Interreg Co-funded by the European Union

Italy – Croatia

STRENGTH

D.2.6.2
Report about risk-informed decision methodology

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Project acronym	STRENGTH
Project full title	STRategies for assessing climate change and natural hazards' impact on urban ecosystems, increasing resilience to ENvironmental hazards, and promoting territorial GrowTH
Programme	Interreg Italy-Croatia 2021-2027
Start date	01/04/2024
End date	30/09/2026
Project ID	ITHR0200318

Deliverable Title	D.2.6.2 - Report about risk-informed decision methodology
Activity	6. Fragility curves for climate- change-hazards resilient buildings
WP	2
WP Leading Partner	UNIFE
Contributing Partners	UNIFE
Dissemination level	Confidential
Version	Finalized
Date	18/07/2025

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Executive Summary

This report implements the vulnerability assessment framework developed in Deliverable 2.6.1, applying it specifically to buildings in the Mezzano area within the Ravenna Municipality. Utilizing detailed building data from Ravenna's open data repository, we apply the structural fragility model developed by Milanesi et al. (2018), incorporating local flood scenarios defined by return periods from the CLIMAAX handbook. The analysis includes comprehensive sensitivity assessments to evaluate how variations in critical structural parameters, including wall characteristics and floor height, influence building vulnerability. The outcomes, communicated through detailed spatial maps and visualizations, support targeted, informed decision-making, facilitating enhanced flood resilience and effective urban planning strategies.

1. Introduction

The Mezzano area, situated within the Ravenna Municipality, is particularly susceptible to flooding, an issue increasingly exacerbated by climate change. Addressing this vulnerability necessitates resilient methodologies that quantify and visualize structural risks accurately. This deliverable builds upon the analytical and methodological foundations established in *Deliverable 2.6.1*. By focusing specifically on Mezzano, the study integrates structural fragility analyses—employing the *Milanesi et al. (2018)* model—to assess the vulnerability of local buildings under clearly defined flood scenarios from the *CLIMAAX handbook*. Results derived from the analysis, enhanced by sensitivity studies, offer practical insights into structural vulnerabilities and support local stakeholders in developing resilient urban environments.

1.1. Area of Interest

The aerial map provides a clear geographical context of *the Mezzano area within Ravenna Municipality*, highlighting the primary area of interest for vulnerability assessment. The marked radius defines the boundary of the case study zone, within which building data were systematically analyzed for flood vulnerability using the structural fragility framework. This geographical reference supports targeted and precise spatial vulnerability assessments and visualization of flood risks.

Figure 1: Mezzano Case Study

2. Methodology Application

2.1. Data Acquisition and Preprocessing

The data utilized for this analysis were sourced from the *Ravenna Municipality open data portal*, providing detailed information for buildings located in the Mezzano area. Building structural characteristics and damage-state definitions follow established standards and typologies described comprehensively in *FEMA P-58 (2012)* ensuring consistent vulnerability assessments. This dataset includes attributes essential for conducting structural vulnerability assessments, such as building height, base area, and perimeter. These parameters directly facilitate the calculation of wall lengths and areas, critical inputs to structural modeling. The dataset also includes ancillary information such as the year of construction and building usage type, crucial for defining structural parameters and assigning boundary conditions accurately.
Prior to conducting the fragility analyses, the data underwent precise preprocessing:

- Verification and correction of missing or inconsistent data points.

- Estimation of building structural characteristics (e.g., wall length and perimeter) using geometrical relationships derived from the available data.
- Categorization and segmentation based on building usage type (e.g., residential, commercial, industrial) and construction year to better inform the assignment of appropriate structural and boundary condition parameters.

2.2. Structural Fragility Analysis

The methodology applied in this analysis follows the simplified structural fragility model proposed by *Milanesi et al. (2018)*. This model assesses the vulnerability of masonry buildings to flooding, explicitly considering critical factors such as:

- Wall thickness
- Wall density
- Building height and floor height
- Wall opening fraction
- Boundary conditions (categorized into mechanisms P1–P4)

Given the absence of direct wall characteristics data in the dataset, these parameters were assigned based on standard regional construction practices and building codes relevant to the year of construction and building usage. The boundary conditions for each building were determined similarly, considering regional design codes, typical construction methods, and building use categories.

2.3. Flood Scenarios

The flood scenarios considered in this analysis were derived from the *CLIMAAX handbook*, covering a range of return periods. Each scenario provides water depths corresponding to specific flood return periods, which served as critical inputs for vulnerability assessments:

- 10-year return period
- 50-year return period
- 100-year return period
- 200-year return period

Additionally, standard predefined water depths were analyzed to provide a hypothetical overall flood scenario of structural vulnerabilities under a broad spectrum of flooding conditions.

2.4. Sensitivity Analysis

A detailed sensitivity analysis was performed to evaluate the robustness of vulnerability assessments, systematically varying two main parameters:

- Wall Quality: Ten distinct wall quality types, ranging from weakest (Level 1) to strongest (Level 10), were analyzed.

Wall Quality Level	Opening Fraction	Wall Density (kg/m³)	Thickness (m)
1	0.29	1600	0.20
2	0.27	1620	0.22
3	0.25	1650	0.24
4	0.24	1675	0.26
5	0.23	1700	0.28
6	0.22	1750	0.30
7	0.22	1850	0.32
8	0.21	1900	0.34
9	0.21	1900	0.36
10	0.20	2000	0.40

Table 1: Wall Quality Levels and their values

Table 1 and Figure 2 3D plot illustrate ten distinct wall quality metrics used in the sensitivity analysis. Each quality level from 1 (lowest quality) to 10 (highest quality) is characterized by three critical structural parameters: wall thickness (m), wall density (kg/m³), and wall opening fraction. The visualization effectively demonstrates how incremental enhancements in wall characteristics substantially influence building resilience to flood hazards.

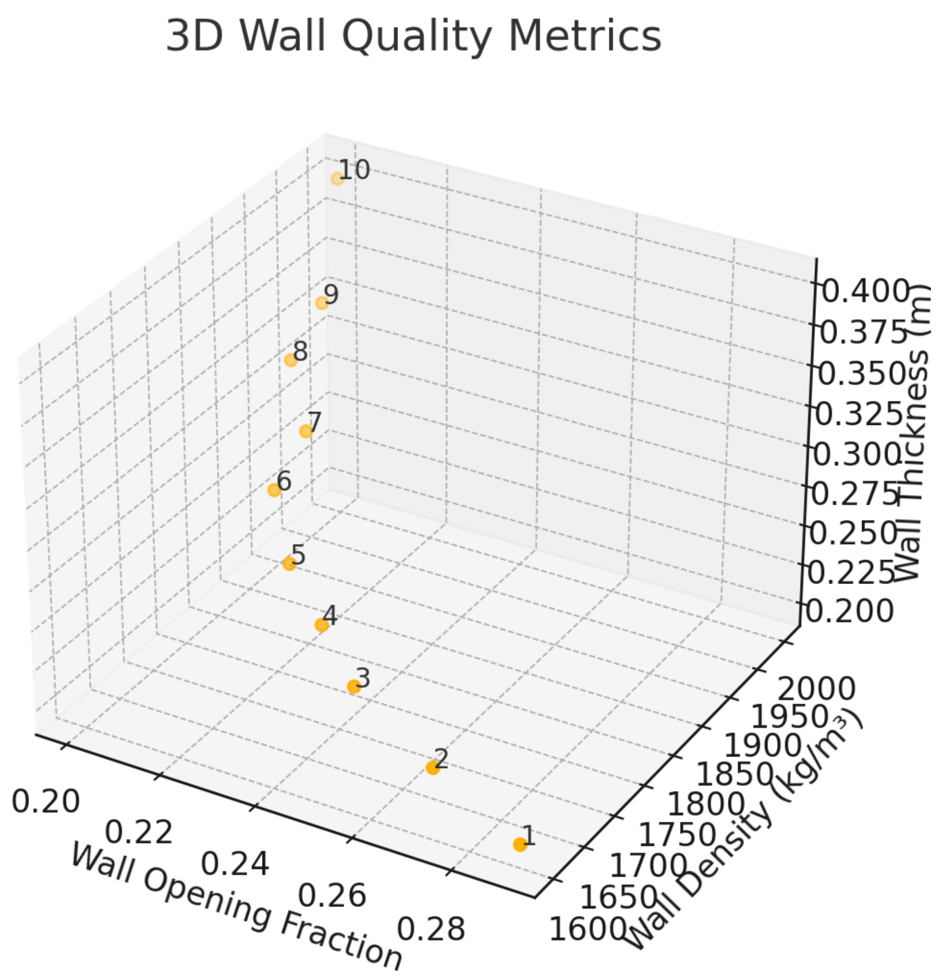

Figure 2: Multi-dimensional Visualization of Wall Quality Metrics

- Floor Height: Various floor heights ranging from 2.6 m to 3.4 m were assessed.

These variations enabled a clear understanding of the relative importance and impact of structural attributes on overall vulnerability outcomes, providing key insights for targeted improvements.

3. Results and Visualization

3.1. Spatial Vulnerability Mapping

The analysis generated wide spatial vulnerability maps for the Mezzano area, clearly illustrating the structural fragility of buildings under various flood scenarios. Maps were developed considering two sets of flooding conditions: flood depths corresponding to defined return periods from the *CLIMAAX handbook* (10-year, 50-year, 100-year, and 200-year), and a set of standard flood depths (0.5 m, 1.0 m, 1.5 m, and 2.0 m) that for clarity and visualization are referred hypothetically as return periods.
Spatial mapping results indicate distinct vulnerability patterns within Mezzano. Buildings closer to the primary flood sources, especially those with lower structural quality ratings and boundary conditions P1 or P2, exhibited significantly higher collapse probabilities. The visualization method employed graduated color scales, with darker shades representing higher probabilities of collapse, enabling intuitive interpretation of spatial risk distributions.

3.2. Collapse Probability Analysis by Return Periods

The four maps illustrated in figure 3 below show the collapse probability distributions at maximum flood depths corresponding to return periods of 10, 50, 100, and 200 years. This spatial visualization presents building collapse probabilities across Mezzano for four distinct flood scenarios based on return periods from the *CLIMAAX handbook*. The visualizations effectively show localized vulnerabilities within the core urban area of Mezzano, with probabilities remaining relatively low for shorter return periods (10 and 50 years) but notably increasing at longer periods (100 and 200 years). Nevertheless, the probabilities of collapse are very low (less than 5%) over the whole range of fluvial flood scenarios. This detailed spatial resolution helps pinpoint exact locations within Mezzano where structural interventions could significantly enhance resilience.

Figure 3: Detailed Collapse Probability Distribution at Maximum Flood Depth by Return Period

3.3. Collapse Probability Analysis by Standard Flood Depths

In this analysis four different scenarios applied. The scenarios correspond to flood depths of 0.5 m (10-year return period), 1.0 m (50-year), 1.5 m (100-year), and 2.0 m (200-year) that applied uniformly across all buildings, unlike the scenario from the *CLIMAAX handbook*, which provided varying water depths for different buildings. The intensity of colors represents the probability of collapse, clearly indicating an escalating vulnerability with increasing flood depth and return periods. Notably, the 200-year hypothetical scenario reveals widespread vulnerability, highlighting the urgent need for targeted structural reinforcements.

Detailed maps for each specific return period scenario revealed clear spatial patterns:

- **10-year Return Period (0.5 m flood depth):** Minimal collapse probabilities, with most buildings indicating probabilities below 5%. Only isolated structures with the lowest structural quality and reduced height displayed notable vulnerabilities.
- **50-year Return Period (1.0 m flood depth):** Increased collapse probabilities, particularly among older residential structures with weaker wall characteristics, achieving probabilities between 10% and 40%.
- **100-year Return Period (1.5 m flood depth):** A pronounced increase in collapse probabilities across broader areas, particularly evident in densely populated zones with a higher proportion of older residential buildings, with probabilities often exceeding 50%.
- **200-year Return Period (2.0 m flood depth):** Extensive vulnerabilities throughout Mezzano, with most residential buildings exhibiting collapse probabilities above 70%, emphasizing the critical necessity for structural reinforcements and enhanced resilience measures.

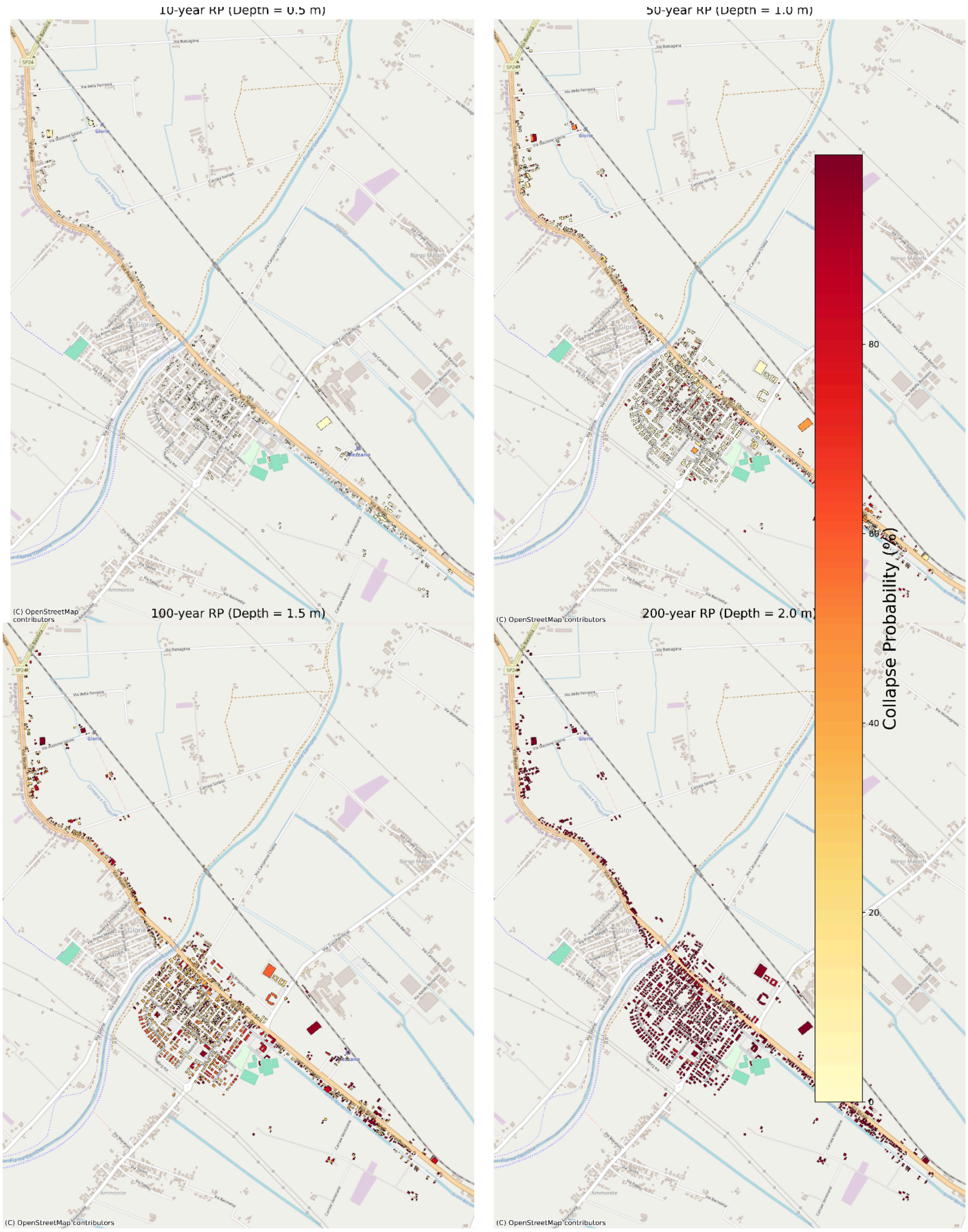

Figure 4: Building Collapse Probability by Defined Water Depths in Hypothetically Return Periods

Maps utilizing fixed flood depths provided additional insights into structural vulnerability, independent of specific return period assumptions. The range between flood depths from 1.0 m to 2.0 m. it represents the critical threshold zone where a substantial shift in vulnerability occurs. Specifically, many buildings transition from low or moderate risk to significantly higher probabilities of collapse as flood depths exceed 1.0 m.

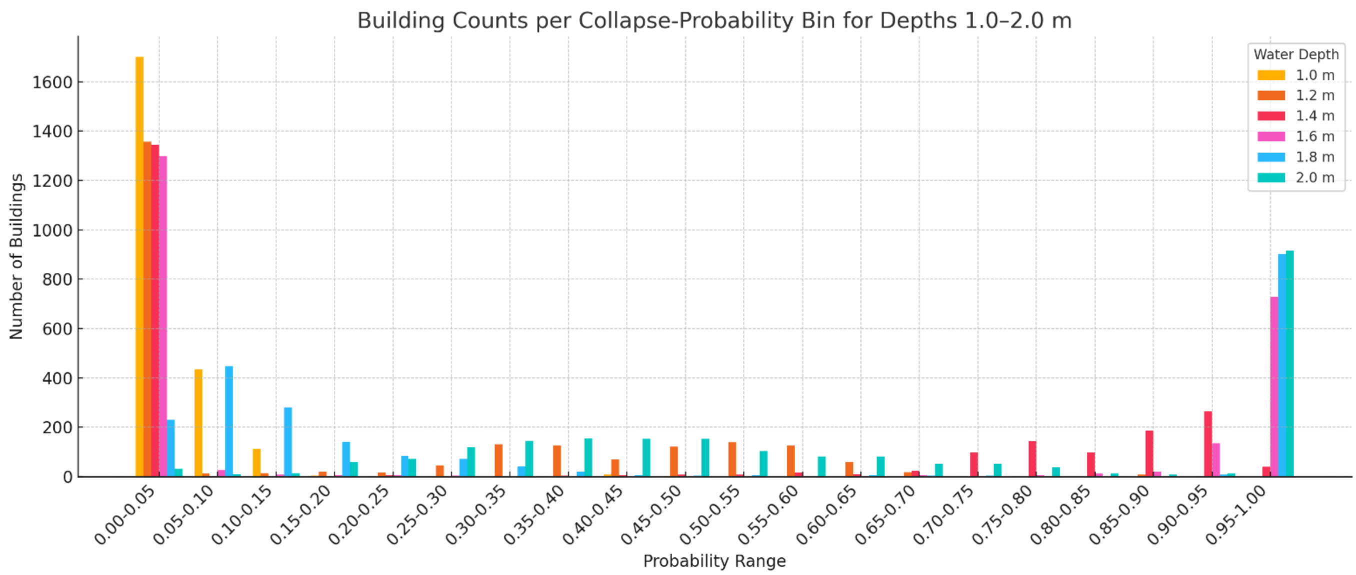

Figure 5: Histogram of Building Collapse Probabilities by Water Depth (1.0–2.0 m)

Figure 5 histogram summarizes the distribution of building collapse probabilities within the Mezzano area across incremental flood depths ranging from 1.0 m to 2.0 m. Each bar represents the count of buildings within specified probability bins for each flood depth. The visualization effectively demonstrates a bimodal distribution with significant building clusters at very low and very high collapse probabilities, particularly evident at deeper flood depths. This clear categorization assists stakeholders in identifying priority buildings requiring immediate intervention.

4. Sensitivity Analysis

4.1. Influence of Wall Quality on Vulnerability

The sensitivity analysis clearly demonstrated that wall quality exerts a substantial influence on building vulnerability to flooding. Visualizations utilizing heatmaps and detailed line graphs highlighted how improvements in wall quality significantly increased the median collapse flood depth, directly correlating to enhanced structural resilience.
The heatmap visualizations depicted the interplay between wall quality and boundary condition clearly, showcasing distinct vulnerability gradients. Buildings classified with the lowest wall quality levels exhibited significantly reduced resilience, with median collapse depths occurring at lower flood heights. Conversely, structures characterized by high-quality masonry consistently presented markedly improved collapse depth thresholds.

Figure 6, line graph clearly demonstrates how median collapse flood depth changes with floor height across ten distinct wall quality levels. The visualization reveals a pronounced positive correlation between structural parameters and resilience. Notably, as was expected, higher wall quality levels consistently result in elevated median collapse depths across all floor height variations. Knowing the combined effectiveness of both parameters is critical for estimating the strength of a masonry building under a flood event.

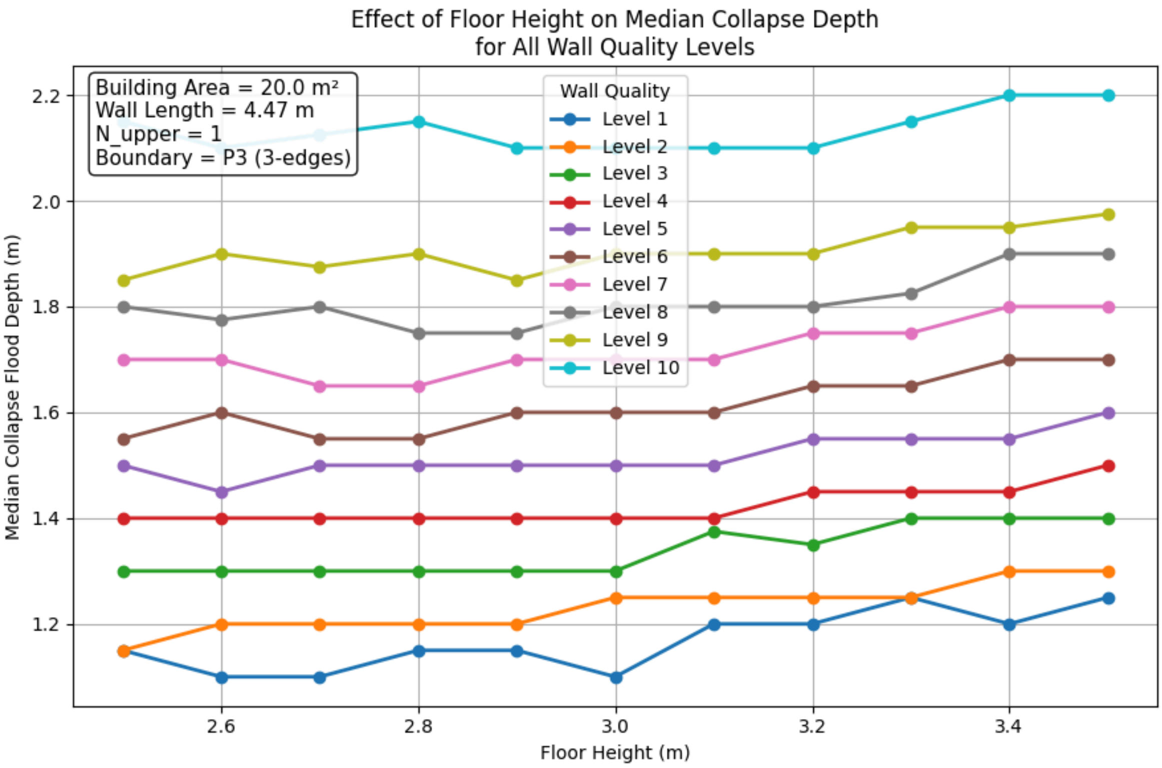

Figure 6: Median Collapse Depth Variation by Wall Quality and Floor Height

4.2. Impact of Floor Height Variations

Floor height emerged as a critical parameter influencing flood resilience. The detailed sensitivity plots revealed that even moderate increases in floor height substantially raised the median collapse depths, especially for buildings with intermediate wall quality levels. This finding indicates a threshold effect, suggesting that targeted enhancements in floor elevation can effectively mitigate flood vulnerabilities, particularly for structurally intermediate buildings.

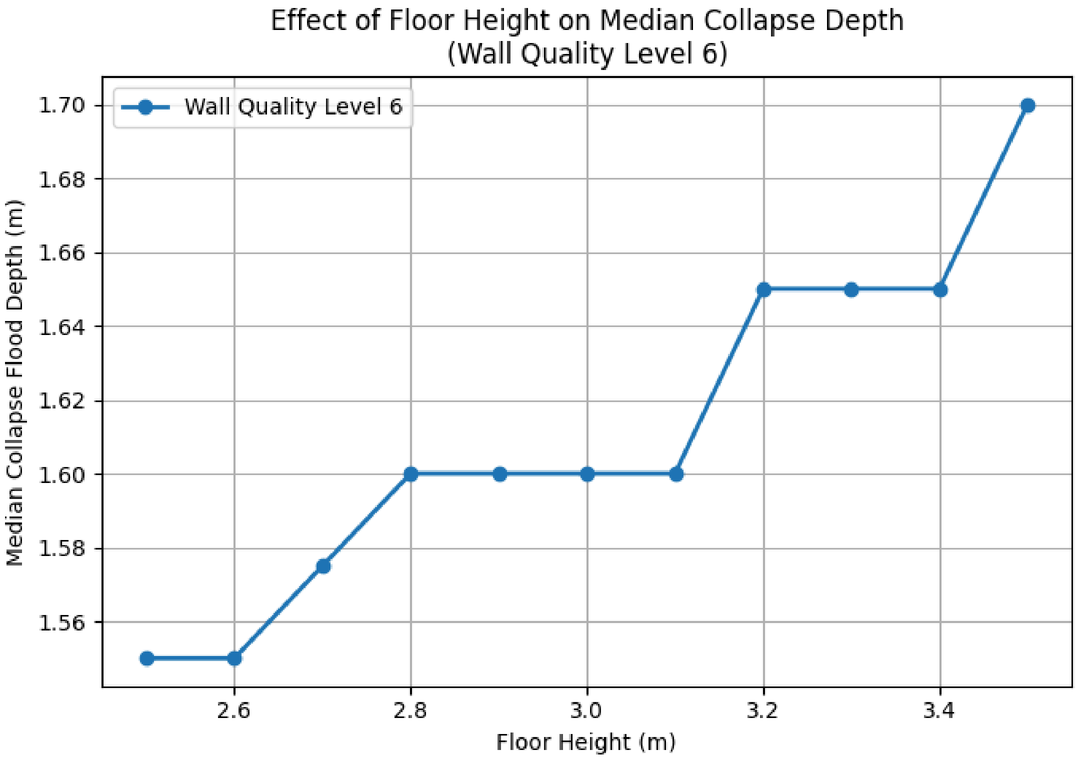

Figure 7: Impact of Floor Height on Median Collapse Depth (Medium-High Wall Quality Scenario)

The line graph in *Figure 7* specifically shows the sensitivity of median collapse flood depth to variations in floor height for buildings characterized by medium-high wall quality (level 6). The results illustrate a clear upward trend, indicating enhanced resilience with increased floor heights, particularly noticeable above 3.1 meters. This highlights the importance of structural elevation as a critical factor for reducing vulnerability even when other structural attributes are optimized.

4.3. Integrated Visualization of Sensitivity Outcomes

The integrated visual analysis—combining heatmaps and line graphs—provided intuitive and actionable insights. Specifically:

- Line Graphs (Figure 6,7): Clearly illustrated how incremental improvements in either wall quality or floor height individually influenced collapse depths, supporting informed decision-making regarding the prioritization of structural upgrades.

- Heatmaps: Enabled rapid identification of combinations of wall quality and Boundary condition that yield optimal functionally outcomes, clearly delineating areas where structural improvements could deliver significant vulnerability reductions.

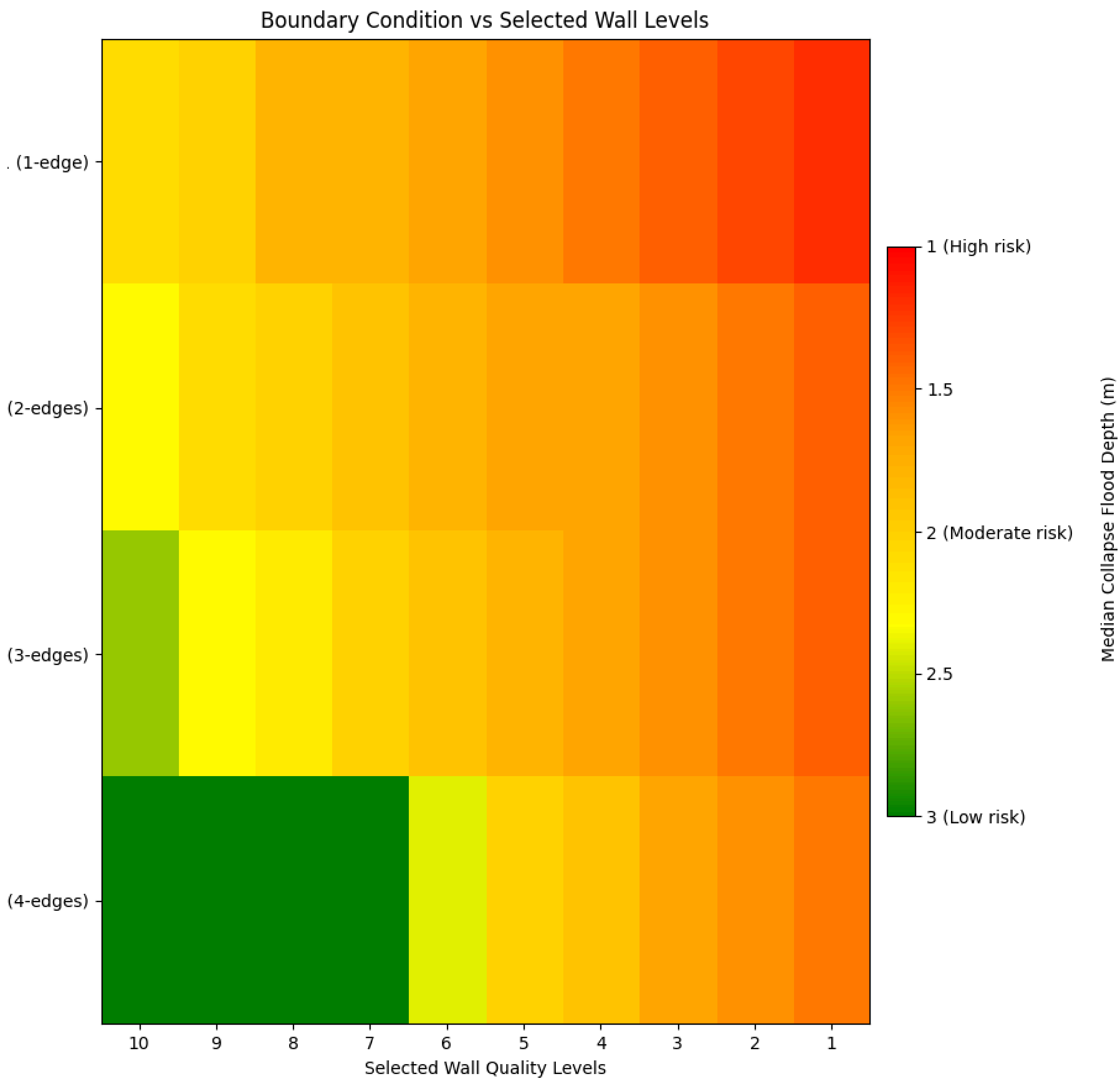

Figure 8: Heatmap of Wall Quality and Boundary Condition Impact on Median Collapse Depth

This heatmap in *Figure 8*, effectively summarizes the sensitivity analysis outcomes by illustrating how variations in wall quality (horizontal axis) and boundary condition (vertical axis) jointly influence median collapse depths. Green regions indicate lower median collapse depths and higher vulnerability, whereas red regions represent significantly improved resilience. The visualization succinctly communicates optimal parameter combinations, clearly guiding stakeholders on structural improvement priorities for effective flood vulnerability reduction.

4.4. Practical Applications for Risk-Informed Decision-Making

The outcomes from this sensitivity analysis offer substantial practical benefits for local stakeholders. By explicitly visualizing the relative influence of critical structural parameters on vulnerability, decision-makers can prioritize structural retrofits, focus resilience investments, and refine building regulations effectively. This targeted approach ensures efficient use of resources, optimizing community resilience against flooding hazards in Mezzano.

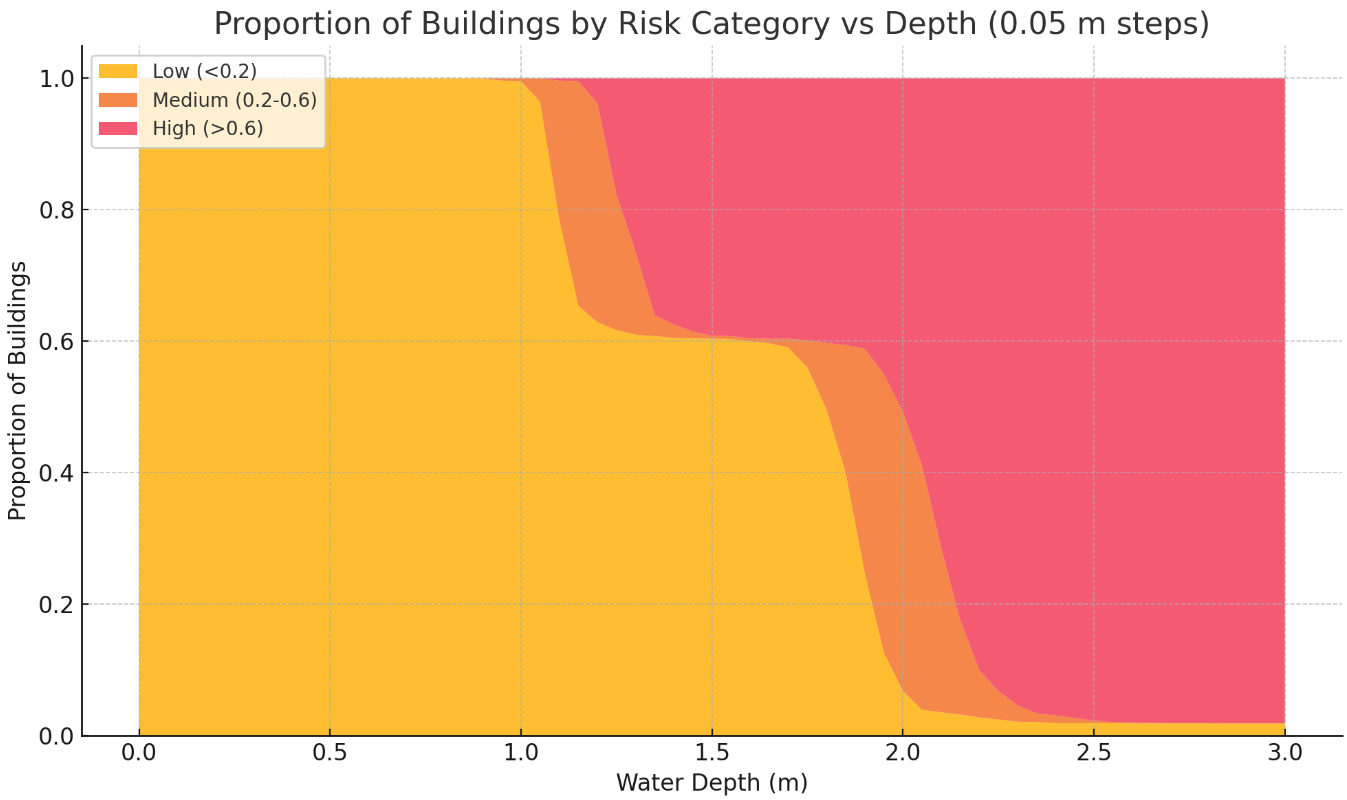

Figure 9: Proportion of Buildings by Flood Risk Category Across Incremental Flood Depths

Additionally, Figures 3, 4, 5, and 9 present significant results that offer an overall picture of the vulnerability across the entire area, providing a clear understanding of spatial patterns and critical risk zones. For instance, this stacked area chart in *Figure 9* illustrates the proportion of buildings within low (<20%), medium (20–60%), and high (>60%) risk categories across incremental flood depths ranging from 0 m to 3.0 m. It visually highlights the critical thresholds where buildings transition from lower risk to higher risk categories, particularly evident around depths of 1.5 to 2.0 meters. This chart is valuable for prioritizing structural interventions based on precise risk categorization.

5. Discussion and Recommendations

5.1 Strengths and Limitations of the Applied Methodology

The methodology implemented in this deliverable effectively combines detailed structural analysis with intuitive spatial visualizations, enabling clear and actionable insights into building vulnerabilities within the Mezzano area. A significant strength of this approach lies in its integration of local structural data with robust flood scenarios from *the CLIMAAX handbook.* The inclusion of sensitivity analyses further enhances the reliability of results, highlighting the critical structural parameters influencing flood resilience.
However, the methodology is constrained by some limitations. Primarily, the dataset's incompleteness regarding detailed structural parameters, such as precise wall thickness and density, required assumptions based on regional construction standards. Furthermore, the reliance on predefined flood depth scenarios and return periods, though practical, may not fully capture the complex variability of real-world flooding events. Additionally, this analysis assumes that all buildings are masonry constructions to capture the majority of cases, and therefore does not include reinforced concrete buildings.

5.2 Comparison with Earthquake and Wind Hazard Fragility Assessments

Compared to traditional fragility analyses for earthquakes and wind hazards, this flooding-focused methodology distinctly emphasizes hydrostatic and hydrodynamic loading rather than dynamic structural responses. While earthquake and wind analyses typically involve more detailed dynamic modeling and structural periods, flood vulnerability assessment prioritizes structural stability against sustained water pressures and inundation levels. This distinction necessitates specific attention to structural parameters, such as wall quality and floor height, uniquely critical for flood resilience.

5.3 Recommendations for Future Refinement

To further enhance the robustness and applicability of this methodology, several refinements are recommended:

- Data Enhancement: Efforts to gather more detailed structural parameters directly from field surveys could significantly improve the accuracy of fragility assessments.
- Advanced Hydrodynamic Modeling: Integrating more sophisticated hydrodynamic flood modeling, capturing variable flow velocities and debris impacts, would provide more precise vulnerability estimates.
- Broader Structural Typologies: Expanding the methodology to include reinforced concrete and steel structures would extend applicability across diverse urban contexts.

6. Conclusions

The application of the vulnerability assessment framework from *Deliverable 2.6.1* to the Mezzano area successfully illustrates the practical effectiveness of detailed structural fragility analyses combined with clear spatial visualization. The comprehensive sensitivity analysis underscores the critical impact of structural parameters, offering invaluable insights into resilience enhancement strategies. This approach significantly supports informed decision-making, providing local stakeholders with essential tools for proactive flood risk management and urban resilience planning.

7. References

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