2023 European Conference on Computing in Construction
40th International CIB W78 Conference
Heraklion, Crete, Greece
July 10-12, 2023

A MODEL-BASED APPROACH FOR BUILDING FIRE EMERGENCY MANAGEMENT

Nabih Mousharbash[1], Marta Di Domenica[1], Alessandro Carbonari[1], Alberto Giretti[1], and Ziga Turk[2]
[1]Marche Polytechnic University , Ancona, Italy.
[2]University of Ljubljana, Ljubljana, Slovenia.

Abstract

Emergency Management is the approach used to avoid and recover from unpredicted events in a building. It is considered part of the facility management, which is the integration of people, spaces, processes, and technology functions within the built environment for ideal optimization. This paper focuses on a systematic analysis of the specifications and requirements of real-time control systems adapted to emergency management.

This contribution will be presented using system modeling language (SysML) diagram notations. The overall system is made of evacuation, compartments, and fire detection system to enable real-time control in case of a fire emergency. The system can be integrated with BIM. Therefore, a future vision is predicted and proposed for the current field. The opportunities concerning the integration between simulation environments for requirements verification over the cycle concluded this paper.

Introduction

Facility Management is the discipline that is articulated within the context of a very broad and disparate set of technical operation domains (Roper and Payant, 2014). In a deeper aspect, emergency management is one of the categories within facility management. Such as maintenance, energy, and organization. The financial management of both current activity and new construction projects is vital to be presented for investors to observe the overall cost (Ozturk, 2020).

The management of daily service is one of the most challenging tasks. They are intended to be changed directly based on a current event in that takes place in the facility. Thus, an emergency management plan should be integrated into the preliminary phases of the building life cycle. Furthermore, fulfilling one of the key requirements of construction includes an evacuation plan and emergency exit routes of the building which are required to be implemented. The permit will not be approved by the authority if the evacuation plans is not set. This is due to the building users' safety and provides guaranteed escape routes and safe gathering points for users.

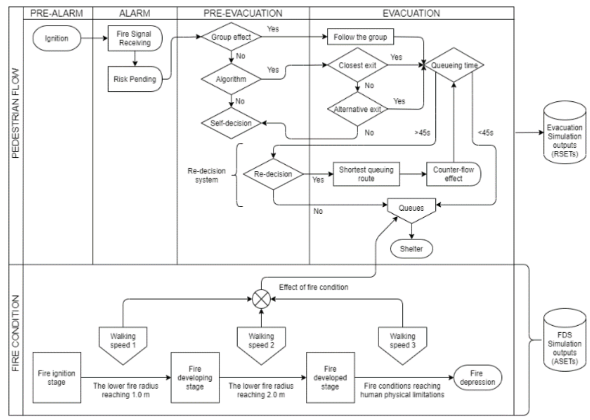

Figure 1: Flowchart of evacuation behavior in case of fire

Many studies show the importance of consistency and interoperability in facility emergency management. However, the management process still lacks a solid data framework to support real-time, data-driven, and decision-making systems (Cui, Wen and Zhang, 2019). The linked data is concentrated on the category of real-time monitoring systems. Prior to designing a system that can manage a real-time emergency,

The focus on a systematic analysis of the specification, requirements, and control of the real-time system will be applied to emergency management. In the first step of our analysis, the overall system was divided into 4 main phases that determine the ideal evacuation exit route from the building, as shown in Figure 1 above.

In this paper, a proposed methodology will be presented for the development of a real-time emergency management system that applies the model-based system engineering approach. For this reason, it is expected to track requirements all over the phases of the project, and to link them with the technical definition of the overall system. This is determined even by the necessity to integrate models of the behavior of people and numerical models to optimize exit routes in the design project. The system is presented using System modelling language (SysML) diagrams. In the next research stage, we expect to build on established semantic web ontologies that will link data together for optimization purposes. The aim of integrating the system is to manage large complex systems. Therefore, this paper is implied to evaluate and showcase the potentials of system modeling language.

Notations and Syntax to Fire Emergency Management (FEM)

Fire emergency management (FEM) is a critical aspect of ensuring public safety and minimizing damage to both property and the environment (Front Matter | Elsevier Enhanced Reader, 2020). The methodology used for fire emergency management should be comprehensive and well-informed to take into account the unique characteristics of each situation and optimize the most effective techniques and resources available. In this section, various methodological approaches to fire emergency management and their relatives effectiveness in different scenarios are indicated throughout the mind map literature review.

A methodology approach to fire emergency management should be based on a thorough analysis of the potential risks and hazards associated with the fire. Therefore, optimizing the available resources and capabilities of the emergency response team (Sole, 2011). This includes the preliminary planning such as evacuation plans, responding teams contact, and the facility management. Furthermore, effective communication and coordination among all stakeholders whether public or private sector. All this essential information will establish a successful fire emergency management response.

The different approaches that can be implemented for fire emergency management include model-based system engineering (MBSE). It can be actualized using the system modeling language (SysML), which has already been tested in the manufacturing industry and just very preliminar applications are known in the industry.

Model-Based System Engineering (MBSE)

Model-based system engineering (MBSE) is getting in high demand to develop complex systems. These include the use of models and simulations that present the system requirements, architecture, behavior, performance, and analyze the system through the building cycle (Hart, 2015). The system aims to enhance the practices by providing a common elaboration and interconnected engineering analysis of the overall developed system.

The outline approach indicates a successful realization of complex systems. Emergency management can be one of the least integrated categories withing the BIM scope of research (Feng et al., 2021). The information about the building environment and the evacuation is the biggest challenge for the facility manager. MBSE relies on common concepts such as functional/structural analysis, interfaces, and behavior models.

The system provides two main methodologies for developing a facility operating model (FOM). The preliminary approach introduces the four-part requirement function structure that permits the highly complex system concept interaction between functional requirements and the physical structure of the facility to be captured and observed.

Model-based system engineering connects the various components at different levels of abstraction by using an expressive set of conceptualization such as components, connections, events, and behaviors (Hart, 2015). Therefore, it provides managers with a complex model to be presented, developed, and automated using system modelling language (SysML) diagrams.

System Modeling Language (SysML)

System Modeling Language (SysML) is a graphical modelling language that represents systems and sub-systems using a group of notation and diagrams (Barbedienne et al., 2014). The system is used to support model-based systems engineering (MBSE) and establish a set of range for application domains. Such as plugins, engineering, and application domains to name a few. SysML provides a consistent language for representing information systems, which enables stakeholders to further understand and manage the system's requirements, design, behavior, and performance (Friedenthal, Moore and Steiner, 2014). This research used SysML to gather and present overall system view that would be used as a base structure to proceed in future development steps for the fire management objective.

The diagrams will be referenced for further investigation to generate high-level view of the system in which enables stakeholders to have a better understanding of the system notations and syntax of fire emergency management.

The diagrams are categorized based on their aim and purpose. Due to length limitations, this contribution will present a representative subset of those diagrams that have been developed by the authors to mode the systems involved in fire emergency management. The diagrams used in the system include requirements, block definition, use case, internal block definition diagrams, behavior, and state machine.

Implementation

Fire can be hazard that leads to death or property damage. Therefore, the main key of preliminary preparations regarding an emergency is undoubtedly to safeguard human life and protect property. Therefore, it is highly advised to plan a good evacuation plan (Front Matter | Elsevier Enhanced Reader, 2020). Emergency management focuses on a strong solid organization. A fire safety management plan details your arrangements to implement, control, monitor, and review fire safety standards set by the government to ensure that the standards are met in a proper matter (Sole, 2011).

The facility manager should prepare the building in case of emergencies such as fire, earthquake, flood and contamination. The developed SysML diagrams are categorized into three main parts. The first one is the system overview, the second compartmentalization and evacuation, and the third one is fire detection-control-extinguishing system. This paper focus mainly on compartmentalization and evacuation systems diagrams with minor focus on other SysML diagrams.

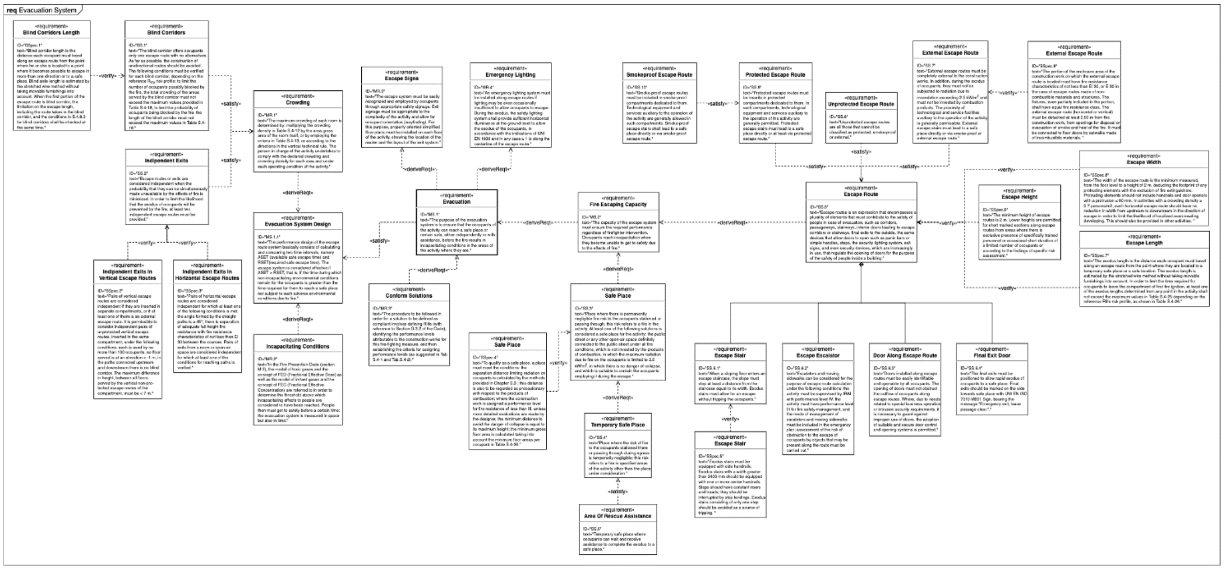

Figure 2: Evacuation Requirements Diagram (ES01)

Controlling the building system involves trying to deconstruct and implement the model behavior in a descriptive, analytical, and simulative matter. Therefore, the diagrams can be segmented into two phases which focus on preparedness and real-time control management of the building lifecycle. The automation process is only possible after formalizing the analytical procedure and systematic knowledge of the whole system with the standards. In this application the Italian technical fire prevention code was chosen as a reference (Espinoza, Espinoza and Feng, 2013).

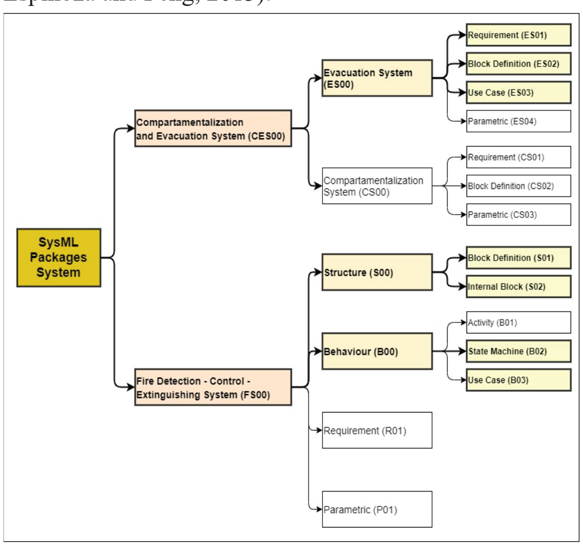

Figure 3: Categorization of the SysML diagrams

The packed diagrams presented in the figure 3 above shows how the models for the compartmentalization (CS00), evacuation system (ES00), the fire detection-control-extinguishing system (FS00) are organized into packages containing the model elements. Model organization is essential to understand, control, and manage the facility as a whole in which give a deepen broaden aspect of understanding of the overall views.

Compartmentalization and Evacuation

The modelling of the compartmentalization system is defined as a real process of deciphering the Italian code of conduct. Following the Italian fire prevention code, the compartmentalization system is based on the characteristics design criteria and procedures for determining the minimum fie resistance class (Fire Safety Management and Emergency Plan | County Durham and Darlington Fire and Rescue Service, 2023).

Compartmentalization is a passive type of fire-fighting strategy, in which the function is to contribute to the prevention of fire by reducing the probability of ignition and restricting its spread. As for the fire compartment, it is referred to as part of the facility designed with constructive elements such as fire, to ensure the safety of building users for the time necessary to reach a safe place and for the rescue teams to take action.

A suitable evacuation system aims to "ensure that occupants of the activity can reach or remain in a safe place, regardless of the intervention of the fire fighters "('FSE: l'approccio prestazionale alla sicurezza antincendio', 2021).

The requirement diagrams is used to graphically imply the hierarchies of requirements or to depict an individual requirement with its relationship to other model elements. It is also used to represent the traceability of a single requirement to examine if that requirement is met or verified across the project phases. Thus, examining the relation with other requirements. These are determined based on prepared or real-time based management interactions withing the environment strategy set by the facility manager.

As shown in the evacuation requirement diagram above in figure 2, all the elements of the evacuation systems are presented. Respectively, the sub categories and the specialization of their performance constraints are

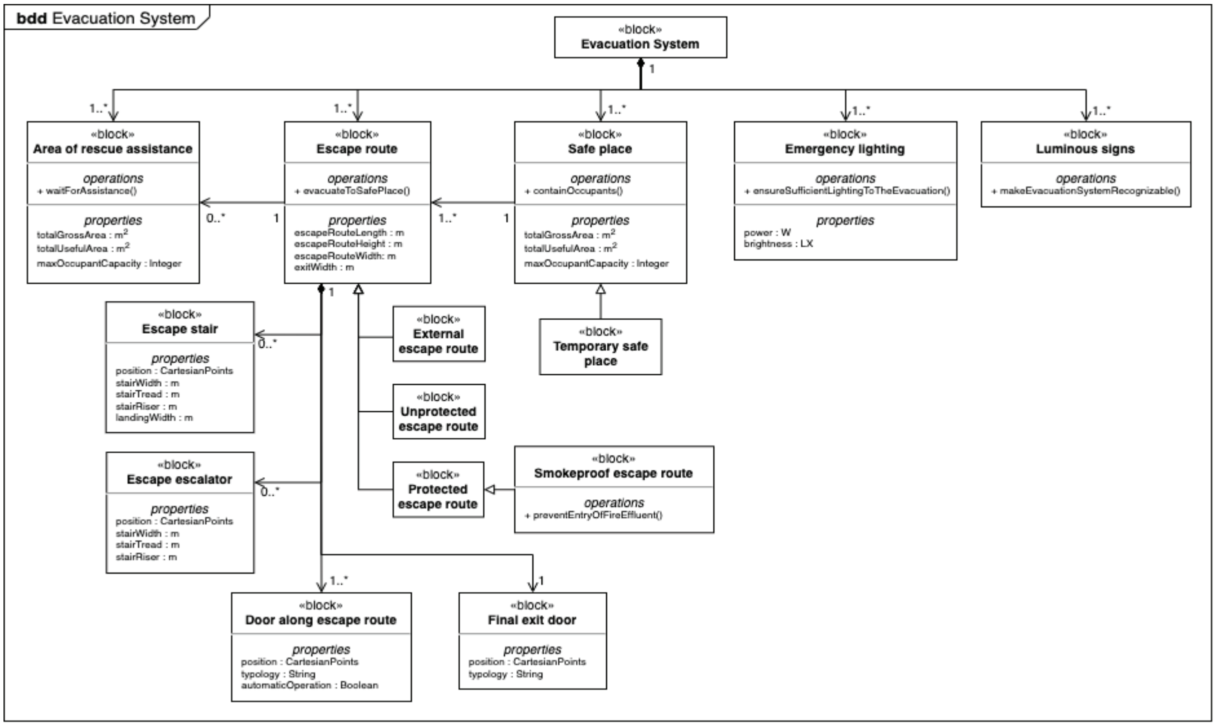

Figure 4: Evacuation Block Definition Diagram (ES02)

required to satisfy and verify mission requirements which leads to optimizable approach.

Each block presents the requirements for the analyzed system to be considered complaint with the standard and meets the principles of suitability and legality.

The block definition diagram depicted in figure 4 help the facility manager to define the characteristics of blocks regarding their structural features, and relationships between the blocks, such as their hierarchy. The entities to which the evacuation system is composed are presented. The escape route allows the occupants to reach a safe place from where they are located on the premises.

Occupants reach incapacitation when they don't have access to safety due to the fire effects. Safe places are needed to host building users in case of fire whether temporarily or permanently. In addition, calm spaces where occupants can wait for assistance can contribute to the same purpose. Finally, safety lighting and signage also play a major role that must be appropriate to the complexity of the activity and allow occupants' orientation in the case of evacuation and provide a safe space for the building users to escape to.

The evacuation use case diagram (ES03) presented in figure 5 is used to indicate the relationship between the subjects of the system. The diagram focused on piloting the evacuation plan in case of fire service representatives are moderated by the head of the emergency evacuation plan which operations affect the behavior of the occupants. Therefore, interaction with the sign and instructions is the best route to safety, and for the firefighters who take action of extinguishing the fire in the building users can escape to a meeting point located priorly.

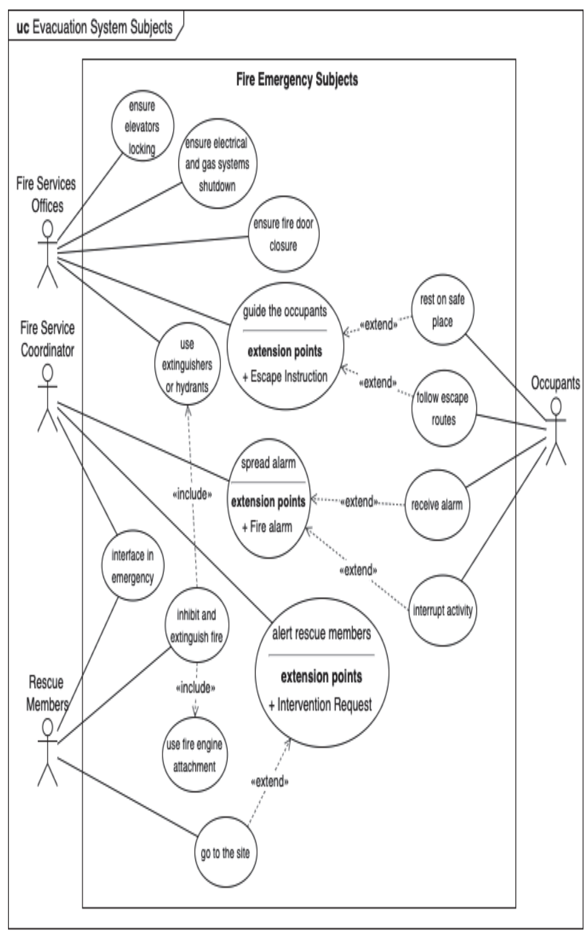

Figure 5 Evacuation Use Case Diagram (ES03)

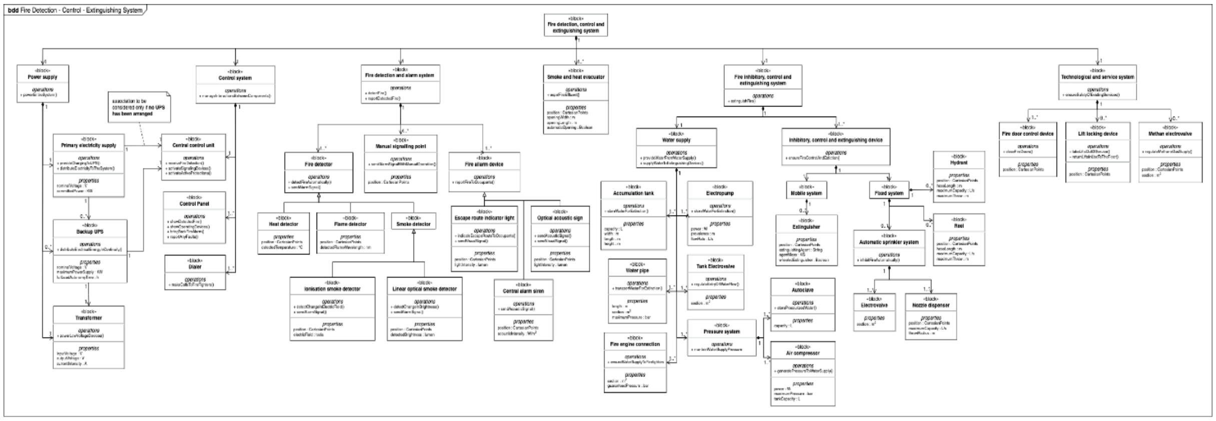

Figure 6: Fire Detection-Control-Extinguishing System Block Definition Diagram (S01)

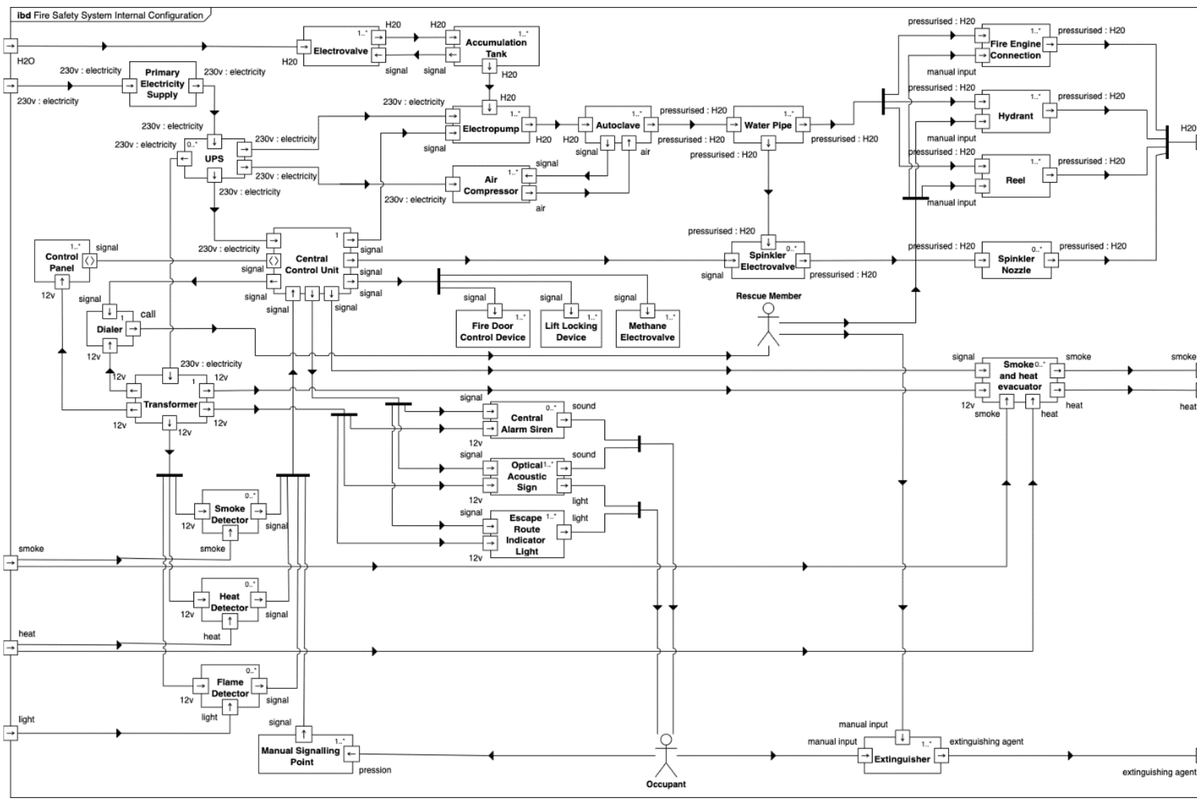

Figure 7: Fire Detection-Control-Extinguishing-System Internal Block Definition Diagram (S02)

Detection, Control, and Extinguishing System

Protection measures taken to be installed in the building to protect the structure and the occupants against the start of a firearm to control and extinguish the fire. The fire prevention code (FPC) is designed and maintained for fire-fighting devices that allow searching the causes and failure modes of the various physical elements that make up the fire detection, control, and extinguishing system.

The fire detection-control-extinguishing system block definition diagram (S01) shown in figure 6 shows the breakdown of the system into different blocks. The systems are grouped into subcategories based on the functions performed. The composition relations are broken down into subcategories in which the physical components correspond to the devices installed in the facility and in case of contribution that satisfy the requirements that have been established in respective diagrams. Overall, fire detection, alarm signaling, the inhibition, control, extinguishing system, smoke, heat, evacuation, technological services, and the control system.

Those are associated with the continuous supply of electric current. However, the generalization has a different relation that specify the components into various typologies of each entity. Therefore, the same system can be differentiated by the typology characterization of the element that involve the occurrence of specific features that are presented in the block definition diagrams.

The fire detection-control-extinguishing system internal block definition diagram (S02) in figure 7 is used to describe the internal structure of a block in regards to their interconnected parts. The function of the entire system and the connections have been made explicitly using the item flows between the various components in the block definition diagram (S01). The exchange of information took place through port , which are identified through input and output data in the system. It is implied that the model consists of various interfaces.

Thanks to this model, various systems interface have been represented, starting from the fire detection, heat, smoke, supply of water, electricity, all the way to the full extinguishing process and the post emergency plan execution. Therefore, it is possible to proceed towards the component analysis failure modes and understand their impacts on the system.

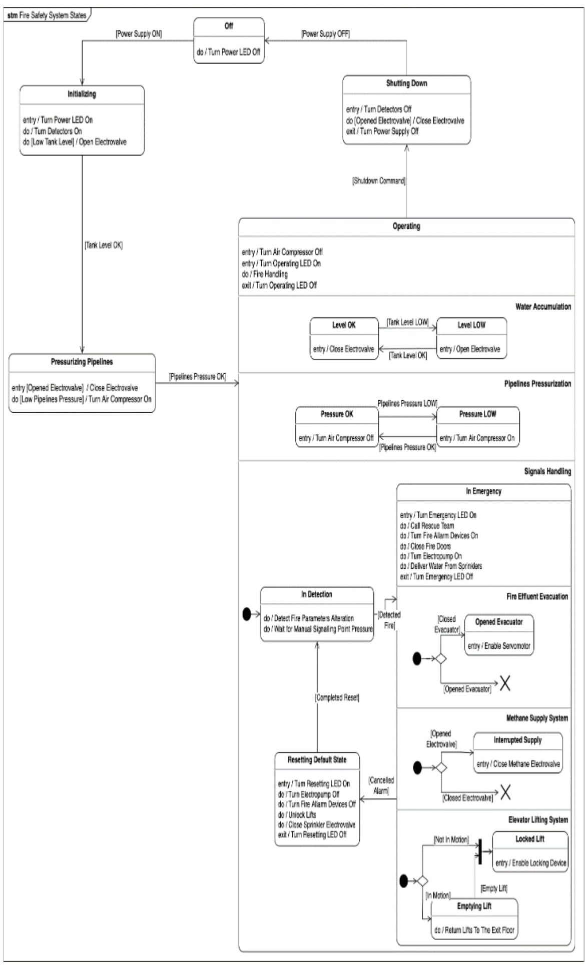

Figure 8: Fire Detection-Control-Extinguishing-System State Machine Diagram (B02)

The fire detection-control-extinguishing-system state machine diagram (B02) in figure 8 depicts the state dependent behavior of a block during its life cycle, in terms of transition of states in between. A state represents a significant condition in the life of a block responds to events and performance behavior. The state is represented with a circular box with its name, and entry/exit behavior.

The diagram shows a simple state machine for the fire safety system (FSS) transitioning from the "Off" states, through a transition that leads to "System Shutdown".

The "Operating" state is a composite state which includes more than one region. States can be composite with nested conditions in one or more regions. During execution, the active state will have one active substate per region. One state in each region should be the beginning or end of a coordinated set of transitions that involve the transition from "Water Accumulation", and "Pipelines Pressurization", to "Signals Handling". In the further region, an additional state machine is presented to analyze the successive states of the system during the fire emergency phase.

The facility manager ensures that the building and its features remain neat, well-maintained, and safe. They also will ensure that all the fire systems are inspected periodically. This will guarantee them to see if the system requires updates or if any damages should be fixed, to ensure effective work.

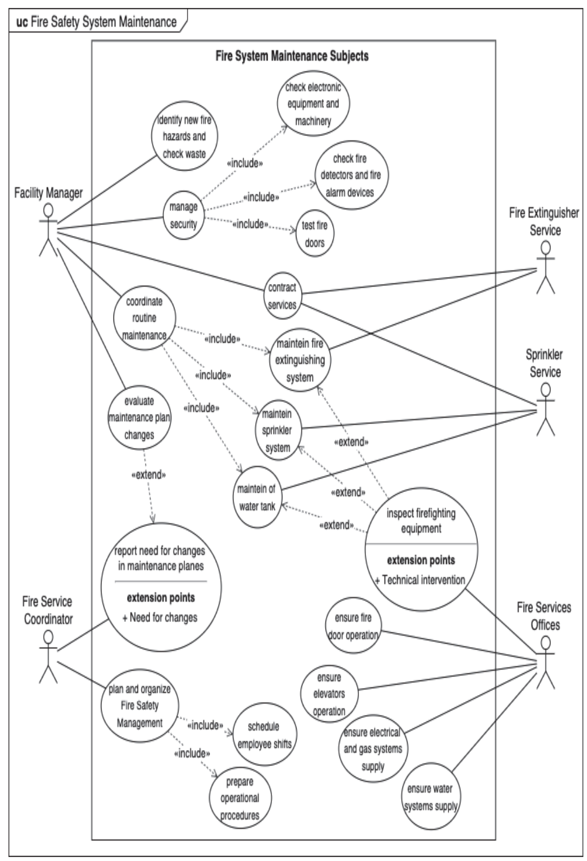

Figure 9: Fire Detection-Control-Extinguishing-System State Use Case Diagram (B03)

The facility manager is responsible to coordinate other leaders, coordinators, and firefighters service providers. This is due to the preplan requirements of the emergency management plan set that is required based on the building location and the region standards.

The fire detection-control-extinguishing-system use case diagram (B03) shows the management of fire safety based on an organization's operation of the suitable activity to ensure and over time the adequate level of safety in case of fire. Well-defined management during the operational phase contributes to the performance of the fire-fighting measures.

In this way, everyone would know their duties, and how human agents interact with the rest of the system. It is emphasized in this diagram mainly on the role of the facility manager. The facility manager is in charge of the maintenance and implementation of the building through the contracting of services.

Conclusion

The managers face cases that need immediate response to reduce the damages to the physical building or the users. Understanding the requirement and how they are linked with the structure and the behaviour of the systems supporting fire emergency management, by using SysML diagrams, can help with emergency evacuation management and fire preparedness in general. The systemic representation of the system provided by SysML within an MBSE approach unveils requirements, activity, interaction, relations, and behavior of the overall system.

This research indicated the benefit of identifying the workflow arounf fire emergency management and representing it to drive the process from the start to the end of the a project development. The staff can determine the influence of the emergency around the facility in an instant and optimizable matter.

The research also present potential interface with digital models such as BIM This is done by isolating the necessary elements and systems related to such force major events, and presenting those elements explicitly while isolating other elements.

This research paves the way to the next steps that will investigate how to build on the current model established to implement semantic web ontologies and defining the linked data to support the development of the fire emergency management system. This is expected to detect immediate emergency and spot instantly the fire source and generate safe and quick paths of evacuation.

Acknowledgement

The Ph.D. research of the author is funded through the excellence department DICEA Scholarship, the Department of Civil Engineering, Marche Polytechnic University.

References

Barbedienne, R. *et al.* (2014) 'Introduction of geometrical contraints modeling in SysML for mechatronic design', in *2014 10th France-Japan/ 8th Europe-Asia Congress on Mecatronics (MECATRONICS2014- Tokyo)*. *2014 10th France-Japan/ 8th Europe-Asia Congress on Mecatronics (MECATRONICS2014- Tokyo)*, pp. 145–150. Available at: https://doi.org/10.1109/MECATRONICS.2014.7018580.

Cui, B., Wen, X. and Zhang, D. (2019) 'The Application of Intelligent Emergency Response System for Urban Underground Space Disasters Based on 3D GIS, BIM and Internet of Things', in *Proceedings of the 2019 International Conference on Artificial Intelligence and Computer Science*. New York, NY, USA: Association for Computing Machinery (AICS 2019), pp. 745–749. Available at: https://doi.org/10.1145/3349341.3349503.

Espinoza, L., Espinoza, H. and Feng, W. (2013) 'Modeling a Facilities Management and Information System by UML', in *2013 10th International Conference on Information Technology: New Generations*. *2013 10th International Conference on Information Technology: New Generations*, pp. 65–70. Available at: https://doi.org/10.1109/ITNG.2013.18.

Feng, Y. *et al.* (2021) 'A BIM-Based Coordination Support System for Emergency Response', *IEEE Access*, 9, pp. 68814–68825. Available at: https://doi.org/10.1109/ACCESS.2021.3077237.

Fire Safety Management and Emergency Plan | County Durham and Darlington Fire and Rescue Service (2023). Available at: https://www.ddfire.gov.uk/fire-safety-management-and-emergency-plan (Accessed: 19 April 2023).

Friedenthal, S., Moore, A. and Steiner, R. (2014) *A Practical Guide to SysML: The Systems Modeling Language*. Morgan Kaufmann.

Front Matter | Elsevier Enhanced Reader (2020). Available at: https://doi.org/10.1016/B978-0-12-817139-4.01001-0.

'FSE: l'approccio prestazionale alla sicurezza antincendio' (2021), 17 November. Available at: https://antifuoco.it/fse-lapproccio-prestazionale-alla-sicurezza-antincendio/ (Accessed: 19 April 2023).

Hart, L. (2015) 'Introduction To Model-Based System Engineering (MBSE) and SysML'.

Ozturk, G.B. (2020) 'Interoperability in building information modeling for AECO/FM industry', *Automation in Construction*, 113, p. 103122. Available at: https://doi.org/10.1016/j.autcon.2020.103122.

Roper, K. and Payant, R. (2014) *The Facility Management Handbook*. AMACOM.

Sole, D. (2011) *Codice delle leggi antimafia e delle misure di prevenzione*. Maggioli Editore.