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A Study of Developing a Big-Data-Based Building Fire and Flood Risk Analysis Model

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Summary

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1. Introduction

Building fires and floods are threats to public safety, and they are projected to worsen due to climate change. Building fires and floods are the most costly of all disasters and accidents that damage buildings and are a major threat to public safety. In particular, the fire at the Coupang distribution center in Icheon in 2021 and the flooding of the Gangnam Station area and the deaths of residents in the semiunderground dwellings in the summer of 2022 have raised the public's demand for secure buildings that are safe from fire and flood.

Analyzing building fire and flood risk is important to ensure building safety. Building characteristics and location influence the extent of damage during a fire or flood event, and insights obtained from them can be used to analyze the building's fire and flood risk. For example, buildings with a large floor area are relatively more prone to fire, and buildings located in low-lying areas are more likely to suffer flood damage. Researchers have been analyzing fire and flood risk in buildings based on the characteristics of the disasters damaging buildings, and the latest technological advancement is a turning point for this research.

The accuracy of risk analysis is improving with the development of the Fourth Industrial Revolution technologies such as machine learning, deep learning, IoT, and ICT. Machine learning algorithms such as decision trees, random forests, and support vector machines have improved risk analysis, and deep learning technologies such as the RNN (recurrent neural network), LSTM (long short-term memory), and CNN (convolutional neural network) have dramatically increased analysis accuracy. Advancements in IoT and ICT have contributed to obtaining data for analysis and are leading to problem solving using big data.

To respond to building fire and flood damage, it is necessary to identify buildings at high risk of fire and flood. It is also necessary to determine the factors that contribute to elevated risk and to practice building safety management with a particular focus on them. Building inspections are already required under the Building Management Act, the Act on the Installation and Management of Firefighting Systems, and the Special Act on the Safety and Maintenance of Facilities. The results of this study will contribute to developing a more reasonable framework for regular building inspections.

Against this backdrop, this study has four main objectives: 1) develop a building-level flood and fire risk analysis model, 2) demonstrate data linkage methods and establish a foundation for future data linkage, 3) identify buildings that require flood and fire preparedness and verify the accuracy of the model, and 4) propose a building management plan to improve building fire and flood safety.

To achieve these objectives, a four-step research process was established. 1) We surveyed fire and flood risk studies and analysis models to define the building fire and flood risks to be addressed in this study and derived the variables to be used in the analysis. 2) We developed and validated building fire and flood risk analysis models, respectively. Machine learning (deep learning) algorithms were applied to the models, which involved the process of collecting, refining, and linking analyzed data. 3) We applied the building fire and flood risk analysis models to Gwanak District and put them together to analyze building fire and flood risk. 4) Based on the overall findings of the study, we drew policy implications, identified limitations of the study, and proposed future research tasks.

Fire and flood risk analysis trends		Develop building fire and flood risk analysis models		Apply the models and draw implications		Draw conclusions
Case studies of fire and flood risk analysis studies and models	Define risks and derive variables	Collect, refine, link analyzed data	Develop and validate building fire and flood risk analysis models	Apply building fire and flood risk analysis models	Implications	Policy implications, limitations, future tasks

Flow of the study

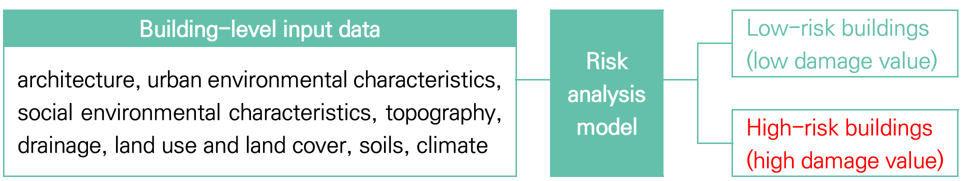
2. Fire and flood risk analysis trends

To analyze building fire and flood risks, we surveyed and analyzed previous studies and analytical models on fire and flood risk analysis. In general, risk analysis is based on the probability of occurrence and functions of damage. We found that the most common way of analyzing the final risk is to calculate the value of the damage. This suggests that while previous studies focused on the occurrence of fires and floods, risk analysis in practice aims to estimate the value of the damage to understand the actual damage better.

Concept of risk estimation

Studies of fire prediction models have been primarily based on statistical methodologies. They allow for analyzing the intensity and value of damage but are considered to have challenges in predicting the occurrence of fire itself. This is because a fire seldom starts spontaneously and is often caused by human error or arson; hence, environmental characteristics and location have a huge impact on fire occurrence. Risk analysis studies use a statistical fire occurrence model and combine it with a function of damage to estimate risks. The risk analysis of buildings seems to follow a similar methodology, which applies to both area- and building-level analyses.

Flood-related studies and analytical models are primarily based on mathematical and hydrological models to predict the probability and intensity of floods. SWMM and SWAT are some of the most commonly used models, which are widely applied to develop local flood countermeasures. Flood analysis models simulate the occurrence of floods in various situations in consideration of changes in precipitation and terrain characteristics, enabling the prediction of the probability and intensity of floods. In addition, models have been developed to perform risk analysis of flood events by combining them with functions of damage to estimate the value of damage. Hazus-MH, HEC-FIA, etc., are used as typical damage-based flood risk analysis models.



Concept of the risk analysis model to be developed

Based on the previous studies and model analysis, we established the framework of the building fire and flood risk analysis models. We designed both fire and flood risk analysis models to estimate the value of damage and categorize buildings into low-risk buildings with low damage value and high-risk buildings with high damage value. For the probability of occurrence and functions of damage, we used a machine learning (deep learning) algorithm based on statistical models. In addition, we selected the variables for fire and flood risk analysis based on the findings from previous studies and model analysis.

Clean up catastrophe–catastrophe analysis variables

Risk	Input Variables
Fire	Variables related to urban environmental characteristics, variables related to social environmental characteristics, weather characteristics, and architecture
Flood	Topography–related variables, drainage–related variables, land use and land cover–related variables, Saturn–related variables, weather–related variables, and building–related variables.

3. Developing the building fire and flood risk analysis models

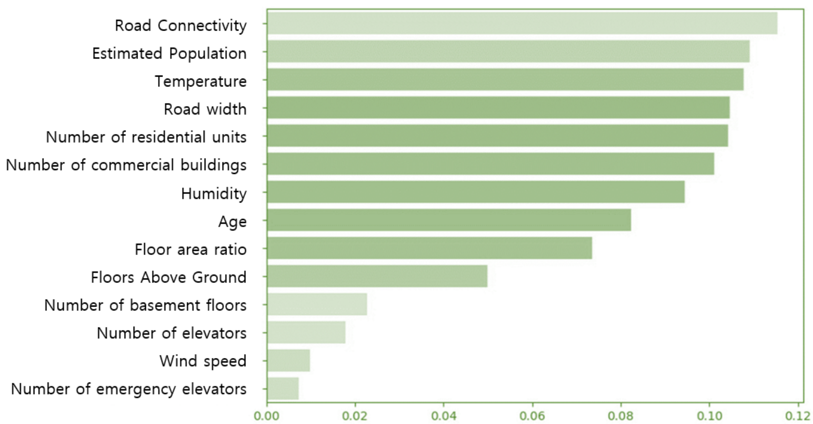
The development of the building fire and flood risk analysis models was divided into 1) data construction and 2) model development and validation phases. 1) The data linkage process involved linking building fire and flood damage occurrence and damage cost data with building register data, and producing and linking additional independent variables. 2) The model development and validation process involved selecting an algorithm for the learning of the analyzed dataset, training the models based on the selected algorithm, and validating and testing the models through a feedback process. The building fire and flood risk analysis models were developed independently.

To develop the building fire risk analysis model, we used a total of 28,266 cases of building fire damage data in Seoul from 2017 to 2021. Buildings with more than KRW 200,000 worth of damage were classified as high–risk buildings, and those with less than KRW 200,000 were classified as low–risk buildings. We applied various machine learning algorithms including the random forest, logistic regression, LightGBM, and XGBoost, and we selected the random forest that showed the highest accuracy.

Data building		Model development and validation	
Link building fire and flood damage occurrence data with building register data	Produce input variables for analysis and link with the building register	Select a machine learning (deep learning) algorithm and conduct the leaning of the database	Validate and test the models and develop the final risk analysis models through feedback

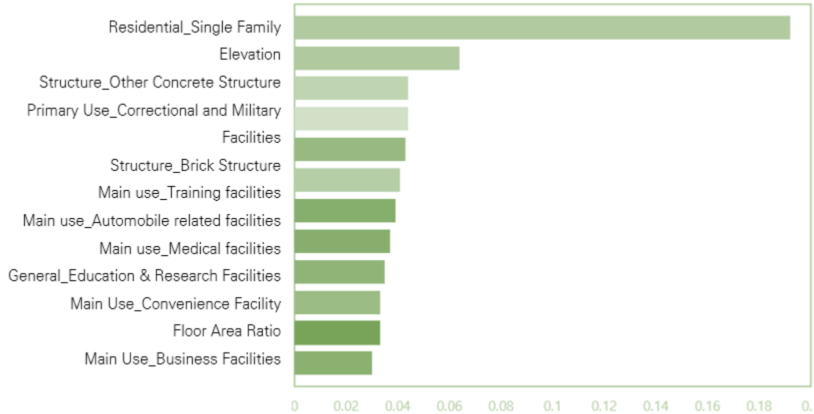
Model development process

The key influencing factors of the building fire risk analysis included road connectivity, estimated population, temperature, road width, number of residential buildings, and number of commercial buildings. The final accuracy of the building fire risk analysis model was 78%. The F1 score was 0.75, and the AUC value, which represents the area under the ROC curve, was 0.89, indicating a quality risk analysis model.



Importance of variables of the fire risk analysis model

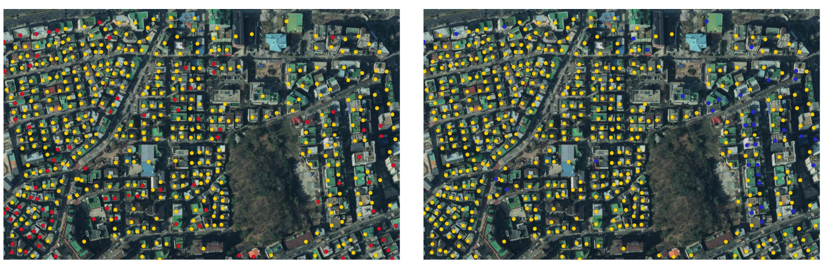
To develop the building flood risk analysis model, we used a total of 27,438 cases of building flood damage data in Seoul from 2016 to 2022. Buildings with more than KRW 3,000,000 worth of damage were classified as high-risk buildings, and those with less than KRW 3,000,000 were classified as low-risk buildings. For the building flood risk analysis model, we used the TabNet classifier. The key influencing factors of the building flood risk analysis included the use and structure of buildings, height, and floor-area ratio of buildings. The final accuracy of the building flood risk analysis model was very high at 88%.



Importance of variables of the flood risk analysis model

4. Application of the building fire and flood risk analysis models

We applied the building fire and flood risk analysis models to Gwanak District, Seoul. To develop the model, we used buildings that had already experienced fire or flood damage, and we applied the developed models to all buildings in Gwanak District to analyze their fire and flood risks. There are a total of 32,079 buildings in Gwanak District, and we developed input variables for the analysis and linked the data with all building points.



[Map of buildings with high fire risk]
red: high risk of fire

[Map of buildings with high flood risk]
blue: high risk of flood

Maps of building flood and fire risk (results of individual analyses)

Feeding the data into the models resulted in building fire and flood risk maps. The analysis showed that there are 8,405 buildings (~31%) at high risk of fire damage, and 446 buildings (~1.5%) at high risk of flood damage.

Yellow: low risk of fire and flood, asterisk: high risk of fire and flood,
red: high risk of fire, blue: high risk of flood

Map of building flood and fire risk (results of integrated analysis)

To obtain comprehensive insight into building fire and flood risk, we superimposed the individual predictions to derive four types of buildings depending on their fire and flood risk levels. Of the 32,079 buildings in Gwanak District, 23,276 buildings were identified at low fire risk and low flood risk, 8,357 buildings at high fire risk, 398 buildings at high flood risk, and 48 buildings at high fire risk and high flood risk.

Categorization of building fire and flood risk

	Low risk of fire	High risk of fire
Low risk of flood	23,276 buildings (72.56%)	8,357 buildings (26.05%)
High risk of flood	398 buildings (1.24%)	48 buildings (0.15%)

5. Conclusions

This study has four policy implications. First, we revealed the need to take advantage of the Fourth Industrial Revolution technologies to respond to disasters and accidents that affect buildings. Using these technologies, for example, machine learning, deep learning, and big data, enables one to analyze fire and flood risk in buildings and ensure higher accuracy than the existing methods. It is believed that embracing these technologies and actively using them will help protect buildings from disasters and accidents.

Second, we proposed measures to reduce building fire and flood risk. Based on the development of the building fire and flood risk analysis models we developed, we found factors that lead to increased risk. For building fire risk, key factors include road connectivity, estimated population, temperature, road width, and number of residential buildings, and for building flood risk, key factors include use and structure of buildings, height, and floor-area ratio. It is expected that improving building management policies with a focus on these factors will help reduce the damage caused by fire and flood.

Third, we proposed the need for integrated disaster response at the building level. Fire and flood are disasters that cause buildings to suffer the most severe damage. To respond to these issues, the existing models and studies have performed risk analysis for individual disasters and hazards. However, in this study, we developed models that enable an integrated response to both fire and flood. While fires and floods may have totally different causes and require totally different responses, it may be more efficient to view them together in terms of identifying response priorities at the building level. Successful building disaster and accident prevention requires developing an integrated building safety system.

Fourth, we identified the need for institutional improvement to prioritize the management of buildings prone to disasters and accidents. We found that smaller buildings are more prone to fire and flood risk compared to larger buildings that are subject to statutory inspections under relevant laws. In other words, the law does not provide for inspections for buildings that are prone to fire and flood; hence, there is a need to improve the system. Currently, Article 15 of the Building Management Act (Inspection of Small and Old Buildings) stipulates the inspection of small and old buildings, but considerations should be given to tightening the regulation. In addition, further research is warranted to utilize public data better and apply new algorithms to improve the accuracy of risk analysis and expand the scope to disasters and accidents other than fire and flood.

Keywords :
Big-Data, Building Fire risk, Building Flood risk, Machine Learning, Deep Learning