EXPERIMENTAL INVESTIGATION OF USING RFID INTEGRATED BIM MODEL FOR SAFETY AND FACILITY MANAGEMENT

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ABSTRACT: *This paper proposes a new system integrating radio frequency identification (RFID) and building information modeling (BIM), which can be used for the lifecycle management for buildings. During the structural and MEP design stage, the locations of permanent tags are designed for facility management purpose. Tags can be designed to be attached to concrete structures, steel structures, ventilation pipes, sewerage pipes. Location information and other information can be written in and retrieved from the tags. During the construction stage, the locations of temporary tags are planned for safety management purpose. Tags can be attached to doors, windows, protection fences, and other temporary safety measures during construction. Space in the BIM is classified into workspaces with different risk levels according to work breakdown structure (WBS) and schedules. Algorithms are proposed for automatic risk analysis using the BIM, which is updated to reflect the real situation on site, resulting in risk-ranged workspaces. RFID receivers are installed on the critical locations on site. Once a tag is detected for specific safety measures, the risk of that workspace will be reduced. Workers also carry tags and their locations can be monitored. Once a worker enters a workspace with high risk, signals can be sent to the worker to remind him/her about the situation. In extreme cases, an alarm is triggered to ask the worker to leave the dangerous workspace. A case study is undergoing to apply the proposed approach on a construction site in Suzhou, China.*

KEYWORDS: *Safety, RFID, BIM, Workspace, Lifecycle, Facility management.*

1. INTRODUCTION

Construction sites are dynamic and on-site situations are changing in terms of permanent and temporary structures and facilities; therefore, information of the construction site should be updated based on the project progress monitoring. Radio Frequency Identification (RFID) is an affordable technology that can be used to collect information for the lifecycle management of a building. Starting with the transportation of construction material, RFID is widely used for tracking the raw materials, precast structural components, and other building facilities (Furlani and Pfeffer, 2000; Song et al., 2005; Song et al., 2006; Torrent and Caldas, 2009). The purpose is to enable lean construction and to reduce storage and labor costs, etc. Location data collected from RFID tags can be used to update construction processes in real-time (Ghanem and AbdelRazig, 2006). Small tools and other objects on site can be tracked to facilitate an efficient construction management (Goodrum et al., 2006). In addition, applicability of RFID technology in construction has been investigated in terms of feasibility, accuracy and reliability, such as Pradhan et al. (2009); Lee et al. (2012); Taneja et al., (2012);

Usually, information saved in those RFID tags attached to components includes the material/component name, type, date of manufacture, transportation, and installation, etc. depends on the characteristics of the material/components. That information can be collected and integrated into a digital model of the structure and analysis can be applied for all kinds of management purposes. For example, Building Information Modeling (BIM) is such a model with the capability in integrating information from different sources. BIM is a new approach to design, construction, and facilities management in which a digital representation of the building process is used to facilitate the exchange and interoperability of information in a digital format (Eastman and Eastman, 2008). Therefore, it is natural to integrate RFID and BIM technology to build the linkage between physical tags attached to building components and the virtual digital model. As indicated by Motamedi and Hammad (2009), a more efficient facilities management system can be built by sharing and exchanging distributed data resulted from the integration of RFID and BIM.

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During construction, it is important to identify risks on construction sites so as to eliminate them before accidents occur. Safety measures are mandatory on site to prevent accidents; however, an effective way is missing to check if those measures are taken properly on construction site, and workers on site are not given enough awareness about where are those dangerous areas. For example, although regulations are defined to use guardrails, safety nets, harnesses, etc., to prevent falling, out of the construction workers that suffer fatal injuries, more are involved in falls than any other single cause (Huang and Hinze 2003). Therefore, tracking or monitoring safety measures (e.g., guard rails) on site should be applied for an effective safety management. This information can also be reflected and integrated by using the BIM. Kiviniemi et al. (2011) have used BIM as a 4D safety planning tool, in which the researchers have indicated that BIM technology can present a new way to solve site safety problems. However, the virtual barriers generated in their project are static and for visualization purpose only, and there is no real-time safety management using those virtual barriers.

The authors of this paper have investigated the feasibility of accurately locating dynamic virtual fences (DVFs), which are generated along hazard zones to prevent workers from falling or other hazardous (Zhang et al., 2012). The heights of the DVFs are determined by the height required for the guardrails, which should be at least 1.2 m above the surface on which the worker is working according to the safety code. However, real-time warning is an issue that needs to be investigated more to provide reliable protection. Ultra Wideband (UWB) devices have been investigated to be applied on construction site for monitoring moving objects on site and checking the presence of safety measures. Although the accuracy claimed from UWB devices is up to 15 cm in an ideal condition, the cost of the UWB system and disturbing to the construction site need to be investigated more. Compared with a high accurate UWB system with high cost, RFID can provide approximate location information with a considerable lower cost. In addition, data can be written into the memory of the RFID tags to store information regarding the properties of the object, which is not applicable for UWB tags. However, delicate design is needed to maximize the advantages of this affordable technology as much as possible.

Based on the experience of the authors in applying radio frequency technology and BIM modeling, the present paper proposes an approach of building a spatial network in the BIM model by registering permanent and temporary RFID tags in the building model, which will be used as a base system for various management that are related to spatial problems. During the current research stage, focus has been put on safety management and facility management during the lifecycle.

2. OBJECTIVES

The proposed research aims to investigate the effectiveness of integrating RFID with BIM for safety and facilities management based on a spatial network. The objectives of the present paper are: (1) to investigate the topology of tag network based on the requirements from safety and facility management; (2) to propose an algorithm for defining workspaces based on schedule and reference objects; (3) to propose an approach for automatic risk assessment during construction process; and (4) to automatically check whether the physical barriers/barricades are installed in the proper locations with proper dimensions.

This proposed method is part of a big vision, which integrates BIM-based safety prevention system with RTLS environmental perception system. The ultimate goal of this research is towards a Smart Construction Site (Zhang et al., 2009) and eventually a smart building can be established by utilizing data collection through sensors embedded in the structures. Furthermore, with all kinds of sensors embedded, data of the operation situation of the building can be collected automatically and transferred wirelessly to facilitate an effective facilities management system.

3. METHODOLOGY

Figure 1 shows the main concept of the methodology, which indicates the integration of RFID and BIM. RFID tags are attached to building components, safety measures, facilities, and other objects that need to be tracked. During construction, data of RFID tags are collected using handheld/fixed receivers and then transferred wirelessly to the office without interrupting the construction activities. The dashed lines in the figure indicate the wireless data transferring. Data collected from the RFID readers are transferred wirelessly through GPRS the server in the office, considering the availability of other techniques, e.g., Wi-Fi may not be available on a construction site. Location of the RFID tags are calculated based on the RSSI value collected from the reader. Then, RFID tags are registered/represented in the BIM as temporary or permanent objects depending on the requirements of safety management system (SMS) and facilities management system (FMS). Location information together with other data stored in the tags are read and saved in the BIM database. By regularly updating the BIM model, other management systems can be developed, for example, construction management system (CMS) can use the information to monitor the progress of the construction; As indicated previously, this paper is trying to investigate the spatial issues while linking RFID and BIM; therefore, building a network of tags in 3D space in the physical building under construction and reflecting the network in BIM is the main topic that is investigated in the present paper.

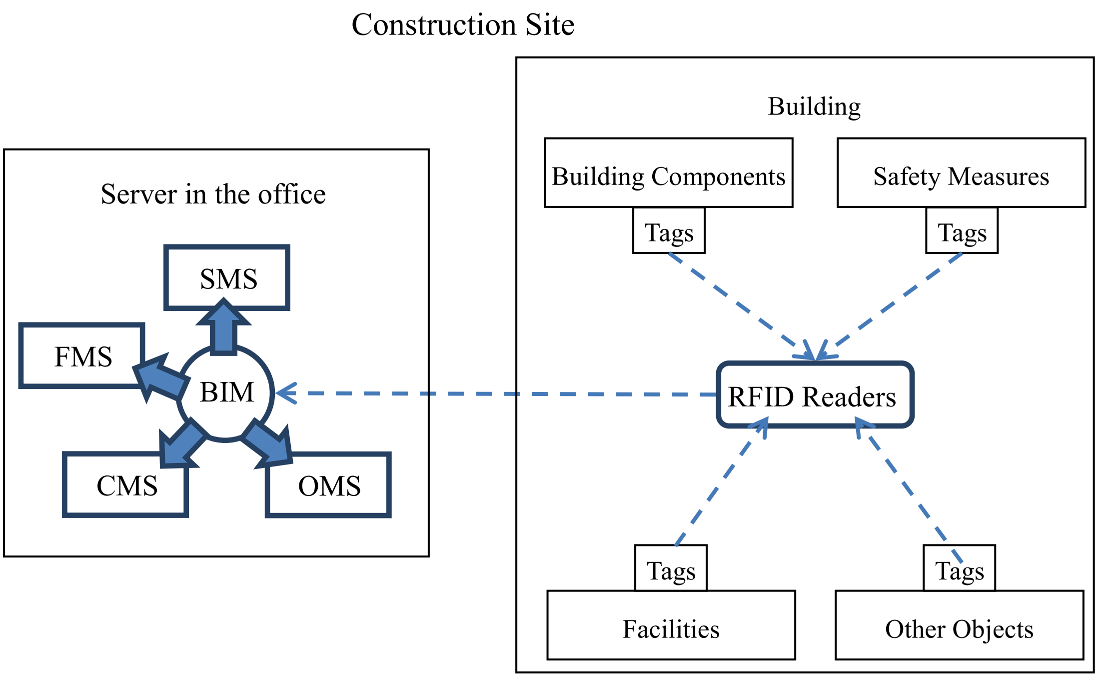


Fig. 1: Conceptual design of integration of RFID and BIM

3.1 Define space-related requirements for safety and facilities management

First of all, the requirements from safety and facilities management should be investigated. For facilities management, tags may be available before transported to construction site. For those tags, information should be collected and tags should be registered in the BIM immediately after the installation. After that, an updating of the tag network should be applied to reflect the changes. Other than those existing tags, careful design should be applied to build a network to facilitate localization. It is ideal to tag all the components to build a complete database; however, this will result in a huge number of tags in the building, and may increase the difficulty in managing scattered data in a centralized database. In order to have a cost-effective system, tags will be attached to components that have distinguished spatial characteristics and cost-effectiveness should be taken into consideration. For example, the scale of the project, types and values of the components will be considered (Motamedi and Hammad, 2009). Therefore, hierarchy is defined to build an effective network according to level of details required. A primary network is built with tags with known locations accurately. Coordinates of those tags are designed for major building structures, for example, major columns. A secondary network is built to indicate the space divisions once the building is under operation, for example, doors and windows. A third level network is built to indicate the facilities in the building, for example, fire extinguishers, and other fixed assets. Information written in those tags should include tag ID, name of objects attached, location, which is different based on different levels, etc. For a primary network, coordinates should be provided; for a secondary network, room number is enough to identify the location of the tag; other descriptions, such as ‘near room X’, can be used to define the location of tags in the third level network.

For safety management, construction safety code should be reviewed and risks with spatial aspects will be extracted and to be represented in BIM. The main category includes protection against falling, scaffolding, confined spaces, electricity safety work zones, and heavy machinery safety work zones (Hammad et al., 2012).

Tags are attached in a way that the height, length or/and width of those safety measures can be calculated based on the number of tags and the data stored in the tags. For example, fixed interval is predefined as 5 m for tags attached to guard rails, and the height of the guardrail is saved in the tag's memory.

3.2 Location design of permanent and temporary tags

Visibility and effectiveness should be considered when deciding the location of tags. Permanent tags are designed in a way to facilitate a long-term data collection purpose for facility management. As described in the previous subsection, three levels of networks will be built to tag different objects. The whole network is built following the progress of the building, which means the network will be partially built during the construction and updating is needed to reflect the real situation on site. Therefore, it is important to ensure there are enough tagged objects to make the network function properly. The simplest way is always have at least four primary tags in the partial network; thus, the approximate location of other tags can be estimated by using trilateration.

In addition, tags should be visible to the reader/receiver in the case of fixed readers/receivers are used. Tests should be applied to the RFID system that is selected for the construction project to investigate the range of the reader/receiver and the visibility of tags. A range test is discussed in Subsection 5.1. A tag's location can be decided using trilateration based on four tags with known location. However, due to the approximate location that RFID system can provide, accurate localization is not feasible. Therefore, buffers will be used to identify the locations of tags according to the properties of the RFID system used in the construction site.

3.3 Define and identify space in BIM model

Space identification is important for safety and facilities management. In a BIM model, space will be classified into two major groups; one is workspaces during construction, while the other is based on the functioning areas of the building. Those two spaces are interrelated but will be defined in a different way. During design stage, space in a BIM model can be created in different ways depending either on the functions available in software tools or designers' habit. Zones, rooms, spaces, are defined differently with various tools or convention. The essential is that the designer should bear in mind the rules for creating spaces that can facilitate the data retrieving from a designed model. Other than the functioning areas, space during construction is also important for safety management. The most vital risk on construction site is falling (Huang and Hinze, 2003). Therefore, openings on the slab, the walls, and the roof are drawing the attention of the authors of this paper. To automatically identify risks related to falling, how to extract the location information of the openings created in the BIM model should be investigated. For example, the coordinates of the bottom left and the upper right corners should be identified automatically.

During construction, workspace identification is applied for each construction task. Work breakdown structure (WBS) is used to create the hierarchy of the tasks and subtasks of the construction project. Each WBS deliverable is associated with a reference object, which can be building components including Mechanical, Electrical and Plumbing (MEP) components, and temporary structures. For example, for installing HVAC ducts in a room, the sections of ducts are identified as reference objects, which will be tagged ideally. The length, height from the floor, and the location of a section is retrieved from the BIM model. The installation task is further divided into subtasks, such as fixing the studs to the ceiling for hanging the ducts. In this case, a scissor lift may be used to help the worker reach the ceiling. Thus, the workspace of the ducts installation task is defined based on the reference object (section of ducts), and dimension of the scissor lift, for that specific task duration. The height of the workspace is equal to the maximum reaching height of the worker, which is the height of the room. A buffer is added around these dimensions to create a box-shaped workspace for the subtask. After the workspace is identified, automatically risk assessment can be applied.

3.4 Automatic risk assessment of space

Schedule will be linked with each construction task. Time intervals will be decided to generate workspaces and risk assessment will be applied to those workspaces. The assessment will be done for the whole building in a backward direction opposing to the building procedure. A basic assumption can be made is that once the building is built and ready for operation, risks will be reduced to 0. At the beginning of the stage, which means a completed building, an initial risk level 0 will be assigned to each workspace, either can be a room, a zone, or the workspace based on WBS. Rules are developed to evaluate the risk of each workspace. If the walls of a room are partially built at a specific time, risk level will be decided based on the ratio of completeness. For example, if an exterior wall exists in the area and only 20% is built, which results in a wall with a height of 60 cm. By comparing this value with the safety code, a physical fence should be installed to prevent falling risks. Therefore, the risk level of that workspace will be increased to 10. Similar rules can be developed to evaluate the risk level of associated spaces with openings that falling may happen. For example, the lower left and the upper right coordinates of an opening can be found and will be used for defining a buffer for detecting safety measures. Based on a predefined time interval, risk level of each workspace can be evaluated based on information extracted from the safety code (Hammad et al., 2012). This assessment result is acted as an input during construction stage. Location information of tags are collected and used for updating the BIM model. If tags are detected in a workspace indicating that a guardrail is installed around that area, the risk-level of that space will be reduced to 5. Otherwise, a warning will be sent to remind installing safety measures. A flow chart is shown in Fig. 2.

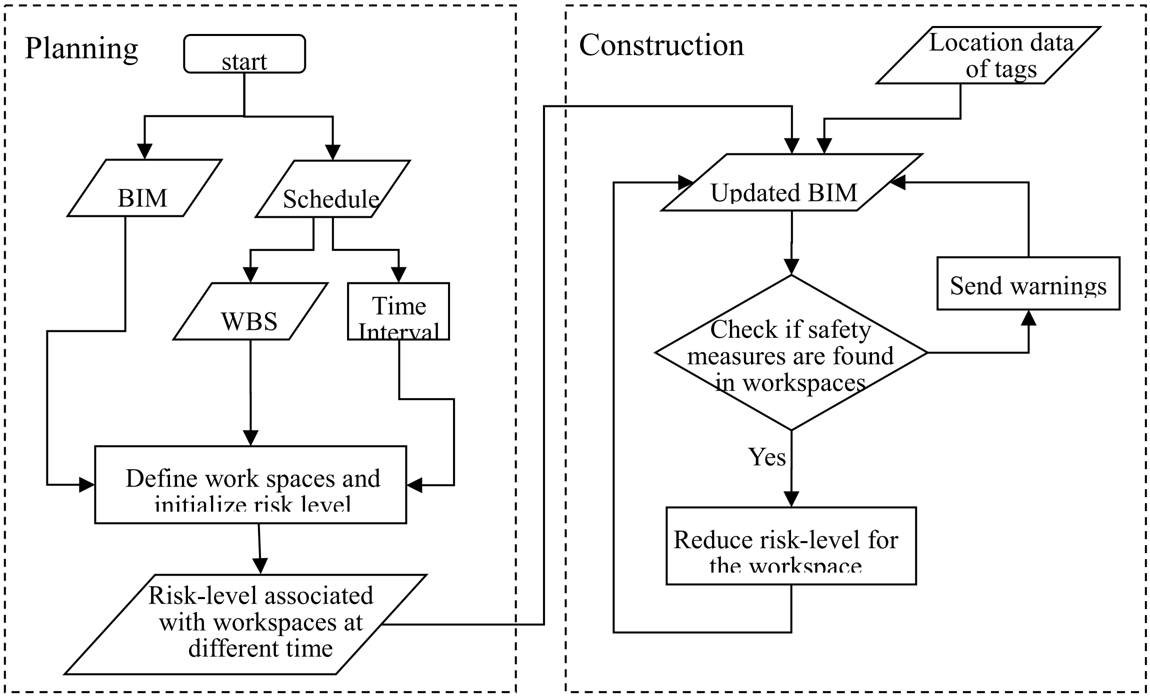
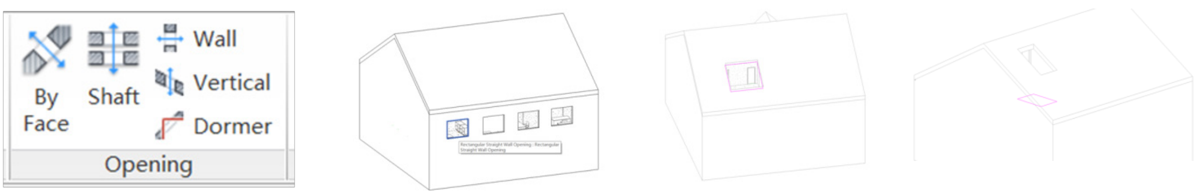


Fig. 2: Flow chart of automatic risk-assessment

4. IMPLEMENTATION

Revit from Autodesk is specially developed for building information modeling, as a BIM authoring 3D design tool. To be more productive, it is preferable to start the Revit model based on a 2D drawing. Revit provides importing CAD or linking CAD option to relate CAD and the difference is whether the Revit model will automatically reflect changes to original CAD file. In Revit, any enclosed spaces can be defined as rooms and the most common room boundaries are walls, doors and room separate lines. Each wall added in the model defines a room boundary by default. Room separate lines are imaginary lines but visible in view to add and adjust room boundaries. In addition, rooms are phase-specific, which means the function of space varies with reference to phases.



(a) (b) (c) (d)

Fig. 3: Creating openings using functions available in Revit

There are several functions available in Revit to create openings vertically or perpendicular to the surface, as shown in Fig. 3(a). 'By Face' means creating an opening perpendicular to the selected face (Fig. 3(c)) while 'Vertical' means creating an opening perpendicular to a level (Fig. 3(d)). 'Wall' is specified to cut a rectangular opening in a straight or curved wall (Fig. 3(b)). If designers want to cut round or other shapes openings in the wall, they need to edit the profile of a wall. 'Dormer' is a combination of vertical and horizontal cuts for dormer openings. In addition, 'Shaft' creates a shaft opening, which is normally more than two floors, by defining a subterranean level and a penthouse level, as shown in Fig. 4. Each opening created by those functions is allocated a unique ID and the location of the opening can be represented by coordinates of lower left point and upper right point assuming the opening is a rectangle parallel to x, and y axis of the coordinate system. If the opening is irregular, it is recommended that placing some small generic models at the critical corner of the space to represent the location. Plug-in is developed to search the openings on the walls, floors, and other structures, and safety measures are generated accordingly. A flowchart is shown in Fig. 5.

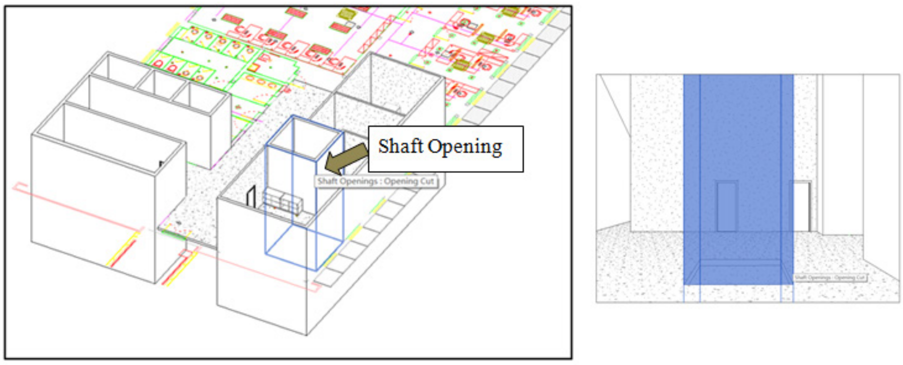


Fig. 4: Creating a shaft opening for elevator space

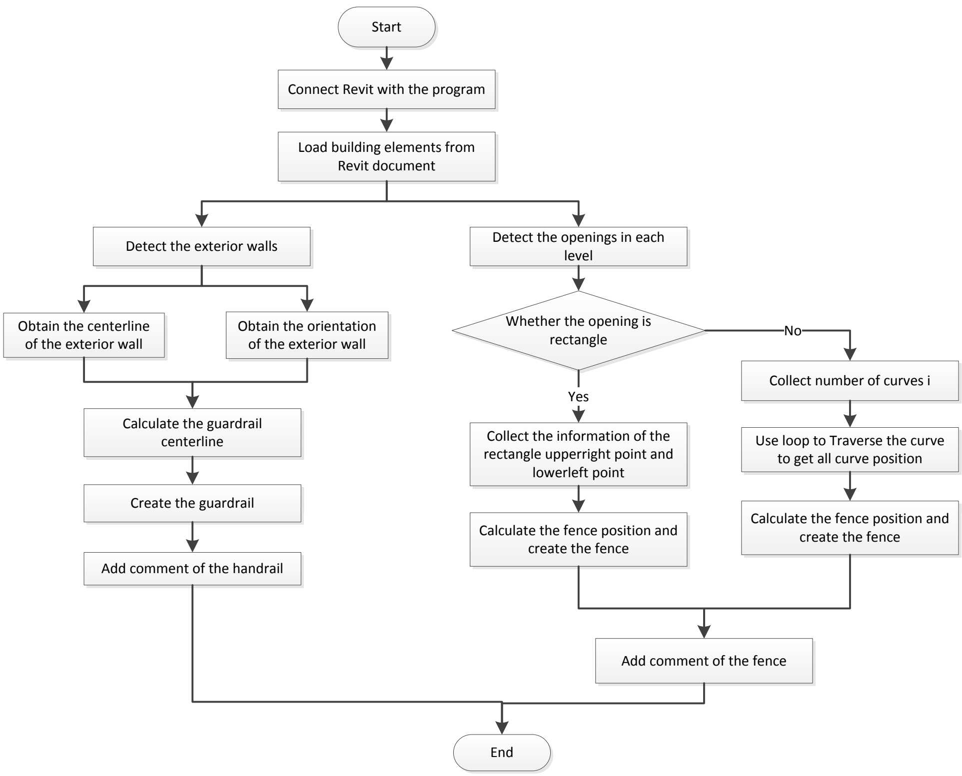


Fig. 5: Flowchart of opening detection

Revit API filter is used to search components, e.g., exterior walls and openings. If an exterior wall is found, the centerline and the orientation of the exterior wall are obtained. Based on that information, guardrail is created accordingly with some offset to the exterior wall (Fig. 6(a)). It should be noted that exterior walls usually extend along several floors; therefore, extra judgment is made to create guardrails on different levels. At the same time, openings are detected on each level, either on the floors or on the exterior walls. If an opening is found, relative information is obtained, such as the lower left and the upper right points, or the curve numbers. Fences are created around the openings (Fig.6 (b) and (c)) based on information obtained from the BIM model. The newly created objects, guardrails and fences, are created as new Family, which can store information in the Property, which includes host of the object, the level, the reference object, etc.

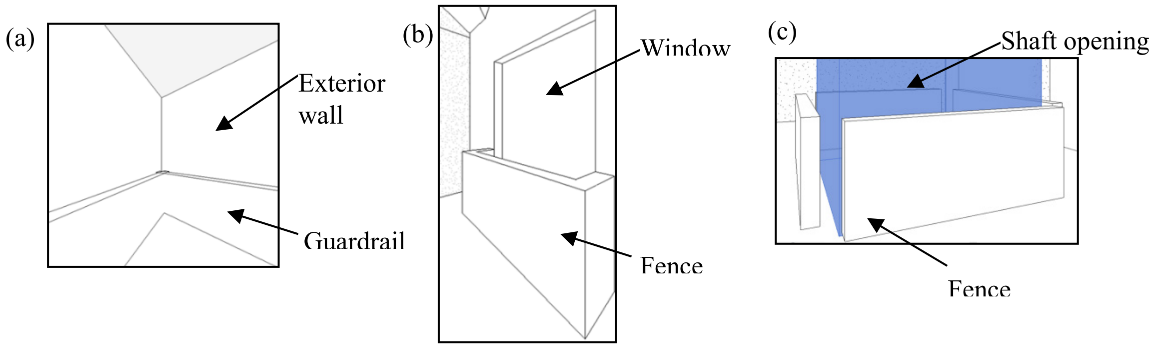


Fig. 6: Guardrails and fences created for exterior walls and openings

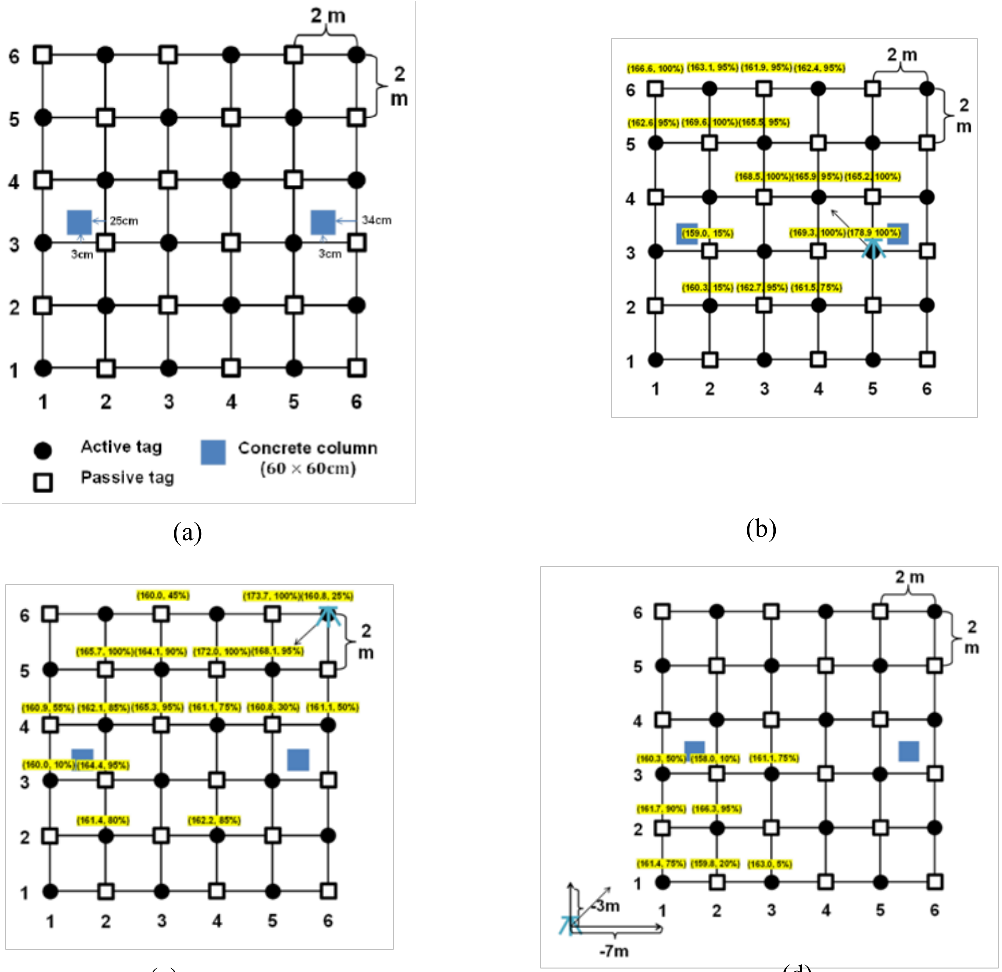
A 2.4G Hz RFID system is selected to be tested in this research. Passive and active tags are both used to test the visibility and effectiveness. Locations of tags are calculated by trilateration based on at least four tags with accurate location information. Distances between tags are decided according to the Received Signal Strength Index (RSSI). Due to the limitation of the accuracy that RFID system can provide, approximate location of tag is used to check the completeness of structures and the installation of safety measures. However, information stored in RFID tags can somehow compensate the inaccuracy of locations. By retrieving the name of the object that the tag is attached, for example, guardrails, reliability is increased for risk assessment for the workspaces. Plug-ins are developed to load data collected from the RFID tags into BIM and to create corresponding tags in the model to build the proposed hierarchical network. The major steps are described as follows:

(1) Initialization of the tag network: fixed readers are installed on site, several tags are attached to permanent structure with measured distances, and the locations of those tags are calculated. Tags with known locations are represented in the BIM model; (2) Fixed/handheld readers will continuously collect readings from all RFID tags within the range to obtain the tag ID, RSSI, and the pre-written data, such as the reference object (guardrails, safety net, etc.). Data read are saved in a text file and sent to the server through GPRS; (3) The approximate locations of tags are calculated based on the RSSI values. Other information obtained from the tags is also taken into account to analyze the possible locations of the host of the tags. For example, by analyzing the density of tags in an area, approximate length of the guardrails can be estimated. Tags with buffers are represented in the BIM model; (4) The tags together with the structure models are export to Navisworks, which is a powerful tool for 4D simulation and conflict detection. By integrating the schedule, the current situation of the building is known by assuming that there is no big difference between the as-planned and as-built models. Plug-in is developed to incorporate rules to evaluate the risks of the space in the BIM model.

5. CASE STUDY

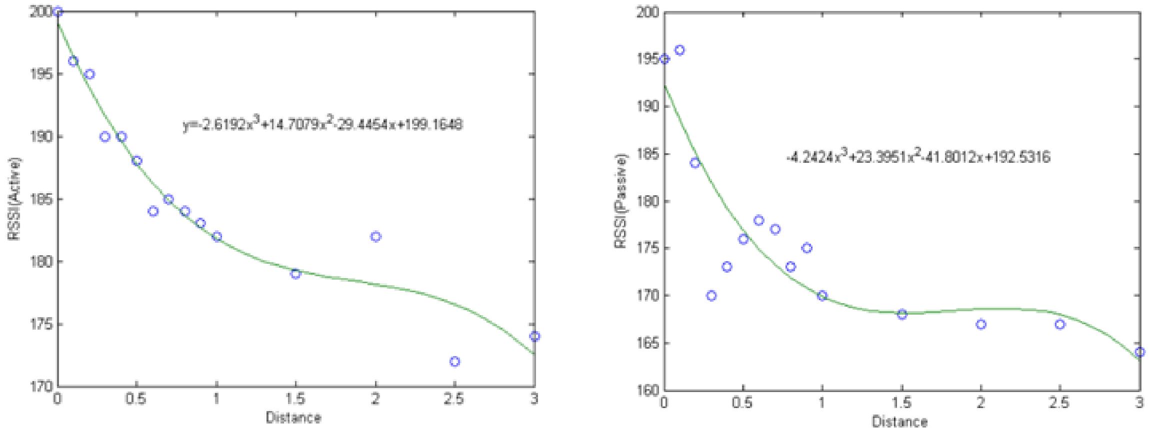
5.1 RFID Tests

A fixed reader ($1,250) is used to collect data from 18 passive tags ($10) and 18 active tags ($10), which are placed to form a 6×6 grid, with a 2-meter gap between two tags, as shown in Fig. 7(a). Two concrete columns are within the area. The fixed reader is placed at different locations and orientations to test the visibility of the tags (Fig. 7(b) (c) (d)). Data are collected for duration of 10 min with a reading interval of 30 seconds. The visibility of each tag is highlighted in the three cases, which indicates a direct line-of-sight is essential for a good visibility. Relationship between the distance and the RSSI is investigated, as shown in Fig. 8. Active tags have a more steady relationship than that of passive tags. Within a range of 1.5 meters, distance can be described in a good accuracy.



(a) (b) (c) (d)

Fig. 7: Tag grid for visibility test

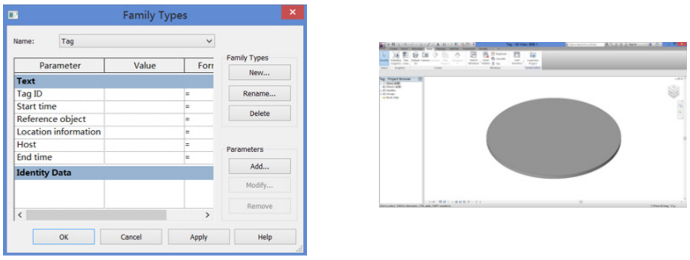


(a) Active tags (b) Passive tags

Fig. 8: Approximate relationship between RSSI and distance

5.2 BIM with Tags

A new object family is created to represent tags in the BIM model, as shown in Fig. 9(a). Tag ID, Location, Reference object, Host, etc. are stored in the property. Those data can be updated automatically or modified manually based on different user requirements. Fig. 9(b) shows the shape used for tag representation in the BIM model. Each RFID read-and-write (RW) tag can store 4KB data, where information including the tag ID, reference objects, etc., can be written to the memory at any stage of the construction. That information will be read and saved to the *Property* of each tag after the tag is detected on site. In addition, once the information in the *Property* of each tag is updated, the same information can be written to the memory of the RFID tag as well.



(a) (b)

Fig. 9: Tag registration in BIM

6. DISCUSSION

This paper describes an approach for building a spatial network by integrating RFID and BIM. Details are shown in the methodology of how to define spatial requirements for safety and facilities management, how to design permanent and temporary tags, how to define and identify space in BIM model, and how to automatically assess risks associated with workspaces. Some lab tests have been done to investigate the property of the RFID system selected for this research. However, more work should be done in the near future to get more solid linkage between RFID and BIM. A case study applied to real construction should be also carried out to investigate the feasibility, the scale, and the cost of the proposed approach.

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