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MODELING SPATIAL AND OPERATIONAL INTERDEPENDENCIES AMONG BUILDING SYSTEMS USING BUILDING INFORMATION MODELING

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Abstract: Over the last decade, building information modeling (BIM) has been utilized as a standardized approach to represent and analyze the complex, diverse and rich design of architectural, structural, mechanical, electrical and plumbing systems. The current state of the art, however, focuses on deploying BIM for applications limited to optimizing the design and construction process of buildings in general. Minor emphasis is being directed to using BIM to operate and maintain buildings against the many risks they face. A difficulty in doing so is that there is no means to adequately trace the effect of hazards across the systems and components of the building. The objective of this paper is the development of a methodology for extracting interdependencies among building systems and components in order to understand how any hazard can affect the resilience of building systems and components. The proposed methodology is developed inside the Revit environment and is composed of two models; 1) a spatial model and 2) an operational model. The spatial model divides a building into spaces and then extracts all of the building elements in each space. The extracted elements are grouped into five domain specific groups; architectural, structural, mechanical, electrical and plumbing systems. The operational model is a processed version of the spatial model that allows for the assessment of the propagation of consequence through the building's operation. It provides novel visualization and understanding of a building's operational risks against all hazards. The proposed methodology expands over the existing functionalities available in the Revit Application Program Interface (API) using the C# language. A case study using a multi-story office building is used to demonstrate the proposed methodology application with discussion for its results and potential improvements.

1 Introduction

Building Information Modeling (BIM) provides a collection of technologies and platforms for representing geometric data and metadata of building systems to facilitate design, construction and lifecycle management. The many and varied BIM software tools allow stakeholders to work collaboratively to manage complexities during the design and to build and administer stages of a project. Building systems include complex, diverse networks of architectural, structural, mechanical, electrical and plumbing elements. The components of these networks are dependent on one another spatially and operationally. When there are failures in a building the dependency relationships can lead to a cascade of effects. In such cases, the building can become ineffective in satisfying the needs of occupants.

The objective of this paper is the development of a methodology for extracting interdependencies among building systems and components in order to understand how any hazard can affect the resilience of building systems and components, and ultimately impact the occupant. Many current research efforts are focused on optimizing the design and construction process of buildings in general with minor emphasis being directed to operate and maintain buildings against the many risks they face. This paper presents a novel methodology for modeling spatial and operational interdependencies among building systems. Spatial interdependency relates to the location of elements within a building. Operational interdependency concerns how the propagation of one element‘s failure can hinder the operation of other elements. After laying out current gaps in the literature, the methodology is discussed comprehensively with a focus on how the proposed methodology accelerates a seamless extraction of interdependencies among the architecture, structural, mechanical plumbing and electrical systems which allows for a risk prioritization assessment using RiskOutlook. The implementation of the approach inside the Revit platform is discussed and a case study is utilized to demonstrate the potential results and benefits of deploying such a method.

2 Literature Review

Building projects are becoming complex due to the many interacting stakeholders, such as financing bodies, authorities, architects, engineers, lawyers, contractors, suppliers and trades (Clough et al., 2008). Bryde et al. (2013) survey of 35 case studies reported in literature in the period between 2008-2010 shows that BIM is utilized most frequently to address: design and construction needs for new projects in particular; cost and time control; communication management; quality assurance; and scope definition. Barlish’s and Sullivan’s (2012) analysis for the benefits of using BIM shows that the majority of stakeholders are concerned with BIM capabilities in cost and time reduction and improving the overall project management process for complex building projects. Eadie et al. (2013) responses from 92 BIM technology experts shows that only 5% use BIM in facility management compared to 47% who use it for architecture, structural and mechanical design of buildings. These surveys show how BIM is becoming a pillar in most large construction projects to meet ever-competing objectives. The studies also provide an impression of the lacking use of BIM when it comes to managing the service life of building systems, especially as it relates to the risks the building systems and the operation it enables.

There are increasingly strict operating requirements of today’s buildings, especially for large buildings where there are increasingly intricate integrations of systems and components. Clients rely on building operations that recover quicker than ever from disruptions to the infrastructure and systems upon which they rely, while also demanding more sustainable operations overall from a complex array of systems (Bristow, 2016). Buildings are subject to human threats (e.g., terrorist attacks) or natural hazards (e.g., earthquakes) and therefore such buildings operate in risky environments with critical demands being placed on connected infrastructure networks.

Research efforts are moving towards solutions that can help deal with the complex risk context of modern buildings. Amirebrahimi et al. 2016 provide a methodology for data integration between BIM and GIS for flood damage assessment of buildings. Oti et al. 2016 offer a methodology for managing the operation and maintenance of buildings to cope with energy needs. Wetzel and Thabet (2016) propose a BIM tool to address safety issues during hazardous events for buildings. The common limitation between the above stated research efforts is; 1) ignoring the interdependencies among building systems, 2) absence of a systematic tool to automatically extract and represent such interdependencies in a BIM environment, and 3) an assessment of the risk of building systems that considers spatial and operational interdependencies.

3 Methodology and Implementation

The methodology concerns mapping structural and operational interdependencies to assess risk the occupants and their operation. Spatial interdependency focuses on dividing a building into spaces and then extracting all of the building elements in each space. The extracted elements are grouped into five domain specific groups; architectural, structural, mechanical, electrical and plumbing systems. The operational interdependency assesses the propagation of failure. This objective is achieved by implementing the methodology shown in Figure 1. The components of the methodology depicted in Figure 1 are as follows:

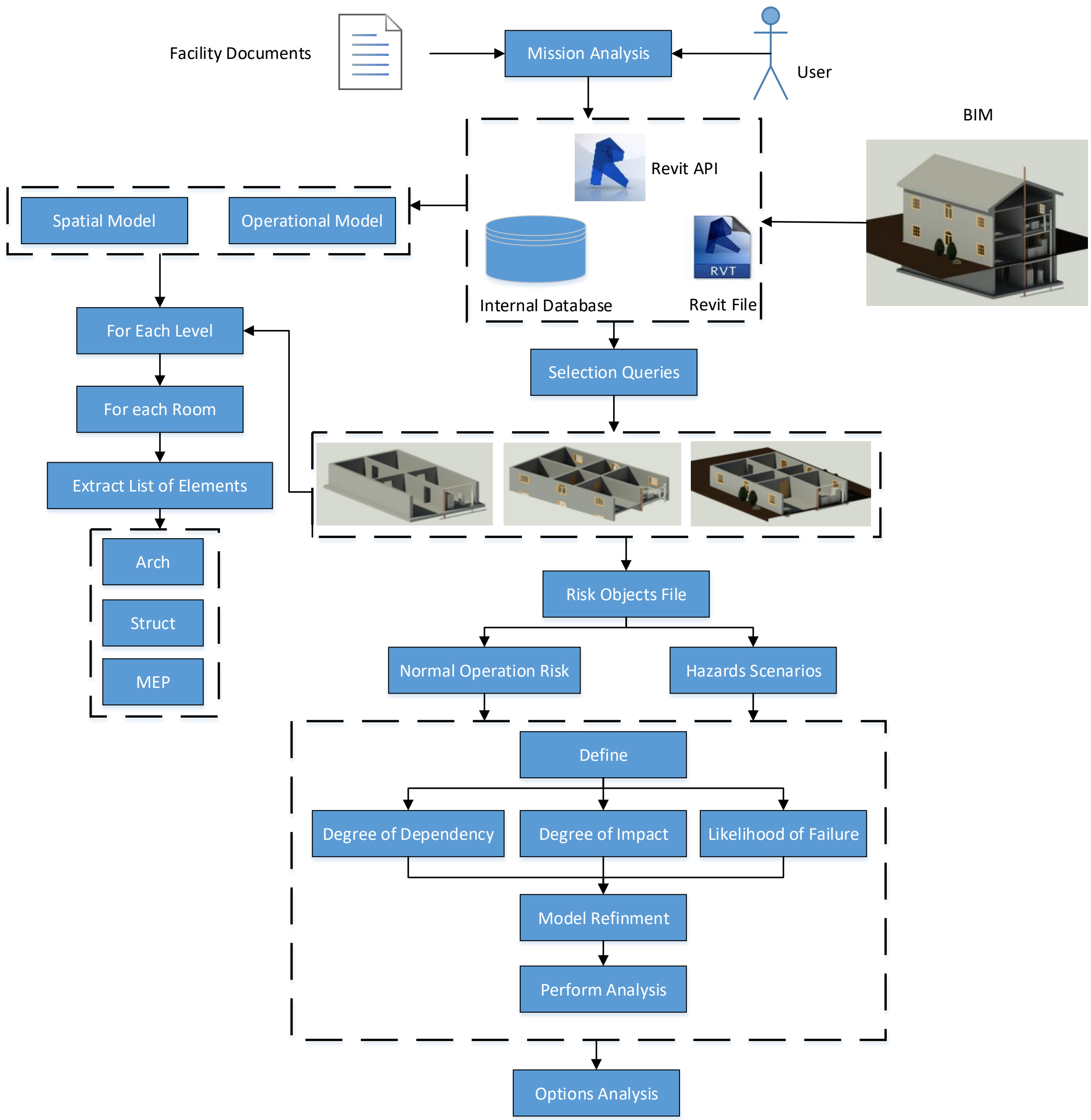

Figure 1 Overview of BIM spatial and operational dependency methodology

1- Mission Analysis: The first step is studying the facility of interest by reviewing available as built or as design CAD drawings and operation and maintenance records if available. This step is important in defining the objective of the risk exercise and hence determining needed inputs, outputs and any identified constrains.

2- Spatial Model: Extracts information related to the location of each building element from the Revit environment and builds a linked list of elements that are interdependent because of their geospatial proximity. Building data is stored in two separate files; one file contains the geometric data of the building elements and another file contains other metadata about each building element (i.e. material type, length, width, fire resistance ..etc.). How these metadata are stored and processed is different from one BIM platform to another. Revit was selected because it provides a convenient and systematic set of tools for creating, updating, deleting and replacing building elements. It also provides a stable and well-documented application programming interface (API). This API is important to understand what functions already exists in the Revit environment and how these functions interact with the stored data. The spatial model uses the Revit API functions as a foundation to develop more functions to facilitate the extraction of spatially interdependent elements. These interdependent elements are grouped in a linked list where each room has a series of dependent elements. Any failure in such element will affect this room and other dependent elements in the linked list.

3- Operational Model: This model traverses each mechanical, electrical and plumbing (MEP) system in the building to extract the following information; 1) the source element and 2) a linked list of elements and their connectors. Each MEP system has a source element (e.g., electrical generator, water pump, heater unit, etc.) and this source provides each building system with the required input from neighbouring civil infrastructure networks. The source delivers the expected service to each room and component in the building by a series of connected elements (e.g, pipes, ducts and cables). These elements are attached together with connectors (i.e. fittings and accessories). The operational model stores a linked list of connectors where each connector has a preceding and succeeding element. Each element also has two connectors; start and finish connectors.

4- Risk Assessment Integration: In this case, after extracting spatial and operational interdependencies the output is imported as a risk object database file (romdl) into the risk analysis engine (RiskOutlook). RiskOutlook is a generic platform for assessing the risk for interdependent entities with tools to rank and prioritize vulnerable elements. RiskOutlook was developed by RiskLogik to provide a platform for assessing risks due to hazardous events. RiskOutlook is selected because RiskLogik is the industrial partner during this research. The input file produced by this methodology has a description of each MEP system's connections, and all of the rooms and their spatially interdependent elements, and relationships between MEP, structural and architectural elements as well. After loading the input file, the decision maker can define the probability of failure, degree of impact of each element and the degree of dependency of each dependency relationship. This enables a cumulative assessment of risk across all building components and supporting infrastructure and operations, which can be used for risk prioritization and assessment of different treatment options. Further details on the risk engine can be obtained from O'Neill (2013).

5- Options Analysis: The decision maker can utilize the developed methodology to understand the performance of a facility during normal operation. The tool helps in generating a risk profile to describe the risk index of each component in the building. Subsequently, the decision maker can introduce hazardous events and see how the risk profile has changed due to such events. The process of selecting the optimum mitigation plan to restore the risk profile to the normal operation stage is not addressed in this paper.

The above methodology is implemented using the C# programming language. Revit API has functions to control the graphical user interface (GUI) and through the GUI the user can access functions related to the architecture, structural and MEP elements. These functions are executed based on the programming instructions stored in the Revit API. The implementation provides a new functionality to filter and select certain elements by class or level. All BIM elements are grouped into classes such as door class, wall class, and duct class. These elements have a reference level, such as first floor or second floor, and this reference level is used to define the location of each element in the building. The user can assess the risk for the entire building or only for particular set of elements. After selecting the targeted elements by class or level, the interdependency model will extract spatial and operational interdependencies automatically to the user and store the output in excel or text file format. The text file is used to feed the extracted BIM interdependencies into RiskOutlook environment. This text file is stored in "romdl" format that is compatible with RiskOutlook. The user, subsequently, can refine the extracted model if needed and perform the risk assessment analysis inside RiskOutlook environment.

4 Case Study

A small residential house is used to demonstrate the application of the method. The residential house is composed of a basement and two above-grade floors. Architecture, structural and mechanical systems are modeled in this BIM model. The BIM model is constructed from CAD drawings in the Revit environment. After building the BIM model, the interdependency model is used to extract the spatial and operational interdependencies among the above stated systems. The BIM model and the developed user interface for the interdependency model is shown in Figure 2. The user can select what building systems need to be analyzed and included or excluded from the final interdependency file. After deciding which elements and systems are included in the analysis the decision maker can run the interdependency model to export the results into the selected format. The interdependency model captures all spatial and functional interdependencies among all systems and hence the decision maker can assess the expected risks inside RiskOutlook. As shown in Figure 3, the decision maker can track how each element can affect the performance of other elements in the building. For example, the decision maker can select parts of the model, such as a mechanical duct, as shown in Figure 3. This element is called the reference element, as the decision maker is interested in understanding how the failure in this element can influence other elements. The spatial model located this element in Room 1 and the operational model traversed the mechanical network and selected the following ducts shown in Figure 3 as the mechanical elements affected by such failure. The interdependency analysis is performed in the Revit environment and RiskOutlook provides a convenient platform for understanding how each element in the building is affecting other elements. Without the interdependency model, extracting spatial and operational interdependencies would be error-prone and time consuming especially for large and complex building systems.

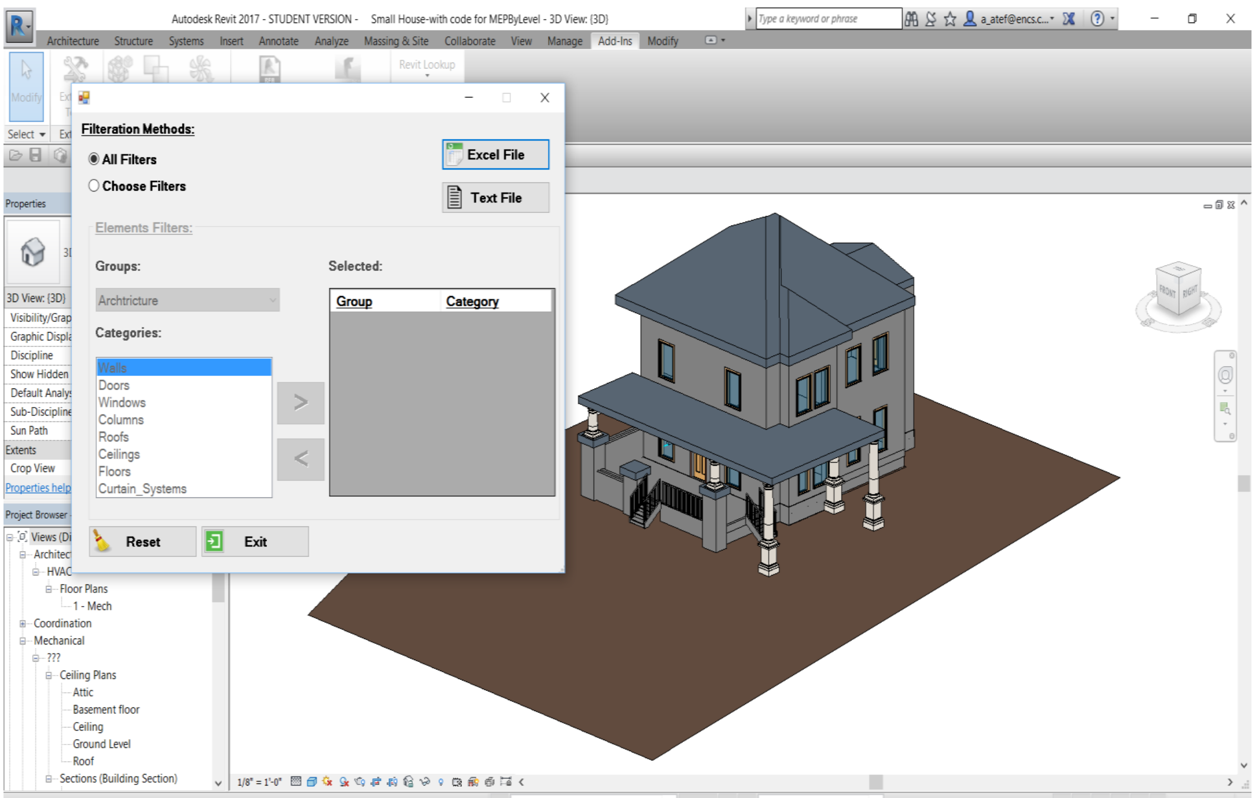

Figure 2 Program Interface

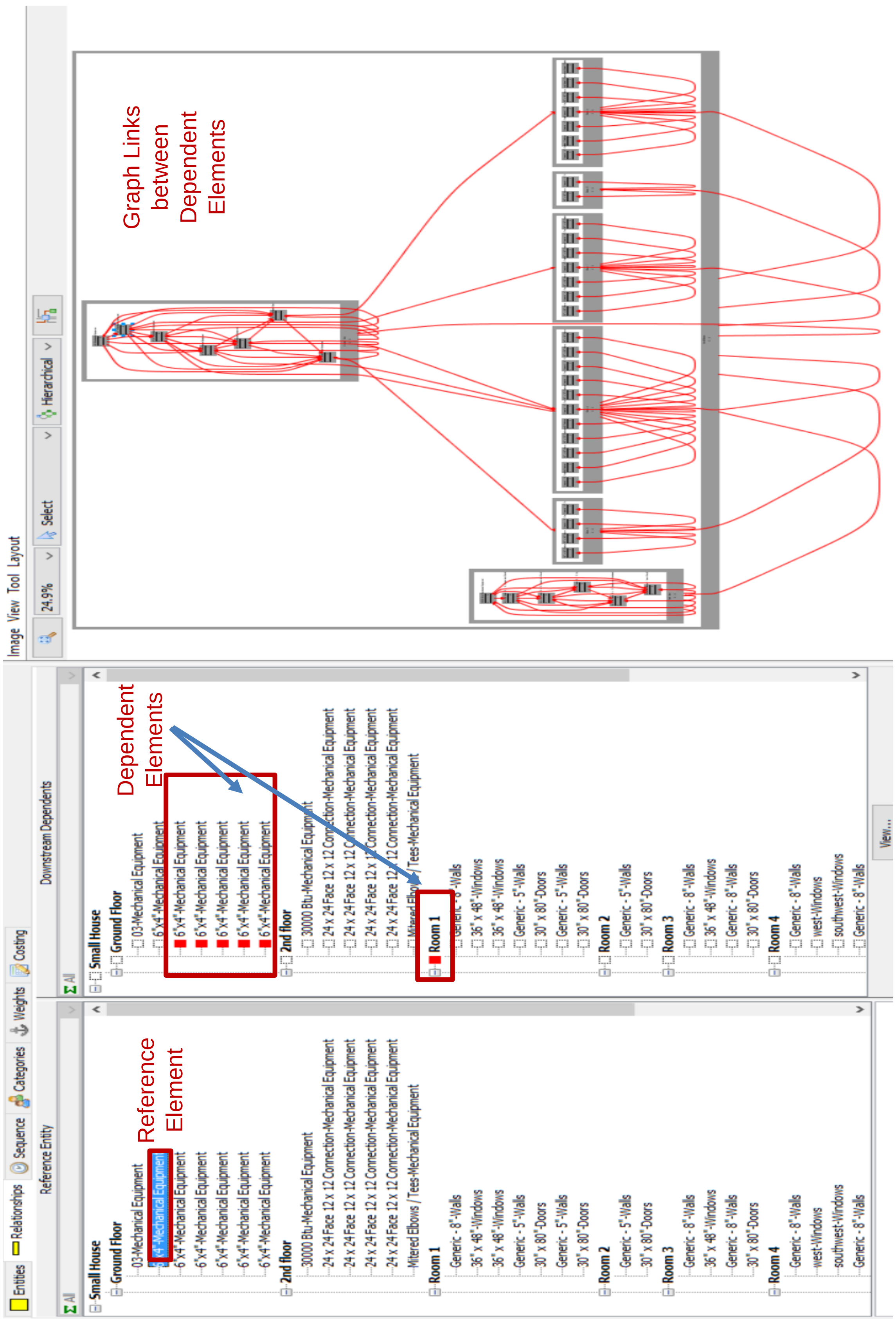

Figure 3 Interdependency inside RiskOutlook

5 Summary and Conclusion

This paper presents a methodology for extracting interdependencies among building systems and components in order to understand how any hazard or failure can affect the state of building systems and components. The methodology is implemented inside the Revit environment using C# to facilitate the extraction of BIM data for buildings into the risk assessment tool (RiskOutlook). The overall approach provides seamless extraction capabilities for all or particular building systems and can aid engineers and operators of buildings in extracting large and complex information from BIM environment to perform the risk assessment analysis inside RiskOutlook. This tool can be enhanced by allowing the analyst to export and visualize risk assessment results inside the BIM environment. In addition, this methodology can be extended to facility management applications.

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