ICCEPM 2024 https://dx.doi.org/10.6106/ICCEPM.2024.0783
The 10th International Conference on Construction Engineering and Project Management
Jul. 29-Aug.1, 2024, Sapporo

Simulation of Urban Environments for Disaster Risk Management: Comprehensive Review of Techniques and Future Directions

Kieun LEE[1], Taeyong KIM[2] and Sungkon MOON[3*]

[1] *Department of Civil Systems Engineering, College of Engineering, Ajou University, Republic of Korea,* E-mail address: dlrldms0803@ajou.ac.kr
[2] *Department of Civil Systems Engineering, College of Engineering, Ajou University, Republic of Korea,* E-mail address: taeyongkim@ajou.ac.kr
[3] *Department of Civil Systems Engineering, College of Engineering, Ajou University, Republic of Korea,* Corresponding author, E-mail address: skmoon@ajou.ac.kr

Abstract: As cities continue to evolve and expand, the importance of accurately modeling and simulating urban environments to predict and assess various risk scenarios has become increasingly recognized. Since city simulation can capture the intricate dynamics of urban life, the versatility of city simulation has been demonstrated in numerous case studies across diverse applications. Owing to this capacity, city simulation plays a critical role in the disaster risk management field, especially in accounting for the uncertainties in natural/man-made disasters. For example, in the event of an earthquake, having detailed information about an urban area is instrumental for evaluating stakeholder decisions and their impact on urban recovery strategies. Although numerous research efforts have been made to introduce city simulation techniques in disaster risk reduction, there is no clear guideline or comprehensive summary of their characteristics and features. Therefore, this study aims to provide a high-level overview of the latest research and advancements in urban simulation under different hazards. The study begins by examining the simulation techniques used in urban simulation, with a focus on their applicability in disaster scenarios. Subsequently, by analyzing various case studies, this research categorizes them based on their unique characteristics and key findings. The knowledge gained from this literature review will serve as a foundation for subsequent research on simulating the impacts of urban areas under various hazards.

Keywords: Urban simulation, Urban modeling, Urban resilience, Disaster management, Scenario prediction

1. INTRODUCTION

In the context of continuous development and change in modern cities, the innovative advancement of technologies for modeling and simulating actual cities to predict outcomes is widely recognized [1, 2]. The field of urban simulation has evolved far beyond its basic visualization, now being utilized in urban policy and management [3]. These simulations serve as critical tools for predicting various urban development scenarios, aiding administrators in addressing urban growth and sustainability complexities [4]. As cities become more interconnected and complex, the need for sophisticated simulation models capable of handling this complexity becomes increasingly evident. This shift in focus from basic visualization to comprehensive urban planning reflects the growing importance of addressing not just the physical structure, but also the social, economic, and environmental aspects of urban areas [5, 6]. Urban simulations play an important role, especially in disaster risk management [7]. In situations such as natural or man-made disasters, these simulations are essential for assessing urban vulnerability and establishing effective response plans [8]. However, systematic research and guidelines for urban simulation to reduce disaster risk are relatively lacking. Existing studies have mainly focused on individual case studies, focusing on exploring different approaches and techniques without an integrated framework. [9-11]. Addressing this gap, this study aims to systematically analyze and synthesize various application methods and functions of urban simulation. In this study, based on extensive related literature, simulation technologies used in disaster city simulation are introduced, and case studies are classified by disaster type to understand how specific technical methods are contributing to the field. Finally, the applicability of these simulations in disaster response and planning is explored, and a comprehensive overview of their status and potential future directions is provided.

2. DISASTER SIMULATION TECHNIQUES

When performing a disaster simulation, it is important to select a simulation technique suitable for the purpose. By selecting the appropriate technique, it is possible to predict and prepare for various possibilities that may occur in each disaster situation [12-14]. The paper introduces three modeling techniques: Numerical modeling, Agent-based modeling (ABM), and Simulation using Geographic information system (GIS). The above three technologies are effective approaches to performing disaster simulations dealing with human behavior and interaction areas, the physical process of disasters, and the spatial characteristics of the affected area [15-18]. Therefore, in the main text, the applicability of each technology will be explained through concepts and examples.

2.1. Agent-based modeling (ABM)

Agent-based modeling is a method of modeling the behavior and interaction of individual actors (agents) in disaster simulations [19]. Taillandier et al. [20] developed an agent-based model called SiFlo (Simulation of flood event) to simulate the behavior of residents in the event of a flood. Vandewalle et al. [21] used an agent-based model to simulate the urban evacuation process in the event of a flood. This study concluded that the overall evacuation time increased as the severity of the disaster increased. Maqbool et al. [22] proposed agent-based modeling and disaster management simulations using GIS by creating virtual scenarios, which were utilized for disaster management strategy analysis. As above, disaster agent-based modeling is an important tool in modeling and simulating complex human behavior and resource management strategies in disaster situations. This will contribute to enabling data-based decision-making for disaster management policymakers and improving disaster response efficiency.

2.2. Numerical modeling

Numerical modeling is the process of expressing natural phenomena as mathematical equations and interpreting them using computers. This process allows researchers to quantitatively analyze and predict complex environments and disaster scenarios [23]. In particular, in establishing and responding to various disasters, numerical modeling provides a powerful way to simulate scenarios before and after disasters [24]. Dong et al. [25] simulated the flooding process in urban areas using laboratory experiments and numerical modeling. Chang et al. [26] developed a high-performance two-dimensional hydrodynamic model using the finite element method and an unstructured grid to facilitate the creation of flood response plans and carried out simulations of floods on an urban scale. These cases show various application methods of numerical modeling in the disaster management process and emphasize how important numerical modeling can be. Therefore, disaster management experts can develop effective response strategies through numerical modeling.

2.3. Simulation using GIS

The geographic information system (GIS) is a technology that collects, stores, analyzes, and visualizes location-based data and processes complex spatial data, allowing users to understand and analyze geographic information [27]. This GIS plays an important role in disaster management by predicting disasters and establishing response plans [28]. Gang et al. [29] sought to develop a 3D disaster management system based on high-capacity geographic and disaster information to establish a rapid disaster response system. In addition, HAZUS was developed by the US Federal Emergency Management Agency (FEMA) and is a GIS-based disaster risk assessment tool. HAZUS is one of the widely used disaster simulation tools and is used as a tool to assess various losses in cities due to disasters [30]. GIS-based simulations enable more accurate analysis and prediction of disaster scenarios, and effective response strategies can be developed based on them. Therefore, GIS is an essential tool to increase the efficiency of disaster management and minimize the loss of life and property.

2.4. Analysis of characteristics of each simulation technique

This section attempts to analyze and organize the characteristics of the three techniques described above. Agent-based modeling, numerical modeling, and simulation using GIS are commonly used to understand and predict systems or processes for disaster management. However, these techniques are different depending on the purpose and characteristics of use. Table 1 below categorizes each simulation technique into a definition, focus, and typical application.

Table 1. Characteristics of each simulation technique

Criteria	**Simulation method**		
	Agent-based modeling	**Numerical modeling**	**Simulation using GIS**
Definition	A computational model that simulates the behavior and interaction of autonomous agents to evaluate their impact on the entire system	A technique for simulating system behavior by solving equations describing the behavior of complex systems.	How to analyze and manage spatial or geographic data using geographic information system technology
Focus	Individual or collective behavior and decision-making processes of agents.	Simulating physical processes and phenomena using mathematical models	Focus on spatial aspects of disasters, mapping, analysis, and visualization of data
Typical applications	Social behavior analysis, evacuation modeling	Flood modeling, earthquake simulations	Disaster Risk Assessment and Spatial Analysis

As can be seen from Table 1, each simulation technique is mainly used in a specific focus area. These differences suggest the importance of performing disaster management simulations by selecting the best simulation technique for a specific purpose. Therefore, it is essential to closely consider the main purpose and characteristics of each technique when determining the simulation approach in disaster management.

3. VARIOUS DISASTER SIMULATION CASES

This section examines the effective use of simulation technology in actual disaster scenarios through case studies related to natural and man-made disasters. Each of the presented cases emphasizes the importance of technology for solving various disaster tasks by presenting the research methodology and application cases of simulation suitable for various disaster types.

3.1. Natural disaster simulation cases

3.1.1. Earthquakes damage

Earthquakes are known to cause casualties and massive economic damage [31]. Therefore, many researchers are working to predict and respond to earthquake damage. However, earthquake prediction is a very complex task, so various approaches have been used for prediction [32]. Zhang et al. [33] introduce a method of evaluating relief demand after an earthquake by performing spatial autocorrelation analysis and hotspot analysis using the ArcGIS program to calculate the damage status using basic building information and to understand the relationship with human damage. Hosseinzadeh-Tabrizi et al. [34] accurately modeled the dam collapse and flood effects caused by earthquakes using programs such as 2DEC-Ras and GIS for Satarkan Dam near Ahar City, northwest Iran, and performed predictive evaluation. Gharehbaghi et al. [35] emphasized the need for seismic damage spectrum prediction and presented a framework for seismic damage spectrum prediction using two computational intelligence methods: multi-gene programming (MGGP) and artificial neural networks (ANNs). Considering the high exposure to disasters caused by population concentration in urban areas, Marasco et al. [36] presented an earthquake damage assessment framework for the portfolio of residential buildings in urban areas.

3.1.2. Flood

Rapid climate change and urbanization have increased the frequency and intensity of flooding [37, 38]. Therefore, it is important to conduct simulations to prepare for flooding, and there are several important reasons. First, it helps to assess the potential damage and impact of flooding on infrastructure and human life [39]. Feng et al. [40] simulated flood flows using various land data and urbanization scenarios to investigate how urbanization affects flood risk. Rong et al. [41] generated an urban model through slope images taken by UAV and performed a flood flooding simulation using a 3D hydrodynamic model. Second, the simulation can evaluate the effectiveness of flood management strategies and mitigation measures, helping to prepare for more efficient emergency responses [42]. Bernardini et al. [43] used a simulation model to evaluate the effectiveness of risk reduction solutions and strategies, such as architectural elements and contingency planning for evacuees' support.

3.1.3. Other natural disasters

In addition to earthquakes and floods, which are representative natural disasters mentioned above, other natural disasters such as drought, tsunami, and hurricanes have also increased in frequency due to climate change and urbanization [44-47]. Therefore, it is important to perform simulations to prepare for such disasters. For example, Li et al. [48] predicted extreme drought frequency changes in China using two large-scale ensemble simulations consisting of 50 CanESM2 members and 40 CESM1 members. Shi et al. [49] investigated the extent and depth of storm surge flooding in the Pingyang region of China using five typhoon intensity scenarios and numerical simulations. Along with the need for realistic tsunami evacuation simulations, Wang et al. [50] proposed a realistic agent-based model for tsunami evacuation that addresses the limitations of previous models, mainly based on assumptions. Roy et al. [51] presented an actor-based model to understand complex decision-making patterns during a hurricane evacuation, considering various interaction factors such as socioeconomic and demographic attributes and decision-making.

3.2. Man-made simulation cases

3.2.1. Building fire simulation

Building fire damage simulation is an important factor in understanding and mitigating the effects of fire. Several studies have suggested ways to accurately simulate building fire occurrence and damage. To understand the behavior of sandstone elements in the event of a fire, Wang et al. [52] have developed a model that performs numerical simulations and predicts changes in temperature distribution, crack behavior, and intensity. The study of Gong and Agrawal [53] focused on numerical simulations of accidental fires in truss bridges, demonstrating the potential of fire structure interaction modeling and simulation of civil structures. Efendi and Aco Wahyudi [54] conducted a thermal simulation analysis to evaluate the effect of the fire on the building elements, focusing on the temperature rise and the magnitude of the thermal conduction.

3.2.2. Urban terrorism and safety accidents

Various studies have been conducted on urban terrorism and safety accident simulations. These simulations can help in assessing the risk of terrorist acts and evaluating the effectiveness of different evacuation strategies [55]. Stoltz et al. [56] present a systems approach to determining the economic loss due to property damage resulting from a terrorist bombing in an American city. Tang et al. [57] establish a Bayesian network to analyze the risk of urban dirty bomb attacks, considering factors such as occurrence time, location, and defense approaches. As in the mentioned studies, urban terrorism and safety accident simulations are important for population protection, and understanding and predicting human behavior of both individuals and groups is important for enhancing population safety to enhance population protection These simulations are used to analyze interactions between users, risks, and built environments, taking into account factors such as the placement of public places and the impact of external temperatures on user behavior [58]. This can contribute to a more comprehensive risk assessment and the development of effective countermeasures.

3.3. Simulation techniques applied to real case studies

In this section, Table 2 summarizes how the disaster simulation technology described in Chapter 2 was applied in real cases.

Table 2. Disaster city simulation methods

Disaster category	Publication	Simulation method		
		Agent-based modeling	Numerical modeling	Simulation using GIS
Flood	Taillandier et al. [20]	●	●	
Flood	Vandewalle et al. [21]	●	●	●
All urban disaster	Maqbool et al. [22]	●	●	●
Flood	Dong et al. [25]		●	
Flood	Chang et al. [26]		●	
Disaster response	Gang et al. [29]		●	●
Earthquake	Zhang et al. [33]		●	●
Earthquake and flood	Hosseinzadeh-Tabrizi et al. [34]		●	●
Earthquake	Gharehbaghi et al. [35]		●	
Earthquake	Marasco et al. [36]		●	
Flood	Feng et al. [40]		●	
Flood	Rong et al. [41]		●	
Flood	Bernardini et al. [43]	●	●	
Drought	Li et al. [48]		●	
Typhoon and storm surge	Shi et al. [49]		●	
Tsunami	Wang et al. [50]	●	●	
Hurricane	Roy et al. [51]	●	●	
Fire	Wang et al. [52]		●	
Fire	Gong and Agrawal [53]		●	
Fire	Efendi and Aco Wahyudi [54]		●	
Terrorist bombing	Stoltz et al. [56]		●	
Dirty bomb	Tang et al. [57]		●	

As indicated in Table 2, numerical modeling is extensively utilized across all types of disasters. This widespread application is attributed to its capability to quantitatively represent complex natural phenomena, proving highly effective for disaster management. Agent-based modeling has established itself as a crucial tool for modeling the complexity of human behavior and resource management strategies and has been effectively employed in empirical research for disaster evacuation strategies and management. Furthermore, simulations utilizing GIS have conducted spatial analysis based on location and topographical data, playing a vital role in enhancing the efficiency of disaster management.

4. CONCLUSION

In this study, the applicability and practicality of disaster city simulation were confirmed through review and case analysis of various urban simulation technologies. Accordingly, the strengths and characteristics of simulation using agent-based modeling, numerical modeling, and GIS, which play an important role in analyzing human behavior, physical process, and spatial characteristics, were explored. In addition, in this study, Table 2 analyzed how the simulation methodology was constructed for various types of disasters, including natural disasters such as earthquakes, floods, urban fires, and terrorism. The results of the study showed that numerical modeling is widely used in a wide range of disaster scenarios. This shows that it has strengths in quantitatively explaining complex natural phenomena. However, numerical modeling can accurately calculate numerical values for analysis, but other modeling techniques such as ABM and GIS can selectively adopt this approach depending on individual goals and purposes. In conclusion, this study proposes that to build a disaster city simulation system that can respond more accurately and quickly to disasters, a multi-faceted approach and development strategy should be established by utilizing the unique characteristics and advantages provided by each technology.

ACKNOWLEDGEMENTS

This research was supported by the Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science and ICT (Grant Number: 2022R1F1A1074039)

REFERENCES

[1] Ogawa, Y., Y. Sekimoto, and R. Shibasaki, Estimation of earthquake damage to urban environments using sparse modeling. Environment and Planning B: Urban Analytics and City Science, 2021. 48(5): p. 1075-1090.

[2] Yun, T.-S., et al. Agent-based modeling and simulation on residential population movement patterns: the case of Sejong city. in 2020 Winter Simulation Conference (WSC). 2020. IEEE.

[3] Liu, G., S. Chen, and J. Gu, Urban renewal simulation with spatial, economic and policy dynamics: The rent-gap theory-based model and the case study of Chongqing. Land Use Policy, 2019. 86: p. 238-252.

[4] Bihamta, N., et al., Using the SLEUTH urban growth model to simulate future urban expansion of the Isfahan metropolitan area, Iran. Journal of the Indian Society of Remote Sensing, 2015. 43: p. 407-414.

[5] Gao, L., et al., Multi-scenario simulation and ecological risk analysis of land use based on the PLUS model: A case study of Nanjing. Sustainable Cities and Society, 2022. 85: p. 104055.

[6] Xing, L., M. Xue, and M. Hu, Dynamic simulation and assessment of the coupling coordination degree of the economy–resource–environment system: Case of Wuhan City in China. Journal of Environmental Management, 2019. 230: p. 474-487.

[7] Jiang, W., et al., Toward Interoperable Multi-Hazard Modeling: A Disaster Management System for Disaster Model Service Chain. International Journal of Disaster Risk Science, 2022. 13(6): p. 862-877.

[8] Zlatanova, S., SII for emergency response: the 3D challenges. J. Chen, J. Jiang and S. Nayak (Eds.), 2008: p. 1631-1637.

[9] Çağlayan, N. and S.I. Satoglu, Simulation analysis of critical factors of casualty transportation for disaster response: A case study of Istanbul earthquake. International Journal of Disaster Resilience in the Built Environment, 2022. 13(5): p. 632-647.

[10] Liu, Y., et al., Large-scale natural disaster risk scenario analysis: a case study of Wenzhou City, China. Natural hazards, 2012. 60: p. 1287-1298.

[11] Shi, Y., et al., How can cities respond to flood disaster risks under multi-scenario simulation? A case study of Xiamen, China. International journal of environmental research and public health, 2019. 16(4): p. 618.

[12] Herman, S., Disaster Scene Reconstruction: Modeling, Simulating, And Planning In An Urban Disaster Environment. 2014.

[13] Gundran, C.P.D., et al., Simulation training needs assessment for disaster preparedness and disaster response among selected agencies in national capital region, Philippines. International Journal of Disaster Risk Reduction, 2023: p. 103824.

[14] Hemadasa, N., et al. DiNS: Nature Disaster in Network Simulations. in 2022 18th International Conference on Mobility, Sensing and Networking (MSN). 2022. IEEE.

[15] Puno, G., et al., Mapping and analysis of flood scenarios using numerical models and GIS techniques. Spatial Information Research, 2020. 28(2): p. 215-226.

[16] Rodrigues da Silva, A., et al., A Web GIS Platform to Modeling, Simulate and Analyze Flood Events: The RiverCure Portal. ISPRS International Journal of Geo-Information, 2023. 12(7): p. 268.

[17] Lee, S., et al., Dynamic-data-driven agent-based modeling for the prediction of evacuation behavior during hurricanes. Simulation Modelling Practice and Theory, 2021. 106: p. 102193.

[18] Feizizadeh, B., S.J. Adabikhosh, and S. Panahi, A Scenario-Based and Game-Based Geographical Information System (GIS) Approach for Earthquake Disaster Simulation and Crisis Mitigation. Sustainability, 2023. 15(14): p. 11131.

[19] Yin, W., et al., An agent-based modeling system for travel demand simulation for hurricane evacuation. Transportation research part C: emerging technologies, 2014. 42: p. 44-59.

[20] Taillandier, F., et al., An agent-based model to simulate inhabitants' behavior during a flood event. International Journal of Disaster Risk Reduction, 2021. 64: p. 102503.

[21] Vandewalle, R., et al. Integrating CyberGIS-Jupyter and spatial agent-based modelling to evaluate emergency evacuation time. in proceedings of the 2nd ACM SIGSPATIAL international workshop on GeoSpatial simulation. 2019.

[22] Maqbool, A., et al., Disaster mitigation in Urban Pakistan using agent based modeling with GIS. ISPRS International Journal of Geo-Information, 2020. 9(4): p. 203.

[23] Liu, Y., et al., Intelligent prediction method for waterlogging risk based on AI and numerical model. Water, 2022. 14(15): p. 2282.

[24] Fakhrzad, M. and H. Hasanzadeh, A new mathematical modelling for relief operation based on stochastic programming. International Journal of Process Management and Benchmarking, 2020. 10(2): p. 224-239.

[25] Dong, B., et al., Experimental and numerical model studies on flash flood inundation processes over a typical urban street. Advances in Water Resources, 2021. 147: p. 103824.

[26] Chang, T.-Y., et al., An operational high-performance forecasting system for city-scale pluvial flash floods in the southwestern plain areas of Taiwan. Water, 2021. 13(4): p. 405.

[27] Goodchild, M., Twenty years of progress: GIScience in 2010. Journal of spatial information science, 2010(1): p. 3-20.

[28] Khan, S.M., et al., A systematic review of disaster management systems: approaches, challenges, and future directions. Land, 2023. 12(8): p. 1514.

[29] GANG, S.-M., et al., A plan for a prompt disaster response system using a 3D disaster management system based on high-capacity geographic and disaster information. Journal of the Korean Association of Geographic Information Studies, 2016. 19(1): p. 180-196.

[30] Schneider, P.J. and B.A. Schauer, HAZUS—Its development and its future. Natural Hazards Review, 2006. 7(2): p. 40-44.

[31] Asim, K.M., et al., Seismic activity prediction using computational intelligence techniques in northern Pakistan. Acta Geophysica, 2017. 65: p. 919-930.

[32] Tehseen, R., M.S. Farooq, and A. Abid, Earthquake prediction using expert systems: a systematic mapping study. Sustainability, 2020. 12(6): p. 2420.

[33] Zhang, L., Z. Tao, and G. Wang, Assessment and determination of earthquake casualty gathering area based on building damage state and spatial characteristics analysis. International Journal of Disaster Risk Reduction, 2022. 67: p. 102688.

[34] Hosseinzadeh-Tabrizi, S.A., M. Ghaeini-Hessaroeyeh, and M. Ziaadini-Dashtekhaki, Numerical simulation of dam-breach flood waves. Applied Water Science, 2022. 12(5): p. 100.

[35] Gharehbaghi, S., et al., Prediction of seismic damage spectra using computational intelligence methods. Computers & Structures, 2021. 253: p. 106584.

[36] Marasco, S., et al., A computational framework for large-scale seismic simulations of residential building stock. Engineering Structures, 2021. 244: p. 112690.

[37] Patel, D.P. and P.K. Srivastava, Flood hazards mitigation analysis using remote sensing and GIS: correspondence with town planning scheme. Water resources management, 2013. 27(7): p. 2353-2368.

[38] Li, W., et al., A rapid 3D reproduction system of dam-break floods constrained by post-disaster information. Environmental Modelling & Software, 2021. 139: p. 104994.

[39] Rangari, V.A., N. Umamahesh, and C. Bhatt, Assessment of inundation risk in urban floods using HEC RAS 2D. Modeling Earth Systems and Environment, 2019. 5: p. 1839-1851.

[40] Feng, B., Y. Zhang, and R. Bourke, Urbanization impacts on flood risks based on urban growth data and coupled flood models. Natural Hazards, 2021. 106: p. 613-627.

[41] Rong, Y., et al., Three-dimensional urban flood inundation simulation based on digital aerial photogrammetry. Journal of Hydrology, 2020. 584: p. 124308.

[42] Gioia, E. and F. Marincioni, Leaving Nothing to Chance: Reducing Flood Risk by Evaluating Simulation Exercises in Urban Contexts, in Disaster Resilience and Human Settlements: Emerging Perspectives in the Anthropocene. 2023, Springer. p. 21-43.

[43] Bernardini, G., et al., Assessing the flood risk to evacuees in outdoor built environments and relative risk reduction strategies. International Journal of Disaster Risk Reduction, 2021. 64: p. 102493.

[44] Fathianpour, A., et al., Tsunami evacuation modelling via micro-simulation model. Progress in Disaster Science, 2023. 17: p. 100277.

[45] Sobhani, B. and V.S. Zengir, Modeling, monitoring and forecasting of drought in south and southwestern Iran, Iran. Modeling Earth Systems and Environment, 2020. 6: p. 63-71.

[46] Luo, Z., et al., Impact of urbanization factors considering artificial water dissipation on extreme precipitation: A numerical simulation of rainfall in Shanghai. Quarterly Journal of the Royal Meteorological Society, 2023. 149(755): p. 2320-2332.

[47] Mutthulakshmi, K., et al., Simulating forest fire spread and fire-fighting using cellular automata. Chinese Journal of Physics, 2020. 65: p. 642-650.

[48] Li, W., et al., Future changes in the frequency of extreme droughts over China based on two large ensemble simulations. Journal of Climate, 2021. 34(14): p. 6023-6035.

[49] Shi, X., et al., Simulation of storm surge inundation under different typhoon intensity scenarios: case study of Pingyang County, China. Natural Hazards and Earth System Sciences, 2020. 20(10): p. 2777-2790.

[50] Wang, Z. and G. Jia, A novel agent-based model for tsunami evacuation simulation and risk assessment. Natural hazards, 2021. 105: p. 2045-2071.

[51] Roy, K.C., et al., Understanding the influence of multiple information sources on risk perception dynamics and evacuation decisions: An agent-based modeling approach. International Journal of Disaster Risk Reduction, 2022. 82: p. 103328.

[52] Wang, F., et al., Numerical simulation of damage behaviour of building sandstone exposed to fire. Rock Mechanics and Rock Engineering, 2021. 54: p. 3149-3164.

[53] Gong, X. and A.K. Agrawal, Numerical simulation of fire damage to a long-span truss bridge. Journal of bridge Engineering, 2015. 20(10): p. 04014109.

[54] Efendi, A.W., Simulation of fire exposure behavior to building structural elements using LISA FEA V. 8. International Journal of Advanced Science and Computer Applications, 2023. 2(2): p. 49-58.

[55] Provitolo, D., R. Lozi, and E. Tric, Topological analysis of a weighted human behaviour model coupled on a street and place network in the context of urban terrorist attacks. Mathematical Modelling, Optimization, Analytic and Numerical Solutions, 2020: p. 117-146.

[56] Stoltz, E.M., J.K. Clutter, and F. Hudson, Modeling property value loss in a city due to terrorist bombings. IEEE Systems Journal, 2009. 3(2): p. 221-230.

[57] Tang, Z., et al., Risk analysis of urban dirty bomb attacking based on Bayesian network. Sustainability, 2019. 11(2): p. 306.

[58] Quagliarini, E., G. Bernardini, and M. D'Orazio, How Could Increasing Temperature Scenarios Alter the Risk of Terrorist Acts in Different Historical Squares? A Simulation-Based Approach in Typological Italian Squares. Heritage, 2023. 6(7): p. 5151-5186.