City Information Model-Based Damage Estimation in Inundation Condition

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Abstract:

Inundation of city facilities may rise to serious damages such as deaths. The aim of this study was as follows: to present the method that can be configured into city information model based on an open data schema, and to utilize the information for estimating the inundation damages of the city. The data schema for the city information model was selected, which focused on comprehensiveness, interoperability, extensibility, and usability. The city information model contains buildings, bridge structures, road, and terrain models. In addition, the availabilities were examined to estimate the damages by detailed queries and responses using information model data and hydraulic analysis data.

Keywords: Damage Estimation in Inundation Condition, Open Data Schema, City Information Model

1. INTRODUCTION

Structural collapse of infrastructure causes a large catastrophe due to its scale. Though prevention is the most effective countermeasure against a disaster, we should also have a strategic plan that can minimize the damage when a disaster occurs in preparation for an invincible situation. The preceding studies related to disaster prevention strategy include Ryu *et al*. (2010), Yang & Ko (2013), in which the focus is mainly to put on the follow-up actions related to the behavioral procedures for government agencies, and collection of situational information through real-time measurement or monitoring and propagation of the collected information for disaster prevention service. In particular, in the Development of u-Disaster Prevention City Standard Model (CDI, 2008) studied at the government level, only construction of the information delivery system with the focus on information communication was taken into account, excluding the viewpoint of city facility. However, an active strategy for actions following occurrence of actual disaster should be established by analyzing its effects on terrain and structures, and efficient and clear analysis is possible only when an environment is formed where the related information is collected, integrated, and accurately reused in accordance with the object area—the purpose of the structure, *etc*. (Raper, 1989). In the aspect of topographic information, we can consider a method of establishing a disaster prevention strategy by arranging buildings, facilities, etc. on the object area modeled by collecting information through the GPS, aerial photograph, etc., and adding the external attributes required for the intended works. In previous studies regarding this matter, Uitto (1998) presented the basic framework where topographic information can be utilized for city disaster prevention; Herold *et al.* (2005) presented a plan where the Web can be utilized. Later, studies focusing on specific applications were conducted, the examples of which include linkage between the national topographic information system and facility information (Kim *et al*., 2008), landslide simulation, selection of shelters, prediction of flood damage, and selection of escape routes, and, further, a spatial data mining technique to support more effective decision making on the basis of topographic information and a method of grafting a system level disaster prevention model were presented (Kia *et al*., 2012; Vijayaraghavan *et al*., 2012; Tehrany *et al*., 2014). And, the studies on disaster prevention, utilizing Building Information Modeling (BIM), began relatively recently and are largely comprised of the studies related to selection of an evacuation route or a fire extinguishment route when a fire breaks out in a building and the studies related to the guidelines for action through monitoring (Chen *et al*., 2014; Shiau *et al*., 2013). It is also similar in the aspect of building and, in the application examples of utilizing BIM, information management takes place only within a single structure and, as pointed out by Cova (1999), a city model has limitations in the aspect that the relation between object that composes the model should be taken into account without failure.

This study is a follow-up study on the 'Methodology of generating an Open Information Model of City to support Disaster Prevention Work' studied in the past by Park *et al*. (2014) and the 'Building Model Information Management Plan in a Flooding Damage Situation' studied by Song *et al*. (2014) to overcome the mentioned limitations in inundation condition. It presented a process that can simulate the flooding situation by generating and utilizing an information model of which the focus is put on the terrain and the ground part of the buildings of an actual city area. And, the presented process was applied to the city information model to estimate the expected casualty and property damage. Also, the resulting value was reviewed to confirm the possibility to utilize the open information model of city for the establishment of action guidelines in a flood damage situation.

2. CONCEPT OF CITY INFORMATION MODEL GENERATION BASED ON OPEN DATA SCHEMA FOR FLOODING DAMAGE INFORMATION MANAGEMENT

The flood damage information management in the aspect of 3-dimensional city information modeling can be stated to be the core of accurate simulation of each structure that composes a city, and the support to be provided for decision making on the actions utilizing the result of a flood simulation carried out based on this. The simulation of structures that compose a city can vary depending on what information item it is based on. In the aspect of structural shape, the Level of Detail (LoD) of the expression varies depending on what elements of the relevant structure are included. What information item shall be the basis and what elements will be included are decided depending on the purpose of the model utilization. For simulation of a structure through generation of an information model, the reliability of the information linkage with other system, and the information utilization permanency and information compatibility should be taken into account. Storage or reuse of information itself with no loss is directly connected to utilization of the model because the items mentioned earlier can be said to be subordinate to the final utilization purpose of the model. In other words, the information should be generated and managed within the framework of a consistent form from the initial planning stage to the model's utilization to support a model-based decision making in response to flood damage. In the aspect of information flow, regarding the pivotal frame, the thing that plays a significant role in linking and reusing the information generated on the basis of 3-dimensional city information model is the data schema. Data schema is advance determination of how to express a certain information item in the form having certain attributes utilizing an abstract object. In particular, an open information model generated on the basis of an open data schema increases the independency of software and interoperability of information for generation and utilization of model due to its feature that it is in a form where anyone can access the model data. Park *et al.* (2014) compared the features of IFC, LandXML, GML, KML, CityGML and Geo4NIEM such as the comprehensiveness of the city objects, 3-D visualization, extensibility of the required information items or attributes, and modeling supportability of commercial software, in the aspect of support for disaster prevention works, utilizing a city information model, and concluded that among those, the CityGML is the most suitable open data schema. In this study, the city information modeling was carried out also using the CityGML. As to the figuration of terrain model utilizing CityGML, the Triangulated Irregular Network (TIN) method of the thematic module *Relief* was followed in accordance with the method presented by Park *et al.* (2014). In CityGML, the thematic module *LandUse* is provided for the management of information regarding the utilization of terrain and, in this study, it was utilized for allocation of administrative districts and land use information to the units of triangular plane groups in the module *Relief.* A building model is the structure that is directly utilized for calculation of the damage in a flood damage situation, and the thematic module *Building* of CityGML was utilized in accordance with the method presented by Song *et al.* (2014) (Table 1). The open data schema based city information model generated accordingly is as shown in Figure 1.

Table 1. City objects and CityGML module mapping (Park *et al*., 2014)

	Object	CityGML Module	Shape Representation
Land Part	Terrain	*Relife* Module	- Regular Raster - Break Line - TIN - Mass Point
Facility Part	Road	*Transportation* Module (Road Element)	- Surface
	Railway	*Transportation* Module (Railway Element)	
	Bridge	*Bridge* Module	- Curve - Surface - Solid
	Tunnel	*Tunnel* Module	
	Harbor	*Generic* Module	
	Dam/Levee	*Generic* Module	
	Retaining Wall	*Generic* Module	
	Environ. Structure	*Generic* Module	
	Building	*Building* Module	
	City Furniture	*City Furniture* Module	
	Vegetation	*Vegetation* Module	
Water Part	Water	*WaterBody* Module	- Curve - Surface - Solid

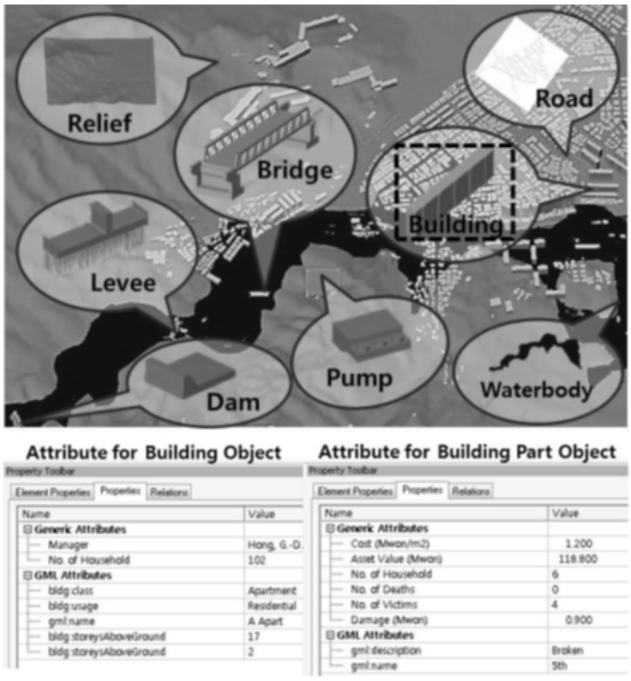

Figure 1. City information model based on open data schema (Park *et al*., 2014)

In this study, for the purpose of supporting decision making on the actions following occurrence of flood damage, the LoD of the building model was set to the level that enables the overall appearance and floor information to be managed. However, as the focus was more on utilizing information model than generating it, there were items that the CityGML elements were unable to provide, for which the thematic module *Generics* of CityGML was applied dividing them into *Task attributes* as explained by Park *et al.* (2014). The terrain model and the building model generated independently from each other were linked utilizing the Terrain Intersection Curve (TIC) method presented by Gröger *et at*. (2012). The TIC method is a concept where the intersection curve along which the terrain plane and the building plane are in contact with each other and is generated on the terrain plane in advance, and the generated building model is aligned to the intersection curve of the terrain model. In this study, the information such as administrative districts managed by the terrain model was linked to the building model in accordance with the TIC. The TIC generated on the terrain plane can contain one or several triangular planes, depending on the size of the triangular planes comprised of TIN which is subordinate to the scale. In this study, if the TIC of one building contains several triangular planes, it is decided that the information item of the triangular plane that accounts for the biggest area shall be considered. The result of flood at the relevant position can be directly drawn through the identifiers of the triangular planes that compose the terrain plane and the points that compose the triangular planes in reference to the terrain plane. In the case of flood damage, internal calculations are required in the process of flood simulation, which is due to the highest flooded floor number of the building and the flood height from the bottom of the building are essentially required.

3. PROCESS OF DRAWING INFORMATION ITEMS FOR CALCULATION OF FLOOD DAMAGE

In this study, the damage caused by flood was calculated for casualties and properties.

As to the casualties, the expected number of the dead and the maximum number of the isolated persons presented by MLIT (2013) were calculated and reflected. This method is comprised of building identifiers, total number of buildings, the population aged 65 or older and the population under 65 in the buildings, the evacuation rate on which the qualitative factors such as weather and local characteristics are reflected, and the mortality of the persons aged 65 or older and that of the persons under 65 affected by the flooded floors. In MLIT (2013), evacuation rates of 0%, 40%, and 80% were proposed, and all the three cases were reflected in this study. The reason why the two factors were separated on the bases of the age of 65 was because the persons aged 65 or older were assumed to evacuate to the highest residential floor of the building during a building flood, while the persons under 65 were assumed to evacuate to the roof of the building. The mortality is divided into flood height of 0 to 1.2 m, 1.2 m to 1.8 m, and 1.8 m and higher, in reference to the evacuation plane, and calculated as 0.00023, 0.12, and 0.9175 respectively. The population of each building required for calculation of casualties was generated in the form accessible through connection of external data as shown in Figure 2, and; as for the mortality, the value was induced by calculating it during the simulation process.

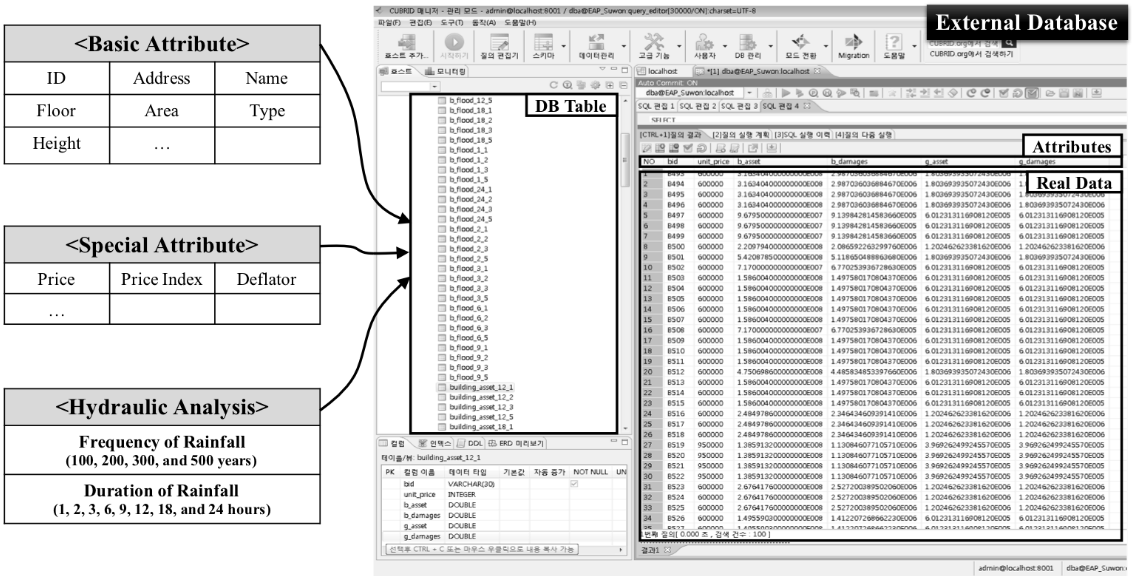

Figure 2. Consist of external database for flooding damage assessment

The result of flood damage presented in this study was drawn by utilizing the basic attributes, special attributes and the numerical analysis data and through the process shown in Figure 3 which uses an internal calculation process.

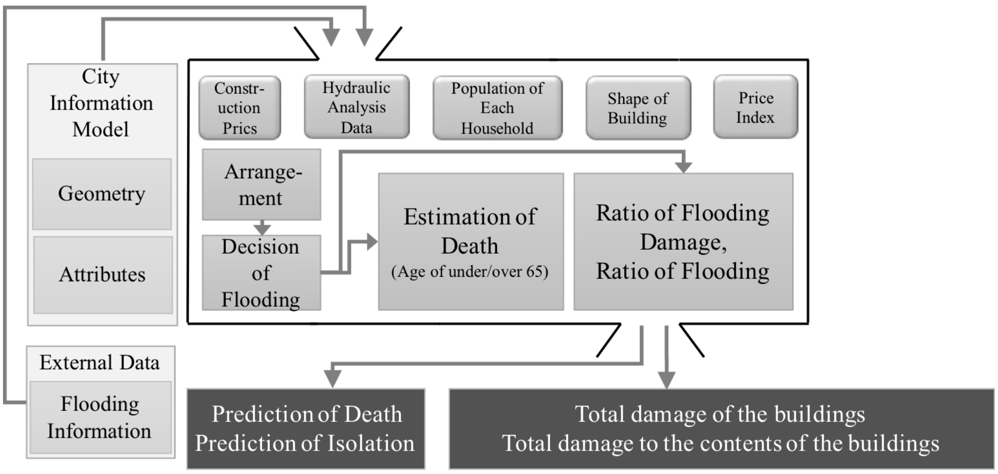

Figure 3. Process of flooding damage assessment

In regard to property damage, the damage to the building itself and the damage to the contents of the building were calculated applying the Multi-Dimensional Flood Damage Analysis (MD-FDA) which was presented by MOCT (2004) and is widely used in Korea. Property damage is calculated by multiplying the value of the relevant property, the rate of damage resulting from flood, and the flood rate of the residential area. At this time, in terms of the value of the property, the value which contains the correction factor on which the inflation is reflected is used. The damage rate is divided into 5 cases, 0.5 m or lower, 0.5 m to 1 m, 1 m to 2 m, 2 m to 3 m, and 3 m or higher, depending on the flood height from the building bottom; the damage rate of the building itself is obtained by dividing 15, 32, 64, 95, and 100 by the average floor numbers of the flooded buildings respectively, and the damage rate of the contents of the building shall have the constant value of 14.5, 32.6, 50.8, 92.8, and 100, respectively. The flood rate was calculated using the percentage of the flooded buildings in the flooded area in accordance with the house types.

The information items that have to be taken into account when calculating property damage and casualties are divided into basic and special attributes. The basic attributes are the building identifier, address, name, lot area, building area, building-to-land ratio, total floor area, total floor area for calculation of the floor area ratio, floor area ration, number of ground floors, number of underground floors, height, main use, house form, and items of architectural structure provided through the building ledger. And, the special attributes are defined to be mainly the items related to damage calculation. The items which belong to these include population by floor (aged 65 or older/under 65), unit price of construction, the reference year related to the calculation of the current unit price of construction, deflector of construction industry, appraised values of housewares for appraisal of housewares, consumer price index, and the reference year. These data were obtained through NSIC (2015) and the local government. Also, to simulate flooding situation in this study, the numerical analysis data was utilized where the situations of 100, 200, 300 and 500-year frequency were applied to the rainfall duration of 1, 2, 4, 6, 9, 12, 18 and 24 hours using the FARD program and Huff method.

4. DAMAGE CALCULATION THROUGH FLOODING SIMULATION

Numerical analysis is a result of reflecting natural drainage, due to which the biggest flood takes place while rainfall continues. In this study, the damage situation is applied on the basis of the maximum flood of each case in order to calculate the maximum damage. The flood value was made to be generated at each end point of the model triangular plane comprised of TIN, and its information was arranged to be directly connected to the terrain model. As the focus was put on the ground part in this study, inner drainage flood and underground infiltration of rainwater were excluded from the scope of the study. Figure 4 shows a part of the flooding situation visualized utilizing the generated CityGML based city information model and the numerical analysis data. Depending on the search conditions, the result in a specific area or for a more concrete scenario can be drawn and visualized.

Figure 4. Example of flooding simulation

5. CONCLUSIONS

In this study, we calculated the casualties and property damage by carrying out flood simulations, utilizing rainfall duration and rainfall frequency and utilizing the result to present the method of incorporating the city information model for decision making on establishment of action plan. The city information modeling was based on the CityGML which shows superior features in the comprehensiveness of the object, possibility of 3-dimensioinal visualization, and extensibility of the required information item or attribute in comparison to other open standard schema.

The generated city information model was linked to the numerical analysis data utilizing the positional information of the terrain model. Also, it was determined whether the building model on the city model was flooded utilizing this information, according to which the expected number of the dead residents, isolated residents, as well as the damage to the building were calculated. The calculated result was stored in an external database connected to the city information model, through which the data contained in the city model and the damage calculation result were arranged to be utilized as input query factors. It can overcome the limitations of the information management in the 2D-based Geographic Information System. The flood simulation which utilizes a 3-D information model has an aspect of being able to minimize the damage by reliably improving the understanding of the residents about a situation where the actual flood damage occurs. Also, a flood simulation based on a city information model that enables queries and drawing of the result in diverse conditions and calculation of the flood damage support the administrator to establish an action plan of a more active form following occurrence of flood damage.

The part covered intensively in this study is not in drawing the accurate damage through a flood simulation but in finding out how an open information model can be utilized to generate an application model in the same situation where flood damage occurs. Many researchers argue that open information modeling can improve construction productivity, and results that can support such an argument appear around the architectural field. However, the studies on application methodology of which the objects are city models that have to handle numerous structures at the same time are still at a very initial level. Only terrain and building among the city constituents were handled.

Furthermore, in this study, part of underground space was also excluded. However, the methodology carried out in this study can be applied to more city constituents and more detailed reality simulation in the future. As a result, it is expected that an action plan with higher reliability can be established for a disaster situation like flood damage.

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