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PERFORMANCE ANALYSIS OF HISTORICAL CHURCHES AND MOSQUES DURING RECENT EARTHQUAKES – SOME PERSPECTIVES ON APPLICATION OF AI/ ML SYSTEMS

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Abstract

The world has witnessed widespread damages and losses suffered by precious cultural heritage structures during recent earthquakes e.g. Emilia-Romagna, Italy 2012; Central Italy 2016; Turkey /Syria 2023; Morocco 2023; Tohoku, Japan 2011; Puebla, Mexico 2017; Nepal 2015; Christchurch, New Zealand 2011; Iran 2017, among others. Based on traditional surveys and reconnaissance using 3D documentation technologies e.g photogrammetry, TLS etc. following the destructive earthquakes, extensive amounts of observed damage data about the damages of historical churches and mosques etc. has been accumulated over the years.

This paper presents the results of attempts to systematically analyze the damage data for historical churches and mosques to identify the lessons we can learn therefrom, determine their patterns of damage, and evaluate the possible causes of damage. The paper first documents the deep experience and knowledge base of performance of Churches in Italy during the past major earthquakes. The results of an analysis of the observed damage data from the historical colonial churches that suffered extensive damages and losses during the 2017 Puebla, Mexico earthquake, are presented next. The paper then analyzes the available data on the performance and damages suffered by historical mosques during the catastrophic Turkey earthquake of 2023; and the Al Houz, Morocco earthquake of 2023, to classify the types of damage, identify the patterns of damage, and possible causes of damage. The results of this study will help in the structural assessment of damaged historical churches and mosques and the development of the plans for their repair and restoration.

This paper further plans to explore the potential application of Artificial Intelligence and Machine Learning (AI/ML) systems for the systematic analysis of observed damage image data for historical Churches and Mosques, including classification of features, types of damage, and determining the patterns of damage of historical churches and mosques during catastrophic earthquakes.

Many data types and sources describe historical buildings, including 3D scans, photogrammetry, survey images and videos. This wealth of data requires the support of deep learning systems to identify types of damage due to natural disasters. The analysis of this large volume of data also offers the opportunity to compare before-and-after images to determine requirements of restoration projects.

Keywords: Heritage Churches, Historical Mosques, Earthquakes, 3D Documentation, Damage Data, Patterns of Damage, AI/ML Applications

1. Background

This paper is an attempt to learn from the extensive damages and huge losses suffered by religious heritage structures during the catastrophic earthquakes around the world during the past decades e.g.

Emilia-Romagna, Italy 2012; Central Italy 2016; Turkey / Syria 2023; Morocco 2023; Tohoku, Japan 2011; Puebla, Mexico 2017; Nepal 2015; Christchurch, New Zealand 2011; Iran 2017, among others. It has been observed that the heritage churches and mosques that were subjected to the fury and aftermath of these catastrophic earthquakes, not only served as places of worship but also as an emergency shelter, and an emotional support system for the affected communities in the aftermath of the devastation brought on by these catastrophic earthquakes.

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2. Objective

The objective of the paper is to explore potential applications of AI/ML methods to systematically analyze the available damage data acquired from reconnaissance surveys for historical churches and mosques following previous catastrophic earthquakes to identify the patterns of damage, possible causes of the observed damage, and the lessons we can learn therefrom as follows:

Documentation of the deep experience and knowledge base of performance of heritage churches in Italy during previous catastrophic earthquakes.

Analysis of the observed damage data from historical colonial churches that were seriously damaged during the Puebla, Mexico earthquakes of September 2017

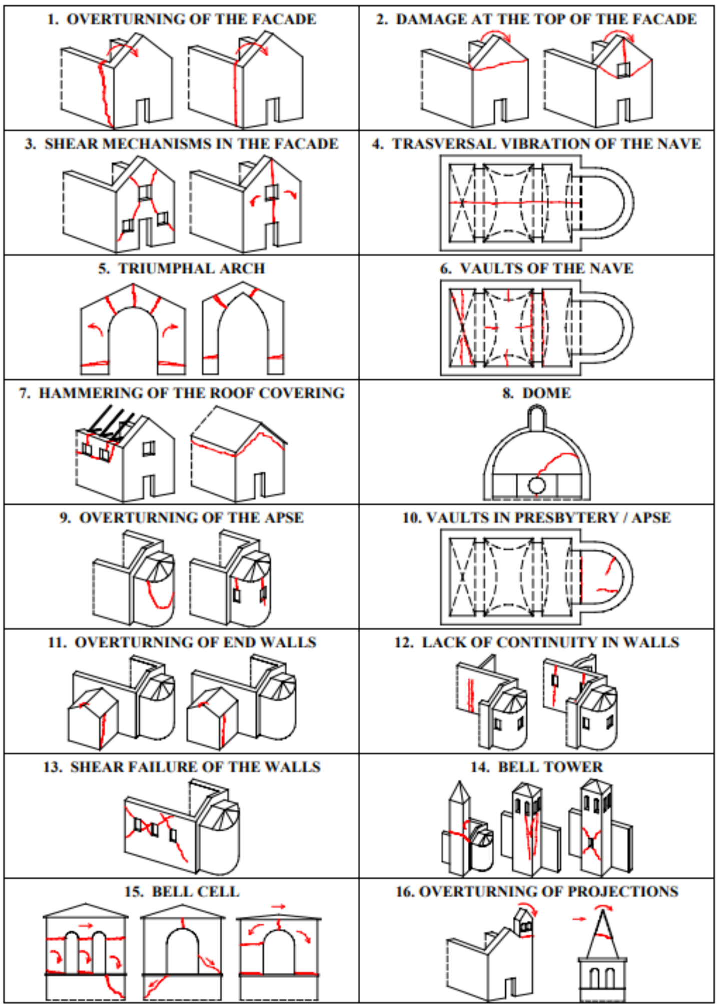
Analysis of the available data on the performance and damages suffered by the historical mosques during the catastrophic Turkey earthquake of 2023, and the Al Houz, Morocco earthquake of 2023

3. Lessons from Churches and Mosques

3.1. Historical Churches in Italy

The records of observed damage data on the beautiful historical churches damaged by catastrophic earthquakes in Italy over the past fifty years and beyond, provide a very important knowledge base for extracting lessons from this massive amount of damage data.

Table 1. Abacus of the damage mechanisms in the macroelements of the church. Source: Lagomarsino [1]



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Lessons from the damages and losses suffered by historical churches during the catastrophic earthquakes in Italy over the past fifty years can best be described in the form of macroelements and damage mechanisms as first proposed by Lagomarsino [1], as presented in Table 1.

An analysis of the observed damage to thirty-six masonry churches during the 2016 Central Italy earthquake has been presented by Ferracuti et. al. [2]. The analysis highlighted the most frequent damage mechanisms and the most vulnerable macro-elements, including development of a damage index based on the observed damage and the macro-elements present in the surveyed churches.

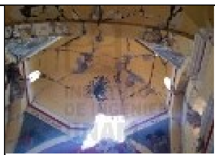
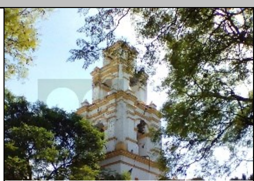
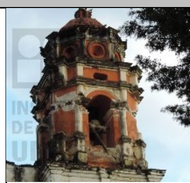
Damage data sets containing images and 3D Point Cloud data have been collected for many of the damaged churches by the Universita di Firenze, and Politecnico di Milano, among others, and archived for later processing and analysis. Point Cloud data presents unique opportunities to perform wellness analysis for undamaged structures as well as documentation of damage after an earthquake.

3.2 Colonial Churches in Mexico

The widespread damages suffered by colonial churches during the September 2017 Puebla earthquakes, were systematically surveyed and recorded by survey teams from UNAM, and compiled in the form of a database as reported by Peña in [3].

Classification and patterns of damages and losses suffered by historical colonial churches in Mexico during the Puebla, earthquakes of September 2017 have been presented by Peña as shown in Table 2.

Figure 2. Patterns of Damage of Colonial Churches in Mexico.

Observed Damage by UNAM				
Features	Vaults/Arches	Domes	Domes and Drums	Facades
Structural Damage Pattern	Cracks in vaulted ceilings/roofs	Severe damage in domes	Severe damages	Diagonal Cracks
Description	Tensile cracks in vaults/ arches	Radial and meridian cracks	Shear cracks	
Observed Damage by UNAM				
Features	Bell Towers	Facades / Bell Towers	Facades	Bell Towers
Structural Damage Pattern	Most damaged elements	Separation between Façade and side walls	Out-of-plane behavior	Most damaged elements
Description	Diagonal shear damage in belfries	Vertical cracks in joints	Horizontal or vertical cracks in the joint between elements	Tension Cracks in structural framing system elements

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3.2. Mosques in Turkiye and Syria

The results of surveys to systematically document the performance and behavior of historical mosques heavily damaged during the February 2023 Kahramanmaras, Turkey earthquake has been presented by Ertugrul et. al. [4].

Severe damage and collapse of the Habib-i-Necca mosque in Anatolia is presented in Figure 2.

Figure 3. Habib-i-Necca Mosque one of the first mosques in Anatolia destroyed. Source: ArkeoNews (https://arkeonews.net/)

Some examples of the types and patterns of damage suffered by historical mosques during previous earthquakes in Turkey has been presented by Kocaman, et. al. [5]

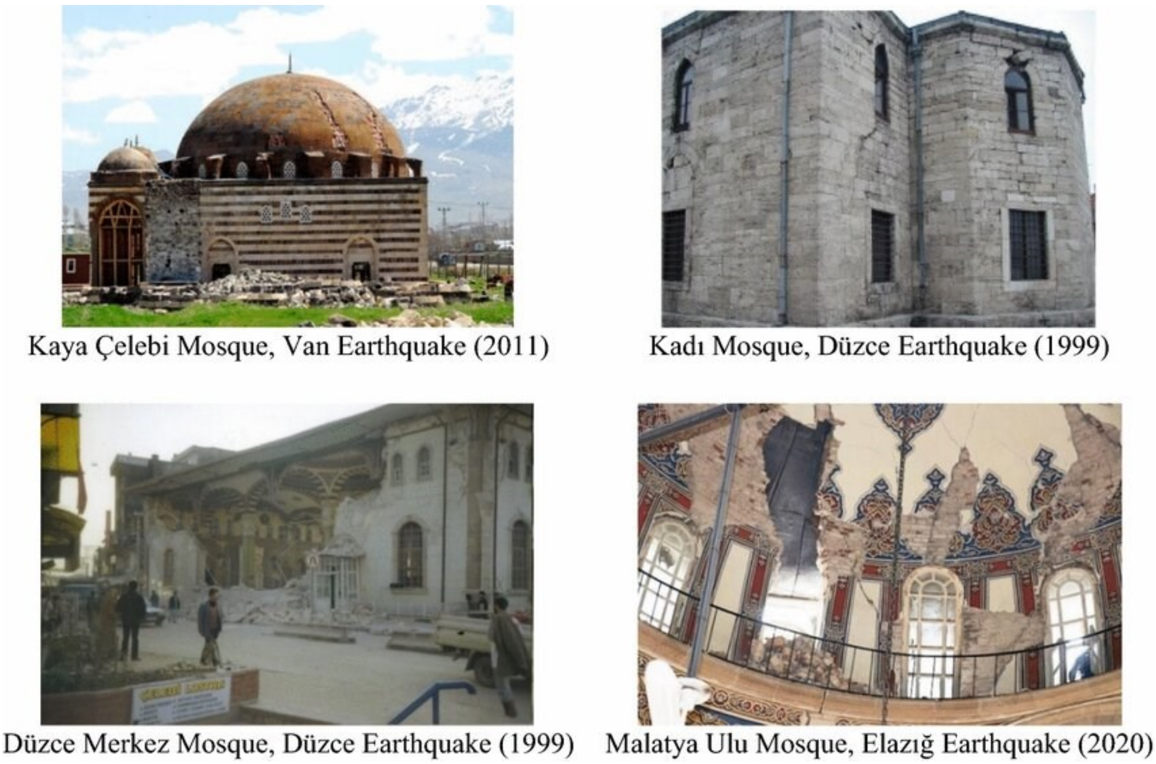

Figure 4. Examples of earthquake damage in historical mosques in Turkiye
Source: DOI: 10.1007/s10518-023-01613-1

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3.3. Historical Mosques in Morocco

The historical Tinmel mosque, considered as a notable example of Almohad architecture, and dating back to the 12th Century, was severely damaged by the 2023 Al Houz, Morocco earthquake, while it was under restoration, as shown in Figure 4.

Figure 5. The Tinmel Mosque – Left: before earthquake, Right: after the earthquake

4. AI/ML Applications

Recent advances in the field of Artificial Intelligence and Machine Learning (AI/ML) offer great opportunities in processing large volumes of data and extract common patterns and lessons to be learned from damage data that is collected after earthquakes, Rihal et. al. [6]. This data includes images, videos, 3D scans and other formats. The benefits of using AI/ML include:

1. *Damage Assessment*: a) Image and Video Analysis: Drones and robots equipped with cameras can capture high-resolution images and videos of damaged heritage sites. AI-powered computer vision algorithms can analyze these images to identify and quantify damage, such as cracks, collapses, or deformations. b) 3D Modeling and Reconstruction: AI/ML can process LiDAR (Light Detection and Ranging) data or photogrammetry to create detailed 3D models of heritage structures before and after an earthquake. Comparing these models helps in assessing the extent of damage. c) Automated Damage Classification: ML models can classify damage into categories (e.g., minor, moderate, severe) based on predefined criteria, enabling rapid prioritization of restoration efforts.
2. *Cultural Value Preservation:* a) Digital Twins: AI can create digital twins of heritage structures, which are virtual replicas that simulate real-world conditions. These twins can be used to test restoration strategies and predict outcomes without risking further damage to the actual structure. b) Material Analysis: AI can analyze the materials used in heritage structures to determine their composition, age, and degradation patterns. This information is crucial for selecting appropriate restoration materials and techniques. c) Cultural Data Integration: AI can integrate historical, architectural, and cultural data to ensure that restoration efforts preserve the original design, aesthetics, and cultural significance of the structure.
3. *Decision Support Systems:* a) Resource Allocation: AI/ML can optimize the allocation of resources (e.g., manpower, materials, funding) for the restoration of multiple heritage sites based on the severity of damage and cultural importance. b) Scenario Simulation: AI can simulate various earthquake scenarios and their potential impact on heritage structures, helping policymakers and conservationists develop effective disaster preparedness and response plans.

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5. Conclusion

Surveys and reconnaissance after a devastating earthquake provide large volumes of data in many formats and require intelligent tools to process and extract useful knowledge to support decision making for recovery and restoration.

AI/ML offers powerful tools for assessing and mitigating earthquake damage to heritage structures, enabling faster, more accurate, and culturally sensitive responses. By leveraging these technologies, we can better preserve our cultural heritage for future generations while enhancing resilience against natural disasters.

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