

Extending IFC for Fire Emergency Real-Time Management Using Sensors and Occupant Information

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Abstract –

The increasing complexity of buildings has brought some difficulties for emergency response. When fires occur in a building, limited perception regarding the disaster area and occupants can increase the probability of injuries and damages. Thus, the availability of comprehensive and timely information may help understand the existing conditions and plan an efficient evacuation. For this purpose, Building Information Modeling (BIM) should be integrated with three sets of information: (1) occupancy that defines the type of space usage; (2) occupants' information; and (3) sensory data. The Industry Foundation Classes (IFC), as a standard of BIM, has the definitions for all areas, volumes, and elements of a building. IFC also has the basic definitions of sensor and occupant entities. However, these entities do not provide enough dynamic and accurate information for supporting emergency management systems. This paper aims to extend IFC for fire emergency real-time management using sensors and occupants' information. The specific objectives of this paper are: (1) extending *IfcSensor* entity for occupant's sensors; (2) adding new attributes to *IfcOccupant* to support emergency response operations and defining a new entity for occupancy; and (3) defining the relationships between sensors, occupants, occupancy, time series, and building components in the context of building evacuation. The feasibility of the proposed method is discussed using a case study.

Keywords –

BIM, IFC, Sensory Data, Sensor, Occupant, Occupancy, Fire.

1 Introduction

Statistics show 1,345,500 fires reported in the United States in 2015; out of which, 37.27% are structure fire that have caused 2,685 civilian deaths, 13,000 civilian injuries, and \$10.3 billion in property damage [1]. During

a fire evacuation, the lack of comprehensive information affects the success and efficiency of emergency management and results in increasing the number of casualties [2].

Wei-Guo et al. [3] stated that the availability of core information about buildings and infrastructure systems improves the effectiveness of managing disasters. Moreover, Tsai et al. [4] emphasized the need of critical building information, such as building evacuation plans and electrical and mechanical equipment. Walder and Bernoulli [5] emphasized the need for critical spatial information and semantic information related to the structure and equipment, as well as the disaster. An approach to enable rapid and safe evacuation in building emergencies requires accessing the dynamic information about the buildings, occupants and fire propagation. Building facilities' information includes building's structure; floor plans; location of stairs, ramps, exits, doors and windows; facility's materials; and fire protective equipment. On the other hand, the attributes of occupants are presence, number, location, age, mobility condition, ID, etc. In addition, the required information regarding fire propagation includes sensory data about smoke, heat, and toxic gases.

Building Information Modeling (BIM) is emerging as a digital representation of a building with the geometric/topological and semantic entities that describe the elements, materials, and relationships between them. Also, highly accurate and detailed data about the current state of building elements can be provided by BIM [6]. Industry Foundation Classes (IFC) as a platform-independent standard for BIM, is an object-based file format that has been developed by Building SMART Alliance (BSA). IFC is based on a taxonomy standard that describes building ontology [7]. Besides, IFC can facilitate interoperability in the Architecture, Engineering, Construction, and Facilities Management (AEC/FM) industry [8]. Although IFC is an object-oriented building model, modeling all objects related to the building is complicated. Thus, BSA presents an extensible architecture for extending IFC [9].

Integration of BIM and sensor networks for

increasing the accuracy and effectiveness of disaster-response decision-making has been discussed extensively in building disaster management [10, 11]. With the spread of Internet of Things (IoT) technologies and intelligent buildings, the need for integrating sensors and sensory data with BIM has also increased. Advanced sensors can collect real-time information about occupants, occupancy, surrounding environment and incidents. Among other applications, such sensory data can provide accurate and useful information to support building evacuation planning and emergency response [12].

For BIM-based fire evacuation planning, several relevant elements along with their common attributes have already been introduced in IFC (e.g., actuators, sensors and occupants). However, creating smart disaster-response decision-making applications requires enhancement of the current standard in at least two major directions. Firstly, to migrate from a static (stateless) to a dynamic (state-full) BIM by adding the sensory data history and associating it with the elements of BIM. Secondly, since having access to comprehensive and accurate data is critical in disaster management, the attributes of some entities (such as *IfcSensor* and *IfcOccupant*) need to be enriched and also relationships among such entities must be established.

The objectives of this paper are: (1) extending *IfcSensor* entity for occupant's sensors; (2) adding new attributes to *IfcOccupant* to support emergency response operations and defining a new entity for occupancy; and (3) defining the relationships between sensors, occupants, occupancy, time series, and building components in the context of building evacuation.

2 Review of Related Works

2.1 Building Fire and Evacuation Planning

In disaster management applications, time is one of the most critical factors to decrease casualties and properties' damages. Furthermore, precise information about an incident, structure [13] and human's behavior [14] can decrease the risk of life threats and asset damages [15]. Dilo and Zlatanova [16] showed that the success of emergency response is related to the perception of environmental elements and events. This awareness is directly linked to the dynamic information in the emergency event. Situational awareness about changes in building components' conditions can minimize the uncertainty in finding directions and improve safety [17]. Many studies have focused on network modeling, indoor navigation and route finding [18] based on the shortest path [19]. In addition, some studies have used dynamic data about people, to find less congested paths [14].

In the context of indoor emergency response,

Tashakkori et al. [15] argued that indoor situational awareness helps in effective emergency management. They used a set of required information for route finding to develop a 3D spatial indoor-outdoor model. However, their solution did not include dynamic information. Tangs and Ren [20] provided a simulation spatial indoor model for fire. This model includes static and dynamic information, such as occupants, fire field, and building geometry.

To summarize, a safe fire evacuation depends on an awareness of the static and dynamic features, especially geometric obstacles, smoke spread and occupants' behavior. These features have a critical effect on individuals' decisions and the evacuation process [20]. Therefore, the provision of a dynamic indoor emergency spatial model that supports situational awareness for building evacuation is vital. Such a model will cover both static and dynamic information including both occupants' behavior and indoor spatial information (e.g., building's structural layout, and fire propagation).

2.2 BIM and IFC

BIM allows to visualize construction processes through 4D simulation and gives an opportunity to manage cost and time effectively [21]. Recently, BIM has been used to improve building disaster management by understanding physical and functional characteristics of objects and visualizing building spatial information in three dimensions [22]. However, effective fire emergency methods should rely on the real-time and dynamic information [10].

BIM, as the base model of a building, can integrate with sensory data to have real-time information about the disaster and occupants. Consequently, occupants can be guided to safe exits rapidly from risky locations. Kensek [23] investigated the feasibility of integrating BIM and sensors such as light, CO₂ and heat. She used Arduino as a single board computer, Revit Architecture as a BIM software, and Dynamo as a visual programming environment to demonstrate how sensory data could change the 3D model. Also, the changes in the 3D model could be actuated on the physical model.

One of the primary goals of BIM is to provide interoperability between different platforms for data exchange, which is currently achieved by the IFC as a common open standard. This standard is used to share physical and functional features of buildings among stakeholders [24].

IFC is a data standard of BIM that has a hierarchical and modular framework consisting different entities. These entities represent tangible components (e.g. walls, doors and windows), as well as conceptual components (e.g. schedules, activities, and spaces). Each entity has common properties (including ID, name, geometry, etc.) as well as relationships to other components [25].

Currently, although IFC is a complex data standard, it can only support a limited number of use cases in the AEC/FM industry. Nevertheless, being an extendible standard, it can be extended to be used for new use cases [9, 25].

2.3 Occupant and Occupancy Information

In disaster management, in order to have occupancy-based control, different sensors are used to accurately determine the occupancy of building spaces and the parameters concerning occupants in real time, such as number of occupants in the spaces of the building. Melfi et al. [26] proposed occupancy resolutions at four levels (occupancy, count, identity, and activity) in three aspects (spatial resolution, temporal resolution, and occupancy resolution). A fifth level was suggested by Labeodan et al. [27] for tracking occupants' movement in different zones. The higher level of accuracy in occupancy detection will lead to better decisions improving safety [12].

2.4 Integrating Real-Time Information in BIM

An intelligent building is a building with smart technologies installation. In such buildings, there is usually a network of sensors and actuators with access to Internet, which can automatically control building components using knowledge-based algorithms and environmental data. For instance, intelligent buildings can monitor occupant's behavior and control building response to decrease energy consumption [28].

The first step towards modelling and managing an intelligent building is adding real-time information to BIM because the current BIM uses static information only. A dynamic BIM, which integrates real-time information and BIM, provides the opportunity of reacting to emergencies in real time by visualizing and monitoring the current situation in the building [29].

Currently, there are several kinds of BIM software (e.g., Autodesk Revit, ArchiCAD, Bentley Building, Solibri, and Vectorworks among other most commonly used tools). Revit is a widely used BIM software for visual analysis, documentation, and design, which also supports IFC. However, these tools can not store and visualize sensory data. To achieve a dynamic BIM with the ability to store and manage real-time information, some add-ins should be developed [29].

2.5 Extending IFC

There are three mechanisms to extend IFC if the current release does not support a specific need: (1) defining new entities, (2) using proxy elements; and (3) using the property sets [28]. Among the three alternatives,

defining new entities can be the best method to extend the IFC standard because the newly defined entities can be used in the same way as the existing ones [9]. However, adding new entities to an IFC release can only happen after availability of some "proof of concept", followed by long discussions within the Model Support Group of the BSA; hence, does not really fit the aim of research projects [28]. The other two alternative mechanisms can extend the scope of IFC without changing the schema, although they require additional implementation agreements about the definition of property sets and proxies when they are used to share data with other software. Therefore, the other two alternatives are more practical to meet specific local requirements [9, 25, 28].

Several research projects proposed new objects, entities, and relationships for extending the IFC standard [9, 28, 30]. However, there is limited research about an extension for occupants. Also, IFC still has challenges to represent the live sensor readings.

3 Proposed extension for IFC

To have a real-time fire emergency management, related information can be classified into two main classes (indoor and outdoor). In both classes, the information can be divided into static and dynamic information. To provide the classes with comprehensive data, they should be connected to external databases. For example, occupants' ID can extract more detailed information from the external database, such as age, mobility and health condition. Furthermore, indoor static information can be modeled in BIM as well as dynamic information collected through various sensors, as shown in Figure 1. Then, sensory data should be fused with the spatial and semantic information in the BIM platform.

Figure 2 shows how the BIM model can be overlaid by the real-time information and how datasets can be related to each other. Occupants and fire sensory data can be enriched by connecting to long-term static data. The static data are rarely changed, such as ID, mobility condition, and health condition. Thus, a comprehensive and real-time dataset containing sensory data and static data can be added to BIM.

After checking the available information in IFC4 EXPRESS diagrams, an extended data model, including the required attributes and the relations, is prepared using the Unified Modeling Language (UML) format.

3.1 Occupant and Occupancy Data

Basic occupants' information, such as name and type of actor are available in IfcOccupant. However, the following detailed occupants' information should be added to IfcOccupant: (1) ID; (2) age; (3) location; (4) mobility condition (e.g., wheelchair users); and (5) health

condition (e.g., occupants with heart and breathing problems need special help). In addition, the occupancy of a space can be defined at a lower spatial resolution. For this purpose, a new entity, IfcOccupancy, is defined with the following attributes: presence of occupant and number of occupant. Figure 3 shows the relationships between existing and new entities.

3.2 Sensors and Sensory Data

Using sensors helps to have awareness about the surrounding conditions. The following relationships should be captured and modeled: (1) the relationship between sensors and building physical/conceptual elements, (2) the relationship between sensors and sensory data expressed by time series, and (3) the relationship between sensory data and occupants' information.

In the current version of IFC, the geometry and definition of all types of spaces (e.g., room spaces) are described by IfcSpace entity. IfcSpace represents a bounded area or volume that provides a certain function within a building. Also, definitions of building elements, such as walls and ceilings, are described by IfcWall and IfcCovering. Furthermore, some mechanical and electrical devices, such as sensors and actuators are available. The sensor is defined as IfcSensor and the sensor type is defined by IfcSensorType, such as gas sensors, temperature sensors, and fire sensors. The static properties relating to the IfcSensorType are defined by the IfcPropertySet. Each property set includes common attributes, such as name, usage, materials, ports, composition, assignments, and representations [7, 31].

To define the dynamic information for the sensors, sensory data should be measured in real-time. IfcMeasureValue is defined to keep different types of measured values, such as volume, time, ratio, mass, count, and area. Also, in order to collect real-time data, IfcTimeSeries entity can be used. This entity describes a set of time-stamped data entries and allows a natural association of data collected over intervals of time [31]. Creating a relationship between IfcSensor and IfcTimeSeries provides a dynamic BIM.

Various types of sensors are defined in IfcSensorType. However, sensors for counting the number of occupants (OccupantCountingSensor) and sensors for determining occupants' location (OccupantTrackingSensor) are proposed to be added in this research. Adding these sensors to IFC and defining a relationship between sensors and time series can help to have dynamic occupants' information in the context of disaster management. Figure 3 shows the proposed model for new types of occupants' sensors and relationships.

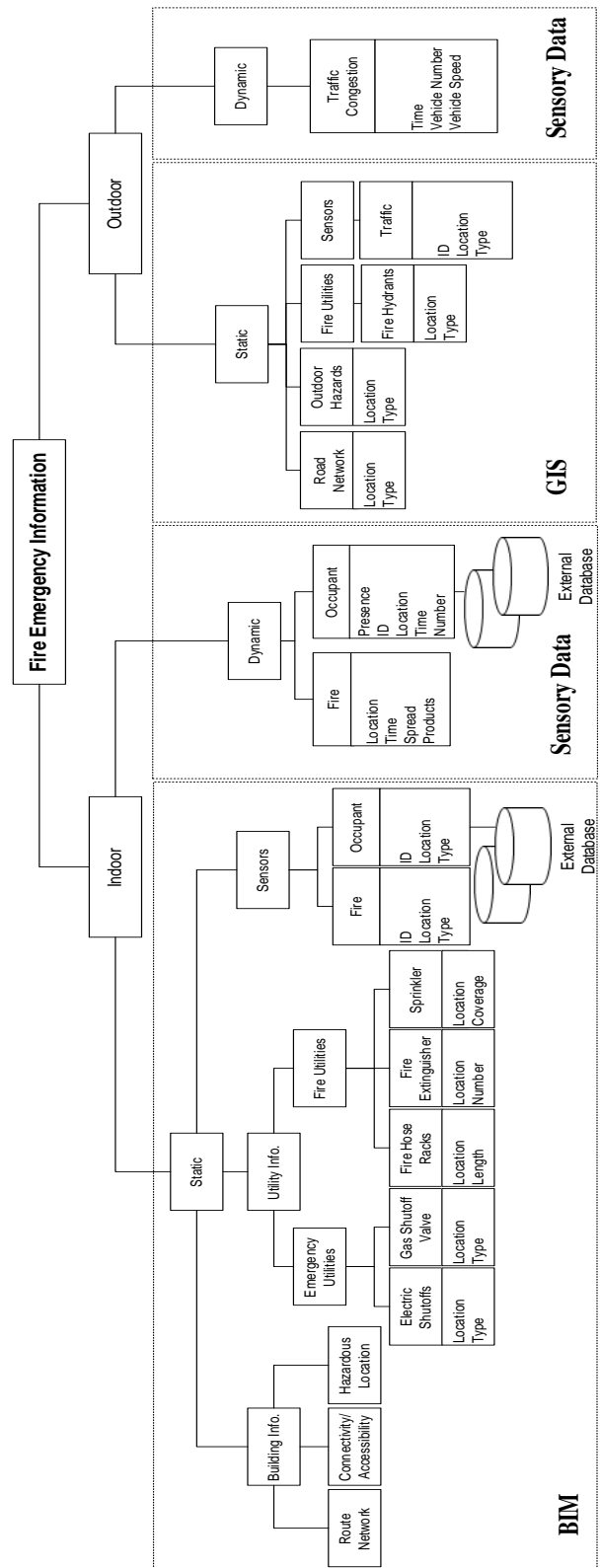


Figure 1. Information classification in fire emergency

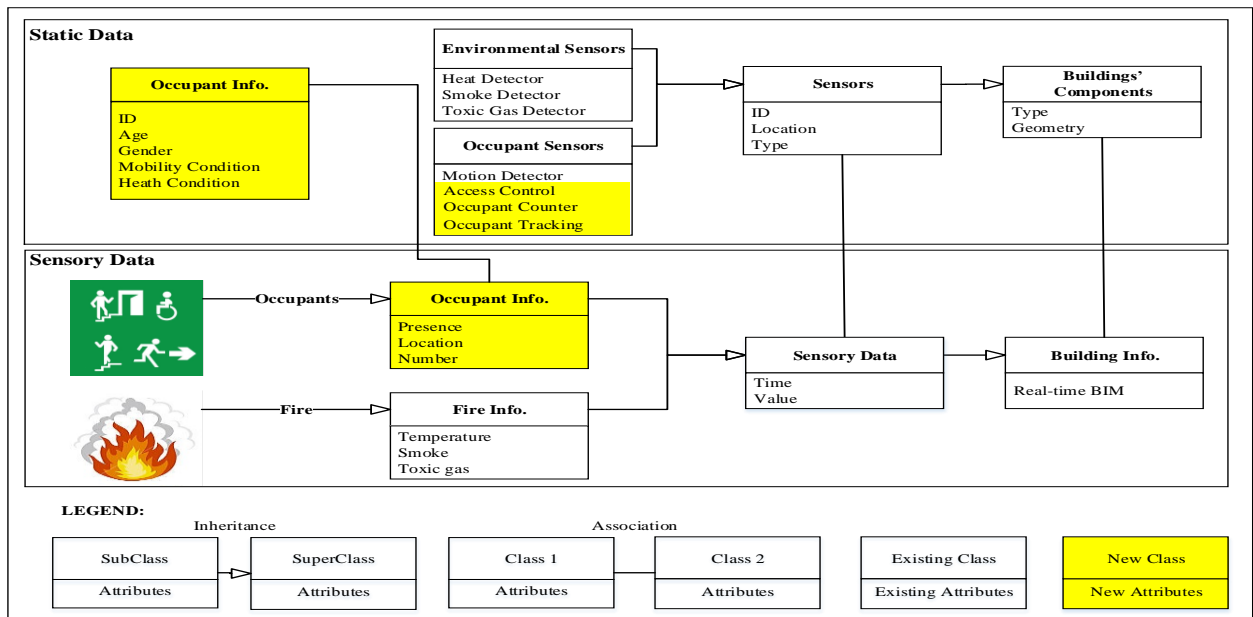


Figure 2. Relationship between sensory data and static data

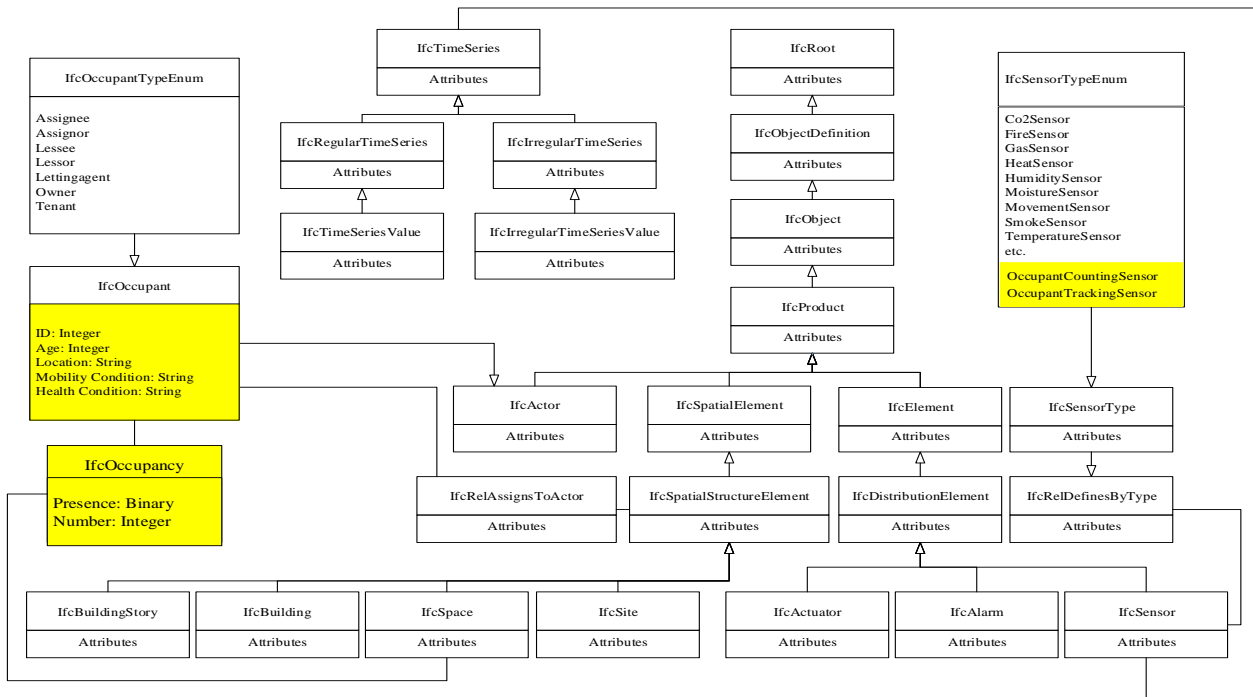


Figure 3. Data model for sensor types and building occupants' information

4 Case Study

In order to validate the proposed method, the 9th floor of the EV (Engineering & Visual Arts) building at Concordia University was chosen as experimentation area. Different types of sensors, including smoke detectors, temperature sensors, heat detectors and

occupant's sensors, installed in the facility were used to collect sensory data of fire and occupants.

Collected sensory data from Siemens-Room Temperature Sensor, and Quuppa Intelligent Locating System (which enable real-time occupants tracking), were used to test the proposed method for extending IFC. Then, a fire in the floor was simulated and the temperature data were visualized in BIM.

4.1 Data Acquisition and Integration with BIM

The floor was modeled in Autodesk Revit Architecture 2018. Sensors were added to Revit under the electrical category (as shown in Figure 4). Then, the model (geometry and spaces) was exported to IFC format.

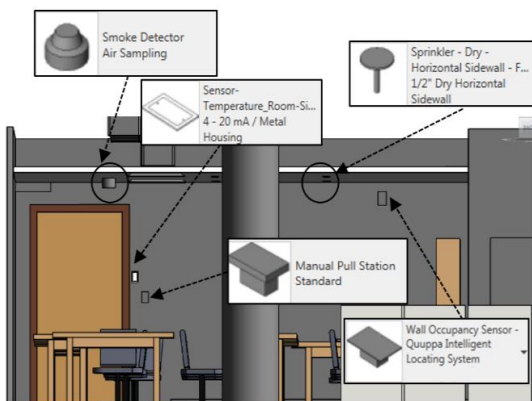


Figure 4. Revit model of a students' lab

Temperature measurement based on date and time were collected by temperature sensors installed in each room and the corridor. Also, Quuppa system gathered information (ID, date/time and X-Y coordinates) of five occupants through wearable tags. The two sets of information were initially recorded as .csv files. In order to avoid overpopulating the IFC file, the procedure of assigning sensory data to BIM can be divided into three major phases: **1. Pre-disaster phase:** In the normal condition, the system is in the “monitoring” mode; i.e. sensing the environmental and occupational information, but not storing the results in the IFC. The sensor elements (both heat sensors and the Quuppa sensor system) were modelled as IfcSensor entities (i.e., Heatsensor and OccupantTrackingSensor types respectively). General properties such as the coverage area and the set point temperature were modelled for the heat sensors. Moreover, the hazard threshold was defined for this sensor type as an IfcPropertySingleValue, representing rate of temperature rise, to be sensed as being hazardous. **2. Disaster detection phase-gate:** Once the reading in the sensor reaches the set-point threshold, the system starts storing in the IFC, the data collected by the two sensor types. This may update the state of the IfcSpace form “safe” to “hazardous” and will associate the environmental as well as occupation sensory data into it. **3. Disaster/evacuation phase:** temperature data collected every second is modelled as an IfcRegularTimeSeries. Storing the occupant information is more complex. For one, the data must be associated with the IfcOccupant, as well as the IfcSpace. Moreover, the data read (by Quuppa

e.g.) has more attributes than the heat sensor. Each data-point in this dataset has the ID of the occupant, date, time, and the X-Y location of the occupant. The data is collected and stored every second; hence IfcRegularTimeSeries was used for storing occupant information during the hazard. The IfcTimeSeries was associated with the IfcOccupant (from whom the data were collected).

The values of the IfcTimeSeries are in fact ordered pairs (representing X and Y location of the occupant at the given time). In our study, however, we used two separate time series for the two coordinates. Table 1 shows the attributes of the IfcTimeSeries used for storing the occupants' locational information (X coordinate as an example) during the disaster.

Table 1. IfcRegularTimeSeries attributes for the Quuppa intelligent locating system data

#	Attribute	Type
1	Name	XCoord
2	Description	X Coordinate of the occupant
3&4	StartTime EndTime	IfcDateTime YYYY-MM-DD Thh:mm:ss
5	TimeSeriesDataType	Continuous
6	DataOrigin	Measured
7	UserDefinedData-Origin	N.A.
8	Unit	LengthExponent
9	TimeStep	1 sec
10	Values	An array of X location (in m) for the occupant, with 1 sec interval time updates

4.2 Data Visualization

In the IFC format, new attributes and relationships for sensors and occupants were added to the EXPRESS file, based on the IFC4 standard. Then, the modified IFC model was viewed by BIM Vision as a freeware IFC model viewer that enables users to work on the file in the format IFC4.

In order to visualize sensory data (environmental and occupants) in BIM, as well as linking sensory data back to the Revit model, the visual programming tool Dynamo was used. Firstly, for visualization of the temperature data the following steps were taken: (1) modelling the 9th floor of the EV building, (2) assigning a number to each space; (3) defining parameters of the model, such as temperature and spaces for visual programming; (4) classifying the space temperature as shown in Table 2; (5) assigning a certain color to each class of temperature; and (6) visualizing the temperature classification of the space

automatically on the Revit model using the colors as shown in Figure 5.

Table 2. Space classification based on temperature

Temperature (°C)	Zone Color	Condition
$T < 23$	Green	Very safe
$23 \leq T \leq 30$	Yellow	Safe
$31 \leq T \leq 50$	Orange	Near dangerous
$T > 50$	Red	Fire/ dangerous

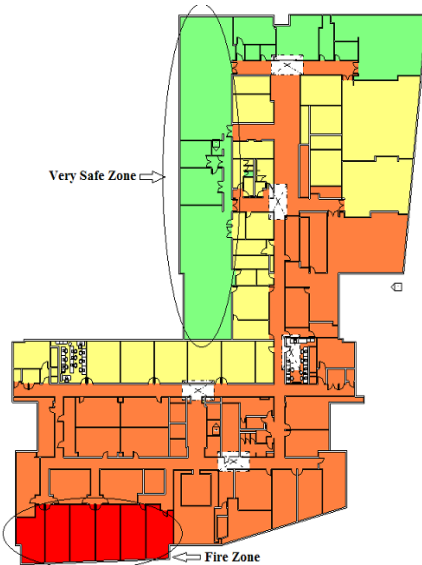


Figure 5. Space classification based on temperature in Revit

Secondly, the locations of occupants in one shared office for graduate students on the same floor (collected through Quuppa system and stored as time series) were visualized through the following steps: (1) modelling the office, (2) changing the coordinate system of the model to match with the local coordinate system used by Quuppa; (3) reading the data related to each occupant for each time step; (4) assigning a certain color to each occupant; and (5) visualizing the locations of the occupants automatically based on the time in the model as shown in Figure 6. This figure shows the locations of two occupants that were present in the office.

5 Conclusion and Future Work

This paper elaborated on the motivations and needs of new types of occupants' sensors and new occupants' attributes to have comprehensive real-time awareness in the case of a fire in a building. An extended IFC model was suggested to identify the entities, attributes, and relationships between sensors, occupants, occupancy, time series, and building components. The proposed

model was tested in a hypothetical case study, temperature data and occupant location were added to BIM for visualizing the space conditions under a fire.

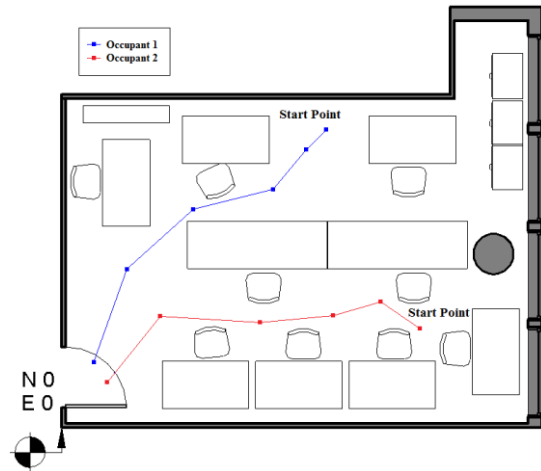


Figure 6. Visualizing the occupants' locations in Revit for the duration of 6 seconds

The proposed method was useful in providing real-time information for effective fire emergency management. Moreover, this work can be used to enhance the emergency first responders' perception by using 3D visualization of the dynamic conditions of the building under fire and occupants' condition.

Our future work will include the following: (1) Further implementation and testing of the proposed method, including the interaction between the occupants and the simulated fire propagation during building evacuation; (2) Extending the proposed model based on the first responders' view of indoor/outdoor fire emergency management; and (3) Developing a platform for the next generation of intelligent building emergency management that can integrate with BIM and IoT.

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