were placed, one opening outward from the larger room and the other inward into the smaller room. Two windows were also placed, one to the outside from the larger room and another internally between the two rooms. The walls were all 2.4 m tall and 100 mm thick single layer of 'common brick'. Flat 150 mm thick slab entities were placed at floor and ceiling level. The building was not created for architectural considerations but is sufficient to test the geometrical conversion abilities of the parser software.

Figure 3 shows a successful conversion of the ArchiCAD generated STEP file as a SmokeView visualisation from FDS and as the dialogue boxes used by BRANZFIRE to define building geometry.

A) Plan view (with dimensions in mm)



B) Isometric view in ArchiCAD 9



C) Perspective view in Revit Building 9

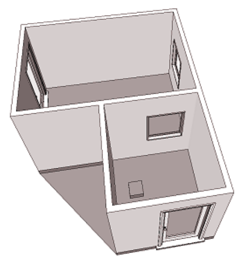


Figure 2. Demonstration two-room building.

In Figure 3B the dimensions of the room and internal window have been correctly identified and the room connection through the internal window defined appropriately. The wall thickness and material defined in the BIM have also been extracted. Similar results were obtained for the corresponding Revit generated STEP file.

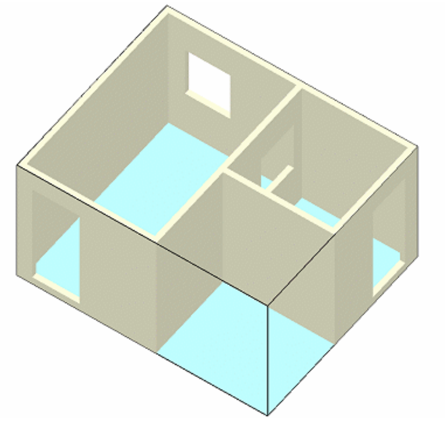
7. CHALLENGES IN DATA SHARING

7.1. BIM implementation of IFC model

The ability to create IFC Model entities in the BIM applications has potential downstream effects on the availability of those entities and their mapping to fire simulation software.

This work has identified that use of the IFC Model and the STEP file output representation implemented by the BIM applications differ in many details. Variations included whether an entity or property was incorporated by default or was optional, how the IFC Model was used to represent a specific entity (such as with walls) and the dissimilar encoding of entities in the IFC file. These variations required that the parsing software had to have specific algorithms to process IFC files from the two BIM applications.

A) SmokeView visualisation



B) BRANZFIRE geometry input dialogue boxes for room dimensions and wall vent dimensions

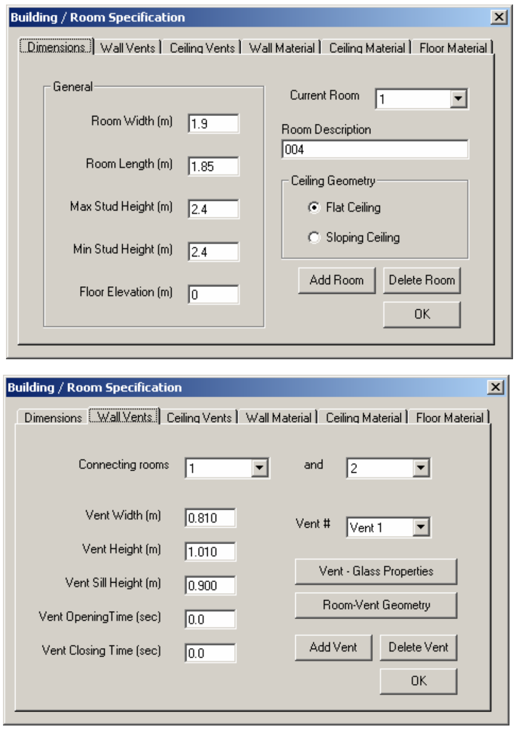


Figure 3. Conversion of trial building into FDS and BRANZFIRE.

For the user there is an associated complexity involved with the creation of large buildings in powerful BIM applications where the exchange process is limited by the ability to make use of the sophisticated software. The ability to exchange information is also constrained where a software vendor does not keep up with the most recently released versions of the IFC Model.

It was found that the BIM applications did not always implement every facet of the IFC Model and that few fire engineering specific entities are available even where they are defined in the IFC Model. Thus the mere existence of an entity or property in the IFC Model does not guarantee that a user will be able to easily create it in their chosen BIM package. In some cases it may be possible to manually add entities or properties in lieu of having an appropriate functionality in a BIM application through the use of the 'property set definition' mechanism provided in the IFC Model.

7.2. Extraction of elements

With the large number of entities specified in the IFC Model, considerable effort could be required to write the algorithms to extract these entities. The interrogation software may also need to be able to handle IFC files in either the STEP or XML encoding. The availability of software such as the SECOM Server (SECOM, 2006), which was used in this work, greatly assists with the interrogation process as it relieves the developer of the need to start from the ground up.

It should be recognised that it is unlikely that every entity present in the IFC Model will be applicable to all domains. The current parser for fire simulation models only processes a limited set of the IFC Model sufficient to obtain basic building geometry and properties. Further expansion to handle other entities is desired but there are many entities in the full IFC Model that have no particular use for fire engineers. However, because of the quite different IFC entity properties needed for geometrical specification for FDS and BRANZFIRE, the extraction of entities is not an insignificant task.

7.3. Mapping to fire simulation models

The mapping from the IFC Model to fire simulation models is constrained by the representation of the fire scenario as well as the implementation of that representation in a specific program. The zone modelling and CFD modelling techniques have particular requirements that have been illustrated in this paper. However, a specific program may also place further constraints on the ability to map IFC entities when compared to another program that uses the same modelling technique.

The interpretation of the product model has many challenges. The structure of entities may not be compatible with the requirements of the specific fire simulation model. This can happen where there might be insufficient detail in the product model but also where the requirements of the fire simulation model include simplifications and assumptions about a building that need to be accounted for during the exchange process.

The exchange of material properties between a BIM and a fire simulation model is likely to require a specific mapping for each simulation model or the user will need to make manual changes to the model settings before any analysis is performed.

Finally, it is important to recognise that the requirements for a structural fire response analysis model will be quite different to those for a people movement simulation or a fire and smoke spread model and considerable effort is likely to be required to identify appropriate mappings for each type of model.

8. CONCLUSION

There are benefits using a standardised general building product model such as the IFC Model but these benefits do not come without challenges. The ability to share building information with fire simulation models has the potential to assist fire engineers during the design process. The specification of a building can be quickly and accurately transferred from commercial BIM applications to fire simulation programs used by fire engineers. However, the mechanics of transferring the information and the need to interpret that information to match the particular representation of a fire scenario in a specific fire simulation program are not trivial matters.

Users and software developers need an appreciation of the limits of the building product model, the capability of specific BIM applications, fire simulation modelling techniques and the extensive range of fire simulation programs that is available (Olenick et al., 2003) each of which differs in their specific requirements. Expertise and up-to-date familiarity of all these aspects is not easy to maintain.

9. ACKNOWLEDGEMENT

The fire engineering programme at the University of Canterbury is supported by the New Zealand Fire Service Commission.

10. REFERENCES

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