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INTEGRATING BIM AND SEISMIC RISK ASSESSMENT: AN AUTOMATED FRAMEWORK FOR RISK-INFORMED EARLY DESIGN

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Abstract

In recent years, BIM (Building Information Modeling) methodologies have become an essential and effective tool for managing a civil engineering project in all its stages. BIM technology provides comprehensive digital insights into a building or infrastructure's structural and non-structural elements. This study introduces a practical, BIM-based framework designed to serve as an intuitive decision-support tool, enabling seismic risk-aware design choice from the early stages of the project. The framework combines a BIM model with seismic risk data such as fragility curves and hazard curves. The process begins with inserting a generic placeholder component into the BIM model. The system then identifies possible alternatives with predefined fragility parameters and calculates seismic risk using location-specific hazard curves. An acceptable risk threshold is defined by the user, and the component with the lowest cost that meets this threshold is selected and automatically updated in the model. The current implementation is focused on MEP components and demonstrated through a case study involving a diesel generator in a wastewater pumping station. Results highlight the benefits of shifting seismic design considerations to early stages. While the current study operates at the component level, future work aims to expand the framework to analyse whole systems and incorporate multi-hazard scenarios. The presented approach enhances the integration of risk and cost into early design, supporting more resilient and efficient infrastructure planning.

Keywords: Building Information Modeling (BIM), Seismic Risk Assessment, Structural Optimization, Fragility Curves, Infrastructure Resilience

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1. Introduction

Over recent decades, modern societies have become increasingly reliant on Critical Infrastructure (CI) for delivering essential services crucial to public health, economic stability, and societal well-being. CI, such as transportation networks, water and wastewater systems, power grids, communication networks, and emergency services, form the backbone of contemporary society [1]. An uninterrupted functioning of these systems is essential for public health, economic stability, and the overall well-being of society. Furthermore, Critical Infrastructures (CI) are inherently complex systems characterized by numerous interdependencies among various infrastructure sectors. Consequently, disruptions within one sector can quickly propagate to others, triggering severe cascading and ripple effects that extend well beyond the initial point of failure, significantly amplifying overall societal, economic, and operational impacts [2], [3], [4], [5], [6].

Seismic hazards pose significant threats to the integrity and continuous operation of CI, often causing devastating economic impacts and tragic loss of human life that extend far beyond physical damage [7], [8], [9], [10]. Recent seismic events, such as the earthquakes in Mexico City (2017), Turkey and Syria (2023), Noto, Japan (2024), and Myanmar (2025), have clearly illustrated the human and societal consequences of such disasters [11], [12], [13], [14]. These events highlighted critical gaps and vulnerabilities in current infrastructure design, operational procedures, and maintenance practices,

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underscoring the urgent need for developing practical frameworks dedicated to seismic risk assessment and management.

The seismic risk assessment process presents a significant challenge, particularly because CI are complex systems composed of interconnected and interdependent components. Traditional risk assessment approaches frequently overlook the vulnerabilities of individual components within these systems [15], [16], [17]. Moreover, typical assessments often concentrate primarily on structural elements, leaving mechanical, electrical, and plumbing (MEP) systems without a dedicated seismic evaluation. However, components, such as pumps, HVAC systems, electrical panels, and sensors, can sustain damage or experience disruptions due to their specific seismic vulnerabilities. Consequently, the failure of even a single component may damage the overall functionality of the entire infrastructure system, intensify the operational damages, and considerably extend recovery periods [17], [18], [19], [20].

Building Information Modeling (BIM) has gained extensive recognition and application within the architecture, engineering, and construction (AEC) sectors [21], [22], [23]. By digitally representing both physical and functional characteristics of structures and infrastructure systems, BIM facilitates improved interdisciplinary collaboration, optimized design processes, effective construction coordination, and comprehensive lifecycle management [24], [25], [26], [27]. BIM provides a comprehensive digital database that include the geometry, materials, and performance characteristics for each component and object in the model. However, despite BIM's proven benefits and widespread adoption, its potential for seismic risk assessment and management remains significantly underutilized.

Early design stage in a construction project provides a window of opportunity to examine design alternatives for project components. In BIM methodology, Levels of Development (LOD) 200–300 are corresponding to this stage, where foundational decisions regarding system components and layout, material selection, and component configuration are established during this stage. The decision made in this stage can highly affect the function of the system after the construction. The goal of this paper is to propose a framework for integrating seismic risk assessment into the BIM model, incorporating it during the early design stage to support informed decision-making and enhance infrastructure resilience. The proposed framework aims to create a decision support tool for engineers for optimizing component selection by systematically evaluating seismic performance, reliability, and cost-effectiveness. Leveraging BIM tools and scripting capabilities, the framework integrates fragility curves, hazard curves, and predefined performance thresholds directly into the digital model, facilitating automated, component-level seismic risk assessment. Its primary objective is to evaluate the vulnerability of individual components and identify optimal alternatives with minimal manual intervention. As a result, the framework enhances design efficiency, minimizes the risk of late-stage modifications, and supports the development of resilient infrastructure aligned with both seismic demands and project-specific constraints.

2. Methodology

The proposed methodology embeds a fully probabilistic seismic-risk workflow directly within the BIM environment, specifically targeted for early design stages (LOD 200/300). The methodological framework, as outlined in Figure 1, illustrates the systematic integration of seismic hazard and fragility analyses within a BIM environment, utilizing Dynamo and Python scripting to automate the selection of optimal components based on predefined risk thresholds and cost considerations.

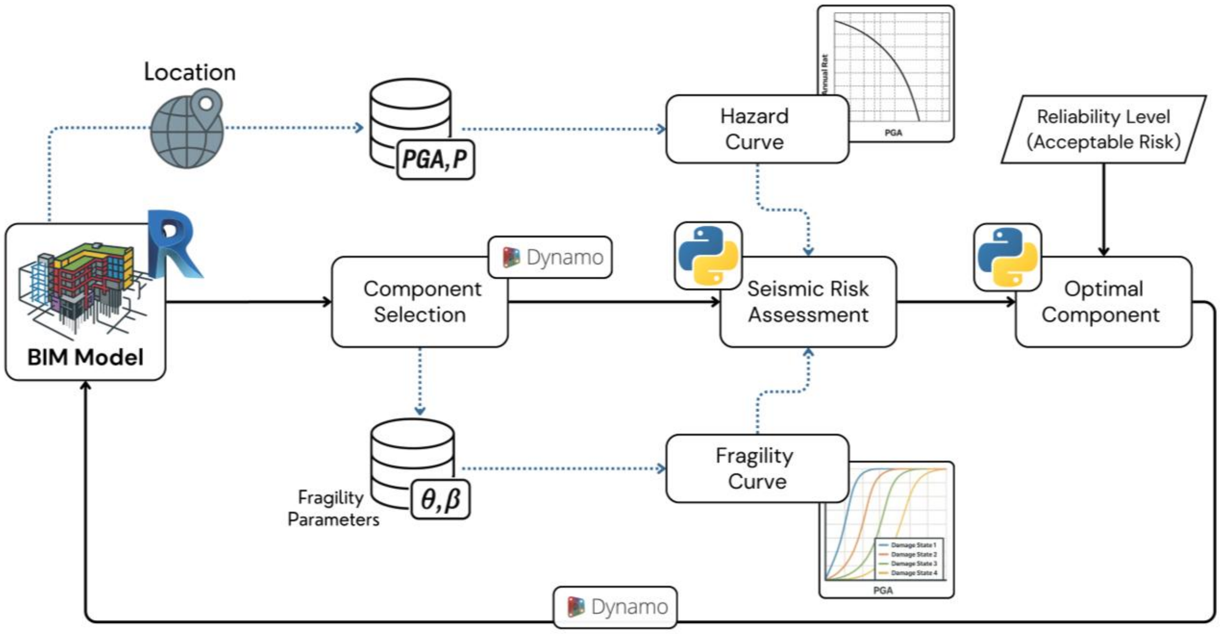


Figure 1 - Schematic representation of the proposed BIM-integrated workflow for seismic risk assessment

2.1. BIM Model

The process initiates by creating a BIM model at LOD 200/300, detailed enough to enable component-level analysis yet flexible for design adjustments. This stage includes:

- Generating an initial BIM model during the preliminary design stage.
- Incorporating placeholder objects representing candidate structural and non-structural components.
- Defining basic geometric information and spatial relationships.
- Assigning approximate dimensions, locations, and preliminary material specifications.
- Establishing functional requirements for systems and components.

2.2. Component Selection

In this phase, critical components requiring seismic assessment are identified within the BIM model. The selection process considers:

- Components essential for system functionality
- Elements with known seismic vulnerabilities
- Components where failure would lead to cascading effects
- Elements with multiple possible design alternatives

For each selected component, alternative design options are identified, which will be evaluated for their seismic performance and cost.

2.3. Seismic Risk Assessment

For every component alternative, a seismic risk assessment is performed through the following steps:

2.3.1. Fragility Parameters Assignment

Fragility parameters are assigned based on established literature, manufacturer specifications, or engineering analysis. These include:

- Median capacity (θ_{ds}) - The median capacity of the component to resist a damage state ds measured in terms of the ground motion intensity measure

- Dispersion (β_{ds}) - The logarithmic standard deviation of the uncertain capacity of the component to resist a damage state

These parameters form the basis of fragility curves (as illustrated in Figure 2), depicting the probability of exceeding specific damage states across varying seismic intensities.

2.3.2. Location-Specific Hazard Curve

A site-specific seismic hazard curve is derived from regional ground-motion data or through probabilistic seismic hazard analysis (PSHA). This curve represents the annual probability of exceeding various levels of ground motion intensity and the return periods for different seismic intensities (as illustrated in Figure 3). The hazard curve provides the probability context against which component vulnerabilities will be evaluated.

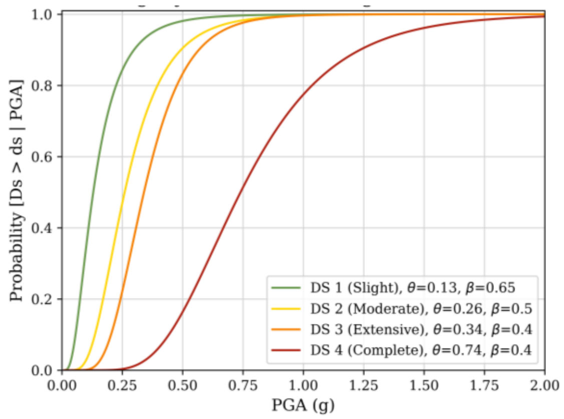


Figure 2 - Fragility curve

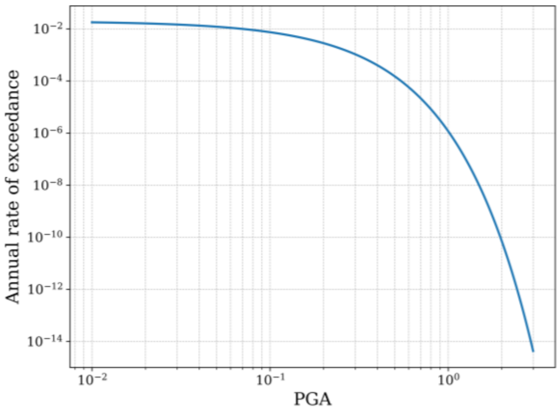


Figure 3 - Hazard curve

2.4. Optimal Component Selection

2.4.1. Risk Threshold Definition

The design team establishes an acceptable seismic-risk level (target reliability) that becomes the benchmark against which every alternative is evaluated. The consideration of the thresholds includes:

- Regulatory requirements
- Developed from organizational risk tolerance policies
- Aligned with infrastructure criticality and performance objectives
- Differentiated by component type and importance

These thresholds serve as clear pass/fail criteria for evaluating component alternatives.

2.4.2. Risk and Cost Ranking

Optimal component alternatives are identified through the following systematic process:

- Mean annual risk is computed by an integration of fragility and hazard curves
- Alternatives that meet or exceed the target reliability are identified
- Compliant options are ranked by life-cycle cost considerations
- The most cost-effective alternative is selected
- Design feasibility and compatibility with other systems are verified

This multi-criteria decision approach ensures that the selected alternative balances risk mitigation with economic constraints.

2.5. BIM Integration

The final phase involves integrating the selected optimal component alternatives back into the BIM model:

- Selected components replace generic placeholders in the model
- Component parameters are updated with detailed specifications
- Seismic performance data is attached as component attributes
- Visual indicators of seismic performance are incorporated

This integration creates a comprehensive BIM model that not only represents the physical infrastructure but also captures the seismic performance characteristics of its components, facilitating future design development, construction planning, and facility management activities.

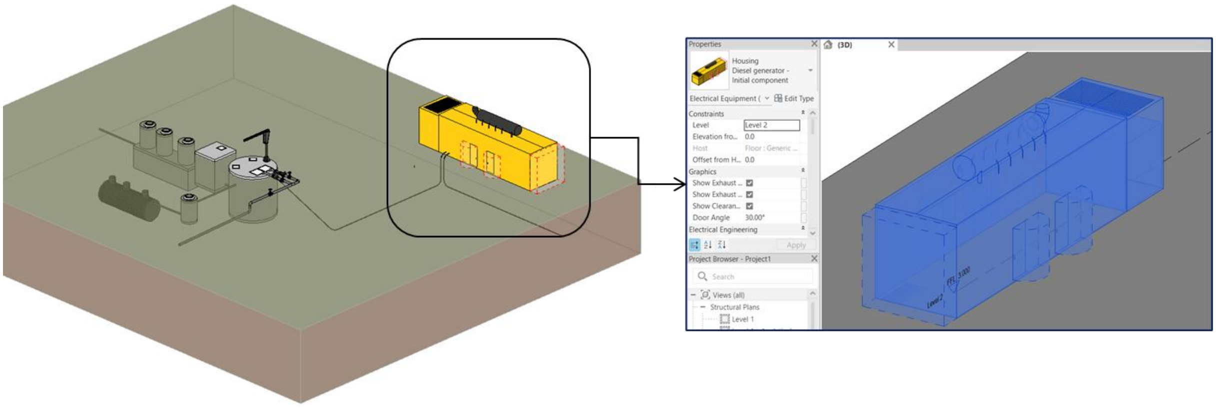
The methodology creates a systematic framework that leverages BIM's data-rich environment to enhance seismic resilience in critical infrastructure systems during early design stages when changes are most cost-effective to implement.

3. Case Study

To demonstrate the practical value of the proposed workflow, a simplified case study was conducted. The focus was placed on a diesel generator supplying backup electricity to a sewage-pumping station. Due to the criticality of its function, the generator must achieve high reliability under seismic conditions. The case study comprises two analyses: (1) the effect of varying seismic risk thresholds, and (2) the effect of changing seismic locations. Thus, the study evaluates whether alternative generator configurations meet predefined risk thresholds when the same facility is hypothetically situated in three distinct seismic regions: Be’er Sheva(Isreal), San Carlos (California, USA), and Los Angeles (California, USA).

3.1. BIM Environment and Initial Component

A BIM model of the plant was developed using Autodesk Revit. The diesel generator was incorporated as the initial electromechanical component and annotated with functional and geometric attributes essential for seismic risk computation (Figure 4). Specifically, the generator was defined with a functional requirement of up to 350 kVA.



Housing
Diesel generator - Initial component
Electrical Equipment (| Edit Type
Level: Level 2
Elevation fro...: 0.0
Host: Floor : Generic ...
Offset from H...: 0.0
Show Exhaust ...: ☑
Show Exhaust ...: ☑
Show Clearan...: ☑
Door Angle: 30.00°

Figure 4 - BIM representation of the sewage-pumping station and the diesel generator component

To automate data transfer and computation processes, Dynamo scripts were integrated directly into the Revit environment, facilitating seamless execution of the fragility-hazard risk assessment workflow.

3.2. Seismic Risk Assessment

The alternatives analyzed comprise three diesel generator configurations, each differentiated by their anchorage and isolation conditions:

1. Unanchored generator
2. Vibration-isolated generator (unanchored)
3. Vibration-isolated generator (anchored)

Fragility parameters for each configuration were adopted from the FEMA P-58 database, defining the median capacity (θ) and logarithmic standard deviation (β) per anchorage condition. Figure 5 presents the resulting fragility curves, illustrating the probability of exceedance versus peak ground acceleration (PGA) for each generator alternative.

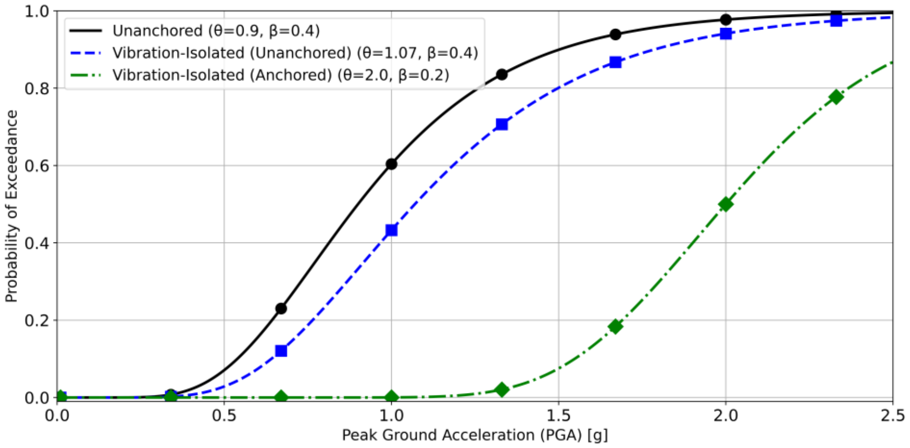


Figure 5 - Fragility curves for diesel generator configurations (capacity: 100–350 kVA)

To further quantify the seismic exposure at the three candidate sites, site-specific hazard curves were generated using exponential functions calibrated with local seismic data. As depicted in Figure 6, Be'er-Sheva demonstrates significantly lower annual exceedance probabilities across all PGA values, indicating a substantially reduced seismic hazard compared to San Carlos and Los Angeles.

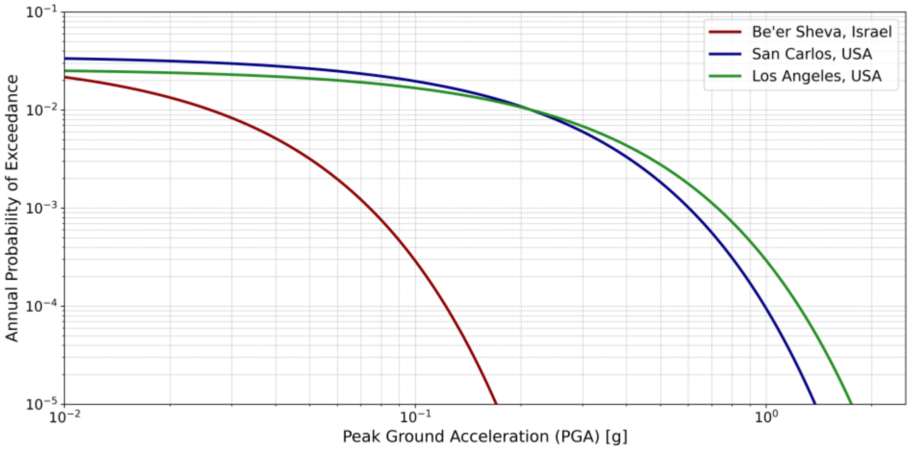


Figure 6 - Seismic hazard curves for Be’er Sheva, San Carlos, and Los Angeles.

4. Results

Figure 7 synthesises the optimal generator configuration for each combination of acceptable reliability level (Low, Moderate, High) and geographic location.

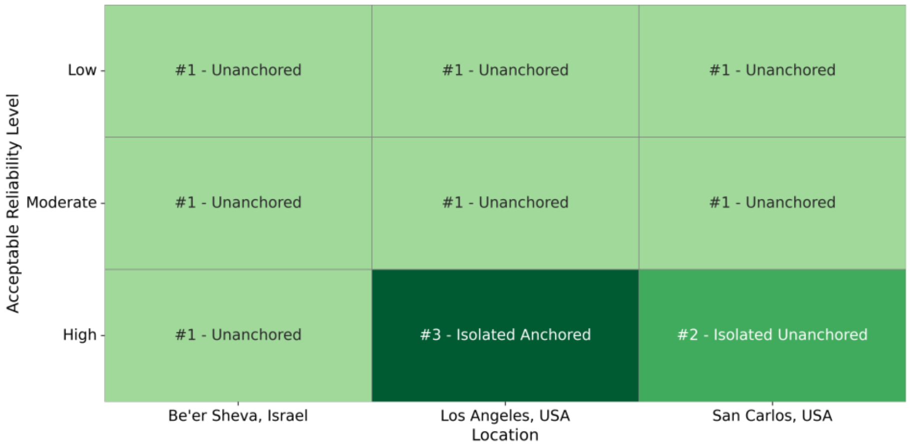


Figure 7 - Optimal generator configuration across various locations and acceptable reliability levels. Each cell represents the most cost-effective diesel generator type that satisfies the target reliability at the specified site

The result indicates that for both Low and Moderate acceptable reliability levels the unanchored generator (#1) is adequate at all three sites, because its probability of experiencing the first damage state remains below the corresponding thresholds even in the Californian hazard environment. When the requirement tightens to the High reliability level, geographic seismicity becomes decisive. Be’er Sheva, characterised by a much flatter hazard curve, still satisfies the limit with #1, whereas San Carlos requires the intermediate solution, a vibration-isolated but unanchored unit (#2), to offset the higher exceedance frequency of moderate PGAs. Los Angeles, having the largest annual exceedance rates, only meets the same target with the fully anchored and snubbed configuration (#3). In practical terms, the heat-map confirms that the workflow selects the least-cost generator that satisfies site-specific seismic-risk constraints, avoiding unnecessary upgrade costs in low-hazard regions while automatically enforcing enhanced detailing where the hazard demands it.

5. Limitation and Future Research

While this study introduces a robust methodology for integrating probabilistic seismic risk assessment within BIM environments, several limitations remain. For above-ground elements, additional calculations are required to account for floor-specific seismic motions, as the current approach assumes uniform ground-level inputs that may not reflect actual interstory dynamics. The framework also does not yet fully incorporate secondary hazard effects such as liquefaction, soil-structure interaction, or interstory drift, which are critical for assessing risks in multistory and complex structures. Furthermore, the methodology has been validated using a specific electromechanical component (diesel generator) in limited geographic settings, limiting its generalizability across diverse structural typologies. Additionally, the current model does not consider maintenance conditions, aging, and material deterioration over time, factors that are essential for realistically evaluating long-term component reliability and for informing proactive risk mitigation strategies.

Future research should focus on enhancing the proposed methodology by addressing current limitations and expanding its applicability. Key directions include incorporating floor-level motion modeling to better capture interstory seismic responses. The framework should also be extended to support a broader range of structural and non-structural components, allowing for more comprehensive risk evaluation across diverse building systems. Additionally, integrating multi-hazard scenarios[28], [29], [30], such as blast loads [31], [32], extreme winds [33], and other non-seismic threats, will enable a more resilient design approach. Finally, the use of machine learning (ML) and artificial intelligence (AI) techniques holds great potential for improving predictive accuracy and decision-making efficiency by learning from large datasets and identifying complex risk patterns that traditional models may overlook [34], [35].

6. Conclusion

This study introduced an innovative BIM-based methodology for integrating seismic risk assessment into the early stages of design. By employing a fully probabilistic approach, the methodology combines fragility and hazard curves directly within a BIM environment, enabling precise seismic risk evaluation at the individual component level. A decision-support algorithm developed as part of this research facilitates optimal selection of structural and electromechanical components based on predefined risk thresholds, reliability criteria, and economic efficiency. The application of this method was demonstrated through a case study involving a diesel generator, evaluated across geographically diverse seismic scenarios in Israel and the USA. Results revealed significant variations in component reliability, emphasizing the importance of site-specific seismic data integration during early design phases. This approach enhances decision-making accuracy, reduces uncertainty, and promotes economically efficient design solutions, significantly improving seismic resilience and structural safety. Future research should focus on expanding this methodology to broader multi-hazard scenarios, comprehensive building portfolios, and integration with lifecycle cost analyses.

References

[1] A. Urlainis, I. M. Shohet, and R. Levy, “Probabilistic risk assessment of oil and gas infrastructures for seismic extreme events,” *Procedia Eng*, vol. 123, pp. 590–598, 2015, doi: 10.1016/j.proeng.2015.10.112.

[2] G. Lifshitz Sherzer, A. Urlainis, S. Moyal, and I. M. Shohet, “Seismic Resilience in Critical Infrastructures: A Power Station Preparedness Case Study,” *Applied Sciences*, vol. 14, no. 9, p. 3835, Apr. 2024, doi: 10.3390/app14093835.

[3] G. Buffarini, P. Clemente, S. Giovinazzi, C. Ormando, M. Pollino, and V. Rosato, “Preventing and Managing Risks Induced by Natural Hazards to Critical Infrastructures,” *Infrastructures (Basel)*, vol. 7, no. 6, 2022, doi: 10.3390/infrastructures7060076.

[4] R. Zimmerman and C. E. Restrepo, “Analyzing cascading effects within infrastructure sectors for consequence reduction,” in *2009 IEEE Conference on Technologies for Homeland Security, HST 2009*, 2009, pp. 165–170. doi: 10.1109/THS.2009.5168029.

[5] G. Pescaroli and D. Alexander, “Critical infrastructure, panarchies and the vulnerability paths of cascading disasters,” *Natural Hazards*, 2016, doi: 10.1007/s11069-016-2186-3.

[6] A. Urlainis and I. M. Shohet, “Probabilistic risk appraisal and mitigation of critical infrastructures for seismic extreme events,” *Creative Construction Conference (CCC2018)*, 2018, doi: 10.3311/CCC2018-121.

[7] A. Urlainis, D. Ornai, R. Levy, O. Vilnay, and I. M. Shohet, “Loss and damage assessment in critical infrastructures due to extreme events,” *Saf Sci*, vol. 147, p. 105587, Mar. 2022, doi: 10.1016/J.SSCI.2021.105587.

[8] S. Espinoza, A. Poulos, H. Rudnick, J. C. De La Llera, M. Panteli, and P. Mancarella, “Risk and Resilience Assessment with Component Criticality Ranking of Electric Power Systems Subject to Earthquakes,” *IEEE Syst J*, vol. 14, no. 2, 2020, doi: 10.1109/JSYST.2019.2961356.

[9] N. Rencoret, A. Stoddard, K. Haver, G. Taylor, and P. Harvey, “Haiti earthquake response: Context analysis,” 2010.

[10] S. Girgin, “The natech events during the 17 August 1999 Kocaeli earthquake: Aftermath and lessons learned,” *Natural Hazards and Earth System Science*, vol. 11, no. 4, 2011, doi: 10.5194/nhess-11-1129-2011.

[11] E. N. Cinar, A. Abbara, and E. Yilmaz, “Earthquakes in Turkey and Syria-collaboration is needed to mitigate longer terms risks to health,” 2023. doi: 10.1136/bmj.p559.

[12] A. Tena-Colunga, E. A. Godínez-Domínguez, and H. Hernández-Ramírez, “Seismic retrofit and strengthening of buildings. Observations from the 2017 Puebla-Morelos earthquake in Mexico City,” *Journal of Building Engineering*, vol. 47, 2022, doi: 10.1016/j.jobe.2021.103916.

[13] J. Montgomery, G. Candia, A. Lemnitzer, and A. Martinez, “The September 19, 2017 Mw 7.1 Puebla-Mexico City earthquake: Observed rockfall and landslide activity,” *Soil Dynamics and Earthquake Engineering*, vol. 130, 2020, doi: 10.1016/j.soildyn.2019.105972.

[14] C. M. Wood, M. Deschenes, C. Ledezma, J. Meneses, G. Montalva, and A. C. Morales-Velez, “Dynamic site characterization of areas affected by the 2017 Puebla-Mexico city earthquake,” *Soil Dynamics and Earthquake Engineering*, vol. 125, 2019, doi: 10.1016/j.soildyn.2019.105704.

[15] FEMA, “Hazus Earthquake Model Technical Manual - Hazus 5.1,” 2022, *Federal Emergency Management Agency (FEMA)*.

[16] NIBS, “Hazus Earthquake Model Technical Manual Hazus 4.2 SP3,” 2020.

[17] P. Gehl, N. Desramaut, A. Réveillère, and H. Modaressi, “Fragility Functions of Gas and Oil Networks,” in *SYNER-G: Typology Definition and Fragility Functions for Physical Elements at Seismic Risk*, 1st ed., vol. 1, Dordrecht: Springer, 2014, ch. 7. doi: 10.1007/978-94-007-7872-6.

[18] A. Urlainis and I. M. Shohet, “Seismic Risk Mitigation and Management for Critical Infrastructures Using an RMIR Indicator,” *Buildings*, vol. 12, no. 10, Oct. 2022, doi: 10.3390/buildings12101748.

[19] A. Urlainis and I. M. Shohet, “Development of exclusive seismic fragility curves for critical infrastructure: an oil pumping station case study,” *Buildings* , vol. 12, no. 842, Jun. 2022, doi: 10.3390/buildings12060842.

[20] A. Urlainis, G. Lifshitz Sherzer, and I. M. Shohet, “Multi-Scale Integrated Corrosion-Adjusted Seismic Fragility Framework for Critical Infrastructure Resilience,” *Applied Sciences*, vol. 14, no. 19, p. 8789, Sep. 2024, doi: 10.3390/app14198789.

[21] A. Mitelman and U. Gurevich, “Implementing bim for conventional tunnels - A proposed methodology and case study,” *Journal of Information Technology in Construction*, vol. 26, 2021, doi: 10.36680/j.itcon.2021.034.

[22] U. Gurevich and R. Sacks, “Longitudinal Study of BIM Adoption by Public Construction Clients,” *Journal of Management in Engineering*, vol. 36, no. 4, 2020, doi: 10.1061/(asce)me.1943-5479.0000797.

[23] A. Urlainis and A. Mitelman, “Implementation of a BIM Workflow for Building Permit Coordination in Urban Metro Projects,” *Journal of Information Technology in Construction*, vol. 30, pp. 319–334, Mar. 2025, doi: 10.36680/j.itcon.2025.013.

[24] O. Fernández García *et al.*, "Modelling As-Built MEP Facilities in a BIM Environment," in *Lecture Notes in Mechanical Engineering*, 2020. doi: 10.1007/978-3-030-41200-5_54.

[25] T. Q. Nguyen, E. C. W. Lou, and B. N. Nguyen, "A theoretical BIM-based framework for quantity take-off to facilitate progress payments: the case of high-rise building projects in Vietnam," *International Journal of Building Pathology and Adaptation*, vol. 42, no. 4, 2024, doi: 10.1108/IJBPA-10-2021-0139.

[26] D. Shah, H. Kathiriya, H. Suthar, P. Pandya, and J. Soni, "Enhancing the Building's Energy Performance through Building Information Modelling—A Review," in *Lecture Notes in Civil Engineering*, 2023. doi: 10.1007/978-981-19-2145-2_20.

[27] S. Isaac and M. Shimanovich, "Automated scheduling and control of mechanical and electrical works with BIM," *Autom Constr*, vol. 124, 2021, doi: 10.1016/j.autcon.2021.103600.

[28] A. Urlainis, M. Paciuk, and I. M. Shohet, "Service Life Prediction and Life Cycle Costs of Light Weight Partitions," *Applied Sciences*, vol. 14, no. 3, p. 1233, Feb. 2024, doi: 10.3390/app14031233.

[29] D. M. Frangopol, D. Saydam, and S. Kim, "Maintenance, management, life-cycle design and performance of structures and infrastructures: a brief review," *Structure and Infrastructure Engineering*, vol. 8, no. 1, 2012, doi: 10.1080/15732479.2011.628962.

[30] A. Urlainis and I. M. Shohet, "A Comprehensive Approach to Earthquake-Resilient Infrastructure: Integrating Maintenance with Seismic Fragility Curves," *Buildings*, vol. 13, no. 9, p. 2265, Sep. 2023, doi: 10.3390/buildings13092265.

[31] T. Borenshtain, A. Urlainis, and A. Mitelman, "3D simulations of large blast loads above underground tunnels," *International Journal of Protective Structures*, Apr. 2025, doi: 10.1177/20414196251333080.

[32] A. Mitelman and D. Elmo, "Modelling of blast-induced damage in tunnels using a hybrid finite-discrete numerical approach," *Journal of Rock Mechanics and Geotechnical Engineering*, vol. 6, no. 6, 2014, doi: 10.1016/j.jrmge.2014.09.002.

[33] S.-G. G. Yum, J.-M. M. Kim, and H. H. Wei, "Development of vulnerability curves of buildings to windstorms using insurance data: An empirical study in South Korea," *Journal of Building Engineering*, vol. 34, p. 101932, Feb. 2020, doi: 10.1016/j.jobe.2020.101932.

[34] A. Mitelman and A. Urlainis, "Investigation of Transfer Learning for Tunnel Support Design," *Mathematics*, vol. 11, no. 7, p. 1623, Mar. 2023, doi: 10.3390/math11071623.

[35] T. Eilat, A. McQuillan, and A. Mitelman, "Machine Learning-Enhanced Analysis of Small-Strain Hardening Soil Model Parameters for Shallow Tunnels in Weak Soil," *Geotechnics*, vol. 5, no. 2, p. 26, Apr. 2025, doi: 10.3390/geotechnics5020026.