IFC Semantic Extension for Dynamic Fire Safety Evacuation Simulation

Nidhal Al-Sadoon, nidhal.al_sadoon@tu-dresden.de
Institute of Construction Informatics, Technische Universität Dresden, Dresden, Germany

Raimar J. Scherer, raimar.scherer@tu-dresden.de
Institute of Construction Informatics, Technische Universität Dresden, Dresden, Germany

Abstract
This paper presents ongoing research aiming at supporting real-time interactive simulations of fire and pollution gas hazardous events. The outcomes of the proposed interactive simulation resulted from the intervention of three main models, namely fire simulation, crowd simulation and building model. To enable this innovative real-time data communication, multiple phases of development will take place; one of them is extending the IFC semantic information, which is the focus of this paper. The proposed extension will enhance specific building elements with properties that have multiple dynamic values, consequently, enable the interaction between the building model and the simulation tools by exchanging the building elements status at the simulation running time. The Multimodel approach developed in the Institute of Construction Informatics-TUD is adopted to facilitate transmitting not only static data of the building elements to the simulation tools but also the possible status changes of the building elements during fire simulation.

Keywords: BIM, IFC semantic extension, fire hazard, simulation, Multimodel.

1 Introduction

The increasing complexity of the built environment imposes the need for improving emergency evacuation management. It is undoubtedly that fire simulation plays a significant role in safety design, particularly in large-scale infrastructure, such as stadiums, tunnels and airports. Nevertheless, simulation tools still utilize data from static building models for fire and crowd simulation, hence, the simulation results will be approximate and unreliable (Scherer et al 2018). As such, providing dynamic information about the buildings, occupants and fire propagation is a key issue (Eftekharirad et al 2018). The interaction between both fire and occupants with the building should be considered to achieve precise and more reliable simulation outcomes in order to satisfy the requirement of dynamic data exchange. In a real fire scenario, as the fire ignites and spreads throughout a building, not only the occupants will react but also the building elements' status will be changed.

The current standard Building Information Model schema IFC (ISO 16739) is an interoperability-oriented data schema formally described by means of the EXPRESS language. It contains detailed digital data of a built facility designed in a BIM-based software environment, typically used within the AEC and FM industries to describe, exchange, and share information (Borrmann et al 2018). As such, it can provide a comprehensive geometric and semantic information about the building in addition to the information about the equipment and technical systems inside the building like furniture and HVAC systems. However, this information is representing the idealized state of the building and usually provided to simulation tools only at the outset to conduct fire simulation. Such idealized information is insufficient to reflect an interactive simulation scenario, therefore, the static building model should be extended with dynamic features that allow transferring the changed status of the building elements in the real time during fire simulation. This paper presents an approach to semantically extend the current IFC schema. Firstly, the IFC standard is analyzed critically to define the relevant building objects that have dynamic features and could affect simulation results. The extension comprises two aspects: (1) create new objects, and (2) semantically enhance the defined building elements to reflect their possible dynamic status by using IFC proxy elements and IFC property set.

2 Related work

The concept of Building Information Modeling was initially raised in the 1980s, which is the inevitable product of the combination of the information and digital technologies. The aim of BIM is to achieve the digital expression of all the building information (elements and functions), build up a considerable database and provide policy support for the decision making of all participants within the complete building life cycle. Key to the success of a building information model is its ability to encapsulate, organize, and relate information for both user and machine-readable approaches. BIM allows the creation of intelligent environments that enable all users of the model to have instant access to all of the information available in the model (NBIMS 2007). As BIM technology progresses and moves beyond structural and architectural models, the fire protection industry as a whole earns the benefits because fire protection engineering encompasses not just active and passive suppression systems, but the overall life safety of buildings and the occupants. Inevitably, the ability to share Building information in an electronic form will lead to a more efficient building design, construction and management. Various forms of building information modeling (BIM) has been used throughout the fire protection industry. Life safety integration could be better applied when the model is constructed to include all systems (Shino 2013). By providing 3D visualization of building physical components and understanding physical and functional characteristics of objects, BIM is used to improve emergency management in the Construction Industry. The BIM model contains a high level of semantic information in addition to the three-dimensional representations of buildings, such as fire properties of the materials and other data that is required for performing fire simulations. In addition, BIM is considered as a rich source of semantic information required for facilitating the design of the simulation and for data integration. Consequently, BIM enhances the simulation used for fire propagation and crowd evacuation (Sun & Turkan 2019). For BIM-based fire evacuation planning, several relevant elements along with their common attributes have already been introduced in IFC. However, getting more reliable simulation output information requires enhancement of the current standard by migrating the static BIM to a dynamic BIM.

IFC is a neutral data format typically used within the AEC and FM industries to describe, exchange, and share information. The IFC model represents not just tangible building components such as walls, doors, beams, ceilings, furniture, etc., but also more abstract concepts such as schedules, activities, spaces, organization, construction costs, etc. in the form of entities All entities can have a number of properties such as name, geometry, materials, finishes, relationships, and so on (Khemlani 2004). Since the first version of the IFC, version 1.0, was released in 1997, many revisions and extensions have followed, ending with the latest version IFC 4 released in 2013, where each subsequent version adds capabilities to represent more entities and more relationships related to a building's life cycle. Up to version IFC4, the IFC standard was mainly focused on buildings. However, due to increasing international demand, significant extension attempts are being carried out (Borrmann et al 2018). The latest IFC model provides useful general information required to the Fire simulation but when considering the existing fire specific properties, it still has limited scope and needs to be extended to describe each particular simulation requirements severally. Property Set Definitions can be used to extend the IFC Model to include additional fire-related properties (Spearpoint 2013). The IFC model does not meant to include every aspect of a building as it might be too complex and take too long to develop, instead entity types are described at a relatively generic level and allow to extend the IFC scope by the use of 'property set definitions' thus, the IFC Model is being implemented and enhanced in many areas of the construction industry.

Fire safety evacuation models are difficult to verify since results of the incident are stochastic and it is impossible to conduct repeatable experiments thus, such disadvantages hinder the development of computer simulation models. However, it is expected that with further development of technology and evacuation research, more complex psychological aspects of escape movement will be considered and a more accurate model could be developed (Shi, et al 2009). The most relevant research work was conducted by (Eftekharirad et al 2018), he integrated BIM based building models with sensory data to have real-time information about the disaster and occupants. He developed an extended IFC model to identify the entities, attributes, and relationships between sensors, occupants, occupancy, time series, and building components. The proposed method was effective in providing real-time information for effective fire emergency management. However, several research projects proposed new objects, entities, and relationships for extending the IFC standard to have comprehensive real-time awareness in case of a fire in a building but simulation tools are still based on static models that allow only rough estimation of the safety (Scherer et al 2018).

Despite the fact of continuing efforts to improve the Industry Foundation Classes (IFC) to represent more concepts in the different domains in the Construction Industry, we believe that there is still a need for a suitable solution for the management and exchange of distributed BIM and non-BIM data from different information sources for tasks that go beyond traditional BIM, and without pre-harmonizing them in one common data model. Such non-BIM data can be found in a variety of tasks from different domains such as energy-efficient design, fire safety, cost estimation, environmental engineering, construction management, facility management, etc. (Scherer & Katranuschov 2019). It is worth mentioning here that, two decades earlier, Khemlani expected that the IFC might not be the best interoperability solution under all circumstances and applications might still need to develop direct links to some others for more efficient communication and tighter integration (Khemlani 2004).

3 Methodology

Computer-based fire simulation models usually used by fire engineers to determine the spread of fire, the response of a structure to high temperatures and the movement of people exiting from a building. To achieve interoperability between electronic building models created in Information Modelling (BIM) applications and fire simulation models, the standardized Industry Foundation Classes (IFC) Building Product Model can be used (Spearpoint et al 2007). The progressive maturity of the IFC standard means more and more entities and property sets but this does not intend to define properties for every building element that may exist or contain entity that may be required by a specialist domain, rather, the IFC standard designed to be extensible for new use cases (ISO 16739 2013). Therefore, taking these advantages in consideration, we will manipulate this possibility to enhance the building elements relevant to Fire and Crowd simulations with the required properties to achieve the dynamic interactive simulation. In this work IFC file was generated using BIM implementation in the Autodesk's Revit Building 2020 software package.

3.1 Principal Concept

During real life cases of fire accidents in a building, people react to the fire or gas propagation, they may open a closed door to escape for example, so, the door state is changed from "closed" to "open". Transferring such kind of building element status changes during fire and crowd simulations is the objective of the IFC scheme semantic extension. Among the three main approaches to extend the IFC schema detailed in item 3.2, we used the *IfcPropertySet* approach to extend the required semantic information to achieve the research objective. We developed the research according to the following steps; firstly, explore the dynamic features of the building elements that may change as a consequence of the interaction between the occupants and the building elements during fire simulation. Then, define building elements that need to be enriched with dynamic properties. Finally, create property set models that define the multiple dynamic features for each extended property.

To validate the developed extended IFC scheme, a case study from an ongoing project is utilized where the Multimodel Container for information delivery is adopted there. The Multi Model unites multiple application models into a singular cross-domain information space. Links generated in an external link model to connect data elements from multiple Application Models by referencing their identifier (ID) (Fuchs et al. 2011). Considering the real-time linking perspective with the simulation tools, the IFC schema extended properties is modeled in a separate text file model "Property set model" as an elementary model to be linked via link model with the related element in the IFC Building model inside the Multimodel Container. Then this link will be mapped to a particular dynamic feature based on a predefined simulation scenario.

3.2 Approaches to Extend IFC

The IFC adopts an object-oriented approach, in which building information is assembled as a set of objects, each object containing attributes describing the object. Within the IFC Schema, several key characteristics of objects can be defined directly with the help of attributes in an entity definition. Including other desirable characteristics of an object would make the already extensive schema unnecessarily bloated and slow its implementation. So, to address describing any supplementary information, two main extension mechanisms have been provided; (1) property definition that can be defined with the help of the subclasses of *IfcProperty* and added to the instance model whenever required. The new object property is defined via a simple name-value-data type, then grouped into an *IfcPropertySet* and assigned to an object *IfcRelDefinesByProperties*. (2) *IfcProxy* used as placeholders without predefined semantics or containers to hold object entities. Using proxy elements, to describe supplementary information may result in a loss of semantic information. As such, proxy elements are considered not suitable for a semantically well-defined description of non-standard IFC objects. (3) Defining new entities. Though it is considered the best method to extend the IFC standard, because the newly defined entities can be used in the same way as the existing ones, but adding new entities to an IFC release can only happen after long processes and approvals (Eftekharirad et al 2018) and (Theiler & Smarsly 2018). Borrmann highlighted development of another approach to extend the IFC model, namely bSDD buildingSAMART Data Dictionary (Borrmann et al 2018). This approach provided by buildingSMART International as a service aims to improve the level of collaboration in the construction industry and improve communication.

3.3 Exploring dynamic features

Ideally, crowd simulation and fire simulation should both consider certain dynamic state changes. Consequently, it should be possible to modify features of certain objects in time. However, the IFC standard does not take such dynamic features into account. Therefore, new features referring to the dynamic simulation procedures have to be introduced via additional annotation of relevant building elements in the IFC standard. Specifically, windows and doors should be assigned by the dynamic features “open”, “closed”, “locked” through the use of an available property set. Depending on these features, windows and doors can be regarded either as openings or as obstacles in the simulations. Moreover, the changes of material parameters (e.g. fire resistance) of building elements can be a dynamic aspect affecting fire propagation and crowd behavior. Dynamic features of equipment are also of concern, i.e. warn devices and HVAC devices installed in a building. Electrically driven devices can be defined with the status “on” or “off”, and their power should be time-varying. As an example, an air terminal box shall have several state changing attributes such as type (“intake” or “outrun”), status (“on” or “off”), and power (defined through the ventilation speed). Normally, in a spacious room, several air terminal boxes are installed and can be treated as a set that affects the simulation and data management process.

Dynamic features should be used for dynamic information interaction between the IFC model, the fire simulation and the crowd behavior simulation. Let us consider a concrete scenario to show what dynamic features serve for. In a normal situation, a building has doors and windows, which could be open or closed, a running ventilation system and alarm devices in stand-by. When a fire breaks out, the ventilation system is shut down and alarm devices are activated. Doors and windows may be open or closed for some specific reasons. These status changes should be first linked with the IFC model and then mapped to the simulation models. A closed door performs as an obstacle in both kinds of simulation; an open door becomes either an exit, an intermediate target in crowd simulation, or a free area in fire simulation. Fire and crowd simulations are both dynamic procedures; hence, the objects’ status must be repeatedly modified based on the simulation results at certain time points. Therefore, after each observation phase, the status in the three models (i.e. the IFC model, the input model for crowd simulation, and the input model for fire simulation) must be mutually considered and accordingly changed to maintain the consistency of the entire multi-model representation of the event scenario. However, the most relevant building objects that need to be considered or are able to affect simulation results are doors, windows, walls, spaces, and other building elements such as Security and Heating, Ventilation and Air Conditioning (HVAC) devices are essential for proper fire and crowd behavior simulation as well. These defined elements are part of the hierarchical structure of the IFC standard where all tangible elements inherit from the entity class *IfcProduct*. The entity classes in the IFC standard, which are primarily relevant for fire and crowd simulations, may include, but not limited to *IfcSpace, IfcWall, IfcDoor, IfcWindow, IfcFurnishingElement, IfcDistributionElement, IfcSensor* and *IfcAlarm.*

4 Implementation

4.1 Implementing IFC extension

The entity types are described at a relatively generic level and allow extending the IFC scope by the use of 'property set definitions' thus, the IFC Model is critically reviewed to define the IFC entities related to the building elements stated earlier. However, the extended dynamic information did not extend by adding additional classes or attributes to classes. Instead, the needed data has been considered by using a non-destructive extension mechanism, namely, 'Property Sets'. The data types of an individual property are single value, enumerated value, bounded value, table value, reference value, list value, and combination of property occurrences. As mentioned earlier, the IFC Model allows additional property sets to be attached so that the task of defining what properties are relevant to a specific object is possible. These property sets shall conform to the Property Set Definition (PSD) sub-schema of the IFC Model. In our research scope, four entities were selected to be extended; *ifcDoor*, *ifcWindow, IfcDistributionElement* and *IfcFireSuppressionTerminal.* Particular detailed sets of properties are accommodated in the model according to the specific requirements. Based on the analysis performed in Item 3.3, the additional properties that proposed to facilitate the real-time interactive scenario are detailed in Table 1:

Table 1. Property set definition and associated IFC class

IFC class	Property set name	Property Name /Type	Property Definition
ifcDoor	Pset_DoorStatus	DoorStatus/ ifcList	Define whether the door status is ”open”, ”closed” or ”locked”.
ifcWindow	Pset_Window Status	WindowOpen/ ifcBoolean	Indication whether the initial window status has changed from open to close (or vice versa) due to interaction between Occupants, Fire and building. (true) for open, (false) for not.
IfcDistribution Element	Pset_HVACStatus	HVAC_Activated/ ifcBoolean	State the HVAC status before and after fire. (On) for activated HVAC, (Off) for not.
IfcFireSuppressionTerminal	Pset_Sprinkler Status	Sprinkler_Activated/ ifcBoolean	State the Sprinkler status before and after fire. (On) for activated Sprinkler, (Off) for not.

To create the property set file, the researcher developed a Prototype software named ”IFC Property Set Extender” as shown in figure 1. The software is developed to define the extended property set scheme for any building element based on a predefined Property Sets template and also to assign multiple values for the extended property.

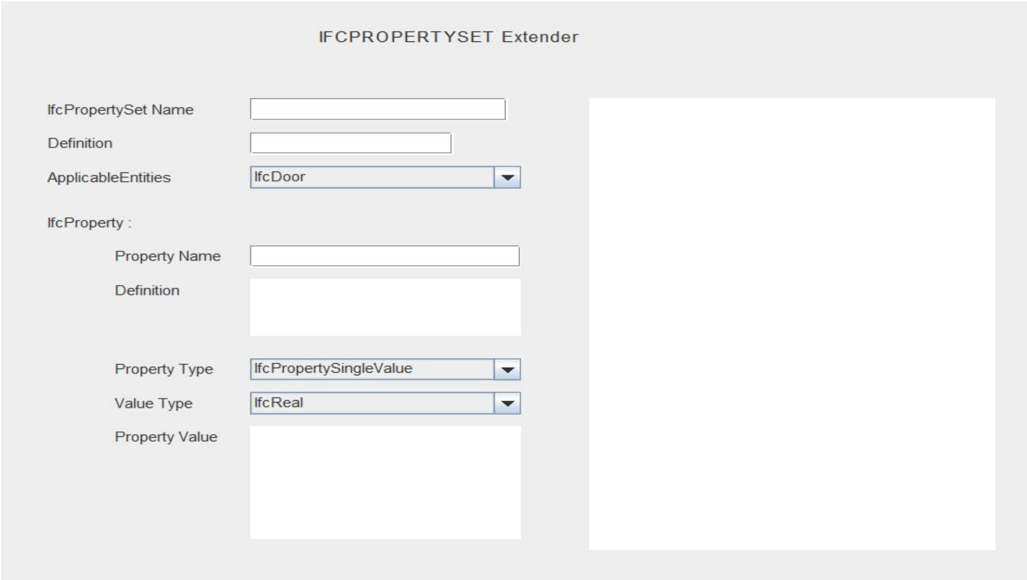

Figure 1. IFC Property Set Extender

For example, to extend the semantic information for the doors, the Property set name and definition are defined and the applicable entity is selected, here is the ifcDoor, then the property values are presented for the door; “Open”, “Closed” and “Locked”. Figure. 2 below shows a snippet of the Property_set model for IFC door.


```
{
    "name":"Pset_DOORSTATUS",
    "definition":" Properties common to the definition of all occurrences of IfcDoor.",
    "hasProperties":[
        {
            "type":"IfcPropertySingleValue",
            "valueType":"IfcText",
            "definition":" Indication whether the element is open or close or locked.",
            "propertyName":"DOOROPEN"
            "guid":"25e5f73d-288a-4fe0-8b6f-0295d185ca17",
            "listvalue":{"Close","Open","Locked"}
        },
    ],
    "applicableEntities":"IfcDoor"
}
```


Figure 2. Property set model for IfcDoor

4.2 Implementing the Multimodel Method

A case study is used to validate extending the IFC model with the extended Property set file. The Multimodel approach is implemented using the ICDD framework (Information Container for Data Delivery) ISO 21597. As proof of concept and verification, a building model representing a two floors university building was prepared as a test pilot model. It consists of offices, meeting rooms, lecture rooms and other building utilities, all of them furnished and equipped with HVAC and sprinklers systems (Figure 3).

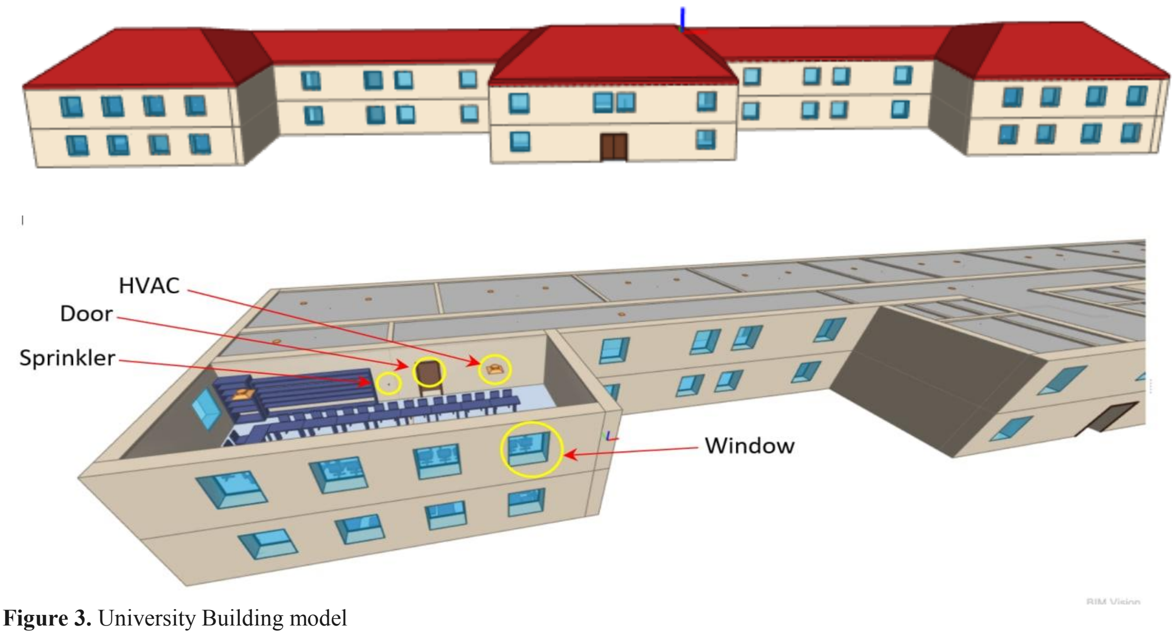

Figure 3. University Building model

Also, a Property_set xml file was created using the above mentioned developed software to define the dynamic features of the extended property according to table 1, for IfcDoor, IfcWindow, IFCDistrubutionElements (for HVAC status) and IFCFireSuppressionTerminal (for the Sprinklers status).

The ICDD framework is used to create the MMC, which in our case study contains two elementary models; BIM (ifc) model and Property_set xml model. Then links created using the URL of specific elements from each of the elementary models and the property value. For example, the linking process to extend the ifc door semantic information will be implemented as follow:

- Based on initial scenario simulation, a Multimodel Container is created and the two elementary models are defined; the building model (ifc) and the Property set model.
- Links are created to connect firstly, the ifcDoor element (from the building model) with Property set DoorStatus and secondly, the Property set DoorStatus with the Property value (for example "closed"). Snippet of the link elements sources is shown in figure 4.
- At this point the selected building element (here the ifcdoor) is connected to its dynamic property and this data becomes ready to be transferred to the simulation engines. Noticing that transferring data between the Multimodel Container and the simulation tools currently is underdevelopment.
- Finally, whenever the building elements' status are updated during simulation running time (the "closed" door becomes "open"), the updated value will be added.

All of the Elementary Models and the Link Models are stored in a Multimodel Container ready for data exchange. The link model describes the relation between individual elements of the two models and by interlinking the elementary models, cross-model interrelationships can be represented, which enables operations and queries over the entire information space created through the achieved interrelationship of the models.

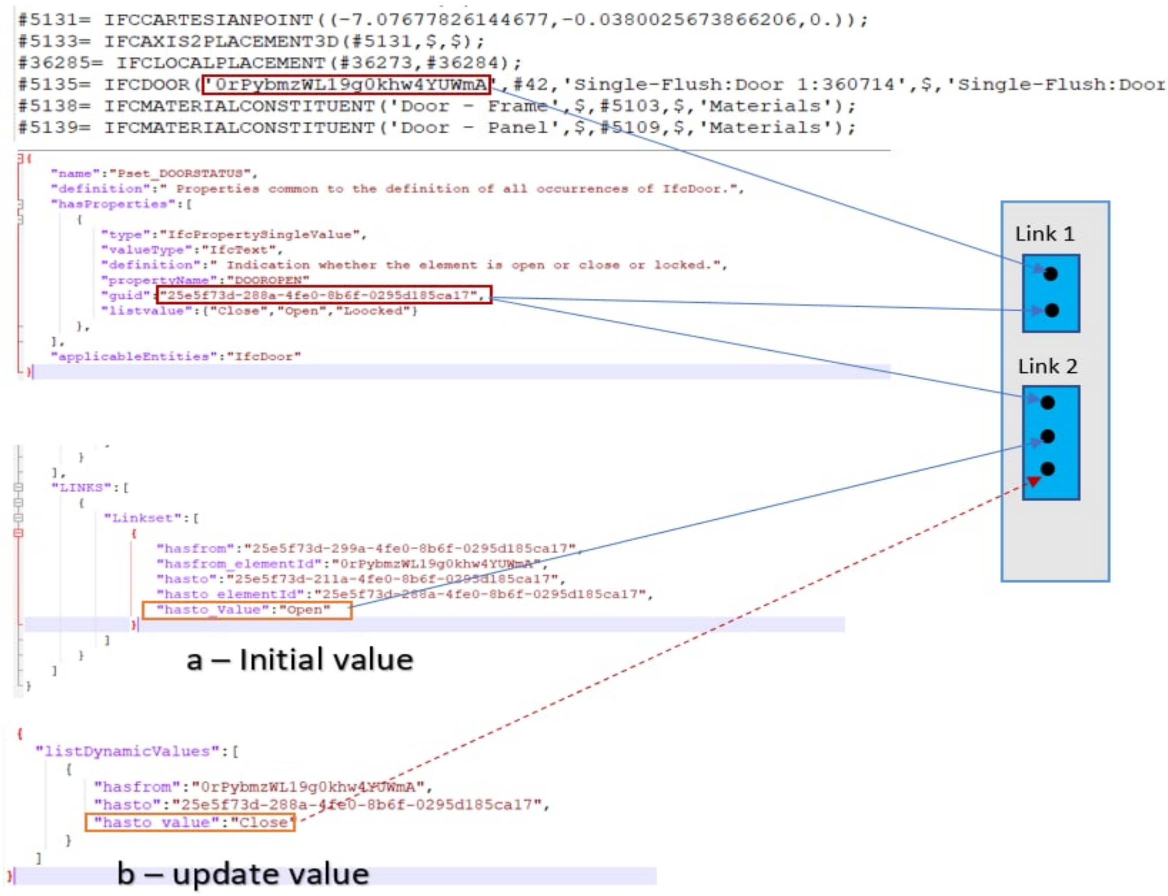

Figure 4. Link elements sources

4.3 Exchange the dynamic data

In the research case study, the simulation tools and the Multimodel Container are connected within a cloud base environment to facilitate the dynamic interaction between them. When the simulation scenario is set by the end user, the Multimodel Container using ICCD framework will be created to include the IFC building model and the Property set file as elementary models. Also, all elements in the IFC file that are defined to have dynamic features will be linked to the predefined elements status in the property set file. Then, to start the simulation, the IFC file and a message containing building elements status will be sent to the simulation tools as initial data to start the simulation. During the simulation, building elements status is subject to be changed, for example, a closed door may have opened or locked, so, to get more reliable simulation, the end user may change the status of specific building elements, these changes will be sent to the Multimodel Container and the updated values will be added. Then, again, a message containing the changed elements status will be forwarded to the simulation tool to resume the simulation with the updated data.

4.4 Discussion

The ongoing research has successfully extended the IFC model with semantic properties that contains multiple values using Multimodel approach. In this way, the Multimodel Container becomes a multi-purpose framework from which, multiple dynamic values for each specific building element can be queried for different scenarios during fire and crowd simulations. We believe that such framework could significantly enhance both training and safety design assessment purposes. It is noteworthy that, the developed framework could be also utilized to connect the BIM model with other disciplines model that contains periodically updated values such as sensor data model.

5 Conclusion and future work

The objective of this research was to semantically extend the IFC schema using non-destructive extension mechanism to fulfill the envisaged real-time interactive simulation. The IFC schema is analyzed critically to define the most relevant building objects that have dynamic features and could affect simulation results, then, particular building elements has been extending with required dynamic features by creating a separate 'Property Set' files where the Single Value Template were utilized. The recently standardized ICDD framework (ISO 21597) which is based on Multimodel approach is adopted to link the original IFC building model with the extended Property Set file. The extended properties are represented by links saved separately in link file to be retrieved according to the developed scenario. In future research work, the implementation of the Multimodel framework will be further broaden with a new ontology-based link approach to interconnect the static and dynamic building models in dynamic manner and enable real-time interoperability for all linked models.

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