논문 19-44-10-16 The Journal of Korean Institute of Communications and Information Sciences '19-10 Vol.44 No.10
https://doi.org/10.7840/kics.2019.44.10.1892

An Information Model and System for Fire Management Based on Integration of Fire Safety and Spatial Information

Hyesun Lee◆, Sang Gi Hong*, Hakjune Lee*, Kang Bok Lee*

ABSTRACT

As urban structures become larger, higher, and more complex, utilizing high-precision spatial information in fire management is necessary to provide efficient countermeasures for urban safety. In this paper, a convergence model for integrating both fire safety and spatial information is defined addressing the following research problems: utilization of indoor spatial information as well as outdoor information; provision of various types of fire safety information; integration of fire safety and spatial information; and formalization of the integrated information. Also, a platform and systems for creating, managing and distributing convergence information based on the proposed model are presented. This is remarkable work to provide fire management based on the convergence model of fire safety and indoor/outdoor spatial information. Prototypes of the proposed platform and systems were implemented and tested with real data to validate the proposed approach. The validation results demonstrated that the proposed model has sufficient expressiveness to specify various types of fire safety and spatial information and has applicability to be utilized in urban fire management.

Key Words : firefighting activity convergence information, fire safety information, spatial information, fire management, firefighting activity support services

Ⅰ. Introduction

The need for utilizing spatial information of urban structures in fire management has been increased recently. As urban structures become larger, higher, and more complex, management of fire safety becomes more difficult and damage to lives and property becomes greater. Providing efficient countermeasures using both high-precision spatial information and various fire safety information (e.g., fire safety facilities and emergency exit routes) is necessary to respond to fires quickly and effectively[1].

There have been active researches on disaster management using spatial information. The outdoor geographic data and geographic information systems (GISs) were widely used for various disaster management activities such as disaster monitoring, simulation[2], forecasting and estimation[3,4], pattern analysis[5], and decision support[6]. The methods to gather and construct geographic information[7-9] and frameworks to provide various spatial data for disaster management[10] were proposed. However, most of the existing researches used mostly outdoor spatial information, not or less considering indoor spatial information. Also, providing a united model for integrating various viewpoints of spatial and safety-related information is rarely discussed.

Recently, there have been attempts to use indoor spatial information in disaster management in cities.

※ This research was supported by a grant (19DRMS-B146826-02) from Development of Customized Contents Provision Technology for Realistic Disaster Management Based on Spatial Information Program funded by Ministry of the Interior and Safety of Korean government.
◆ First and Corresponding Author : Electronics and Telecommunications Research Institute, hyesun.lee@etri.re.kr, 정회원
* Electronics and Telecommunications Research Institute, sghong@etri.re.kr, 정회원; hakzoon@etri.re.kr; kblee@etri.re.kr
논문번호 : 201908-163-C-RU, Received August 20, 2019; Revised September 1, 2019; Accepted September 1, 2019

Systems providing indoor maps and location to firefighters were proposed[11,12], but they visualized only basic spatial information using two-dimensional plane maps and fire safety-related information such as firefighting facilities was rarely considered.

In Korea, the government has constructed and provided spatial information of major urban structures[13], and there have been attempts to utilize spatial information for national safety, such as the fire safety map of Seoul and the life safety map of the Ministry of the Interior and Safety[14]. However, they are still in an initial stage, and indoor spatial information for fire management is still very limited.

The following problems should be addressed for effective urban fire management based on both spatial and safety information.

1) Utilization of indoor spatial information as well as outdoor information. To cope with large-scale fires and complex disasters in cities, indoor spatial information, as well as outdoor information, is necessary for quick response, rescue, and evacuation in urban structures.

2) Provision of various types of safety information. To support various disaster management activities such as prevention, investigation, response, etc., various types of safety-related information (e.g., fire inspection information, fire safety facilities, emergency exit routes, and firefighting activity plans) should be constructed and provided.

3) Integration of safety and spatial information. For the practical usage of safety and spatial information in disaster management, various types of safety and spatial information should be specified, managed, and distributed as a single integrated model.

4) Formalization of the integrated information model. For automatic analysis and verification of safety and spatial integrated information, the information model should be defined formally.

To address these challenges, a *firefighting activity convergence information model* that integrates safety information and indoor/outdoor spatial information is formally defined in this paper. The model especially focuses on fire management including various firefighting activities (e.g., fire prevention, fire suppression, rescue, etc.) and can be further extended to include other types of disasters. Based on the model, a platform and systems to construct, manage, and utilize convergence information for fire management are also proposed in this paper.

This paper is organized as follows. The related work is discussed in Section **II** and the proposed model is described in Section **III**. The platform and systems based on the model are presented in Section **IV** and the implementation and validation of the approach are explained in Section **V**. Section **VI** provides conclusions and future work.

Ⅱ. Related Work

As mentioned in Section **I** (Introduction), there have been active researches on utilizing outdoor geographic information in disaster management[2-6]. Van Der Knijff *et al.*[2] presented a spatially distributed LISFLOOD model for simulation of hydrological processes in large European river basins. Sun *et al.*[3] proposed an integrated GIS-based tool to estimate side effects related to the earthquake hazards in an area of Gyeongju, Korea. Poser and Dransch[4] used volunteered geographic information for rapid flood damage estimation. Pew and Larsen[5] examined spatial and temporal patterns of human-caused wildfires in a temperate rainforest of Vancouver Island and concluded that spatial variation in their occurrence could be used to delimit fire management zones. De Silva and Eglese[6] presented a prototype of a spatial decision support system for contingency planning for emergency evacuations.

In addition to these researches, methods to construct, discover and provide relevant geographic information for disaster management have been studied[7-10]. Goodchild and Glennon[7] and Zook *et al.*[8] described methods and case studies about utilizing volunteered geographic information in disaster management. Klien *et al.*[9] provided an ontology-based method to discover suitable information in an open and distributed environment of geographic information web services. Mansourian *et al.*[10] proposed a Spatial Data Infrastructure model and its implementation, which is a framework for a web-based system for facilitating disaster management.

However, these researches explained so far mostly focused on outdoor spatial information and outdoor disasters. As the need for disaster management in urban areas increased, methods to construct and utilize indoor spatial information of urban structures have been increased. In this context, there have been studies on constructing and utilizing high-precision indoor spatial information for disaster management.

To define indoor spatial information, information formats such as CAD, BIM, and CityGML[15] have been widely used. For integrating indoor spatial information with other aspects of information (such as facilities and sensors), some papers proposed new models extending existing spatial information models[16,17]. Isikdag *et al.*[16] proposed a new BIM-based model which provides detailed semantic information for indoor navigation. Becker *et al.*[17] presented a conceptual framework for a multi-layer space-event representation which can be used for route planning, localization and tracking within an indoor navigation system.

The concepts of these methods[16,17] are somewhat similar to ours, as our proposing model integrates spatial information with other aspects of information and has a multi-layered shape. However, our model is defined specifically for fire management; it can sufficiently specify various types of fire safety information and integrate them with spatial information by creating mappings (Details are explained in Section **III**).

Recently, methods and systems for indoor disaster management using indoor spatial information have been presented[11,12]. Rueppel and Stuebbe[11] presented a BIM-based indoor emergency navigation system to support rescuers in finding the shortest and fastest route in a building. BIM data was exported via Green Building XML to display plans on mobile devices and generate routing networks including route calculation. A multi-method-approach (combining wireless LAN, RFID, and UWB RTLS) was used for positioning of rescuers. Lee *et al.*[12] proposed a flexible system reference architecture for developing systems for supporting firefighting and rescue in the scene of an indoor and outdoor fire. As an application, they presented systems and intelligent services to support firefighters in the scene of an indoor fire where communication infrastructure was not available[18]. In the application, indoor positioning (using IMU and UWB sensors) and indoor maps were used to provide firefighters with current positions and routes.

These researches[11,12] provided useful indoor spatial information and positioning information to firefighters. However, they visualized only basic spatial information using two-dimensional plane maps and providing safety information (such as firefighting facilities, emergency exit routes, and firefighting activity plans) was rarely considered. For more effective disaster management, not only spatial information but also essential safety information needs to be provided.

Some recent studies proposed models integrating spatial and safety information[18,19]. Tang and Ren[18] proposed an indoor fire evacuation model which represents interacting essential variables (i.e., building environments, occupants, and combustion products) and used GIS technology to analyze the distributions of the essential variables and support the modeling of human-fire interactions (e.g., human evacuation behaviors and fire gas hazards). Their model includes both spatial information and safety information (such as human distribution, fire spread, and smoke concentration) required for fire evacuation simulation. Tashakkori *et al.*[19] proposed an Indoor Emergency Spatial Model based on the Industry Foundation Classes (IFC) standard. This model integrates 3D indoor architectural and semantic information with outdoor geographical information to improve situational awareness about both interiors of buildings and their interactions with outdoor components. The model includes safety information such as fire utilities, environment detectors, and emergency utilities.

These two studies[18,19] are meaningful attempts to provide disaster management based on an integrated model of safety and spatial information. However, safety information they considered was restricted to specific fire management activities. To support various fire management activities, diverse types of safety information should be considered and reflected in the integration models. The *firefighting activity convergence information model* that we propose in this paper has sufficient expressiveness to specify various types of safety information and is highly flexible to be extended to include new types of information. The proposing model is described in the following section.

Ⅲ. Firefighting Activity Convergence Information Model

The *firefighting activity convergence information* is defined as a multi-layered model composed of information of various viewpoints required for urban fire management. First of all, each information layer is defined as entities and their relations of the corresponding viewpoint (Definition 1).

Definition 1 - Information (*I*). An information layer defines information of a specific viewpoint and can be defined as a 3-tuple: (*vp*, *E*, *R*):

- *vp*: the viewpoint of the information.
- *E*: a set of entities that specify meaningful concepts related to *vp*. An entity $e \in E$ can be further refined and it has a 3-tuple: (*en*, *et*, *eA*).
  - *en*: the name of the entity.
  - *et*: the type of the entity; the types can vary according to *vp*.
  - *eA*: a set of attributes characterizing the entity; an attribute $a \in eA$ can be defined as the name, the data type, and a value of the attribute.
- *R*: a set of relations between entities in *E*. A relation $r \in R$ can be further refined and it has a 4-tuple: (*rn*, *rt*, *rsp*, *rep*).
  - *rn*: the name of the relation.
  - *rt*: the type of the relation; the types can vary according to *vp*.
  - *rsp*: the starting point of the relation.
  - *rep*: the ending point of the relation.

An information layer that specifies abstract concepts can be composed of more specific information layers that specify more concrete concepts, which is defined in Definition 2.

Definition 2 - Abstract Information (*AI*). An *AI* is the abstract information that inherits *I* (Definition 1) while having *L* specifying a set of information layers.

For example, if an abstract information layer I_1 is composed of specific information layers, I_2 and I_3, then $I_1.L = \{I_2, I_3\}$.

Composition relations between abstract information layers and contained information layers can be defined recursively; That is, an information layer contained in an abstract information layer can also be an abstract information layer which is composed of more specific layers. For example, I_3 in the previous example can also be an abstract information layer which consists of more specific information layers, I_4 and I_5; i.e., $I_3.L = \{I_4, I_5\}$.

The entities and relations of an upper layer composed of some lower layers can be defined by combining entities and relations of the lower layers. That is, if an information layer, I_1 includes an information layer, I_2 (i.e., $I_2 \in I_1.L$), then $I_2.E \subset I_1.E$ and $I_2.R \subset I_1.R$.

The proposed firefighting activity convergence information model consists of two major layers (i.e., *fire safety information* and *spatial information*) and mapping information between them (Fig. 1). The fire safety and spatial information layers are abstract information layers (Definition 2), each of which consists of specific information layers related to the corresponding viewpoints. The mapping information specifies mappings between entities in the fire safety information and those in spatial information. Details of each information are explained as follows.

The *fire safety information* consists of various viewpoints related to fire management. For example, the information is composed of firefighting activity

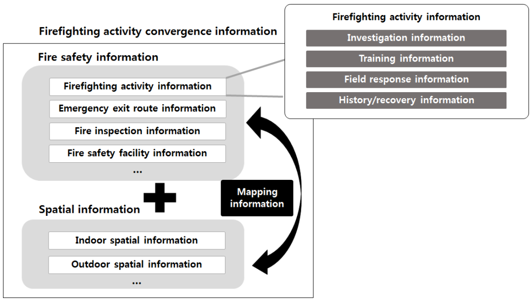


Fig. 1. The concept of the firefighting activity convergence information model

information, emergency exit route, fire inspection information, fire safety facilities, etc. Note that, each sub-layer of the information can be composed of more specific layers, recursively. For example, the firefighting activity information can be further refined and consist of investigation, training, field response, and history/recovery information (the right side part in Fig. 1).

The *spatial information* consists of high-precision indoor and outdoor spatial information, and additional viewpoints of information can be flexibly added. Each sub-layer of the spatial information can be composed of more specific layers as well. For example, the outdoor spatial information can consist of ground and underground spatial information.

The *mapping information* specifies mappings between entities in the fire safety information and those in the spatial information. The entities in the fire safety information are mapped to the corresponding entities in the spatial information using location data. For example, assigning location coordinates to an entity of fire safety facility (e.g., extinguisher), the entity is mapped to the corresponding indoor spatial entity (e.g., room). Based on the mapping information, the fire safety and spatial information can be integrated, traced, and updated.

The firefighting activity convergence information model explained so far is formally defined as in Definition 3.

Definition 3 - Firefighting activity convergence information (FCI). An *FCI* can be defined as a 3-tuple: (*FI*, *SI*, *MI*):

- *FI*: the fire safety information. An *FI* is the fire safety information that inherits the abstract information (Definition 2) while having *vp* = *fire safety viewpoint*.
- *SI*: the spatial information. A *SI* is the spatial information that inherits the abstract information (Definition 2) while having *vp* = *spatial viewpoint*.
- *MI*: the mapping information between *FI* and *SI*. A *MI* is a set of binary relations on *FI.E* × *SI.E* and defined as:
  - $\{(e_1, e_2) \mid$ the coordinates of e_1 correspond to $e_2\}$.

Based on the formal definition of the firefighting activity convergence information model, rules for checking *syntactic completeness* and *consistency* of the model can be defined formally. The syntactic completeness checking rules (Definition 4) identify dangling references or any incompleteness in specifications. The consistency checking rules (Definition 5) identify anomalies in composition relations of the model.

Definition 4 - Syntactic completeness. An *FCI* specification is syntactically complete if the following conditions are satisfied:

- Every information layer in *FI* and *SI* must be specified.
- In every information layer specification:
  - The value of *vp* must be unique.
  - *E* has at least one entity.
  - Every entity in *E* and every relation in *R* must be specified and must have a unique name.
  - If there is more than one entity in *E*, every entity in *E* must have at least one relation.
  - For every relation in *R*, *rsp* and *rep* of the relation must be defined in *E*.
  - If the information is abstract, *L* must have at least one information layer and every information layer in *L* must be specified.
- In every mapping information specification:
  - For every mapping relation in *MI*, e_1 of the relation must be defined in *E* of *FI* and e_2 of

the relation must be defined in *E* of *SI*.

Definition 5 - Consistency checking rules for composition relations. A set of composition relations of information layers in an *FCI* specification must satisfy the following conditions:

- Every information layer is not directly contained in more than one abstract information layer.
- There must be no cycle in composition relations.
- For every pair of layers that have a composition relation:
  - The layers must be included in either of *FI* or *SI*.
  - Every entity and relation of the contained (i.e., concrete) information layer must be included in the container (i.e., abstract) information layer.

One of the biggest advantages of the formalism is that the process of checking syntactic completeness and consistency of the model can be automated by implementing the defined checking rules. The detailed definitions of the rules and an automatic tool for rule checking will be introduced in a future paper.

The firefighting activity convergence information model proposed in this section has the following advantages.

- **Applicability.** The model has sufficient expressiveness to specify various types of fire safety and spatial information. Therefore, the model has high applicability to be utilized in various fire management activities. The applicability of the model was validated using real data, which will be explained in Section **V** (Implementation and Validation).
- **Extensibility.** The model is highly flexible to be extended to include new types of fire safety and/or spatial information. If a new type of safety information needs to be added, we can easily define a new information layer in *FI* and create new mapping relation(s) between the inserted layer and *SI*.
- **Automatic analysis and verification.** The formal definitions (Definition 1-3) and checking rules (Definition 4 and 5) enable automatic analysis and verification of the model. This is very important in practical applications, as the variety and size of real information is usually huge and thus manual analysis and verification require impractically high costs.

How to construct, manage, and utilize firefighting activity convergence information based on the proposed model is explained in the following sections.

Ⅳ. Proposed System

Based on the firefighting activity convergence information model defined in the previous section, a platform and systems to construct, manage, distribute, and utilize convergence information are proposed in this section. The proposed platform and systems form a system that consists of three major parts (Fig. 2): *information collection systems*, *firefighting activity convergence information platform*, and *firefighting activity support application services*.

The *information collection systems* (the upper left part in Fig. 2) include systems for collecting and creating each information of various viewpoints. The mandatory systems are safety inspection system, firefighting activity information collection system,

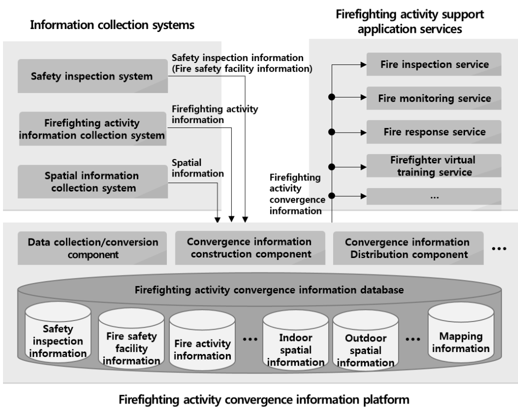


Fig. 2. The overview of the proposed system

and spatial information collection system.

- The *safety inspection system* is hand-held equipment that inspectors use for collecting fire safety inspection information and fire safety facility information of urban structures. Inspection of a building is performed for the first time after the building is constructed and then performed regularly following the law and regulation of a country. After performing inspection, the safety inspection system generates results as a report and sends safety inspection information with fire safety facility information to the platform.
- The *firefighting activity information collection system* collects firefighting activity information from Firefighting Activity Information Card (FAIC) documents[20]. An FAIC contains essential information required for various firefighting activities including inspection, training, response, and recovery. FAIC documents are developed and managed by fire stations. The firefighting activity information collection system creates FAICs by taking inputs from FAIC managers and sends firefighting activity information to the platform when there is any change in FAICs.
- The *spatial information collection system* collects high-precision indoor and outdoor spatial information from the national spatial information platform[13] and the architecture administration information system[21]. The system reads spatial data in BIM or CAD format and converts it to a lightweight spatial format. This format follows the CityGML[15] style, but unlike CityGML it can define objects of points of interests (POIs). Therefore, spatial objects for fire management, such as fire safety facilities (e.g., fire detectors, extinguishers, etc.), can be defined in the spatial information as POI objects. The system creates spatial information, creates and manages POI objects, and sends the information to the platform.

The *firefighting activity convergence information platform* (the lower part in Fig. 2) is the core part that constructs firefighting activity convergence information based on the proposed model (Section **III**) by integrating various fire safety and spatial information from the information collection systems. The form of the platform database is defined based on the model described in Section **III**. Information of various viewpoints (e.g., various fire safety information such as safety inspection information and firefighting activity information; and various spatial information such as indoor and outdoor spatial information) is stored in separate tables, respectively. The mapping information between fire safety and spatial information is stored and managed in a separate table. The detailed database schemas of the information are described in Section **V** (Implementation and Validation).

The platform continuously manages the constructed convergence information database and updates it if necessary (e.g., when certain information is changed). When updating the database, the syntactic completeness and consistency of the information are automatically checked based on the definitions described in Section **III**. The platform includes components providing basic functionalities such as data collection/conversion, convergence information construction, and convergence information distribution. The platform provides the convergence information to various application services on request via REST API.

The *firefighting activity support application services* (the upper right part in Fig. 2) are customized services that provide useful functionalities based on the firefighting activity convergence information in order to support specific fire management activities. Each of these services obtains the entire or a part of firefighting activity convergence information from the platform according to the needs and provides useful features for a specific firefighting activity. The representative application services are fire inspection, fire monitoring, fire response, and firefighter virtual training service. Application services can be flexibly added to or deleted from the system architecture.

To validate the applicability of the proposed model and systems, we implemented prototypes of the platform and systems and validated them using pre-built fire safety and spatial data. The implementation and validation results are explained in the following section.

V. Implementation and Validation

To validate the proposed method, prototypes of the platform and systems (Section **IV**) were implemented and tested using pre-built data of a test-bed building. The following pre-built data was used.

- A Fire Protection Work Function Checklist for the safety inspection system.
- A Firefighting Activity Information Card (FAIC) for the spatial information collection system.
- BIM and CAD data for the spatial information collection system.

First of all, entities and relationships of the following information were defined: safety inspection information, firefighting activity information, and spatial information.

First, a part of the database schema of safety inspection information is shown in Fig. 3. An InspectionReport object specifies the report resulted by a certain safety inspection. This object is associated with the information of a target building (i.e., TargetObject), the structure of the building (i.e., BuildingStructure), and the inspector of the safety inspection (i.e., Inspector). A set of InspectionCheckList objects specify checklists required for the safety inspection. The required checklists are defined according to the type of inspection report (e.g., Fire Protection Work Function Checklist, Total Detailed Inspection Checklist, etc.). A set of Facility objects represent fire safety facilities located in the building. Every safety facility should be tested in the safety inspection, thus a Facility object has an associated InspectionCheckList object(s). If any problem is identified in the inspection, a Problem object(s) is defined by specifying problem details and countermeasures.

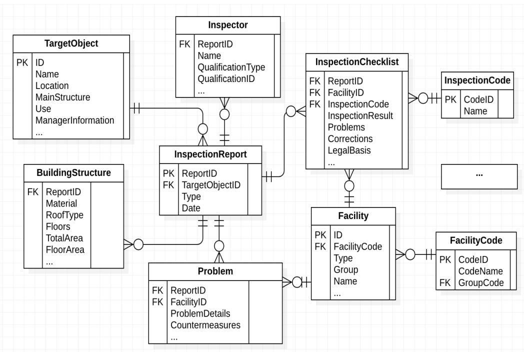


Fig. 3. A database schema of safety inspection information

Fig. 4 represents a part of the database schema of firefighting activity information. A FirefightingActivityInformationCard object defines a specific FAIC card. The FAIC contains information of general building condition, firefighting activity plans, firefighting activity results, and fire facility status. The FirefightingActivityPlans specifies surrounding environments of the target building, fire suppression plan, rescue/evacuation plan, firefighter organization, etc. The FirefightingActivityResults includes results of various firefighting activities such as FireInspectionResults, FirefighterTraining, and FireHistory. The FireInspectionResults object specifies a summary of the problem and correction history of safety inspection. The FirefighterTraining object and the FireHistory object define a summary of training history and fire occurrence history, respectively. The FireFacilityStatus represents a number of fire safety facilities on each floor for each type. The StatusDetail object of the FireFacilityStatus describes detailed status information of a corresponding fire safety facility.

A part of the database schema of spatial information is depicted in Fig. 5. The spatial information contains essential objects, such as Level, Door, Wall, Space, etc., required to define indoor space. As explained in Section **IV**, the format of the spatial information follows the CityGML style, but unlike CityGML it can define objects of points of interests (POIs). Objects related to fire management such as fire safety facilities can be defined as POI

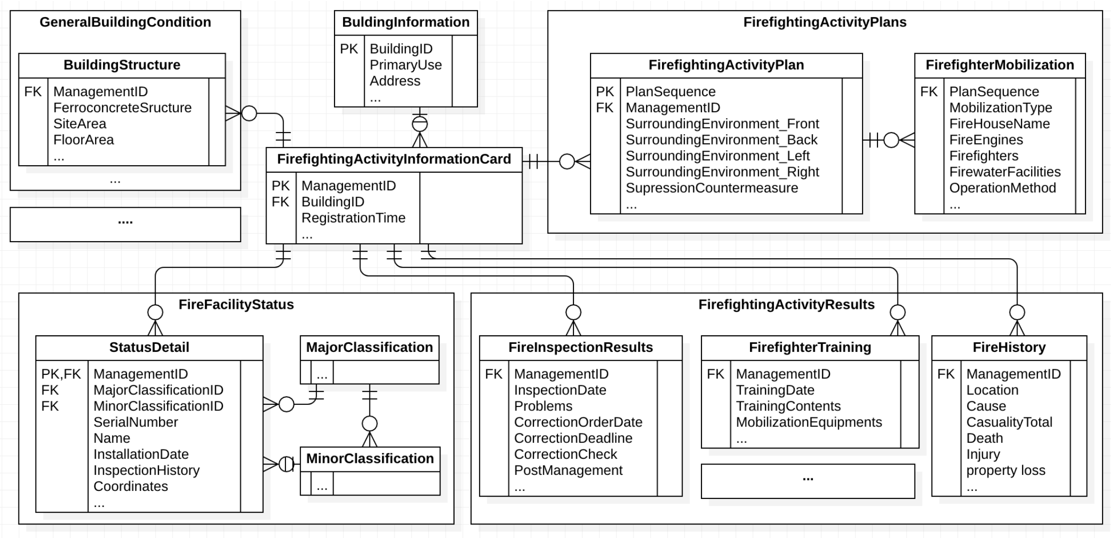


Fig. 4. A database schema of firefighting activity information

objects in Fig. 5. Each POI object has location information (e.g., X, Y, and LevelID) as attributes.

The prototypes of the information collection systems (except the safety inspection system) took input data explained earlier, converted the inputs to the corresponding formats (following database schemas described so far), and provided them to the firefighting activity convergence information platform. As the safety inspection system is currently being developed, instead of applying the safety inspection system, the pre-built data of an FAIC was directly provided to the platform.

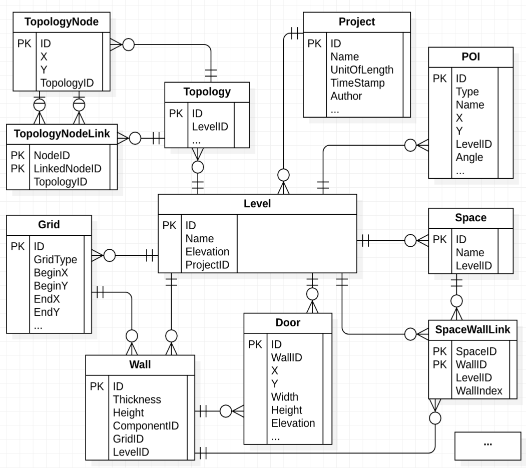


Fig. 5. A database schema of spatial information

The database of the firefighting activity convergence information platform was constructed following the database schemas of safety inspection information (Fig. 3), that of firefighting activity information (Fig. 4), and that of spatial information (Fig. 5). Taking the various input data (i.e., safety inspection, firefighting activity, and spatial information) from the prototypes of the information collection systems, the platform constructed the information of various viewpoints in the internal database and created and managed the composition relations of information layers. The platform also created and managed mapping information between safety and spatial information. For example, a Facility entity in the safety inspection information (Fig. 3) and a StatusDetail entity of FireFacilityStatus in the firefighting activity information (Fig. 4) can be mapped to a corresponding POI entity in the spatial information (Fig. 5). This mapping can be created using the name and the coordinates of the entities for the fire safety facility. The platform distributed the constructed firefighting activity convergence information to firefighting activity support application services via REST API.

Among the application services, a prototype of the fire response service was partially developed and validated using a portion of the firefighting activity convergence information. The prototype retrieved the indoor spatial information of the firefighting activity convergence information and visualized a two-dimensional plane map of a building. The prototype is currently being further developed to retrieve and visualize fire response route information and firefighting facility information as well as indoor spatial information. We are also implementing prototypes of other types of firefighting activity support application services to demonstrate the utility of the constructed convergence information.

The implementation and validation results demonstrated that the proposed firefighting activity convergence information model has sufficient expressiveness to specify various types of fire safety and spatial information. The various pre-built data on fire safety and spatial information was successfully constructed in the database based on the proposed model. In addition, the applicability of the platform and systems was validated. The process of obtaining various fire safety and spatial information and creating and managing firefighting activity convergence information was successfully demonstrated using the prototypes of the platform and systems. Also, the process of utilizing the convergence information in application services was partially demonstrated.

Ⅵ. Conclusions

In this paper, a method to provide fire management based on both fire safety and indoor/outdoor spatial information was proposed. The main contributions of the paper are as follows.

1) The provision of firefighting activity convergence information model. The convergence model was defined to address the following challenges: utilization of indoor spatial information as well as outdoor information; provision of various types of fire safety information; integration of fire safety and spatial information; and formalization of the integrated information. The proposed model has high applicability to be utilized for various fire management activities and provides high extensibility to be extended to include new types of fire safety and spatial information. Also, the formal definitions and checking rules for the model enable the development of an automatic tool for analysis and validation.

2) The provision of a platform and systems based on the model. To provide a concrete method for applying the proposed model in fire management, a platform and systems for constructing, managing, and utilizing the firefighting activity convergence information based on the model were presented. The plat- form and systems were designed considering pre-built data (e.g., outdoor and indoor spatial data provided by the national platforms[13,21]) and existing document types (e.g. Fire Protection Work Function Checklist, Firefighting Activity Information Card, etc.) used for specifying fire safety-related information. The detailed inputs, outputs, and functionalities of the platform and systems were described for actual implementation.

3) The implementation and validation of the method. To validate the expressiveness of the proposed model and the applicability of the systems, prototypes of the proposed platform and systems were implemented and tested with real data. The results demonstrated that the proposed information model has sufficient expressiveness to specify various types of fire safety and spatial information. It was also demonstrated that the platform and systems operate properly implementing the proposed concepts and have applicability to be used in fire management.

We are currently developing the entire platform and systems and plan to apply them in test-beds and real buildings. The proposed model and systems will be updated based on feedback. In addition, we have a plan to study the following research items as future works.

1) Automatic recognition and detection of fire safety facilities. The most fire safety inspection is performed fully manually, thus a lot of manual efforts are required for accurate inspection. To address this difficulty, the development of an automatic (or semi-automatic) method to reduce inspection cost and effort is needed. We plan to apply image recognition and detection technology for automatic detection and analysis of fire safety facilities.

2) Indoor positioning of fire safety facilities and firefighters. After automatically detecting fire safety facilities, allocating accurate coordinates to them is a challenging problem. Also, providing accurate positions and navigation routes to firefighters in a building is necessary for efficient firefighting, but it is also a challenging technology. The existing methods that use pre-installed infrastructure are difficult to be used in the scene of a fire, as the infrastructure can be easily damaged or destroyed. To address this challenge, we plan to develop visual-inertial odometry for indoor positioning and use visual-inertial SLAM for error correction.

3) Intelligence services using firefighting activity convergence information. For preemptive fire management, there is a need for intelligent services to infer and provide information required for proactive activities[22]. We plan to develop a service for predicting fire safety facility failures using fire safety inspection history. We also have a plan to develop a decision support service for firefighting, based on standard operating procedures (SOPs).

References

[1] H. Lee, S. G. Hong, H. Lee, and K. B. Lee, "Integration of spatial and disaster management information for supporting effective firefighting activities," in *Proc. 2019 World Congr. Inf. Technol. Appl. and Serv.*, pp. 39-45, Jeju, Korea, Feb. 2019.

[2] J. Van Der Knijff, J. Younis, and A. De Roo, "Lisflood: A GIS-based distributed model for river basin scale water balance and flood simulation," *Int. J. Geogr. Inf. Sci.*, vol. 24, no. 2, pp. 189-212, 2010.

[3] C. G. Sun, S. H. Chun, T. G. Ha, C. K. Chung, and D. S. Kim, "Development and application of a GIS-based tool for earthquake-induced hazard prediction," *Comput. Geotech.*, vol. 35, no. 3, pp. 436-449, May 2008.

[4] K. Poser and D. Dransch, "Volunteered geographic information for disaster management with application to rapid flood damage estimation," *Geomatica*, vol. 64, no. 1, pp. 89-98, 2010.

[5] K. L. Pew and C. P. S. Larsen, "GIS analysis of spatial and temporal patterns of human-caused wildfires in the temperate rain forest of Vancouver Island, Canada," *Forest Ecol. Manag.*, vol. 140, no. 1, pp. 1-18, Jan. 2001.

[6] F. N. De Silva and R. Eglese, "Integrating simulation modelling and GIS: spatial decision support systems for evacuation planning," *J. Oper. Res. Soc.*, vol. 51, no. 4, pp. 423-430, 2000.

[7] M. F. Goodchild and J. A. Glennon, "Crowdsourcing geographic information for disaster response: a research frontier," *Int. J. Digit. Earth*, vol. 3, no. 3, pp. 231-241, Apr. 2010.

[8] M. Zook, M. Graham, T. Shelton, and S. Gorman, "Volunteered geographic information and crowdsourcing disaster relief: A case study of the Haitian earthquake," *World Med Health Policy*, vol. 2, no. 2, pp. 7-33, Jul. 2010.

[9] E. Klien, M. Lutz, and W. Kuhn, "Ontology-based discovery of geographic information services—an application in disaster management," *Comput. Environ. Urban Syst.*, vol. 30, no. 1, pp. 102-123, Jan. 2006.

[10] A. Mansourian, A. Rajabifard, M. V. Zoej, and I. Williamson, "Using SDI and web-based system to facilitate disaster management," *Comput. Geosci.*, vol. 32, no. 3, pp. 303-315, Apr. 2006.

[11] U. Rueppel and K. M. Stuebbe, "BIM-based indoor-emergency-navigation-system for complex buildings," *Tsinghua Sci. Technol.*, vol. 13,

no. S1, pp. 362-367, Oct. 2008.
[12] H. Lee, S. G. Hong, and K. B. Lee, "An internet of things system architecture for aiding firefighters in the scene of disaster," *J. Inf. Process. Syst.*, vol. 14, no. 5, pp. 1286-1292, 2018.
[13] *V-world spatial information open platform*, Ministry of Land, Infrastructure and Transport, Korea. Retrieved Aug. 9, 2019, from http://map.vworld.kr/map/maps.do.
[14] *Life safety map*, Ministry of the Interior and Safety, Retrieved Aug. 9, 2019, from http://safemap.go.kr.
[15] G. Gröger, T. H. Kolbe, A. Czerwinski, and C. Nagel, *OpenGIS® city geography markup language (CityGML) encoding standard, OGC Project Document no. OGC 08-007r1*, ver. 1.0.0, Aug. 2008. Retrieved Aug. 9, 2019, from https://www.opengeospatial.org/standards/ci tygml.
[16] U. Isikdag, S. Zlatanova, and J. Underwood, "A BIM-oriented model for supporting indoor navigation requirements," *Comput. Environ. Urban Syst.*, vol. 41, pp. 112-123, Sep. 2013.
[17] T. Becker, C. Nagel, and T. H. Kolbe, A multilayered space-event model for navigation in indoor spaces, in *3D Geo-information Sci.*, Springer, Berlin, Heidelberg, pp. 61-77, 2009.
[18] F. Tang and A. Ren, "GIS-based 3D evacuation simulation for indoor fire," *Build. Environ.*, vol. 49, pp. 193-202, Mar. 2012.
[19] H. Tashakkori, A. Rajabifard, and M. Kalantari, "A new 3D indoor/outdoor spatial model for indoor emergency response facilitation," *Build. Environ.*, vol. 89, pp. 170-182, Jul. 2015.
[20] *Regulations on firefighting activity investigation*, Legislation, the Office of Legislation, Korea. Retrieved Aug. 9, 2019, from http://www.law.go.kr/LSW/admRulLsInfoP.do?admRulSeq=2100000097438.
[21] *Seumteo architecture administration information system*, Ministry of Land, Infrastructure and Transport, Korea. Retrieved Aug. 9, 2019, from https://www.eais.go.kr.
[22] H. Lee, S. G. Hong, H. Lee, and K. B. Lee, "A firefighting activity information platform and intelligent service framework for customized firefighting activities based on spatial information and fire safety information," in *7th Korean Inst. of Hazardous Materials Conf.*, Busan, Korea, Jul. 2019 (Korean).

Hyesun Lee

She received her Ph.D. degree in Computer Science and Engineering from Pohang University of Science and Technology in 2015. She has been a senior researcher at Electronics and Telecommunications Research Institute (ETRI) since 2015. Her research interests are in the area of software reuse, software product line engineering, and IoT platforms and systems.
[ORCID:0000-0002-8419-8792]

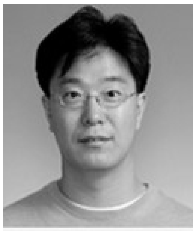
Sang Gi Hong

He received his Ph.D. degree in Electronic Engineering from Chungnam National University in 2013. Since 2001, he has been with ETRI, Daejeon, Rep. of Korea, where he has been working on IT convergence technologies. His current research interests include sensor signal processing and IoT collaborative architecture.
[ORCID:0000-0001-8135-3286]

Hakjune Lee

He received the B.S. and M.S. degrees in electrical and computer engineering from Seoul National University, Seoul, South Korea, in 2014 and 2016, respectively. Since 2016, he has been a researcher with the Electronics and Telecommunications Research Institute, Daejeon, South Korea. His current research interests include electromagnetic wave and deep learning.
[ORCID:0000-0003-0035-8515]

Kang Bok Lee



He completed his Ph.D. course in Information and Communication Engineering from Chungbuk National Univ. in 2002. He was a senior researcher at LG Semicon Co., Ltd. from 1993 to 2000. He has been a Principal researcher at ETRI since 2000. His research interests are in the area of RFID/NFC, ROIC, Bio-signal processing, and IoT sensor application technology.
[ORCID:0000-0001-9508-5577]