Combining Building Information Modeling and Ontology to Analyze Emergency Events in Buildings

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Abstract

Building information modeling (BIM) is a new technology that supports lifecycle information management for buildings. Ontology, derived from philosophy, is another technology utilized to describe real-world entities and to infer their semantic relationships. Each year disasters such as fires, earthquakes and floods affect not only buildings but all occupants inside, and hence, identification of critical building elements and devices vulnerable to a disaster is a must in order to perform countermeasures to ensure the safety of lives and property. At present, many simulation-based tools such as FDS have been successfully employed to mimic the impact of a disaster. Nevertheless, most of such approaches consider only the spatial or geometry data of a building. Other building-related attributes such as materials and equipment that certainly influence how a disaster proceeds have not been thoroughly examined. Thus, this research develops BIM plug-in programs to extract not only geometry but building materials and equipment/devices information in order to craft a disaster-specific ontology. Semantic relationships are modeled using Semantic Web Rule Language (SWRL) constructs, so as to represent the interdependencies among building elements and devices under a given disaster. The combined approach can accommodate not only spatial relationships but functional constraints pertaining to internal building elements and devices. It may help disaster mitigation officials forecast and assess the impact and progress of a disaster. A train station was utilized to demonstrate the proposed approach, with focuses on the fire and flood types of disasters. Better disaster mitigation strategies can be prepared if the proposed approach is adequately utilized.

Keywords –

Building Information Modeling; Ontology; Ontology Web Language; Semantic Web Rule Language; Disaster Mitigation

1 Introduction

Much research on critical infrastructure (CI) can be traced back to U.S. President Clinton's Executive Order 13010, which formally defines CI as the systems that whether real or virtual, the stop and destruction of these systems will have an impact on national society, economic and public health security [1]. The September 11 attacks on the World Trade Center demonstrate the urgent need for subsequent CI-related studies [2-3]. Among CI-related studies, one area of significant importance is about interdependency relationships among CI systems. For instance, according to the survey conducted by Mendonça and Wallace, the total loss of the power, telecommunication, oil and gas, and water sectors in the September 11 attacks due to indirect factors is more than that due to direct factors [4]. The term, CI interdependency, has been coined to denote such a cascade effect because one system failure will often trigger a series of failures of different CI systems. Mitigating the impact of such CI interdependency relationships thus has been regarded as one of the most important tasks during the disaster response phase.

Although it is worthwhile to collect and analyze the interactions of large-scale CI systems at the national level, in practice for a CI owner or operator it may be more useful and desirable to limit the CI scope to all components within a CI system, i.e., investigating the interdependency relationships among all subsystems or components of a given CI system. For instance, a wafer fabrication plant is often a large building with numerous specialized equipment and devices. Such a building is too valuable to be shut down. Thus, when a disaster occurs, one needs to identify vulnerable building elements and devices so as to perform appropriate countermeasures in hopes of mitigating the impact resulting from CI interdependency.

In the architecture, engineering and construction (AEC) sector, building information modeling (BIM) is a new and promising technology and can be defined as a digital representation of the physical and functional characteristics of a facility [5]. In fact, a building's BIM model contains not only detailed geometric information but materials and equipment-related data. Such data sets could be a valuable asset to disaster mitigation; nevertheless, previous research majorly investigates how to extract the geometry information of a BIM model in support of disaster simulation tools such as FDS. During the course of a fire incident, actually both the location and status of each automatic sprinkler device may need to be obtained and analyzed so as to help predict how the fire will proceed. BIM certainly can provide such assistance and requires further investigations.

Ontology comes from the philosophy field. It can be used to represent BIM and disaster-related attributes and to perform reasoning tasks. In other words, if we can build a BIM model close to the real world and transform it into an ontology model with disaster-related concepts, we could apply the ontology model to the identification of critical building elements and devices vulnerable to a given disaster. To this end, the objectives of this research include:

1. Developing a model transformation tool that can extract needed BIM data into the proposed ontology model. The design of the ontology model is based on the disaster-mitigation-related literature. Nevertheless, actual values or individuals need to be generated based on the corresponding BIM model. A computerized tool is developed to expedite such a transformation process.
2. Solving the problem regarding the lack of semantic relationships in the current BIM-based geometry data set. Current disaster simulation tools can extract only the geometry data; however, having such semantic relationships can further improve the disaster simulation process. For instance, currently if a FDS-based tool is supplied with the geometry descriptions of each room or space, since doors or windows inside such rooms or spaces are represented as openings, they are not linked into any wall. Because fire can be prevented from entering another room if a fire-proof door is installed, such information can be easily encoded into a semantic relationship and be used to help the disaster simulation process. Nevertheless, in current geometry data sets derived from BIM tools, no such semantic information exists.
3. Developing rule-based constraints to locate critical building elements and devices vulnerable to a given disaster. Once the semantic relationships can be encoded into the proposed ontology model, one can develop Semantic Web Rule Language (SWRL) constructs to formally describe different behaviors under the context of a different disaster. SWRL constructs are frequently utilized in other domains with ontology models and reasoning tools. Here the SWRL constructs pertaining to functional constraints of a critical building element and devices will be defined.

The manuscript is structured as follows: Section 2 describes important literature to highlight key features of ontology models. Section 3 presents the proposed approach with tools, while Section 4 discusses the application with a real case data set. Finally, Section 5 concludes the research and indicates future research work.

2 Related Work

In the previous research conducted by Leite and Akinci [6-7], they proposed an ontology model with four classes for handling building emergency events, i.e., Content, ContentType, BuildingSystemSupply, and Threat. ContentType is defined as the type of an asset within a building. An asset (represented as Content) in a building must be worth protecting, e.g., a painting or a critical device. These assets require the building to provide some supply (represented as BuildingSystemSupply), which may be water, electricity, gas, etc., to work properly; therefore, asset types and building systems supply form a many-to-many relationship. Additionally, one asset may be subject to one or more threats (represented as Threat). It is hypothesized that the threat posed by a building system is causing the asset to be destroyed or malfunctioned.

In their papers, two types of such damage have been identified. The first one is about spatially adjacent influence, which makes the assets close to the destruction point also damaged. For example, the water leakage event can be expanded from the lowest position of the event. If the leakage problem is not fixed, all the assets close to the event location will be affected. The second type is about connectivity, which means that any system failure resulting from a pipeline can be expanded into other places along the pipeline, so as to create more system failures, such as power failure. In fact, all the systems needing power supply within the circuit loop are stopped. Cascading effects may occur among all the devices and equipment needing such systems.

In order to solve the problem regarding CI interdependency, researchers have utilized the input-output model and obtained positive feedback [8]. However, there are two issues associated with this approach. One is about the difficulty of collection inoperability information for a facility, which is common to almost all CI-related approaches. The other is about the difficult of identifying all relationships between the target CI systems or components. The input-output approach does not provide a clue to such identification; hence, qualitative analysis such as expert evaluations is often utilized and have been criticized for years.

Because BIM contains both geometric and non-geometry information, it could be used to assist in the CI analysis. Based on Leite and Akinci's ontology model, the research team utilizes BIM tools to automatically craft an ontology model representing the spatial layout of a given building. Since it is difficult to manually convert a BIM file to an ontology model, such model transformation tools can not only reduce the conversion time but ensure the quality of the model, which has not been seen or reported in the literature.

3 Methodology

This section will first describe the entire research process. First use the Add-in function of Autodesk Revit 2015, the BIM model editing software. Using Revit API to write the convert program from BIM model to ontology model in Visual Studio 2015. Extract and compile the BIM model information required by the disaster impact architecture into the OWL file format. Then use Protégé 5.0.0 to turn on the converted ontology model. Begin to construct disaster impact rules with semantic web rule language. And use the disaster impact rules to infer the impact of disasters. Finally, we use semantic query web language to present the results through the query.

Autodesk Revit 2015 provides Add-In function. Users can use it to write C # programs with the Revit API for working in Revit. The OWL file format is derived from the RDF file format and is similar to the XML format. Therefore, the convert program is mainly written using the XML library and the Revit API. OWL file format can be divided into declaration area, category area, property area and object area. The declaration area is an OWL file attribute declaring to be used in other areas, such as swrlb, owl, swrl, and protege, and is represented by xmlns: swrlb. Since the OWL file format is not, after all, an XML file format, not all XML libraries are available. This method requires the use of a flexible XML library to successfully write. For example: Some XML libraries have header files that do not allow "<? Xml version =" 1.0 "?>", Which must be added to "encoding" or something else. The category area is a category that is written in the ontology model, for example: the category of the door, denoted by "<owl: Class rdf: ID =" Door "/>. The property area describes the Object Property and Data Property in the ontology model. The difference with the category area is that it needs to define Domain and Range. The object area is Instances that describe the ontology model. The formation of the OWL file format across four regions enables Protégé to access a nearly real-world ontology model transformed from BIM with vast information.

Revit API can be divided into the main categories of objects, names and declarations. An object's category and name are simple compared to the association. From ElementCategoryFilter, you can filter the required object names and categories to IList <Element>. However, it must describe its association with other objects. That is, it must describe what gate is at what wall in the object area of the OWL file. In the program, in addition to using the Insert function to describe what the door is located outside the wall, there is also the use of BuiltInParameter.ELEM_ROOM_NAME and BuiltInParameter.ELEM_ROOM_NUMBER describes the relationship between the object room. Finally, the format in the OWL file is combined with the object information retrieved by the Revit API.

After the process of conversion to form ontology model, you can use ontology editing software Protégé to open it. SWRL is to write rules and make inferences about ontology models. Flooding was used as a case study in this research. First, the categories of disaster impact architecture include doors, walls, rooms, appliances, flooding, sockets and switchboards. Properties then include HasDoor for the door, Height for the flooding height, and DoorFlood for the flooding height of the door. HasDoor is mainly the object-to-object property, and Height is the property of the object and the value. Through the combination of the object and the property, HasDoor describes the framework for analyzing the disaster impact.

Then, in order to set the rules, the pre-defined scenarios need to be designed. Therefore, based on the research needs to infer the impact of flooding, the key is to prove the feasibility of this method, so only in a simple way to infer the flooding, and mainly flooded by the door so highly reduced way to research.

The research will be set to the following assumptions:

1. Assume that the main corridor flooded at a height of 2000mm.
2. The doors have their height reduction coefficient. If the flooding height is 2000mm, the coefficient of the door is 0.8, then after the door, the flooding height is 1600mm.
3. Electrical appliances have their damage height and damage properties. If the damage height of the computer is 600mm and the flooding height is 800mm, then the computer's damage attribute will be YES.
4. Sockets and distribution boards have their own damage properties, and will affect the electrical properties of the stall. If the distribution board is damaged, then all the electrical stalls. If the outlet

is damaged, the appliance associated with it will stop.

5. The rule will deduce that if the flooding height of a certain area is a certain height, it will affect the flooding height of all the places, the situation of electrical damage and stalling.

The research is based on the above assumptions SWRL preparation. It should be noted that the rules of the SWRL because it can only be simple reasoning and no difference set concept. After the rules are written, inferences about the effects of flooding can be obtained, and its process as shown in Figure 1.

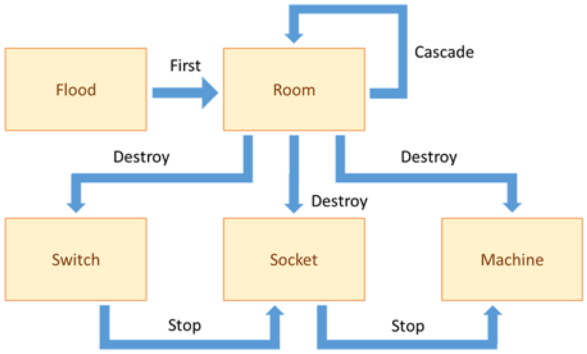


Figure 1. Reasoning Process Diagram

The disaster impact rules of SWRL can be divided into two types, one is to infer the flood level, as shown in Equation 1, and the other is to infer the electrical state, as shown in Equation 2.

Room(?r) ^ HasWall(?r, ?hw) ^
HasDoor(?hw, ?hd) ^
Room(?r2) ^ HasWall(?r2, ?hw2) ^
sameAs(?hw, ?hw2) ^ differentFrom(?r, ?r2) ^
DoorWeak(?hd, ?dw) ^
RoomHeight_1(?r2, ?rh1) ^
swrlb:multiply(?new, ?dw, ?rh1)
-> RoomHeight_2(?r, ?new)

(1)

Machine(?m) ^ MaBreakLevel(?m, ?mabl) ^
MaInRoom(?m, ?mair) ^
RoomHeight_1(?mair, ?rh1) ^
swrlb:lessThanOrEqual(?mabl, ?rh1) ->
MachineDestroy(?m, "1"^^xsd:int)

(2)

Equation 1 first use *sameAs(?hw,?hw2)* to find rooms with the same wall, and then use *HasDoor(?hw, ?hd)* to select the wall has door, and use *differentFrom(?r, ?r2)* to exclude the room itself, and next use *DoorWeak(?hd,?dw)* to get the height reduction factor, and finally get the reasoning result of flood. Equation 2 mainly uses *swrlb:lessThanOrEqual(?mabl, ?rh1)* to compare *MaBreakLevel(?m, ?mabl)* and *RoomHeight_1(?mair, ?rh1).* If *MaBreakLevel(?m, ?mabl)* is less than or equal to *RoomHeight_1(?mair, ?rh1),* MachineDestroy(?m, "1"^^xsd:int) will be expressed as 1, that is, destroyed.

SQWRL uses MySQL-like settings to further refine the results of SWRL for completeness and alignment. it uses in the research was to reduce the flooding height by using a factor so that the flooding height only decreased as a result of the cascade effect. Therefore, the method of determining the final value is to take the maximum value of the result as its setting criteria. The rule also uses numbers to indicate the stalling and destruction of equipment. If the flooding height reaches its height of damage and stall, set its associated value attribute to 1 to indicate that the device has been destroyed or stopped. Corollary results were generated electrical stall table, electrical damage table, flooded altimeter table, socket damage table, outlet stop table and power distribution board damage table. Equation 3 uses SQWRL to select the flooding height of each room.

Room(?r) ^ RoomHeight_All(?r, ?rh) ˚
sqwrl:makeBag(?b, ?rh) ^ sqwrl:groupBy(?b, ?r)
˚ sqwrl:max(?max, ?b) -> sqwrl:select(?r, ?max)

(3)

4 Case Study

The model of Taipei MRT Nanjing Sanmin Station comes from the project and station managers. The station's main body is divided into three floors, ground floor, hall floor and platform floor.

The top floor of the MRT station is the ground floor. It usually has a device to prevent floods. The height of the pump's switch is located at a flood level of 200 years plus 110 cm. The basic height of the entrance also increased. Used to prevent flood entering MRT station.

The hall floor for the main flow through the site. The name of the space through the hall can be divided into recreation room, environmental control room, uninterruptible power system room.

The bottom of MRT station is platform floor. This floor more facilities for the ventilation shaft, exhaust and intake. It is mainly to solve the pressure caused by vehicles entering and leaving the rise and fall. And by air pressure to provide vehicle braking and deceleration features. In addition, this layer is also equipped with pumping equipment, pumping equipment for the entire body of the site. While others are similar to the through-hall, possessing the space for environmental control and power supply system and also based on the symmetry.

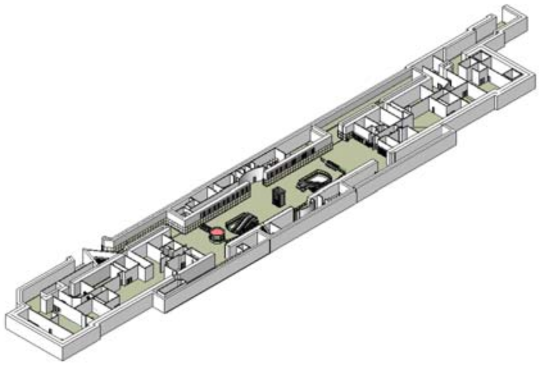


Figure 2. Hall Floor of Nanjing Sanmin Station

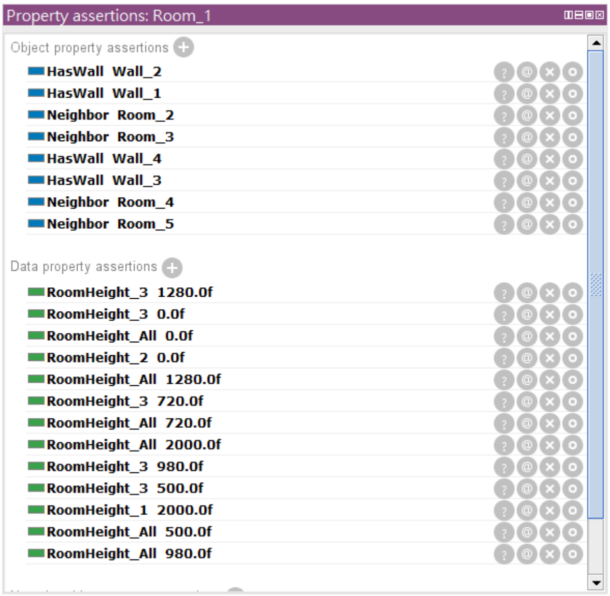
However, the details of the platform floor are not clear. And the ground floor only has entrance, not too many objects. Therefore, research proposals, the main reference to about the hall floor. Only in this way can we get the complete and accurate research results.

When the building information model is transformed into the ontology model via Add-in, the model itself is not a model that can be correctly analyzed.

In addition to the designer's design habits may cause differences, but also the following possibilities. First, the BIM software used in this research is Revit, which has the settings for connecting appliances and sockets. However, there is no clear classification of objects requiring electricity, resulting in the need for electricity if not for mechanical equipment, electrical equipment, etc. Objects, are required in the program clearly defined as the need to power the object is also defined in the ontology editor software. Second, most building information models have not yet added switchboards, sockets and electrical appliances. Therefore, the model used for the construction of the Nanjing Sanmin Station in this research has not been provided yet. Therefore, it is necessary to establish electrical appliances in each area so as to understand flooding mechanism is the more appropriate approach, and the ontology model to add, is a more efficient approach.

As shown in Figure 3, this is the result of SWRL reasoning. RoomHeight indicates the water height of the room affected by flooding. RoomHeight_1 indicates the results obtained by cascading the first flood effect. Similarly, RoomHeight_2 is the second time. And RoomHeight_All sets the value of all the water heights. The research is to find the maximum of all water heights because we defined the water height of room comes from the other rooms that would cause this room the highest water height after cascading effect.

However, although SWRL successfully deduced the result, it did not sort it out. So we need to use SQWRL to rank the results we need. As shown in Figure 4, the research continues by writing the SQWRL in SWRL and shows the results in the program, while Figure 5 shows the detailed results. In Figure 5, “1” indicates that the appliance has been damaged, “0” indicates that the appliance continues to operate, and Total_Machine_Stop tab, Total_RoomHeight tab, Total_Socket tab and Total_Switch tab in addition to the Total_Machine_Destroy tab.



Property assertions: Room_1

Object property assertions

HasWall Wall_2
HasWall Wall_1
Neighbor Room_2
Neighbor Room_3
HasWall Wall_4
HasWall Wall_3
Neighbor Room_4
Neighbor Room_5

Data property assertions

RoomHeight_3 1280.0f
RoomHeight_3 0.0f
RoomHeight_All 0.0f
RoomHeight_2 0.0f
RoomHeight_All 1280.0f
RoomHeight_3 720.0f
RoomHeight_All 720.0f
RoomHeight_All 2000.0f
RoomHeight_3 980.0f
RoomHeight_3 500.0f
RoomHeight_1 2000.0f
RoomHeight_All 500.0f
RoomHeight_All 980.0f

Figure 3. Room_1 Result of SWRL Reasoning

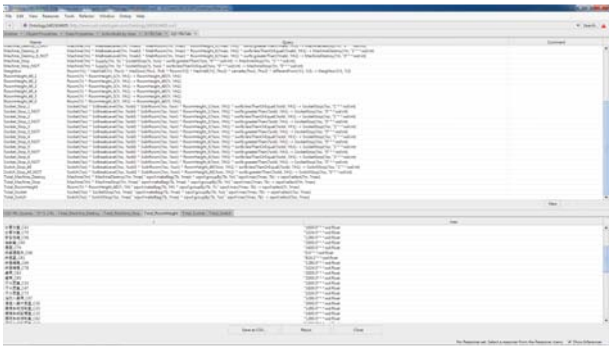
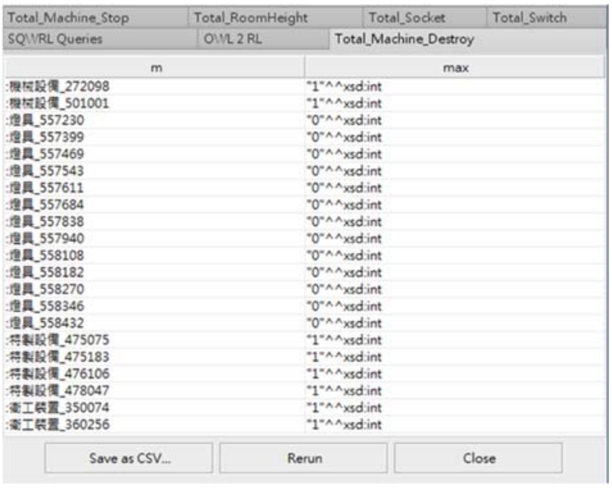


Figure 4. Result of SQWRL Query

5 Conclusions

When analysing the progress of a disaster inside a building, one needs a model representing the building's spatial layout with important building-material-related attributes. Certainly, the Revit tool developed in this research can provide such information. In addition, disaster-specific properties and their interactions with buildings can be modelled using SWRL constructs. Take flooding as an example, one may be able to retrieve watertight doors, sluice gates and pumps information from a building's BIM model. In the future, if this method can be more complete and common method of analysis, or design the user interface to allow users to make self-defined special analysis, and based on this research method, we can analyse all kinds of disasters comprehensively at the same time and use them to get the advantage of more disaster-affected data quickly. Finally, we can analyse the matrix and vector of input-generating model. In addition to contributing to disaster preparedness, expecting to send the results back to Autodesk Revit for visualization will provide a better understanding of the impact of the disaster.



m	max
:機械設備_272098	"1"^^xsd:int
:機械設備_501001	"1"^^xsd:int
:燈具_557230	"0"^^xsd:int
:燈具_557399	"0"^^xsd:int
:燈具_557469	"0"^^xsd:int
:燈具_557543	"0"^^xsd:int
:燈具_557611	"0"^^xsd:int
:燈具_557684	"0"^^xsd:int
:燈具_557838	"0"^^xsd:int
:燈具_557940	"0"^^xsd:int
:燈具_558108	"0"^^xsd:int
:燈具_558182	"0"^^xsd:int
:燈具_558270	"0"^^xsd:int
:燈具_558346	"0"^^xsd:int
:燈具_558432	"0"^^xsd:int
:特製設備_475075	"1"^^xsd:int
:特製設備_475183	"1"^^xsd:int
:特製設備_476106	"1"^^xsd:int
:特製設備_478047	"1"^^xsd:int
:衛工裝置_350074	"1"^^xsd:int
:衛工裝置_360256	"1"^^xsd:int

Figure 5. Detail Result of SQWRL Query

Taking the ontology model as the main reasoning can take advantage of the logical relationship between objects. If the building information model as the main body of analysis, in addition to only have to write the program is not good at logic inference analysis, the building information model of the huge information also caused the analysis time-consuming. The ontology editorial software is not only based on the advantages of logical reasoning, but also because of its SWRL and SQWRL, making it easier to write and manage. Taking the information model of the Taipei MRT Nanjing Sanmin Station as an example, the time it takes to open and change is quite time-consuming. Even when operating on a general-purpose laptop computer, it still takes about 3 minutes for the program to open the file, or change the viewing angle to wait 5 seconds. The ontology model of file capacity is better. The file size of the information model of the Taipei MRT Nanjing Sanmin Station is about 2 GB. However, the information extracted by ontology accounts for at most 1 MB, and the difference between the visualizations is not significant. Due to programmatic transformation and the extraction of valid information, it is expedited to research the reasoning. However, the version of Revit API has been greatly changed. Due to the complexity of building information model, the classification of its functions is cluttered and flawed. If this weakness can be solved, Software replacement or version has a considerable improvement, will be able to have more space for this research.

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