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Life Cycle Approach for Facility Resilience Information Modeling (FRIM)

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Abstract

Disasters have affected more than 3 billion people, killed over 750,000 people, and cost more than $600 billion over the past three years in the US. Research efforts have been made in the domain of community resilience attempting to mitigate disaster impacts at a community level. However, inadequate attention was drawn from researchers to the area of disaster resilience at a facility level. In fact, facility resilience plays a significant role because most of social activities take place in such built facilities. Facility spaces are dynamic in aspects of time and space for its users, including both facility occupants and its operation staffs. Extreme events also interrupt normal operations of a facility. In current practice, a comprehensive facilities information model is missing to monitor and predict the resilience capacity of a facility, and to coordinate disaster response and recovery during and after a crisis.

In this research, the authors present the theoretical framework of facility resilience information modelling using a life cycle approach. An object-based data structure was designed and presented to integrate workspace representation into facilities management models, and a workspace identification and adjustment method was created to facilitate the modelling and planning of resilience operation spaces. This solves the current challenges in facility resilience including the delay in accessing facility information during disaster response, and extra losses of time and money caused by lack of accurate facility information from the available facility information systems. The final product, the Facility Resilience Information Model (FRIM), will improve facility resilience by providing the facility management team more approachable and accurate facility information, engaging facility occupants in crisis assessment and responding, and laying a foundation to achieve occupant-centered facility resilience management.

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1. Introduction

During the aftermath of a disaster, mitigation and recovery activities always interrupt normal operations in the affected facility. Such activities frequently cause congestions in parts of the facility due to unsuitable conditions of normal operation. Change of space usability and maintenance needs would incur change of flows, social interactions, and building services.

Current methods to analyze space needs for resilience activities do not adequately identify the dynamic nature of space fitting during different phases of an emergency – the space usability in the affected facility change greatly over an emergency management cycle responding to the changing level of risks, changing needs of workspace, and changes in the final product that incorporates resilient thinking. Such dynamic nature of most resilience activities, together with the normal activities of occupants, make it impossible to track such changes in space overtime manually.

However, space assignment for facility resilience maintenance (FRM) remains a human experience-based decision process right now, and suffers from many delays and extra cost due to unexpected conflict of time and space for resilience activities and normal operations of building occupants. More information on space assignment and minimum requirement on various building systems to assure normal operation of a building is needed, as well as an automated workspace representation mechanism to capture the temporal-spatial needs of FRM.

Facility management can benefit significantly by adopting BIM [1]. Dynamic workspace representation mechanism has been developed for construction phase by several scholars over the past decade [2,3]. However, research in dynamic space planning for facility management is still in lack. Indeed, beyond emergency response and recovery, facility resilience can benefit from dynamic space fitting at large. For instance, as an essential part of resilience building, preparedness training can benefit from such a dynamic facility space planning model greatly. Such model visualizes real-time space usage with auto generation of workspace matching the available spaces around the affected area. It enables knowledge transfer from experienced building recovery specialists to facility managers who may know much less about building mitigation and recovery.

This paper presents such a dynamic facility space planning model to automated representation of facility maintenance activity life cycles. It first investigates space needs of resilience maintenance activities and defines such space needs into a workspace life cycle pattern. An object-based data structure is then presented for the facility resilience maintenance model. Such model considers both spatial and temporal requirements that each FRM activity might possess, and the dynamic nature of such space needs is considered using parametric of facility space capacities, space types, FRM project durations, and FRM space needs dynamics.

2. Facility management

Facility management is the administration of multiple systems and people reside in it [4]. According to IFMA, the operation and maintenance cost contributes to more than 60% of the total facility life cycle [5]. Best practices to facility life-cycle cost saving have therefore became a prevailing goal of the facility management community [4], as well as a mandatory for public facilities in terms of public safety and community resilience [6]

Disasters once happened, will interrupt normal operation and schedule maintenance due to its difficulty of forecasting, and its intensity that physical damages or temporary loss of normal operation resources unavoidable [7]. Certain repair and recovery efforts are needed in the aftermath of a disaster, which can include unscheduled maintenance and repair to the building structure or building service systems that got affected, and damage recovery of facility contents including occupants belongings, indoor finishes, and other components related to facility operation.

In practice, immediate mitigation activities are more and more becoming a mandatory for facility management teams due to the requirement of insurance claims, therefore a series of maintenance activities are incurred by the strike of a disaster. Such disaster-related maintenance activities, which are not included as regular or scheduled services, are defined as facility resilience maintenance [8].

3. Facility resilience maintenance

FRM here in this article refers to the maintenance activities incurred directly or indirectly by a disaster. FRM activities have the characteristics of urgent in need of service [4], hard to forecast, and great needs of integrated facility information including technical data regarding the building systems [9], business data regarding asset safety [10], occupant schedules and needs [11], and more. Both types of information are necessary to generate accurate plan to perform FRM with the minimum interruption to normal operations within unaffected areas of a facility.

Based on the characteristics of activities in terms of time stringency and their impacts on normal facility operation, two phases of activities are identified in FRM. First phase is mitigation, second phase is recovery. Mitigation phase happens immediately after a disaster takes place. It is the efforts that the facility management team make to take control of the scope of damage. Recovery phase starts after the mitigation phase, when necessary steps are taken to avoid damage get out of control, and when the situation has been stabilized, with basic supplies back in place [12].

FRM affects normal facility operation in three ways. Firstly, normal work space might be needed for FRM purposes, which might interrupt normal operations in adjacent spaces. Secondly, spaces surrounding the affected area of some FRM activities, such as mold mitigation, might be unsuitable to operate due to air quality reasons. Thirdly, normal operation spaces might be unworkable for a period of time before they have been fully recovered to workable condition. Therefore FRM affect normal operation schedules in such cases, and the durations of such interruptions vary depending on the FRM activities and the possible temporary space occupancy incurred in the above scenarios.

Therefore, planning for FRM in a timely manner requires a tempo-spatial representation of the dynamics of FRM space needs including workspace and affected spaces within a facility. With quick and accurate representation of real FRM space needs, facility management professionals can expect to minimize business loss caused by interruptions to normal operations of facility occupants, and to avoid potential legal issues caused by IAQ problems that might incurred by FRM activities.

4. Representation of workspace

A review of current workspace modelling techniques reveals the fact that most research focuses on the dynamic modelling of construction workspace during the construction phase. Akinci et al. [2] presents a project-specific4D production model, 4D SpaceGen to enable automatic space generation for planning. In the 4D SpaceGen, time-space conflicts are shown through the generic work space ontology based on specific parametric of different construction methods. However, the methods require large amount of manual input, which is time consuming especially in the aftermath of a crisis when other aspects of facility resilience management needs efforts prior to the space assignment. Also such manual input parametric still suffer from the drawbacks of human flaws in making abrupt decision under time pressure, and the limited building science knowledge of some facility managers.

Su and Cai [3] presents an automated workspace evolution pattern using an object-based approach. The workspace evolution pattern captures the lifecycle nature of a construction activity. It presents the object-oriented data structure that is parametric and enables automatic space generation over time using the common attribute in each workspace object, but was not applicable to FRM projects because the lack of consideration of facility occupants and business continuity in construction activities. Therefore, to minimize the interruption of a disaster to facility operation and economic losses, a parametric object-oriented chaining framework is needed to enable automatic FRM space assignment considering both the technical and business aspects of facility management.

IfcSpace is the class specifically defined to associate the spatial data within the building information model [13]. However, current data classes cannot capture the dynamic nature of facility space, as it lacks the capability of associating the duration of each space occupancy with the specific geometric space information, as well as not being able to represent the unplanned changes in flow fittings due to extreme events such as a disaster. Retrieval of such temporal-spatial information immediately after a disaster is essential for FRM planning and emergency responses. A new data class to capture the temporal-spatial integrated information, and the automatic representation of the dynamic space needs considering significant factors including FRM space needs, occupants fitting, and business continuity is necessary to support efficient emergency response and facility management.

A dynamic FRM space representation model is proposed to integrate the parametric of FRM workspace needs in the FRM lifecycle, operation suitability, and normal operation and maintenance. Based on the prevailing methods of 4D representation of workspace, FRM spaces are first categorized into several types based on the workability caused by the occupancy needs. Based on the types of FRM spaces, the dynamic FRM space generation mechanism is presented with other significant parameters identified and reasoned. The data diagram to be used with such mechanism is then presented. A motivating case is included after the theoretical framework has been presented for validation purposes.

5. Types of FRM spaces

FRM activities are restricted by workability of the affected space and its surrounding areas in many cases. Sometimes the restrictions on FRM activities can cause serious delay in recovery that lead to extra business loss to facility occupants, and extra operational loss due to the extended exposure of building systems to water, smoke, microbiotic, and many other factors in the aftermath of a disaster.

Based on the level of restriction of different spaces on FRM activities, FRM workspaces can be categorized with the following four types:

Non-workable spaces (S1) – occupied, strict requirements for IAQ, sounds, and schedule. No interruptions can happen. For example, intensive care unit, or ICU, in a healthcare facility always require 24/7 special supplies, and strict requirement of the indoor air quality including temperature,

Restricted work spaces (S2) –occupied, or have special requirements due to operations in other related spaces, including IAQ, temperature, sounds, work area, and work schedules. For example, classrooms as the educational space requires the neighbouring spaces to be quiet. Many repair and recovery activities involve great sounds and heat, which will affect the learning conditions and efficiency of students located in nearby classrooms. Therefore the FRM activity planning has to consider such restrictions on work schedule and methods.

Limited work spaces (S3) –spatially temporally limited work spaces, but no other restrictions. For example, equipment rooms and elevator shafts always have limited free space, but are relatively open to any repair and recovery activities at any time, without restrictions from surrounding operating spaces. When planning for FRM activity in such spaces, space planning becomes primary with scheduling as a less stringent factor.

Unlimited work spaces (S4) – spaces that could be used freely as workspaces during any time. Hallways, or when occupants have been relocated completely, are typical unlimited workspaces, where greater areas are available for carrying out FRM activities, and no special concerns to coordinate FRM work schedule with the operation time and needs of neighbouring spaces.

Such work space type is a key parameter in determining FRM workspace. Different weights are assigned to work space types to represent the priority of space restrictions on the workspace to be automatically generated using the FRM space representation model.

6. Motivating case

The motivating case happens in a reading room in the southwest corner on the second floor of a university library. An internal flood (fire sprinkler breakage) happens on a weekday night around 8p.m., the reading room is occupied with students, with a room manager on duty at the time of the event. The workspace is identified as S2, or restricted work space as it takes place in a workable setting with enough space but work schedule restrictions for FRM activities and support (S2). During the mitigation and recovery phase, because of the nearby conference room which is relatively large and loose in schedule, the extra storage in it does not cause too much operational problems to the disaster mitigation and facility management team.

Figure 1 shows such dynamic space needs at different stages of the FRM activities incurred by fire sprinkler breakage. It first starts when occupants in nearby spaces notice the problem. The librarian on duty (person of authority) is notified by room occupants. He or she immediately clear the affected space by evacuating the area, and covers up book shelves with water proof materials available. Meanwhile, facility manager is notified by the librarian for emergent mitigation. He or she turns off the maintenance valve controlling the specific sprinkler, janitors on duty are notified to bring adequate amount of tarp, water containers, towels, and available drying fans to the reading room. Water damage recovery contractor and insurance agent are also notified by the facility manager while he takes the mitigation steps. Water damage recovery contractor arrives at his earliest convenient time to check the scope of damage. He found that 36 ceiling tiles were soaked and need to be replaced, while the surrounding ceiling tiles need to be dried within 48 hours to avoid structural damages to the library building. He found that at least 200 books and 100 sf of carpet were damaged by water, which need to be dried as well. Book shelves were made of steel and painted with stainless paint and were not affected. Two writing tables located under the broken sprinkler has been soaked and need to be replaced after comparing the cost of drying with replacement.

After reporting the above results to the facility manger and got approved, the contractor relocates wet and dry books separately to the hall way for temporary storage, the damaged writing tables were also relocated to the hall way to be discarded. Drying carpet would use dehumidifiers which generates large amount of heat, therefore all wood writing tables and unaffected books were relocated into a conference room close to the reading room. Books are then delivered to an offsite recovery center. The hallway is then used for storage of recovery equipment and supplies. Recovery workspace is now changed to be the whole reading room, including a part of the hall way and the adjacent conference room for storage. After the recovery is complete, belongs of the reading room can be restored, the reading room is back into normal operation with approval of the facility manger. The FRM workspace is now evolved into FRM product space, and normal operation begins. Such FRM activity dynamic space needs can be represented using an associated 4D workspace and product space modeling structure, as shown in Figure 1 below.

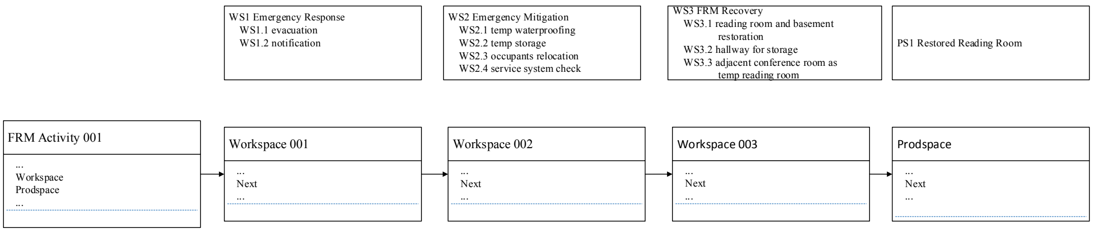

Figure 1 4D workspace and product space modeling structure

7. Data structure diagram

Object-oriented data structure is one of the biggest benefit that current BIM has. Such feature enables the associated representation of geometric, temporal, and resource information, which are allowing intuitive linking of semantic information with the geometry of a specific object, in this case a space. An object-oriented data structure is therefore developed for implementation in the FRM workspace model. An UML class diagram of the data structure for FRM activity space modelling is presented in figure 2 below. Table 1 shows what are included in each class.

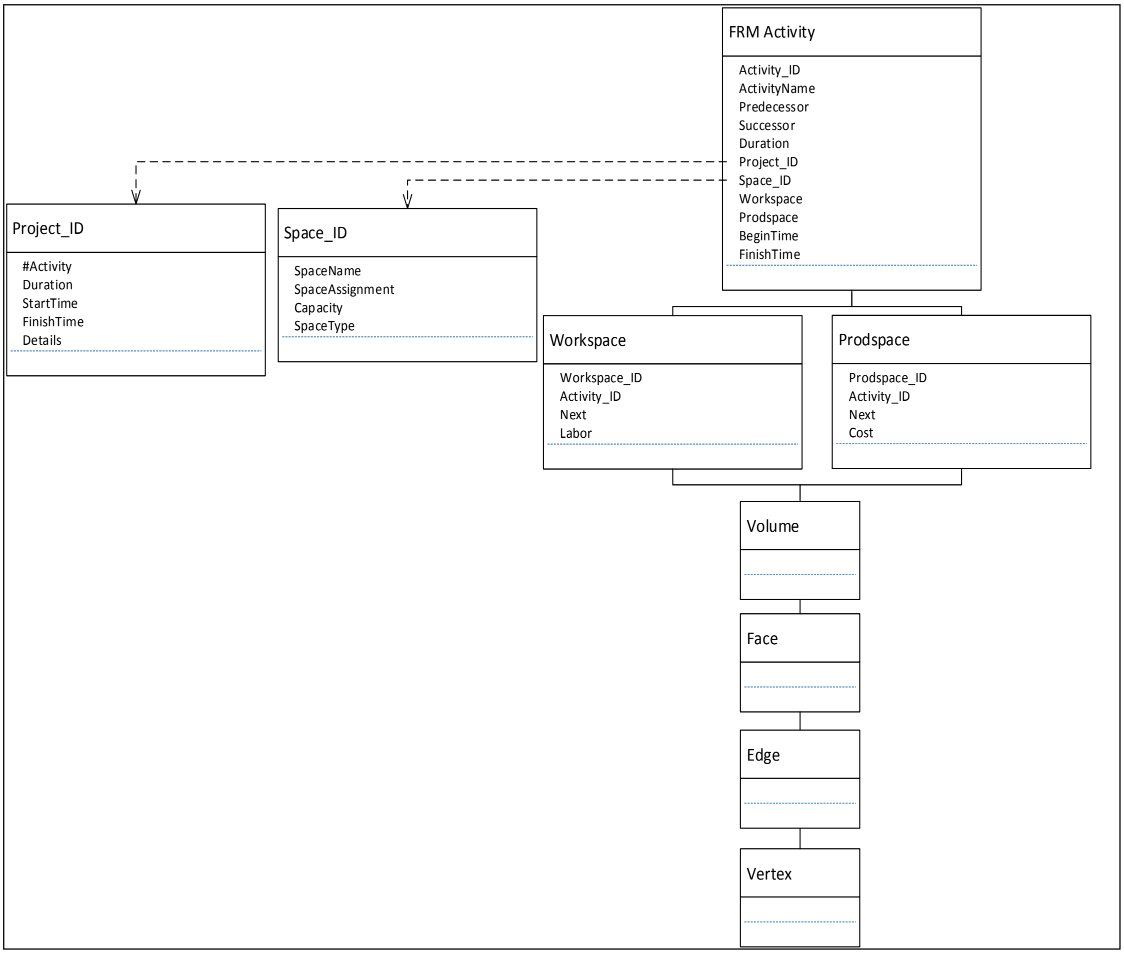

Figure 2 data structure for FRM activity space modeling

In this framework, FRM activity is a 4D object with dynamic geometries. It can be depicted of multiple workspaces, WS1, WS2, WS3, and one or none product spaces. Product space refers to the completed resilience-integrated space or assets, and in the case of FRM activities that results in temporary resilience products, for instance, temporary shelters during the response phase within the facility boundary. Such temporary facilities will be removed once FRM projects complete, so the product space is zero for such cases.

As the upper classes, FRMActivity, Workspace, and Prodspace are all 4D objects with geometries and temporal attributes. They together form a complete system to depict the FRM projects as a dynamic process. Space classes within such a system are associated to the FRM activity that they belong to. Using the key attribute Activity_ID. Workspace and Prodspace depict the fixed geometries during specific phases of an FRM activity, and the class volume, face, edge, and vertex are used to represent their geometries. Multiple Workspaces and Prodspace are linked on the temporal dimension using the attribute *Next. An FRM activity is associated with nothing, and the Prodspace is associated to nothing to fully depict the start and completion of an FRM activity. Figure 3 illustrates this linked structure consist of the series of one-way associated fixed space model using the scenario in the motivating case.

Table 1 Information within the data classes for FRM activity space modeling

Class Name	Key	Descriptions
FRM Activity	Activity_ID	Information in this class includes activity name, predecessor and successor, duration of the activity, project and space the FRM activity belongs to, if any workspaces and product spaces are included (1 for 1 or more workspace/product space, 0 for none), begin and finish time of the activity.
WorkSpace	Workspace_ID	Information in this class includes activity IDs that links the workspace to the specific FRM activity as defined in the upper level class FRMActivity, semantic information about the crew size and construction method, which is a key parametric in adjusting the workspace.
ProdSpace	ProdSpace_ID	Information in this class includes activity ID that links the product space to the specific FRM activity. As the finish state of the FRM, semantic information about the final cost of the work is included in this class, which can be imported directly from the specific CAFM platform of use, as an important record of the FRM activity.
Space_ID	Space_ID	This is to associate FRM acitivity, and the relevant classes Workspace and Prodspace with specific spaces in the facility, for the practical use by facility managers. Information in this class includes space name, space number, the occupancy information and durations, as well as the space type as predefined in the CAFM platform describing the workability of a specific space, and can be readily imported.
Project_ID	Project_ID	This is to integrate FRM information based on the occurrence of an extreme events. Information in this class includes number of the FRMActivity included in the project, duration of the project as a sum of all these activities, and necessary semantic information for the purpose of space determination and adjustment in the future.

8. Mechanism for dynamic FRIM workspace representation

Despite the diverse and dynamic space needs of FRM activities, certain pattern exists for most such FRM activities involves several steps. In the FRM workspace representation model, an FRM event is considered using the life cycle approach with discrete phases. Space changes dynamically overtime, and such changes can be illustrated using diagrams as shown in Figure 3, as a one-way chain of space change dynamics associated with an FRM activity.

Four discrete FRM phases can be identified based on the changes of workspace in the motivating case. Each phase within a FRM activity contains the attribute *NEXT, which is used as the key ID to link all the operation and maintenance spaces within the life cycle of an FRM activity as a complete space dynamics. As shown in Figure three, the FRM space starts as OS001, during the beginning of the FRM lifecycle, the space operates normally until the sprinkler broke and internal flood takes place. The FRM space now becomes MS001, the maintenance-mitigation phase, and disaster mitigation activities take place where facility management staff act to take control of losses caused by the disaster. Once the damage and space situation have been stabilized, with utilities back in supply, the FRM space evolves into MS002, the maintenance-restoration phase, disaster recovery contractors arrive, and start to examine and restore the building service systems, structures, and contents are repaired and restored to the operable condition. Once the maintenance finished, the FRM space is ready to operate as OS002, the operation phase, and the affected facility space, for this case the reading room, is back into normal operation and reopened.

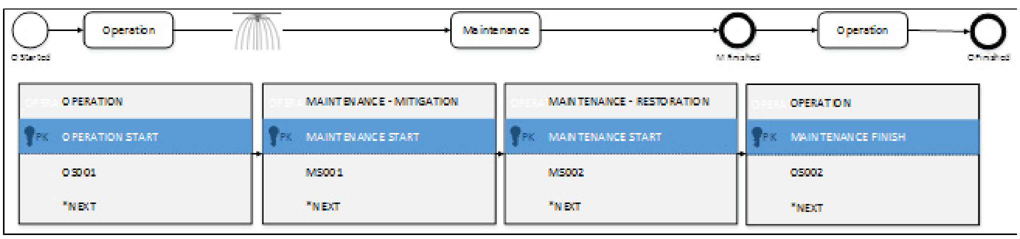

Figure 3 Space dynamics timeline of an FRM Activity

Such FRM phases are consistent with the emergency management cycle. Based on the author's observations of disaster recovery projects and literature reviews, it can be applied to most kind of FRM situations.

9. Theoretical prototype

The system will be able to automatically generate workspace based on different phases of FRM activity life cycle with certain information. Three modules are included in the proposed system: raw data input interface, space generation algorithm module, and the visualization module. The process of information within the system is demonstrated in Figure 4 below.

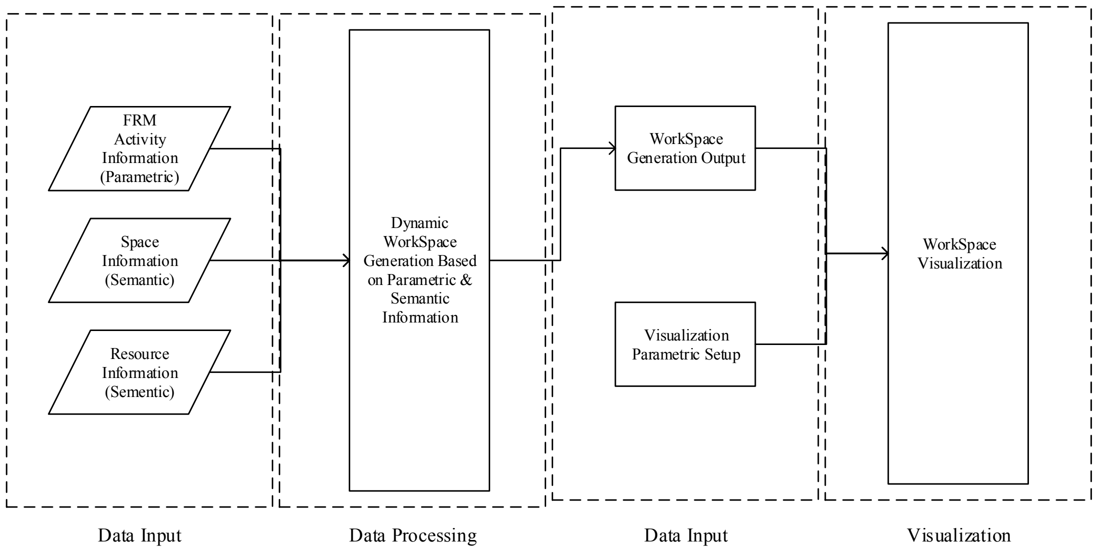

Figure 4 FRM workspace automatic representation structure

The object-oriented data model is adopted so to associate semantic information with the geometries of an object which defines an object. Such association enables intuitive retrieval of key information in terms of FRM planning, especially during the emergency response phase of a crisis, during which time is critical. Such semantic information are the key to efficient emergency response and recovery, and may include FRM activity information including: 1). the activity information – activity duration, special work conditions in terms of operation interruption, and safety concerns; 2). space information – name of the space, space occupancy information including the duration of each occupancy assignment, type of the space, and associated building service interruptions associated with the FRM; 3). resource information – cost, space needs, crew size, and materials and equipment needs.

All the information are nested within the data class Project_ID and Space_ID, and can be retrieved from the upper class FRM Activity. The analytical module contains a parametrical algorithm to perform work and product space generation using such semantic information and the geometric information of the specific space of interest. Once the analysis is completed, the automatic generated work or product space can be visualized using the specifications input from the user interface.

10. Conclusions

This paper presents the theoretical framework of the lifecycle approach of FRM space representation. The model will help facility mangers and emergency responders to optimize space use during the aftermath of a disaster, and to incorporate resilient thinking into the final product of FRM.

The data structure in the presented in this article supports unlimited space entities for each FRM activity and associates each FRM activity with specific spaces and zones within a facility using the format the facility managers are familiar with. The separate representation of the geometry attributes of each class enables the interoperation of the proposed FRM space modelling with the IFC and other geometric representation formats or data models.

Tracking of workspace and product space enables space assignment analysis. It helps building managers to identify changes in usable space, so to increase efficiency in terms of assigning work places, control energy usages, and resilience planning.

11. Discussions

The remaining part of this research is the development of the automatic FRM space generation algorithm. The automatic FRM space representation model will be the ontology to present other resilience related semantic information of a facility on both system and end-user's level. The model this paper presented will enable tempo-spatial analysis of facility resilience, and will associate many resilience related semantic information with dynamic spaces. A mitigation and recovery activity library is under development in collaboration with RIA. Each activity in the library include properties including space need parameters and durations. Such mechanism can also be applied to normal facility maintenance activities to enable better planning of space and resources within the facility management team.

References

[1] B. Becerik-Gerber, F. Jazizadeh, N. Li, G. Calis, Application areas and data requirements for BIM-enabled facilities management, Journal of Construction Engineering and Management, 138 (2011) 431-442.
[2] B. Akinci, M. Fischer, J. Kunz, Automated generation of work spaces required by construction activities. Journal of Construction Engineering and Management, 128 (2002) 306-315.
[3] X. Su, H. Cai, Life cycle approach to construction workspace modeling and planning. Journal of Construction Engineering and Management (2014).
[4] K.O. Roper, R.P. Payant, The Facility Management Handbook, AMACOM Div American Mgmt Assn, 2009, New York.
[5] F. Leite, B. Akinci, Formalized representation for supporting automated identification of critical assets in facilities during emergencies triggered by failures in building systems. Journal of Computing in Civil Engineering, 26(2004) 519-529.
[6] A. Boin, A. McConnell, Preparing for critical infrastructure breakdowns: the limits of crisis management and the need for resilience. Journal of Contingencies and Crisis Management, 15(2007) 50-59.
[7] W.L.Waugh Jr, Management Capacity and Rural Community Resilience. Disaster Resiliency: Interdisciplinary Perspectives, 4（2002）, 291.
[8] P.Teicholz, BIM for facility managers, John Wiley & Sons, 2013, New Jersey.
[9] M. Turoff, M. Chumer, B.V.,de Walle, X. Yao, The design of a dynamic emergency response management information system (DERMIS), Journal of Information Technology Theory and Application, 5(2004) 3.
[10] M. Wallace, L. Webber, The Disaster Recovery Handbook: A Step-by-step Plan to Ensure Business Continuity and Protect Vital Operations, Facilities, and Assets. AMACOM Div American Mgmt Assn, 2010, New York.
[11] F. Gibb, S. Buchanan, A framework for business continuity management, International Journal of Information Management, 26(2006) 128-141.
[12] R. R. Rapp, J. Pan, Disaster restoration professional body of knowledge, International Journal of Construction Education and Research, 6(2010) 202-218.
[13] E. William, N. Nisbet, T. Liebich, Facility management handover model view, Journal of computing in civil engineering, 27(2012) 61-67.