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A SYSTEM FOR DEVELOPING AND EVALUATING FIRE EXTINGUISHER PLANS OF CONSTRUCTION PROJECTS IN VIRTUAL ENVIRONMENTS

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SUMMARY: *Fires in under-construction threaten to worker safety and have a lot of negative impacts on many aspects of construction that were reported the past few years. Many constructions do not possess the permanent fire protection system, and only rely on the fire extinguisher or water tank to extinguish the fire. Moreover, a construction site has numerous features that make its uncommon and unanticipated structure. In a construction environment, changing is one of the characteristics that make it unique compared to others. Due to the dynamic nature of construction, the fire safety plan in construction needed to be reviewed and updated according to construction progress. The convention approach or manual process to develop the fire safety plan for a construction project can be a time-consuming and enormous labour-intensive task. BIM technology and Game engine can present the object in 3D and provide programming for the rule-based modelling. Therefore, this paper proposes a framework to assess the fire extinguisher installation plan (FEIP) and recommend the locations of fire extinguisher by considering the dynamic nature of construction. This research develops the prototype that enables the users to define the parameters for the fire extinguisher installation plan such as finished and unfinished building objects (walls, stairs and slabs), exists, the locations of fire extinguishers (FE) and flammable substances (FS). This prototype provides the appropriate locations of fire extinguishers and shows the unsafe area. To validate the proposed approach, the case study using the sample BIM model is executed. The proposed system is expected to have the capability of assisting the safety engineers in developing and assessing the fire extinguisher installation plan.*

KEYWORD: *Building information model, Fire extinguisher installation plan, Safety rule and regulation, Portable fire extinguisher, Game engine*

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1. INTRODUCTION

Due to the occurrence of immense accidents, the construction field has negative fame, based on the Health and Safety Executive (HSE) statistics, and a construction site is considered as a hazardous and dangerous workplace. A construction site has numerous features that make its uncommon and unanticipated structure. In a construction environment, changing is one of the characteristics that make it unique compared to others. Not only the progress of construction but also the types of machines, crews, materials used, and location are taken into account as changes of construction development, on a daily basis. Considering the dynamic nature of construction, the fire safety plan in construction needed to be reviewed and updated according to the construction progress. As a result, developing the fire safety plan for a construction project that can be a time-consuming and enormous labour-intensive task if done manually. Therefore, most of the construction projects do not have the updated and practical fire safety plans.

Regarding the publications of a United States (US) organization, the Federal Emergency Management Agency (FEMA) , about 4800 annual fire accidents occurs in construction projects. Regarding the report in the Bureau of Labour statistics, 99 workplace deaths occurred due to fire and explosion in 2019 and 115 fatalities in 2018. The figures are considerably higher than the one in 2016, which is 88. As regards the Occupational Safety and Health Administration (OSHA), surprisingly, the main major source of death and injury is not from construction fire is, while the number of workers, a frequent occurrence, and the evacuation plan reflect the worker's safety. However, the fire events happen in construction caused $172 million direct losses in the very year (Campbell, 2017). Hence, it is crucial to fend off the occurrence of fires in a construction site, which decides not only the safety target but also the control of construction costs for contractors (Robertson, 2011).

Many construction workers often use the flammable substance and work in the complex environment, where injuries like burns and blasts are common (Khan et al., 2020). Since fire protection arrangements are not available or afforded during the construction, fire extinguishers or storage of water are mostly depended on by the construction sites, (US Fire Administration, 2019).

Similarly, planning for a fire extinguisher installation that based on the safety rule is not considered by most construction sites (Khan et al., 2020). The Occupational safety and health administration impose that construction safety plan in every construction should include the fire protection plan. In case of fire in construction, construction workers must be mindful to search an escape route or a fire extinguisher. The perfect placement of fire extinguisher plays the important role in extinguishing the fire in time. Therefore, this study aims to develop the system for developing the fire extinguisher installation plan and assessing the locations of fire extinguishers to provide the safe and unsafe areas.

2. LITERATURE REVIEW

For fire safety planning, many researchers have focused on evacuation route planning for completed buildings as well as construction sites. However, few studies have conducted the fire extinguisher installation planning. Hence, this study is intended to focus on the fire extinguisher installation plan. In this section, the usefulness of the game engine in the fire safety was discussed and to understand the research gaps, the conventional methods and previous research attempts were reviewed.

2.1 Current status of Fire safety planning in Construction

According to the reviews of previous research, it is assumed that many construction firms are still using a conventional disaster prevention management system consisting of evacuation route planning, educational training and accessing fire safety equipment that assists the safety of an individual personal(Wang et al., 2014b). Currently, most of the construction industries use site-oriented safety plans which requires constant updates and reviews with interval. Therefore, Kim and Lee (2019) have mentioned that the updated and practical fire safety plans are not provided in most construction. Nevertheless, the conventional ways still rely on the manual operating procedures, which are burdensome and complicated. For developing the safety plan, conversion of 2D floorplan to 3D mental pictures is difficult for safety engineers (Chantawit et al., 2005). Moreover, they also need to integrate the converted information with the real construction site by themselves and interpret the text-based rule and regulation to apply in the real world. Bansal (2020) has stated that the mental-integration process also needed the capability of experience, knowledge, and individual perspective of the construction personnel.

2.1.1 General requirement for Installation of Fire Extinguishers

In order to develop the rule-based system, the general requirement for fire extinguishers is needed to understand and it will be reviewed in this section. This research adopted not only the rule and regulation relating to fire extinguisher installation for functioning buildings but also for construction sites. The installation of fire extinguisher is considered depending on characteristics such as the type, specification, capacity, and location.

In general, the specification of a fire extinguisher is to let out a chemical agent which has the property of diminishing fires during the initial stage. It is a mandatory for employers to provide the employees with fire extinguishers because of their unmistakeable importance, either by mounting or indicating at the construction (Kelechava, 2017). It is crucial to put out a fire during its initial stage, otherwise, it will become relentless or uncontrollable. To prevent injuries, a loss assets or fatalities, the key consideration would be the facts that fire extinguishers must be available at hand, and they must be guaranteed of normal functioning. Only the appropriate maintenance, inspection, selection, installation, recharging, and testing of portable fire extinguishers would bring assurance (Kelechava, 2017). Regarding the National Fire Protection Association (NFPA, 2008), general information of the requirements of a fire extinguisher installation plan will be stated below.

(1) The Quantity of Extinguishers

The following facts determine the desirable quantity of fire extinguishers that are required to keep a property safe: (a) Even if a property has fire protection equipment, such as water-hose or sprinklers, the determination of the minimum requirement of fire extinguishers is a different matter. (b) If necessary, additional fire extinguishers should be allowed to install, in order to provide safety. (c) If the fire extinguisher has a low rating compared to the qualified one is permitted for installation, however, it is not considered as satisfying the minimum requirements.

(2) Extinguisher Readiness

While not being used, fire extinguishers shall be preserved in an operable and fully charged condition. They shall also be maintained in their designated places all the time.

(3) Placement

Regarding the fire event, it is crucial for fire extinguishers to be situated in the position where they can be immediately assessed. The suitable location of fire extinguisher placement shall be along the normal paths of travel, and more importantly, exits from each building or area.

(4) Visual Obstructions

It is important for fire extinguishers to not be blocked from sight, during the occurrence of fire. If the obstruction cannot be entirely evaded, noticeable signs must be used to specify the placement of fire extinguishers. Moreover, the signs or indications must be situated in close proximity to the fire extinguisher and must be noticeable while viewing from the travel path.

(5) The following regulations can be applied to install portable fire extinguishers:

- Place the fire extinguisher securely on a designated hanger.
- Use the bracket which is approved or provided by the respective manufacturer.
- Only apply the registered bracket which is permitted to fulfill the desired purpose.
- Put inside cabinets or wall recesses.

Other than the portable fire extinguisher, wheel-type extinguishers shall be positioned in elected placements.

(6) If the environment is prone to bodily damage, the fire extinguisher shall be provided sufficient protections from these harmful damages.

(7) Installation Height

If the weight of a fire extinguisher does not exceed 40 pounds, it should be installed at the limit of 5 feet from the floor. If the weight is more than 40 pounds, the high limit should be 3 and 1/2 feet above the floor.

(8) Label Visibility

The extinguisher operating instructions shall be located on the front of the extinguisher and shall be clearly visible. Instead of Hazardous materials identification systems (HMIS) labels, 6-year maintenance labels, hydrostatic test labels or other labels, the fire extinguisher instruction tag shall be positioned on the visible front.

Based on the standard, the type of hazard is also classified into four: Class A hazard, Class B hazard, Class C hazard and Class D hazard., where each class has their own variant materials. In this study, however, only ordinary combustible hazard which is listed as Class A and flammable liquid Hazards which is regarded as Class B will be focused because these types of materials are commonly found on sites during construction stage. Class A results from materials such as wood, cloth, paper, and many plastics, while Class B is the consequence from burning of flammable liquids, combustible liquids, petroleum greases, oils, alcohols, and flammable gases (O'Connor, 2021). Regarding the class of hazard, 2A fire extinguisher, which is used for Class A hazard, and 10 B fire extinguisher, which is used for Class B hazard will be fixated in the study.

2.1.2 Standards for Fire Extinguisher Placement in Construction Sites and Workplace

There are several standards to guide the placement of fire extinguishers in construction site. Among the standards, four standards from different organizations will be presented in the following table.

Table 1: Rules and regulations for the portable fire extinguishers in construction and workplace

Organizations	Country	Location and Placement of the fire extinguishers	Distance
Occupational Safety and Health Administration (OSHA, 1970)	United States	Should be mounted on brackets or inside wall cabinets with the carrying handle placed (3 and 1/2 feet to 5 feet) above the floor For Class A hazards, one 2-A extinguisher should be placed for every 3000 square feet.	Class A: 100 feet (30.49 m) or less from the flammable substance Class B: 50 feet (15.2 m) or less from the flammable substance
National Fire Protection Association (NFPA, 2008)	United States	The fire extinguisher should be placed in the hallways, inside meeting rooms, near the exit doors, and in other common locations. If extinguisher weighs more than 40 pounds (18.14 kg), the top of the fire extinguisher cannot be more than 3.5 feet (1.07 m) from the ground and the bottom must be at least 4 inches (102 mm) off the ground. If extinguisher weighs less than 40 pounds (18.14 kg), top of extinguisher cannot be more than 5 ft (1.53 m) from the ground and bottom must be at least 4 inches (102 mm) off the ground	Class A: no more than 75 ft (22.9 m) Class B: no more than 30 ft to 50 ft (9.1 m to 15.25 m)
Australian Fire Regulations (2001)	Australia	Extinguisher should not be mounted higher than 1200 mm (120 cm) off the floor. The bottom should not be less than 100 mm (10 cm) from the floor.	
JCW Energy Services (2005)	United Kingdom	The fire extinguisher should be installed on a close proximity to exits and fire alarm call points. It should be fixed to the wall or attached to a stand. At least two Class A fire extinguishers shall be designated on each floor of the premises.	No more than 30 meters apart

In this research, the information for the installation of fire extinguishers is mostly carried out according the regulations of Occupational Safety and Health Administration (OSHA, 1970) and National Fire Protection Association (NFPA, 2008). Since the OSHA standard only considers the construction sites and mentions the distance limitation for each fire extinguisher, this study will follow the NFPA 10 standard, which applies for buildings, in deciding the area of placement.

2.2 Need of technology in fire extinguisher installation planning

During construction stage, fire extinguishers and the temporary storage of water are the main source for fire protection. The current fire extinguisher installation plan is the 2D-paper based on manual observation. Average people from the construction site unable to understand and place the fire extinguisher in correct position. Moreover, if this task is done manually, according to the section (2.1), it can lead to have several issues regarding the time-consumption, labour-intensive and human error. Therefore, Khan et al. (2020) has attempted to overcome the limitations of the conventional way for creating the fire extinguisher installation plan. The scholars have developed the automatic generation of an installation plan for firefighting in the completed building design, however, the dynamic nature of construction is not considered. Therefore, this study aims to develop the rule-based system in creating the fire extinguisher installation plan, regarding the changes of construction site. Moreover, in order to solve the problem of human limitations in planning, the system aims to take the necessary information from the user input automatically and produce the result in 3D model. Furthermore, this prototype is intended to operate solely by the safety engineer or construction personnel, and to produce the result as fast as possible.

2.3 Game Engine in Fire Safety

Integrating game engines with BIM is one of the effective technologies for the evacuation process. Using the first or the third person perspectives, instantaneous information and interactive visualization are the perks of using 3D game engines (Kumar et al., 2011, Yan et al., 2011)). A prototype that uses the Unity 3D game engine and BIM for virtual walk-through is introduced by Yan et al. (2011). They have mentioned that the use of game engines in creating virtual walk-through has several advantages such as low cost, a navigation system, network support, equipment simulation and visualization, collision detection, and support for a higher frame rate per second.

In the Naval Research Laboratory, a virtual or simulated training system is designed by the scholars for the purpose of drilling firefighters' standardized operation and reaction speed (Tate et al., 1997). Then, the kickback during an emergency is compared between two workers, the one who partook the simulation or training and the one who did not. The conclusion is that the one who participated in the training has a significantly low error rate, regarding the aspect of path finding, and a quick reflection.

To unveil the problems in building emergency management, a BIM-based virtual setting is proposed by Wang et al. (2014a). The setting is constructed using the virtual reality (VR) and a game engine to deliver a simultaneous guidance for evacuation during a fire emergency. Bourhim and Cherkaoui (2018) have developed the virtual environment simulation for pre-evacuation emergencies. The result shows that the player's action in the simulation is almost the same as real human behaviour and using virtual environment simulation as the emergency drill can improve the evacuation process. In this research, the virtual environment and a game engine are implemented to develop the fire extinguisher installation plan for the construction site.

2.4 Unity's NavMesh

Navigation mesh (NavMesh) has become a popular concept which is used in the shortest pathfinding problem of 3D games because the 3D environment mostly uses polygon structure. The shortest pathfinding process in navigation mesh can be implemented with several algorithms, but the most effective and popular nowadays is the A* algorithm (Cui and Shi, 2011). In addition to this, several authors have used the NavMesh as the pathfinding tool in indoor navigation (Tadepalli et al., 2021), evacuation simulation (Wächter et al., 2021) and evacuation simulation for older adults (Du et al., 2020). In this paper, NavMesh is used in order to measure the distance from random points and fire extinguishers. Moreover, it is also applied in identifying the types of location such as the corridor, hallway, common locations and stairs.

2.5 Research gap

Numerous researchers have proposed different methods in order to deal with fire safety plan during a construction. Kim and Lee (2019) have introduced a platform that can generate the daily fire evacuation path in 4D BIM. A labor evacuation planning framework is presented by Marzouk and Al Daour (2018) to contribute the fire evacuation in construction sites for safety engineers. This framework makes use of agent-based simulation system to mimic the response of workers while they are facing an emergency situation. For creating the construction scenario, Building Information Modelling (BIM) and computer simulation is applied. This results in assessment of time factor for execution and evacuation, and the overall cost for construction projects. Another safety assessment method is offered by Hui et al. (2012) for construction fire with specific indexes where the weight of assessment is decided using AHP and fuzzy methods. For the construction site of high-rise buildings, Li et al. (2020) discover three index level fire risk assessment system, including 5, 13 and 33 indexes respectively in each level. Then, the unascertained measure theory is proposed to take out the uncertainty in assessment process and verified it on a hospital construction project as an example. Thomas (2002) also presents efficacy and reliability as the two elements to incorporate the effectiveness of fire safety system. The elements are then put into the historical USA fire data and the efficiency levels in terms of flame size, property loss, injury and fatality rate. Regarding these researches, there seems to be numerous frameworks for fire protection, evacuation path planning, fire safety education (Bourhim and Cherkaoui, 2018) and assessment of fire safety while quite a few of them focused on the fire extinguisher installation plan.

Khan et al. (2020) which are developed to guide the installation of fire extinguishers in the design phases and do not consider the dynamic nature of the construction, which is clearly unavoidable in a real-life situation. Without taking account the dynamic changes, there will not be a suitable fire extinguisher installation plan. Covering the changes of the construction could also be cost effective by deciding whether a certain fire extinguisher is required or not in a new scenario. In addition, the detail verification of locations such as common area or corridor which could highlight the accessibility of fire extinguisher are also not taken into consideration. It would be an obstacle in bringing out the planning of fire extinguisher location to the maximum potential. Moreover, the previous research put the 10 B fire extinguishers on a general basis, in attempt to fulfil the requirement. However, this research examines the location of flammable substances and set the designated fire extinguisher precisely. All in all, this research attempts to overcome these gaps by using the accurate planning and manoeuvring the technology of 3D game engine.

3. RESEARCH METHODOLOGY

There are five stages in the research methodology section, which are revealed in Figure 1. The first stage of the research methodology is a literature review and field observation. This research focused on the cased studies of fire extinguisher installation plan in building.

Using the information relating to the fire prevention from the first stage, the conceptual framework is created, and the system prototype is designed. The Unity game engine and the Visual Studio are utilised in developing the system. The prototype is tested with a sample building by creating different conditions and the output of the prototype is used to test our concept and recommendations.

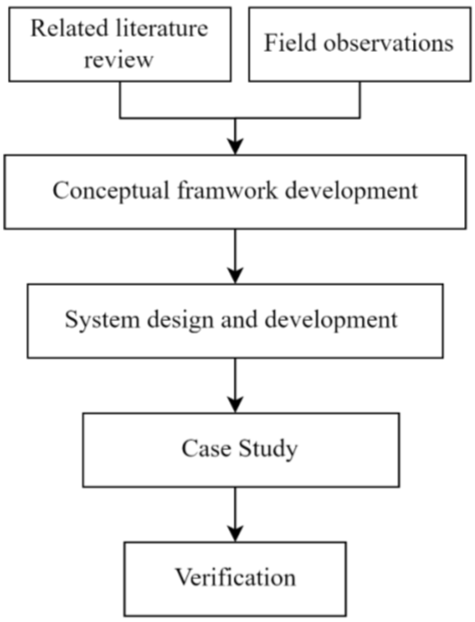


FIG. 1: Research methodology of the research

4. CONCEPTUAL FRAMEWORK FOR DEVELOPING FIRE EXTINGUISHER INSTALLATION PLAN

The main objectives of this research are to reduce the time-consuming, labour-intensive, and human errors in developing and assessing the fire extinguisher installation plan. To enhance the level of construction fire safety management and reduce accidents, the safety engineer needs to develop the plan for fire prevention and protection, and they should not consider only construction layout plans and fire safety requirements. They should also consider other factors which influence on the fire prevention plan, such as the dynamic nature of construction and the location of flammable substance. However, the majority of information is presented in two-dimensional, text-based, paper format. After the safety engineer obtains all of the information, they need to convert 2D drawing to 3D, interpret the text-based rule and regulation to apply in the real world, and integrate the actual construction site condition with 2D drawing which they consider being of concern to them. The capability to perform these tasks depends upon the level of experience, knowledge, and the individual perspective of the engineers and the supervisors. They mentally transform and generate combined pictures. Then they make decisions and produce the results of the fire extinguisher installation plan. Due to the nature of the construction, the safety engineer needs to collect information and adjusted the plan on a daily basis.

Therefore, this research gains ideas from the mentioned problems to improve fire safety. The proposed system is designed to generate and assess the fire extinguisher installation plan, taking the building design and changes in the construction site in terms of progress as user inputs. All essential information (building model, actual construction site condition, the location of flammable substance (FS) and fire extinguishers (FE), OSHA rules and regulations, and construction current practices) is transformed, integrated, and generated the fire extinguisher installation plan in this proposed system by implementing the virtual environment, as shown in Figure 2.

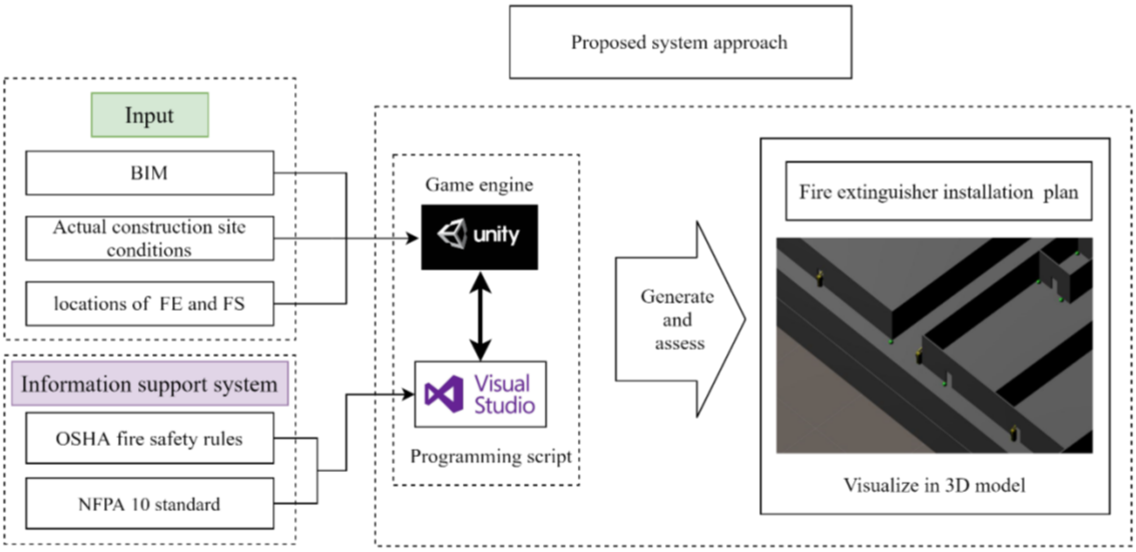


FIG. 2: Conceptual framework of the proposed system approach

5. SYSTEM DESIGN AND DEVELOPMENT

5.1 System design

In this section, the flow of the proposed system will be clearly demonstrated using a flowchart. In the construction site, fire extinguishers play an important role in fighting the fire because buildings under construction do not possess permanent due to the dynamic nature of construction activities. These dynamic situations may impact on adjusting fire extinguisher location. The incorrect position of the fire extinguisher can affect the fire extinguishing process. This process is required safety engineer to adjust and check the suitable fire extinguisher location during construction period. Therefore, this proposed system will be designed to provide the fire extinguisher installation plan and assessment based on OHSA rules and regulations, NFPA 10 standard and current practice.

Regarding the related literature and technological reviews, the system design will be chosen to develop the conceptual framework of this research. First, the limitations of the previous research such as the dynamic changing of building structure, locations of flammable gas, and fire extinguishers were defined as key variables for data analysis. According to the previous studies, the virtual 3D model was selected as the presentation style for fire extinguisher installation plan. The main benefit of the virtual 3D model expression is the visibility, which is better than the two-dimensional one, whereas the latter not only has poor visibility but also takes time to understand the drawing of large construction sites. This is due to the dynamic building structures of complex construction sites, in terms of construction progress. The flowchart of the proposed system is revealed in Figure 3.

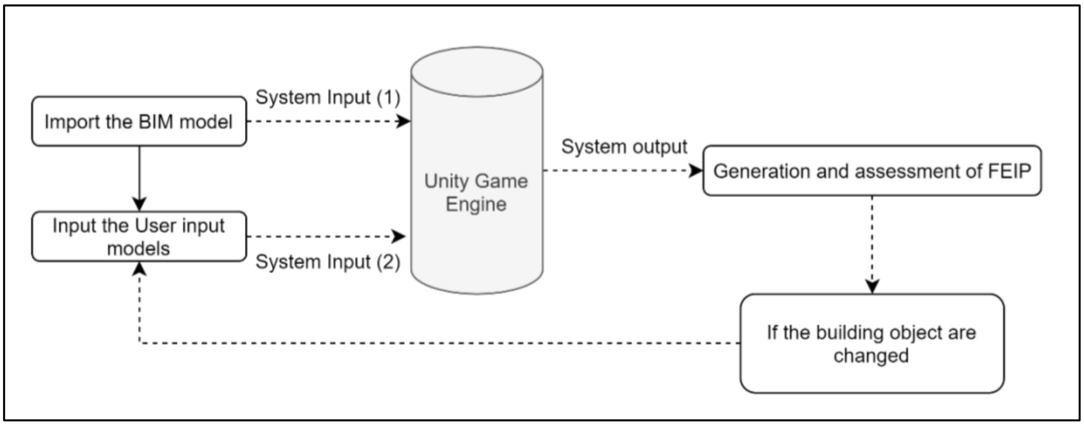


FIG. 3: Flowchart of the proposed system approach

According to the framework, there are two system inputs: the BIM model and user input. In this system, the BIM model is used as the 3D model because BIM technology allows storing both geometric information and rich semantic information of building models, as well as their relationship. User input will be determined with key parameters that have a great impact on the locations of the fire extinguisher installation plan. Based on the findings of previous researcher (Choe and Leite, 2017), rules and regulations, and feedback from experts, the significant parameters in this research include dynamic nature of the construction site, exit gates and locations of flammable substance.

A prototype system is designed and developed to handle the dynamic building structure by defining it as finished and unfinished parts. In generating the fire extinguisher installation plan, the following fire protection rules are applied (OSHA, 1970)

- Travel distance from any point of the protected area to the nearest fire extinguisher shall not exceed 100 feet. [Standard Number - 1926.150(c)(1)(i)]
- A fire extinguisher rated not less than 10B, shall be provided within 50 feet of wherever more than 5 gallons of flammable or combustible liquids or 5 pounds of flammable gas are being used on the Jobsite. [Standard Number - 1926.150(c)(1)(vi)]

Moreover, the system can also generate the fire extinguisher plan according to the NFPA 10 standard (fire extinguisher should be at corridor, common location and entrance) and OSHA rules and regulations. According to the OSHA, failure to provide the 2-A rating of fire extinguisher within 100 feet of an area where class A fire hazard exist in the building is one of the most frequently cited fire hazard violations. Therefore, regarding the Standard Number - 1926.150(c)(1)(i), it will be checked that the travel distance between the fire extinguisher and every area within the building is 100 feet.

5.2 System development

In this section, the development environments which are prepared for proceeding the proposed system are described. The process of the proposed system is mentioned in Figure 4. The system development was divided into two parts such as generating the fire extinguisher installation plan (blue line) and assessment of fire extinguisher installation plan (red grid line). Autodesk Revit (2019), Navisworks (2019), Unity (2019) and Visual Studio (2017) are the main software in developing the prototype. Unity is the cross-platform game engine, and it supports more than 25 platforms. It has a powerful engine and is easily operable. To achieve the objective, NavMesh is added to Unity. The NavMesh, a building component making tool, is used to generate the NavMesh or a polygon mesh of the building. Microsoft Visual studio is used to create the script or programming language in Unity.

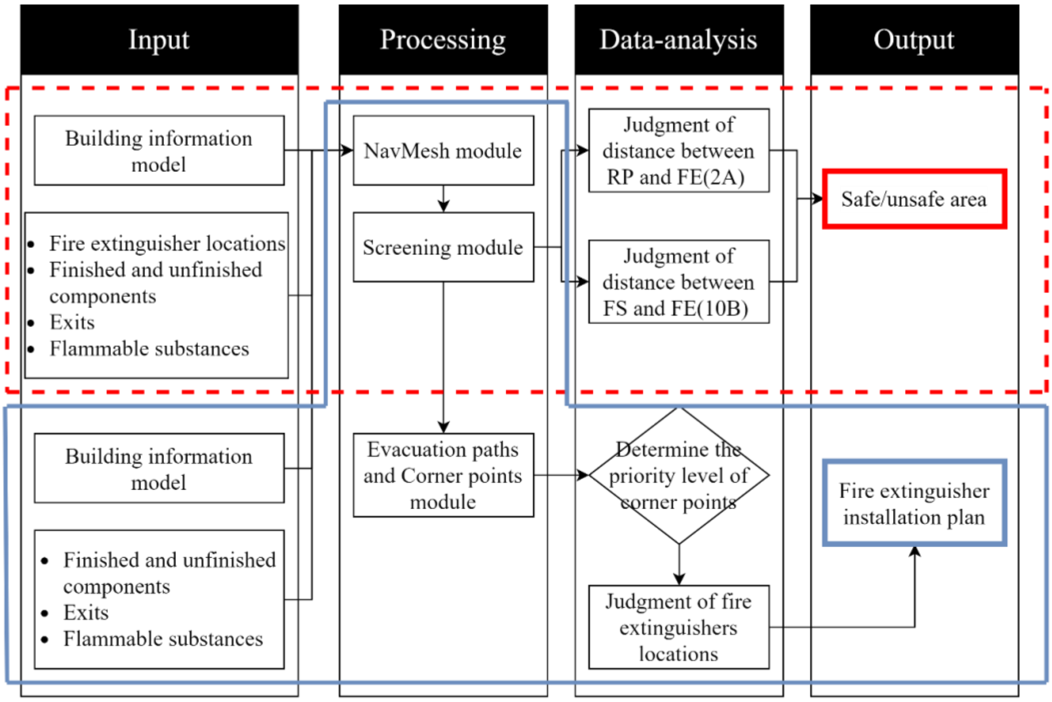


FIG 4 : The process of the proposed system

5.2.1 Input

Revit is a typical and popular BIM software. It is used to create the 3D model of the building. In order to export the 3D model to unity, the 3D model file type must be converted to FBX file type. The exported FBX file from Revit only shows the name of the material of the components, while the exported FBX files from Navisworks can provide rich information, showing the components with categories such as levels (floors), walls, doors, and so on. The differences between the exported FBX file from Revit and Navisworks are shown in Figure 5. Therefore, the FBX file from Navisworks will be used in this prototype. The Revit export the RVT file to the NWC file, and then opens it to Navisworks to generate the FBX file.

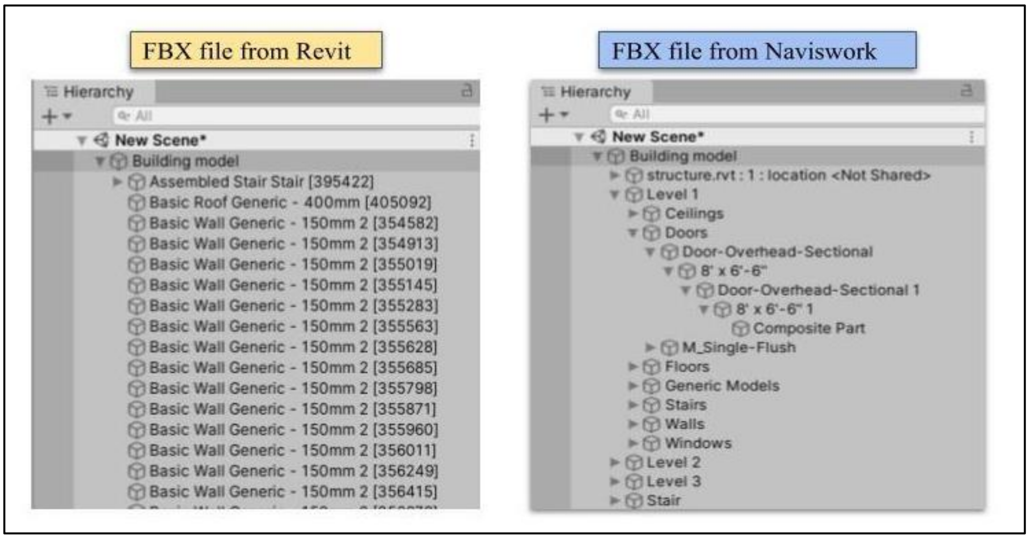


FIG. 5: The differences between the exported FBX file from Revit and Navisworks

The user input model and data will be created in terms of key parameters that are mentioned. The input models are fire extinguishers, exits of the building and location of flammable substances. The input data is applied in identifying finished and unfinished components for the dynamic building structure in terms of construction progress. The action of the finished part and the unfinished part of the polygon mesh will be created by using the NavMesh Surface and the mesh of unfinished components were disappeared in user interface.

5.2.2 Information Processing

This section explains the necessary data for the data analysis. The data processing is divided into three modules: (a) NavMesh module, (b) Screening module, and (c) Evacuation paths and corner points module

(a) NavMesh Module

NavMesh module is the first process after providing BIM model and user inputs into the system. According to the fire safety rule and regulation, the distance between any area within the building and fire extinguishers should not be exceeded 100 feet. In order to carry out this safety rule, a system is needed to create points or random points and place them in construction buildings. For this purpose, the NavMesh module is performed to collect the location of vertices. The NavMesh vertices are shown in Figure 6. After that, all of the vertex positions put into the array and arrange to the ascending order based on the X-axis, and the random points are created at these vertex points.

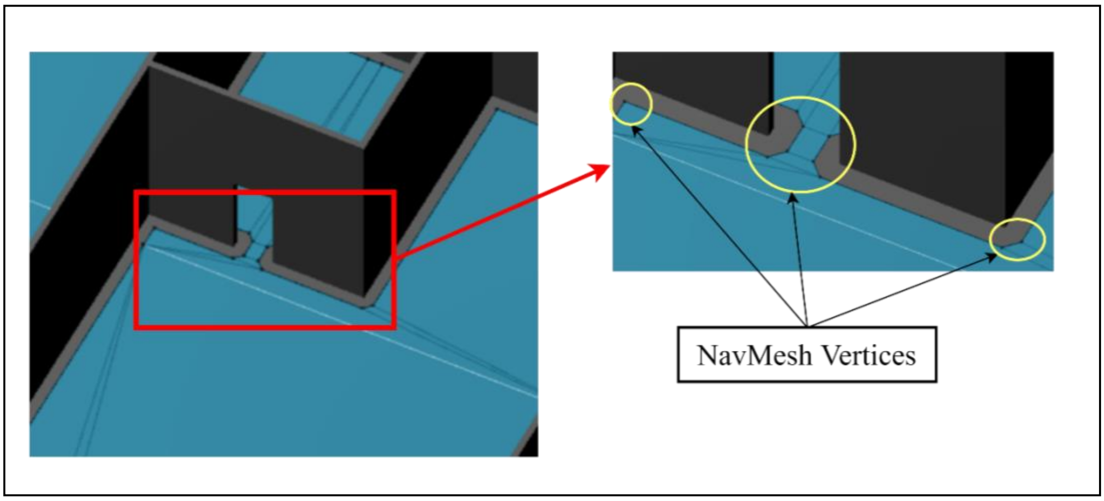


FIG. 6: Vertices of NavMesh

(b) Screening module

The main purpose of screening module is to reduce the running time by discarding the number of random points. To perform this task, A star algorithm is used, aiming to calculate the travel distance between two points. The feature of this search algorithm is that it searches for an ideal best path using the navigation grid between the two nodes: start and end. If the path finds a block node, it will avoid, and will pass through the unblocked one. Overall, the path will begin from one start node while growing itself through unblocked nodes and terminate at the end node as a complete one.

$f(n) = g(n) + h(n),$

Where, $f(n)$ = the final distance for the path

$g(n)$ = the distance of the path from starting node to node n,

$h(n)$ = the straight distance from node n to exit node.

By using the Unity navigation function that applies the A star algorithm, random points are removed if the travel distance between reference random points and the other random points is less than 2 meter. The 2 meter limit is chosen for a fact that the maximum width of a door in this building is 2 meters and only one random point is expected to place there. The array of random point is arranged in the ascending order of the x-axis coordinate. The random points are taken as the reference random points in terms of the array of vertices. The concept of this task is explained in Figure 7. In this example, A point is taken as the reference point (the red point) and measures the travel distance to other points. If B and C points are within 2 meter of A point, these two points are removed. And then, A point is put into the resulting random points, and the D point is taken as the reference point. The above process is repeated through all points.

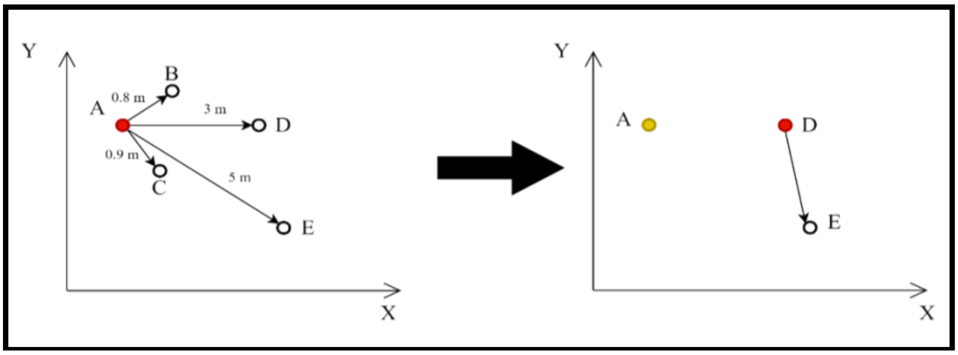


FIG. 7: The way to reduce the random points

(c) Evacuation paths and corner points module

Evacuation paths and corner points module support the proposed system to get the temporary position of fire extinguishers. From the resulted random points, a star algorithm is applied to generate the corner points on the evaluation routes towards the nearest exit. In Figure 8, the green lines are the evacuation routes from the random points, and the yellow spheres represent the temporary locations of the fire extinguisher or the corner points. The next step is to place all the locations of the corner point into the array. Then, the system examines the duplicate positions in terms of the 3D vector (x,y,z) and counts the number of duplicate positions or the frequency. The corner points are removed when the frequency is less than 4. The corner points are arranged in ascending order based on the frequency.

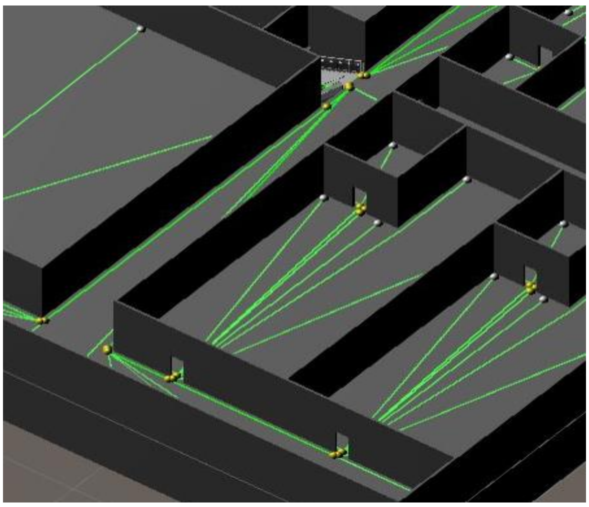


FIG. 8: Corner points on the evacuation routes

5.2.3 Data analysis

Data analysis can be distinguished into two parts: the determination of the priority level of conner points and removal of unnecessary levels while matching the rules and regulations. The purpose of first part is to distinguish the area such as the common area or corridor. To generate the FEIP, the system has to determine whether the certain point is appropriate to place the fire extinguishers. For example, the fire extinguishers should be placed in the hallway, common location, and near exits. To process this task, all the corner points is required to rank with frequency. Figure 9 shows the determination of the level of priority of the corner points is in terms of frequency (e.g., the priority levels of the corner points near the main stair is higher than the priority levels of the corner points near the room). As the result, the corner points have a higher frequency will have chance to place the fire extinguisher, however, it is necessary to consider about rule and regulation in the next step.

The second part is performed to achieve the final decision on fire extinguisher placement location. The distance between any random points and the nearest corner points or temporary fire extinguisher should not exceed 100 feets. Starting from the lowest priority level, the conner points are removed one by one. If the rest of the temporary fire extinguisher locations comply with the rule and regulation, the removed points are permanently discarded. If not, the removed corner point is added to its original state. After these processes have been performed on every corner point, the final decision of fire extinguisher locations appears on the 3D building model. This analysis is focused on Class A hazard.

For Class B hazard, the rule and regulation stated that 10B fire extinguishers shall be provided within 50 feet of wherever more than 5 gallons of flammable or combustible liquids or 5 pounds of flammable gas. With the procedure mentioned above, the 10B fire extinguishers are allocated in designated area, even though the random point is replaced with the position of flammable substance.

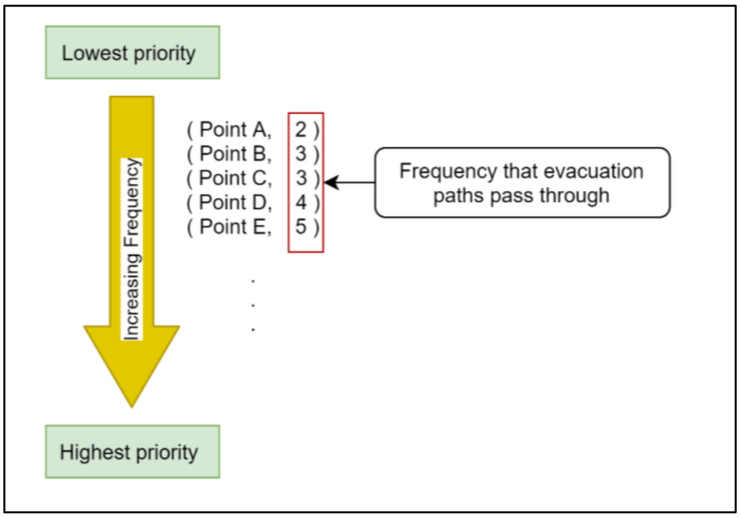


FIG. 9: Determining the priority with frequency

For the assessment of current FEIP, the system checks the distance between created random points and fire extinguishers (2A) is over 100 ft or not. If the distance is over 100ft, the system will this random point as the unsafe area. For 10B fire extinguisher locations, the system shows the flammable substance location as an unsafe location when the 10B fire extinguisher is not provided within 50ft from the location of flammable substance.

5.3 Output

The output section can be divided into two parts: the generation of FEIP and, Safe/unsafe area. The first system can provide the recommended location and specific rate of fire extinguisher in the 3D building. The generation of fire extinguishers and their locations will be inserted into the 3D building as shown in Figure 10. 2A fire extinguisher is represented as the fire extinguisher in yellow colour while 10B fire extinguisher is depicted as the purple fire extinguisher.

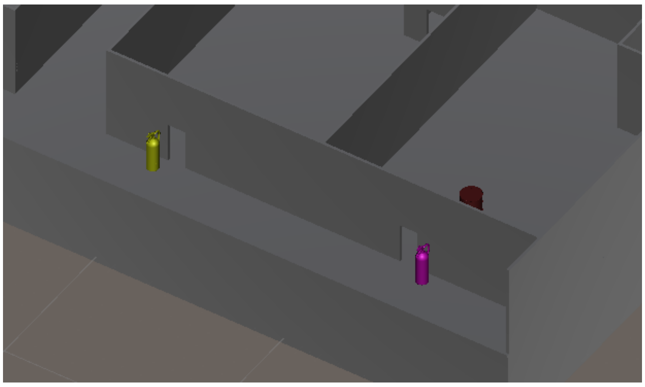


FIG. 10: The output of fire extinguisher installation plan in Unity

The locations of fire extinguishers should be complied with fire safety rules and regulations. In the assessment part, the system helps to assess the manual process of fire extinguisher's location. The assessment of fire extinguisher locations can be evaluated by using variables such as the rule and regulation of fire safety and types of fire extinguisher. In the system, unsafe area for 2A fire extinguisher is represented by small red sphere and that of 10B fire extinguisher is represented by big red sphere (see Figure 11). The location of flammable substance is represented as the red cylinder. For 2A fire extinguisher, the result of assessment will illustrate the safe/unsafe area where the distance between the random point and the nearest 2A fire extinguisher fire is over 100 feet. Based on the case study shown in Figure 10, the distance between flammable substance and the nearest 10B fire extinguisher exceeds 50 feet, opposing the rule and regulation. As a result, the big red sphere appears on the locations of the flammable substance, claiming the location is unsafe.

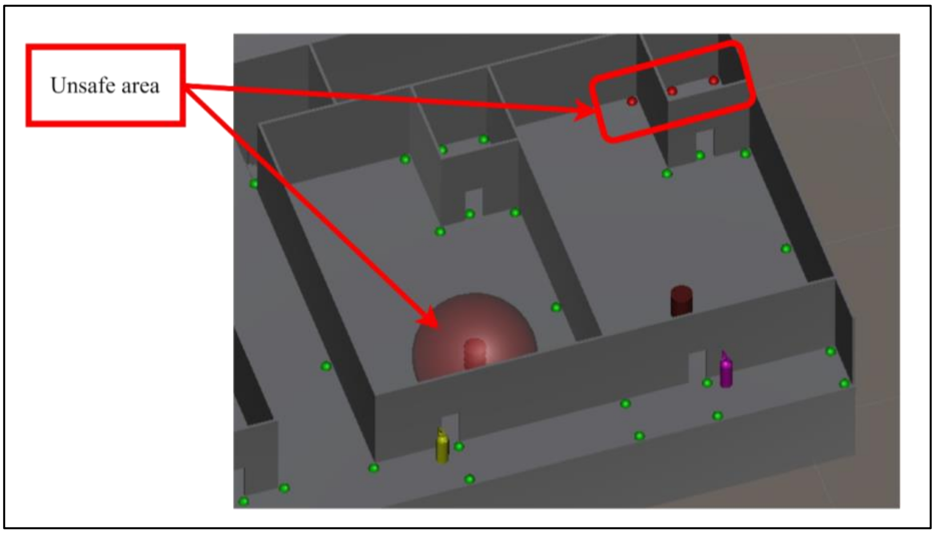
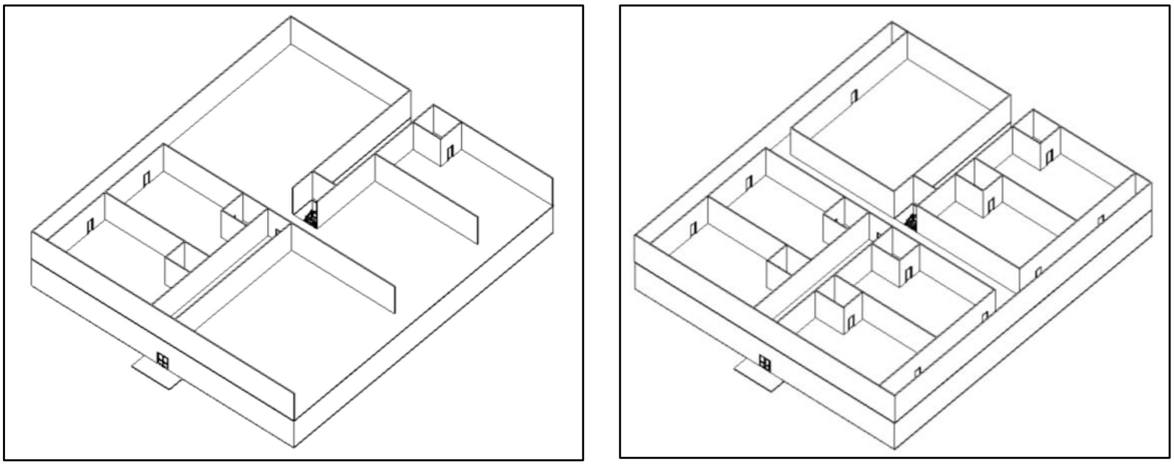


FIG. 11: The output of assessment of fire extinguisher installation plan in Unity

6. CASE STUDY

This section investigates the feasibility and applicability of fire extinguisher installation planning by applying on a sample model as shown in Figure 12. This model has two floors, and the second floor is taken as a representative to test the proposed system. Two scenarios are created on the sample building, and they will have different construction progress and structural designs. The main purpose is to validate the fact that the proposed system is able to generate the locations of fire extinguishers according to the rules and regulations and can also handle the dynamic nature of the construction.



(a) Scenario (1) (b) Scenario (2)

FIG. 12: 3D view of the scenario (1) and (2)

6.1 Import the BIM to unity

At first, the architectural model from the Revit was export into NWC file in order to open the model on Navisworks. After that, the FBX file was exported from Navisworks and input the model to the Unity game engine. In Unity, the doors and windows from the model need to delete.

6.2 The user input

The user input is depended on the purposes of analysis, which are generation and assessment of fire extinguisher plan. For generation of fire extinguisher plan, user provides finished and unfinished components, exist, and flammable substance. For assessment of fire extinguisher plan, user provides location of fire extinguishers and similar information as previous purpose. First, building element status is defined the structural design in terms of current construction progress (e.g., the wall (1) is finished or not). Second, the location of flammable substance, fire extinguishers and exits should be defined from the construction site and flammable conditions. Figure 13 shows how to assign the user input that simulate the desire construction site conditions. To identify the finished components and unfinished components, users need to click the building object in Unity's scene (green box) and change the properties by using the layers (yellow box). The other user inputs such as fire extinguisher (2A and 10B), exits and flammable substance can be input by dragging the model from prefab file (red box) into the scene and then place to desire locations.

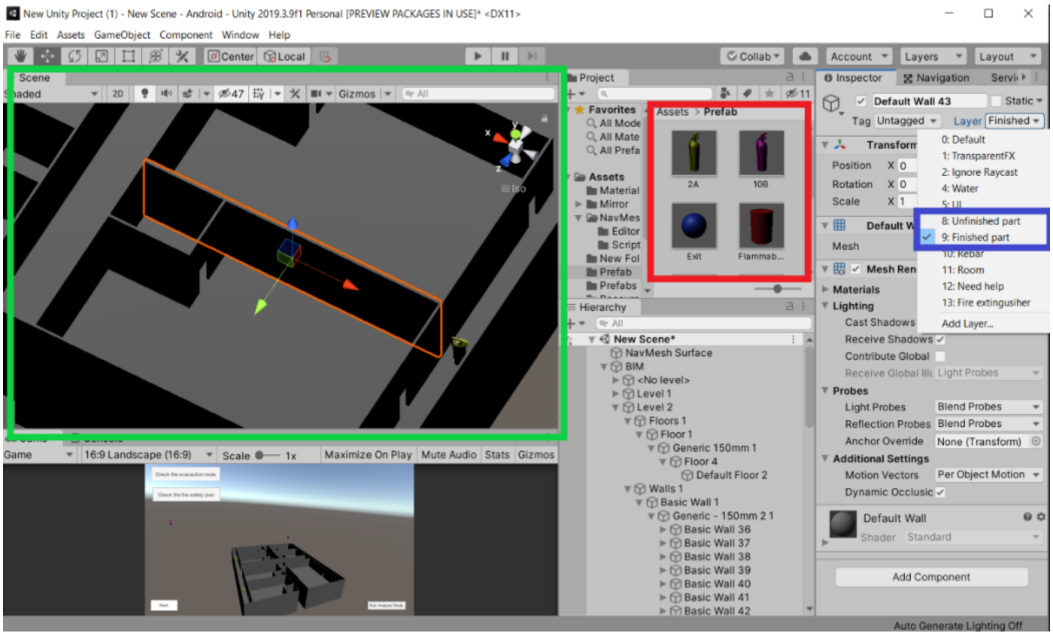
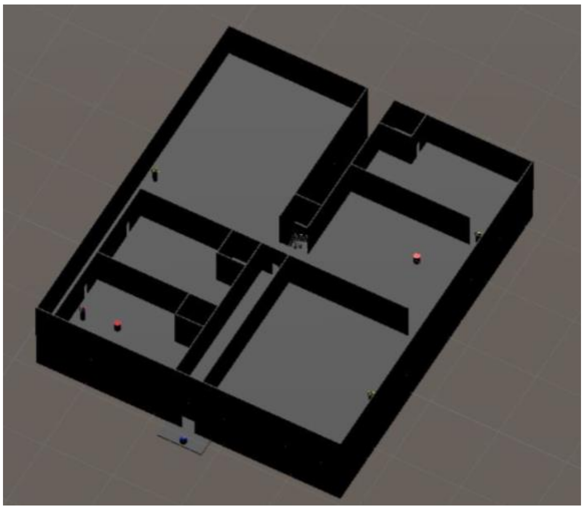


FIG. 13: Input the user input in Unity

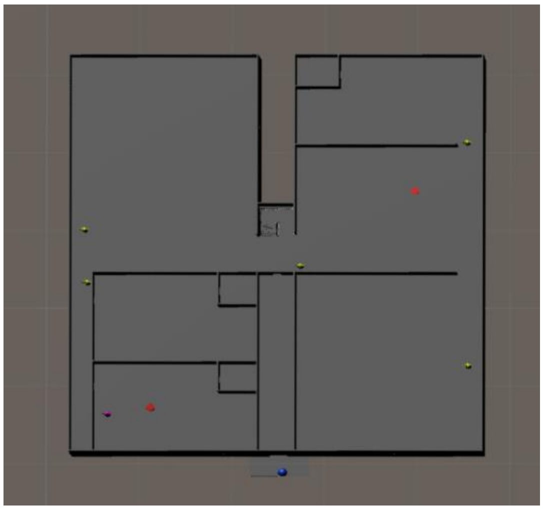
In this study, two different scenarios are created on this sample building and tested. Scenario model 1 shows that some walls from the second floor are not finished (see Figure 14). 2A fire extinguishers (yellow) are placed on each floor with the same pattern. 10B fire extinguisher (purple) and 2 flammable substances are added at the second floor (see Figure 15). Scenario model 2 simulates the all models of the structure and architectural works are completed. The locations of fire extinguishers and flammable substance are the same as the scenario 1. In this system, the blue sphere and red slender represents the exit and flammable substance, respectively.

6.3 Fire extinguisher installation plan

This section shows the result of two scenarios that was using the proposed system. After running the proposed system, the user can choose the building object to be either transparent or not transparent. (e.g., the transparent model can see-through all of the floor). In this study, the only second floor is tested, and the opaque is selected. The fire extinguisher installation plan is automatically generated by using the two scenario models. The assessment is also performed on these two models by claiming the fire extinguisher location as a user input to determine whether an area is safe or unsafe.

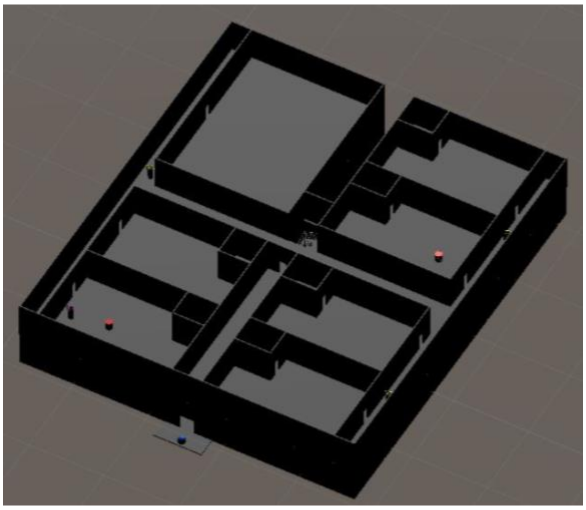


(a) 3D view of scenario 1 in Unity

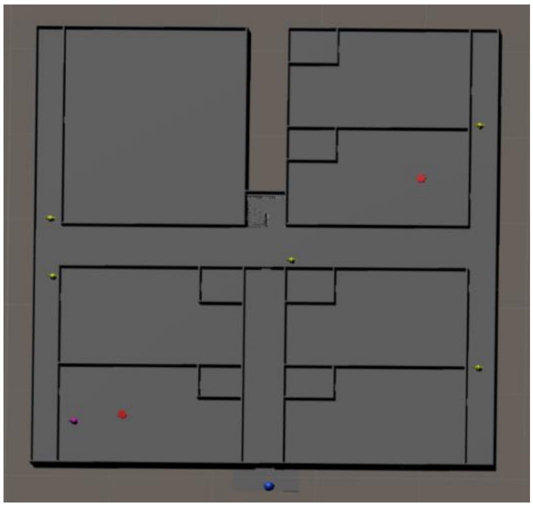


(b) The Top view of the scenario 1 in Unity

FIG. 14: Fire extinguishers, flammable substance, exits and site conditions of scenario 1



(a) 3D view of scenario 2 in Unity



(b) The Top view of the scenario 2 in Unity

FIG. 15: Fire extinguishers, flammable substance, exits and site conditions of scenario 2

6.3.1 Generation of fire extinguisher installation plan

Figure 16(a) shows the locations of fire extinguishers for scenario (1) that are generated from the system. According to the result, 10B fire extinguishers (yellow) are added on the right-hand side and the location of 10B fire extinguishers from the left side is moved to the hallway. 10B fire extinguisher (purple) is also placed at the exit. Regarding to the Generated FEIP, 4 fire extinguishers with the level of 2A and 2 fire extinguishers with the level of 10B are necessary for the second floor. The result of the scenario (2) shows that safety engineer needs to add extra one fire extinguisher with the 2A rate when all the walls are completed. (See Figure 16(b)). This result indicates that the wall status can influence on the number and location of fire extinguishers.

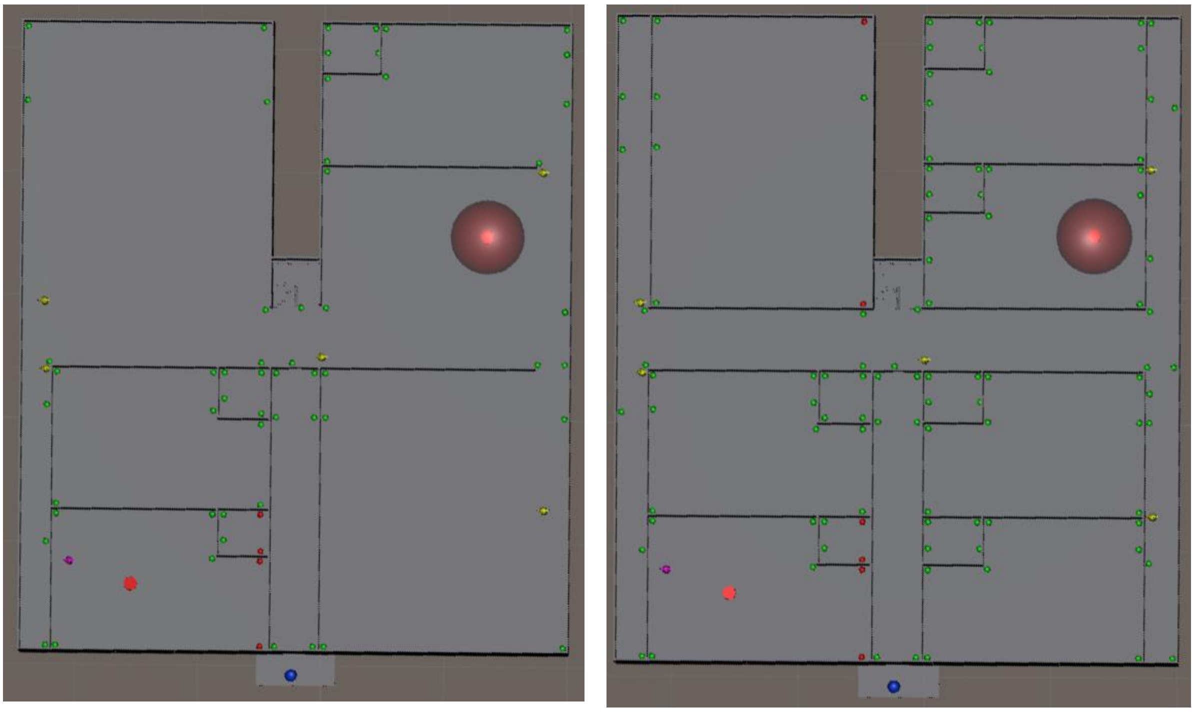
6.3.2 Assessment of the fire extinguisher installation plan

Figure 17 illustrate the assessment of the fire extinguisher installation plan of scenario 1 including the finished and unfinished walls, flammable substances, fire extinguishers and exits. Some areas from the left side of the building show as an unsafe area that are not complied with rule and regulation. There is a 10B fire extinguisher near the flammable substance at the left side of the building, while there is no 10B fire extinguisher on the right. According to the system result of the assessment of the scenario (1), more 2A fire extinguishers need to be added on the left side of the building and 10B fire extinguisher needs to place near the flammable substance from the right side of the building.

(a) Generated fire extinguisher installation plan for scenario 1

(b) Generated fire extinguisher installation plan for scenario 2

FIG. 16: The Result of the generation of Fire extinguisher installation plan in scenario 1 and 2.



(a) The Assessment of the fire extinguisher installation plan in scenario 1

(b) The Assessment of the fire extinguisher installation plan in scenario 2

FIG. 17: The assessment of the fire extinguisher installation plan in scenario 1 and 2.

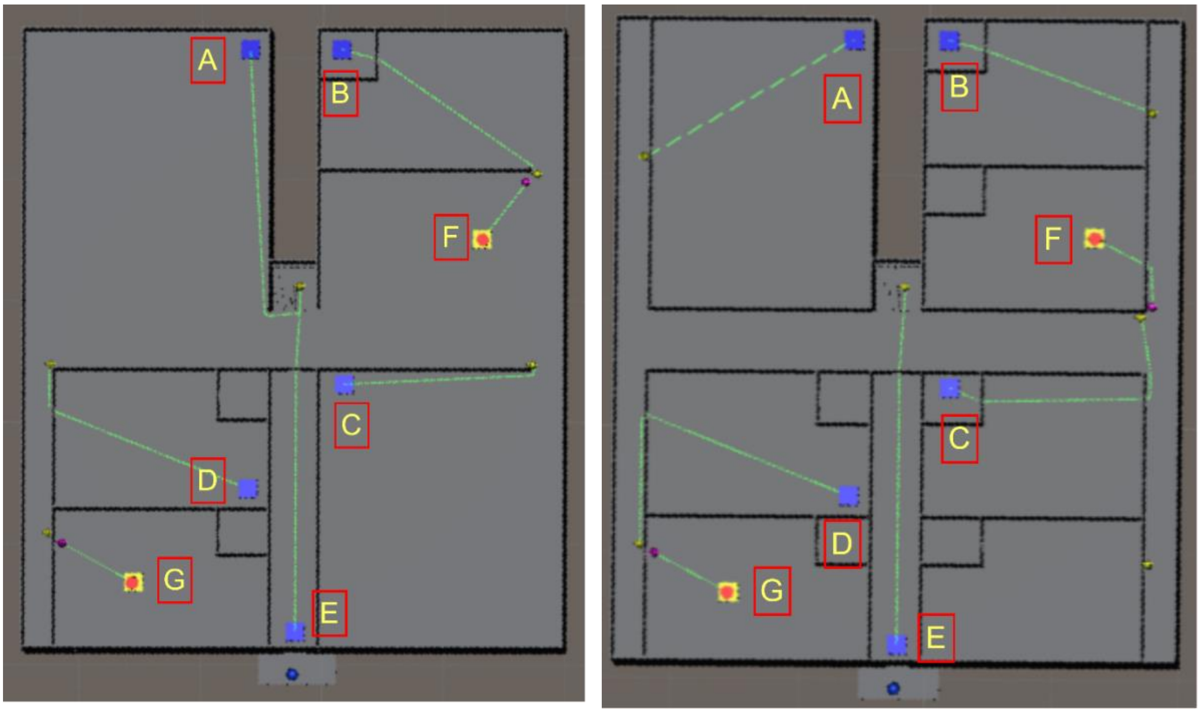
The assessment of the fire extinguisher installation plan for scenario 2 are shown in Figure 17(b). The assessment result from the proposed system shows that three random points or locations and the flammable substance from the right side of the building do not comply with fire safety rule. Regarding to the result, the proposed system recommends placing the additional 2A fire extinguisher in the left side of the building and to add the 10B fire extinguisher near the flammable substance from the right side of the building.

7. VERIFICATION OF OUTPUT AND PROTOTYPE

Seven random points (blue and yellow cubes) are placed manually in order to verify that the result actually follows fire rules and regulations which are mentioned in 5.1. A to E random points (blue cubes) are tested for 2A fire extinguishers and, F and G random points (yellow cubes) for 10B fire extinguisher. If the distances between random points and their respective nearest fire extinguishers are within acceptable distances from fire safety rules, the colour of line will be green. The line will be presented as a red line when the distance exceeds the maximum distance.

Figure 18 shows that the seven random points are placed in the generated fire extinguisher installation plan of scenarios 1 and 2. According to the verification, all distances from random points to nearest fire extinguishers are complied with fire safety rules and regulations. The verification of assessment section is shown in Figure 19. In scenario 1, the areas of random points C, D and F are not following the fire rules and, the outcome of the assessment results as unsafe areas. Regarding the Figure 19(b), the unsafe and safe areas from the verification process and the assessment of fire extinguisher installation plan produce the same result. The data of verification are shown in table 2.

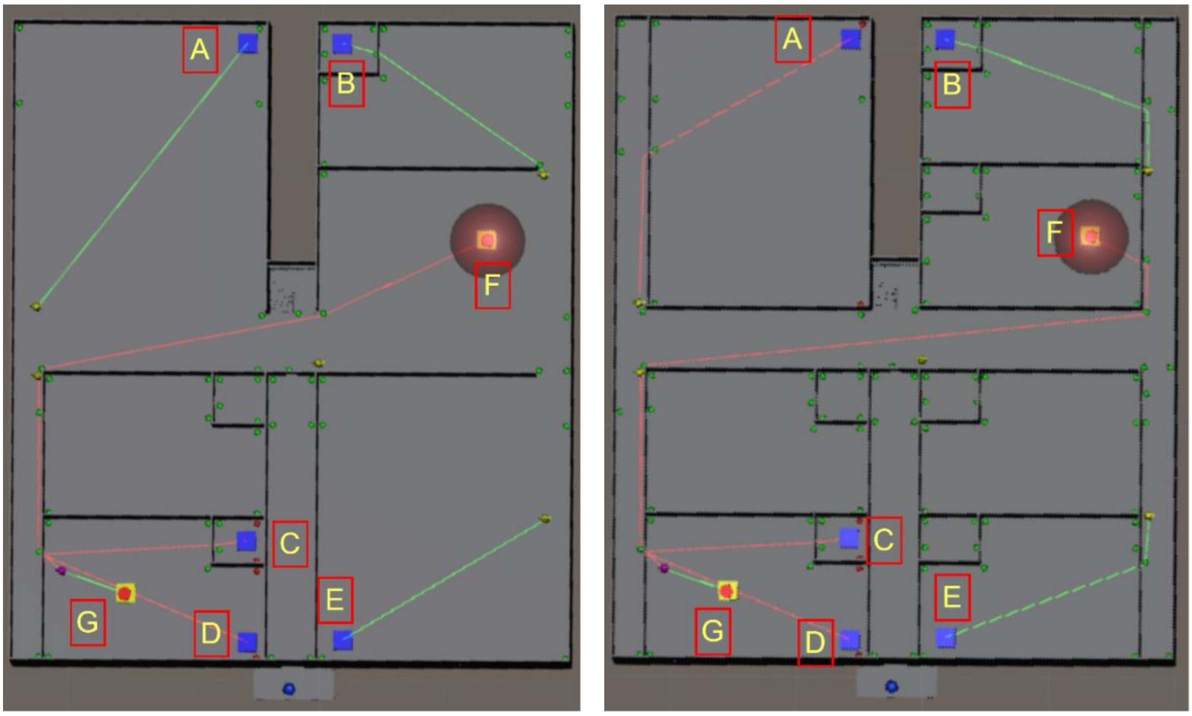
In order to validate the performance of prototype, the average system running time to get the result will be collected. For the generation part, the system running time of scenarios 1 and 2 are 5 to 6 seconds and 9 to 10 seconds, respectively. The system running times of assessment are less than 1 second.



(a) Verification of the generated fire extinguisher installation plan in scenario 1

(b) Verification of the generated fire extinguisher installation plan in scenario 2

FIG. 18: Verification of generated fire extinguisher installation plan in scenario 1 and 2.



(a) Verification of the assessment of fire extinguisher installation plan in scenario 1

(b) Verification of the assessment of fire extinguisher installation plan in scenario 2

FIG. 19: Verification of assessment of fire extinguisher installation plan in scenario 1 and 2.

Table 2: Distance between random points and fire extinguisher from verification.

			A	B	C	D	E	F	G
Distance (feet)	Generation part	Scenario 1	79	62	55	71	92	20	20
		Scenario 2	62	57	75	92	92	27	20
	Assessment part	Scenario 1	101	72	101	106	68	178	18
		Scenario 2	88	65	101	106	62	178	18

8. DISCUSSION AND CONCLUSION

Developing the fire extinguisher installation plan and assessing of fire extinguisher locations for the construction project based on changing construction site conditions requires to consider a lot of information. Moreover, the fire extinguisher installation plan in construction needed to be reviewed and updated according to construction progress. As a result, developing the fire extinguisher installation plan for a construction project that can be time-consuming and enormous labour-intensive task if done manually. To resolve this challenge, this research proposed a framework to automatically generate and assess the fire extinguisher locations using project information in the Game engine. In order to prevent the fire risks in the construction site, the proposed approach has successfully developed the fire extinguisher installation plan that is complied with OSHA rules and regulations. The developed system requires users to manually identify the finished or unfinished building objects and input non-building objects in order to take account for current construction site conditions. The main contribution of this paper is introducing a system that can verify the type location (common locations or hallways or exits) where this information is essential for generating fire extinguisher placement. Moreover, the system can generate and assess the fire extinguisher installation plan according to the construction architectural design, regarding the construction progress. A case study on two sample construction scenarios successfully generated rational fire extinguisher installation plan and provided the unsafe area and the safe area.

According to the verification of the prototype output, the functions of the generation of fire extinguisher installation plan are operable and the generated results are also complied with fire rules and regulations. Moreover, the output of the assessment for fire extinguisher installation can determine the safe and unsafe area. Furthermore, the function for generation of fire extinguisher installation plan only takes about 5 to 10 seconds, and also the assessment only needs one second to finish the task. It can be concluded that the outputs of prototype are also processed according to the rule and regulation and it can also reduce the processing time of safety engineers and construction personnel.

Even though this prototype provides valuable output for the fire extinguisher installation plan, there are some limitations that should be addressed. The first limitation is that there is a need for manual updates on building objects such as walls and non-building objects such as fire extinguishers and flammable substances. The construction site's conditions from virtual reality or Game engine should reflect the actual construction site conditions. Many researchers have attempted to automate the data updating process by integrating with sensors. However, this is out of scope of this research. Another limitation is fire safety rules and regulations. In this research, the assessment of fire extinguisher location only considers rules and regulations that are related to distance. This system is unable to check the location of fire extinguishers that are in the common location or inside the room. Therefore, the rules and regulations that are related to location should be added in the assessment section.

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