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Digital twin-based decision support systems for natural disaster management: A systematic review of current trends and approaches

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ABSTRACT

Increased urbanization and extreme climate events in recent years have led to a rise in the frequency and severity of widespread natural disasters. The disaster management cycle is a common framework that helps emergency management organizations develop procedures that can minimize the devastating impacts of natural disasters. Recently, researchers have begun to explore how big data and artificial intelligence can be used to develop virtual digital twin (DT) models of disaster situations that provide real-time decision support for each phase of the disaster management cycle. This study presents a systematic literature review of the burgeoning research area of DT-based decision support systems for disaster management. We identify the various locations and disaster types featured in DT case studies, the data collection techniques and computational methods utilized to create virtual representations of disaster-affected areas, and the decision-making tasks that DTs have been applied to. Based on our findings, we highlight several research gaps in the current literature and provide a set of recommendations that can serve as guidelines for future studies. Overall, this review provides researchers and practitioners with insights into the current trends and future research directions for DT-based decision support systems for natural disaster management.

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Figures and tables

Fig. 1. The four phases of the disaster management cycle adapted from Song et al. [1]

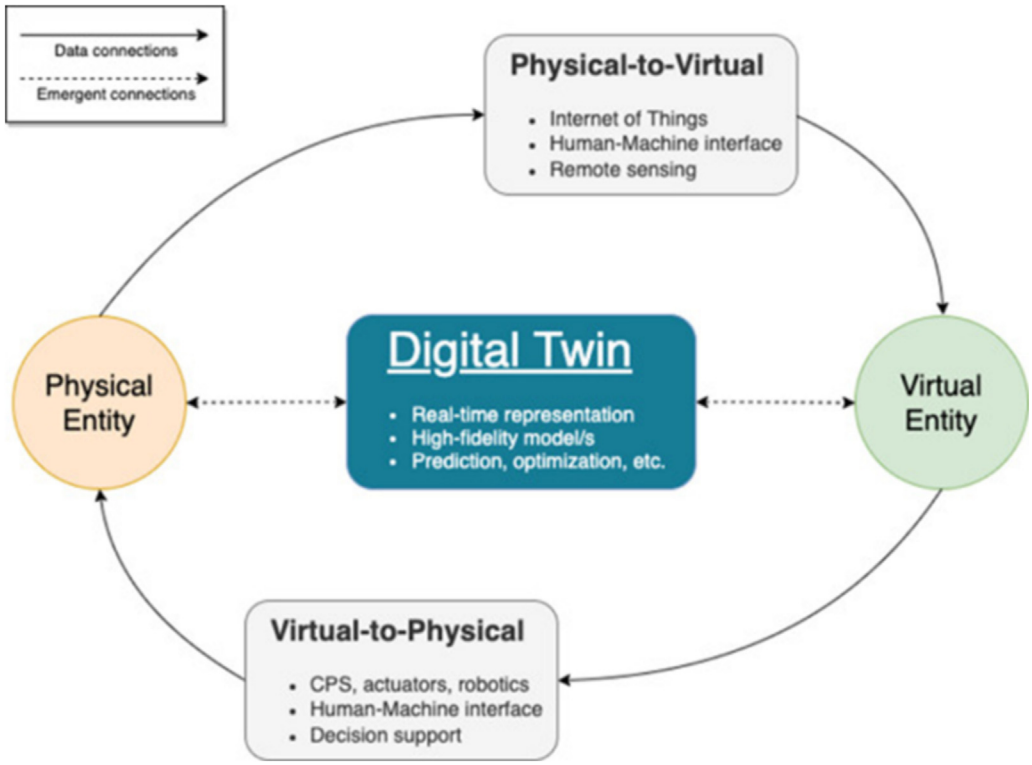

Fig. 2. A conceptual model of a digital twin. This figure is adapted from Purcell and Neubauer [2].

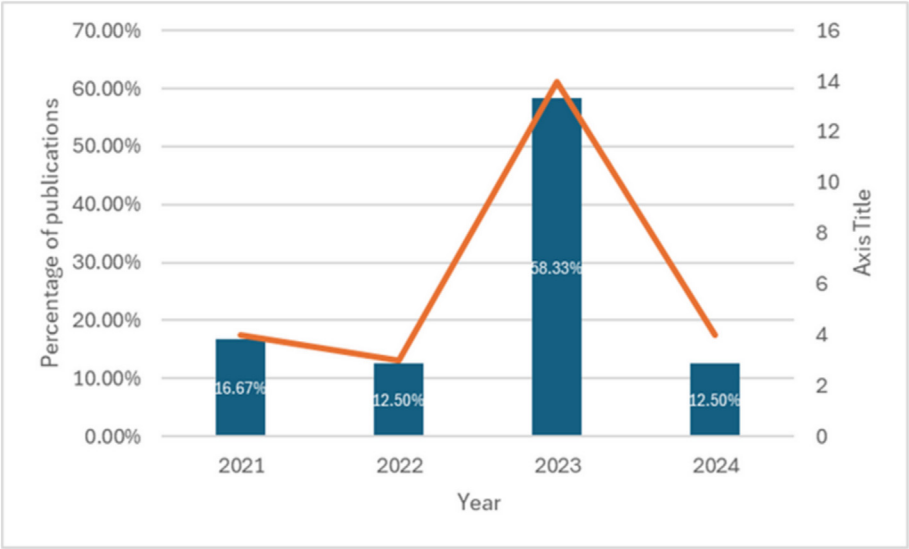

Fig. 3. The temporal distribution of the reviewed publications on DT-based DSS for disaster management.

Fig. 4. A keyword cloud illustrating the keywords that appeared most frequently in the reviewed publications.

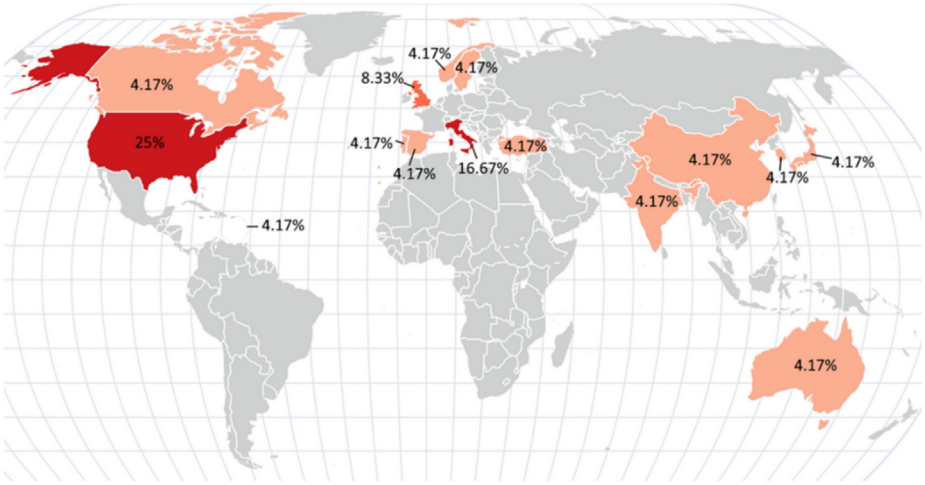

Fig. 5. The worldwide distribution of countries featured in the reviewed DT-based DSS for disaster management case studies.

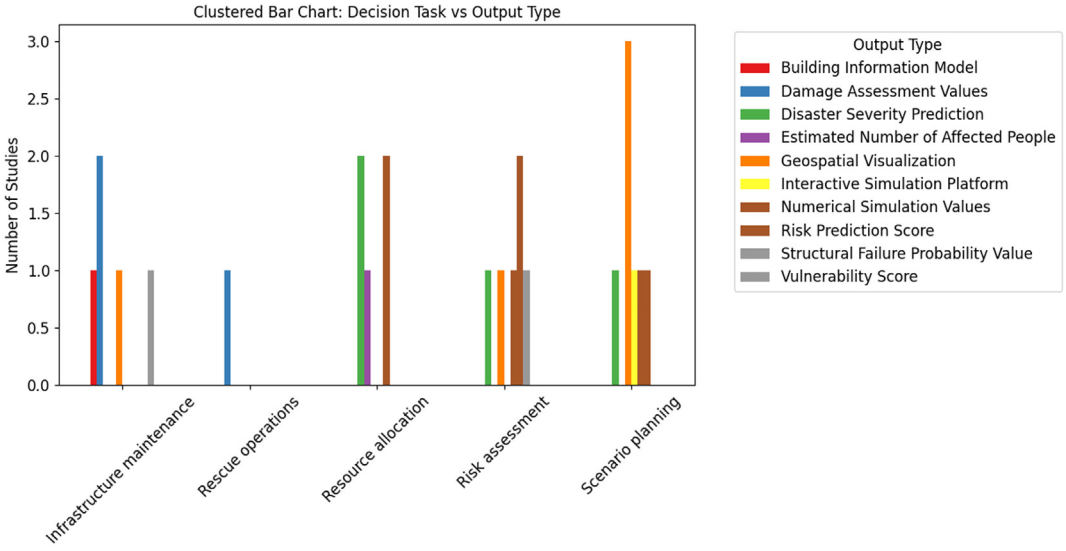

Fig. 6. A comparison between the outputs produced by the DTs in the reviewed publications and the decision tasks they are associated with.

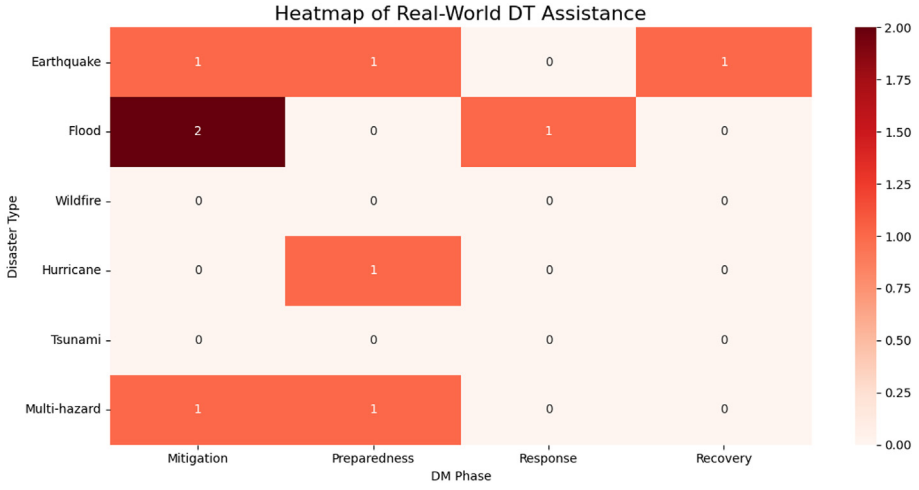

Fig. 7. The number of DTs that have provided real-world DM assistance for each disaster type and DM phase.

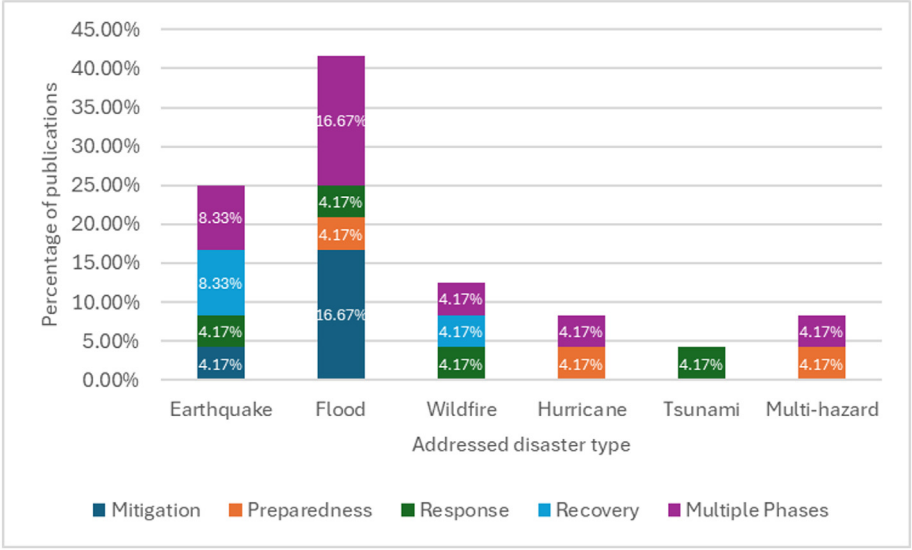

Fig. 8. The disaster types studied in the reviewed DT-based DSS publications and the DM phases being addressed.

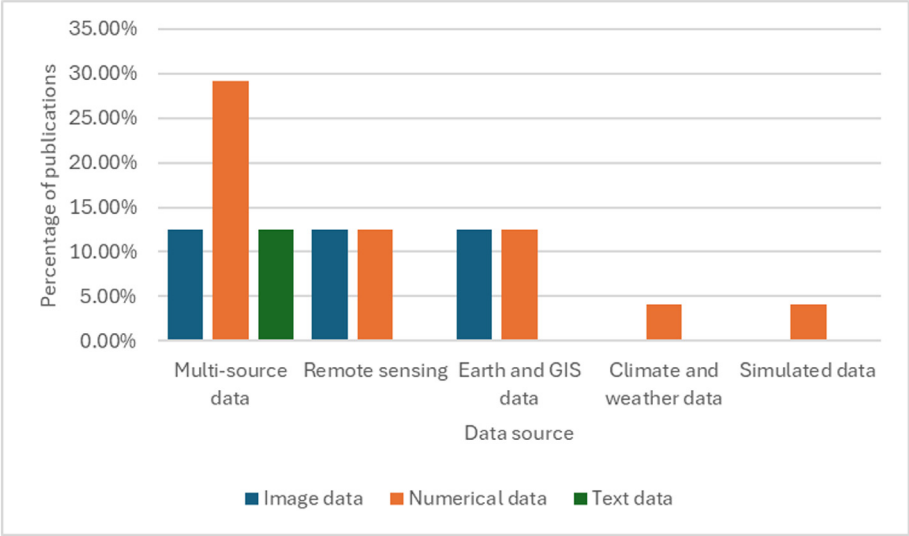

Fig. 9. The data sources and data types used to develop DT-based DSS for disaster management in the reviewed publications.

Table 1
Summary of research questions, findings and identified research gaps based on the reviewed publications.

Research Question	Findings	Research Gap
RQ 1 - What are the most common disaster types that have been studied in the DT-based DSS for DM literature?	Earthquakes, floods, and wildfires are the most commonly studied disasters.	There is a lack of DT cases studies on disasters in non-urban locations and no studies conducted in Africa or South America.
RQ 2 - What data sources and data types have been used to develop DT-based DSS for DM?	Most DTs for DM use multi-source heterogeneous data for DT development.	Expert knowledge is rarely used as a data source during DT development.
RQ 3 - What computational methods have been used to create virtual models of disaster situations in DT-based DSS for DM?	Many DT implementations use a combination of process-based models, 3D modelling and ML.	There are very few computational methods that can be used to develop virtual DT models for disaster situations with limited data availability.
RQ 4 - How have DTs been used to facilitate decision making in each phase of DM?	DTs primarily provide decision support for multiple phases of DM through scenario planning and disaster risk assessment.	There is a lack of DT-based DSS that facilitate interorganizational collaborative decision making for DM.

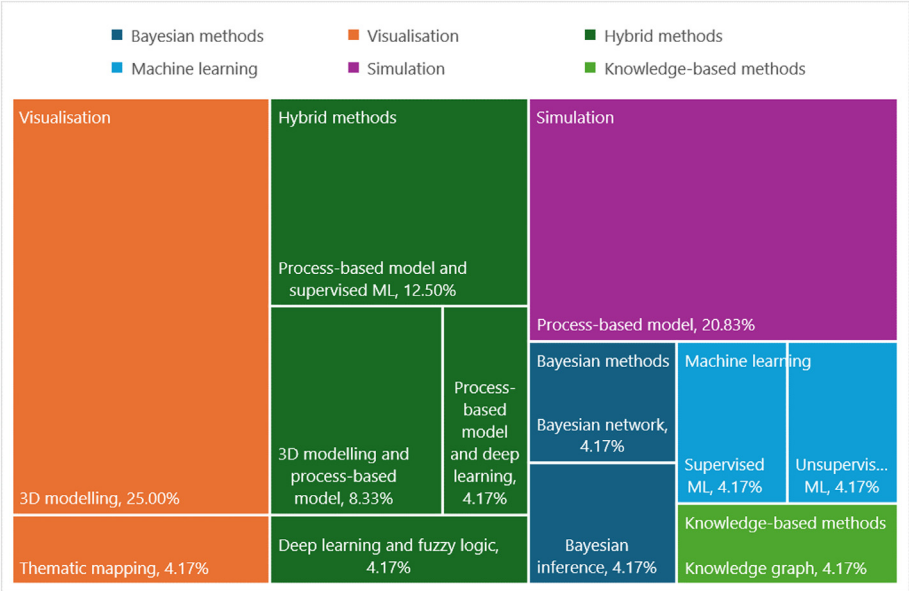

Fig. 10. The six categories of techniques mentioned in the reviewed DT-based DSS for disaster management publications.

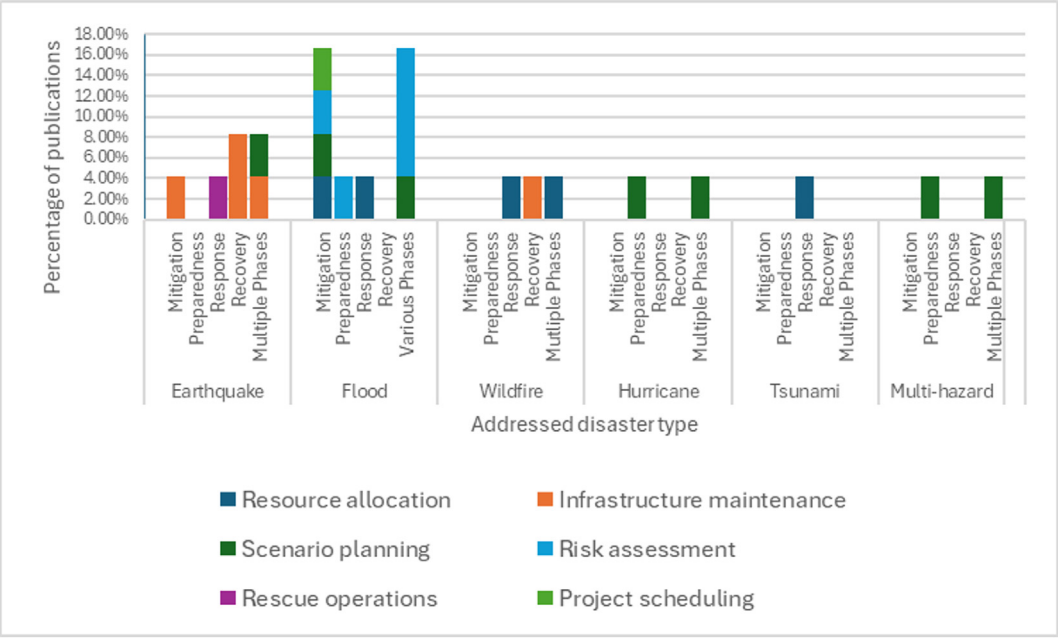

Fig. 11. The decision-making applications mentioned in the reviewed DT-based DSS for disaster management publications and the DM phases being addressed.

CRediT authorship contribution statement

Solomon Inyang: Writing – original draft, Visualization, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Firouzeh Rosa Taghikhah:** Writing – review & editing, Validation, Supervision.

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Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Data availability

Data will be made available on request.

References

[1] B.D. Song, S. Jun, S. Lee, Integrated System Design for Post-Disaster Management: Multi-Facility, Multi-Period, and Bi-Objective Optimization Approach, Systems 12 (3) (2024) 69.
[2] W. Purcell, T. Neubauer, Digital Twins in Agriculture: A State-of-the-art review, Smart Agricultural Technology 3 (2023) 100094.

Further readings

[1] S. Ghaffarian, F.R. Taghikhah, H.R. Maier, Explainable artificial intelligence in disaster risk management: achievements and prospective futures, International Journal of Disaster Risk Reduction 98 (2023), 104123.
[2] K.S. Haque, M. Uddin, J.D. Ampah, M.K. Haque, M.S. Hossen, M. Rokonuzzaman, ... M.Z. Rahman, Wildfires in Australia: a bibliometric analysis and a glimpse on 'black summer'(2019/2020) disaster, Environ. Sci. Pollut. Res. 30 (29) (2023) 73061–73086.
[4] M. Grieves, J. Vickers, Digital twin: Mitigating unpredictable, undesirable emergent behavior in complex systems, Transdisciplinary Perspectives on Complex Systems: New Findings and Approaches 2017, pp. 85–113.
[6] M. Segovia, J. Garcia-Alfaro, Design, modeling and implementation of digital twins, Sensors 22 (14) (2022) 5396.
[7] A.M. Braik, M. Koliou, A novel digital twin framework of electric power infrastructure systems subjected to hurricanes, International Journal of Disaster Risk Reduction 97 (2023), 104020.
[8] C. Chioni, C. Pezzica, S. Favargiotti, Territorial digital twins: a key for increasing the community resilience of fragile mountain inner territories? Sustain. Dev. 32 (2023) 1548–1563.
[9] F. Espejo, J.L. Molina, S. Zazo, R. Muñoz-Sánchez, C. Patino-Alonso, Low-cost "buffer" structural measure for flooding risk reduction in irrigation reservoirs, J. Hydrol. 131017 (2024).
[10] F. Ghahari, N. Malekghaini, H. Ebrahimian, E. Taciroglu, Bridge digital twinning using an output-only Bayesian model updating method and recorded seismic measurements, Sensors 22 (3) (2022) 1278.
[11] F. Ghahari, D. Swensen, H. Haddadi, E. Taciroglu, A hybrid model-data method for seismic response reconstruction of instrumented buildings, Earthq. Spectra 87552930241231686 (2024).
[12] M. Ghaith, A. Yosri, W. El-Dakhakhni, Digital twin: A city-scale flood imitation framework, Canadian Society of Civil Engineering Annual Conference, Springer Nature Singapore, Singapore 2021, May, pp. 577–588.
[13] M. Hofmeister, G. Brownbridge, M. Hillman, S. Mosbach, J. Akroyd, K.F. Lee, M. Kraft, Cross-domain flood risk assessment for smart cities using dynamic knowledge graphs, Sustain. Cities Soc. 101 (2024), 105113.
[14] N.M. Levine, Y. Narazaki, B.F. Spencer Jr., Development of a building information model-guided post-earthquake building inspection framework using 3D synthetic environments, Earthq. Eng. Eng. Vib. 22 (2) (2023) 279–307.
[15] S. Liasi, N.S. Ghiasi, R. Hadidi, An evaluative framework for regional vulnerability and power system resilience against flooding: A case study of Charleston County, South Carolina, 2023 IEEE International Conference on Energy Technologies for Future Grids (ETFG), IEEE 2023, December, pp. 1–6.
[16] A. Manocha, S.K. Sood, M. Bhatia, Digital twin-assisted fuzzy logic-inspired intelligent approach for flood prediction, IEEE Sensors J. (2023). https://doi.org/10.1109/JSEN.2023.3322535.
[17] D. Park, H. You, A digital twin dam and watershed management platform, Water 15 (11) (2023) 2106.
[18] A. Rodrigues da Silva, J. Estima, J. Marques, I. Gamito, A. Serra, L. Moura, ... R.M. Ferreira, A web GIS platform to modeling, simulate and analyze flood events: the RiverCure portal, ISPRS Int. J. Geo Inf. 12 (7) (2023) 268.
[19] N. Rojas-Mercedes, K. Erazo, L. Di Sarno, Seismic fragility curves for a concrete bridge using structural health monitoring and digital twins, Earthquake and Structures 22 (5) (2022) 503–515.
[20] S. Sabri, K. Alexandridis, M. Koohikamali, S. Zhang, H.E. Ozkaya, Designing a spatially-explicit urban digital twin framework for smart water infrastructure and flood

management, 2023 IEEE 3rd International Conference on Digital Twins and Parallel Intelligence (DTPI), IEEE 2023, November, pp. 1–9.
[21] R. Teeuw, M. Cannata, A.V. Argyriou, O. Lieberman, Geoinformatics for Caribbean hurricane risk management and improved community resilience, 2023 Joint Urban Remote Sensing Event (JURSE), IEEE 2023, May, pp. 1–4.
[22] M. Truu, I. Annus, J. Roosimägi, N. Kändler, A. Vassiljev, K. Kaur, Integrated decision support system for pluvial flood-resilient spatial planning in urban areas, Water 13 (23) (2021) 3340.
[23] F.M. Ugliotti, A. Osello, M. Daud, O.O. Yilmaz, Enhancing risk analysis toward a landscape digital twin framework: amulti-Hazard approach in the context of a socio-economic perspective, Sustainability 15 (16) (2023), 12429.
[24] S. Yu, Q. Lei, C. Liu, N. Zhang, S. Shan, X. Zeng, Application research on digital twins of urban earthquake disasters, Geomat. Nat. Haz. Risk 14 (1) (2023), 2278274.
[25] P. Jiang, N. Meinert, H. Jordão, C. Weisser, S. Holgate, A. Lavin, ... P. Barnard, Digital Twin Earth–Coasts: Developing a fast and physics-informed surrogate model for coastal floods via neural operators, 2021 arXiv preprint arXiv:2110.07100.
[26] Ö. Doğan, O. Şahin, E. Karaarslan, Digital twin based disaster management system proposal: DT-DMS, Journal of Emerging Computer Technologies 1 (2) (2021) 25–30.
[27] S.J. Yun, J.W. Kwon, W.T. Kim, A novel digital twin architecture with similarity-based hybrid modeling for supporting dependable disaster management systems, Sensors 22 (13) (2022) 4774.
[28] M. Zamari, A Proposal for a Wildfire Digital Twin Framework through Automatic Extraction of Remotely Sensed Data: The Italian Case Study of the Susa Valley, Doctoral dissertation Politecnico di Torino, 2023.
[29] C. Zhong, S. Cheng, M. Kasoar, R. Arcucci, Reduced-order digital twin and latent data assimilation for global wildfire prediction, Nat. Hazards Earth Syst. Sci. 23 (5) (2023) 1755–1768.
[30] S. Koshimura, E. Mas, Digital twin computing for enhancing resilience of disaster response system, EGU General Assembly Conference Abstracts, 2023, May , (pp. EGU-11756).

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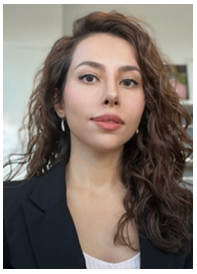

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