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Historic Roofless Masonry Structures: The role of Environmental Factors that Contribute to Decay and Collapse

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Abstract – **Heritage roofless structures, while being invaluable heritage assets, face considerable risk of deterioration. This risk is usually increased when there is extensive water ingress and moisture in the structure. This paper focuses on masonry heritage buildings and ruins in England and has stemmed from an extensive literature review to identify recurrent causes of the disintegration of these structures. Researchers from the University of West London have processed the available literature to create a database that identifies taxonomies of buildings and scientific paths relating to ruinous historic structures. The paper concludes with recommendations for future research, focusing on the acquisition of additional data on the behaviour of masonry structures under varying environmental conditions, emphasising the potential implementation of advanced non-destructive testing techniques.**

Keywords: historic buildings, masonry structures, environmental effects, taxonomies, statistical analysis.

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I. INTRODUCTION

The challenges associated with the conservation of masonry heritage buildings in England, particularly those that are partially ruined or lack structural elements such as roofs, are vast and often a compromise between safety and heritage preservation. These structures, often remnants of ecclesiastical, defensive, or industrial buildings, represent significant cultural and historical value. However, they are especially vulnerable to environmental degradation and human-induced damage due to their incomplete envelopes and exposure to the structural elements.

In this study, an extensive literature review highlights that the deterioration of these structures is rarely due to a single cause. Instead, it results from a complex interplay of environmental, material, and anthropogenic factors. Common environmental contributors include moisture ingress, freeze-thaw cycles, biological colonisation, and wind-driven rain, all of which are intensified by the absence of protective roofing systems. At the same time, human activities such as vandalism, tourism-related wear, neglect, and inappropriate conservation interventions also significantly affect structural integrity. Building defects—whether inherent in the original construction or a result of age-related degradation—further compound the vulnerability of these structures.

Compounding these issues is the increasing impact of climate change. Rising temperatures and changing precipitation patterns are intensifying the frequency and severity of natural hazards such as flooding, wildfires, and debris flows, thereby accelerating decay processes in exposed heritage assets [1] Climate change not only introduces new risks but also alters the behaviour of traditional materials in ways that are not yet fully understood [2] making hard their structural response.

Accurately diagnosing the causes of material decay in such complex and layered contexts presents significant challenges. The task is further complicated by limitations in available documentation, funding, and time, which frequently lead to misdiagnoses. As a result, well-intentioned but poorly informed conservation efforts may cause more harm than good, by either over-intervening or implementing incompatible repair techniques [3] Addressing these challenges requires a multidisciplinary and evidence-based approach to conservation that considers both the technical and socio-cultural dimensions of heritage preservation.

In this paper, the authors aim at depicting the most influencing factor which affect the roofless heritage structures and suggest a methodology of intervention for their assessment and mitigation.

II. AIM AND OBJECTIVES

The primary aim of this research is to critically analyse and synthesise existing literature to develop a comprehensive and structured list that classifies ruinous masonry heritage buildings according to architectural typology, geographical distribution, and observed patterns of decay. This list serves as a foundational tool for understanding the variety and commonalities of deteriorated historic structures—particularly those lacking roofs within English territory—and provides a framework for further empirical and methodological inquiry.

A key objective is to identify and assess current practices employed in the recording, diagnosis, and conservation of roofless masonry structures. This includes an evaluation of documentation techniques (*e.g.*, photogrammetry, laser scanning, condition surveys), assessment protocols, and intervention strategies used in the field. By mapping these methodologies against real-world case studies and scientific literature, the research aims to highlight both strengths and gaps in the existing approaches across the country.

Another critical goal is to define the interdisciplinary competencies required to address the unique challenges posed by roofless ruins. These include not only technical skills in structural assessment and material analysis but also broader contextual knowledge in heritage values, environmental conditions, and site-specific risk factors.
Furthermore, the study seeks to pinpoint recurring zones of deterioration across building typologies—such as wall tops, openings, and interfaces between original and repaired elements—where decay processes are particularly active due to exposure or material incompatibility and where environmental factors are more likely to act. By recognising these patterns, conservation professionals can more effectively prioritise inspections and interventions.
Ultimately, the research proposes to establish guiding principles and methodological frameworks for the systematic investigation, documentation, and treatment of ruinous masonry heritage structures. These principles aim to support more consistent, informed, and sustainable conservation practices within the heritage sector. Findings from this research can also support evidence-based policymaking, directing financial and research resources toward structurally and historically sensitive building categories.

III. STATE OF THE ART

A thorough and systematic literature review was undertaken to gather and categorise existing knowledge relevant to roofless and ruinous masonry heritage structures. Using a targeted set of agreed-upon keywords, sources were selected across a range of themes including architectural typologies, environmental exposure, material degradation, structural vulnerability, conservation practices, and assessment technologies. The reviewed literature encompassed peer-reviewed journal articles, technical reports, heritage databases, and conservation guidelines, with a focus on both national and international case studies—particularly those from England. The information extracted from the literature was recorded and organised in a structured and searchable spreadsheet designed to allow both qualitative and quantitative analysis. Each entry was coded according to several interlinked macro-categories, enabling a cross-comparison of findings and identification of recurring patterns. These categories are as follows:

- Identification of the Building. This includes basic metadata about each case study—such as the building's name, country, whether its geographic location, particularly focusing on English context, and whether it has been physically visited or only remotely assessed.

- Building Description. Details about the physical characteristics of the structure are noted here, including building type (e.g., ecclesiastical, military, industrial), typical height, whether the structure is classified as ruinous, whether it is roofless, and the known or estimated date of construction. This information helps in mapping the typological and chronological distribution of vulnerable buildings.

- Assessment of Current Damage. A critical aspect of the review involves categorising the present state of deterioration. Each structure was evaluated according to the level of damage observed in a specific building element affected (e.g., wall, arch, roof foundation), and whether the damage could potentially lead to partial or full collapse. This is supplemented by an analysis of exposure levels (environmental or structural), vulnerability ratings, and the presence of specific hazards such as water ingress, frost, vegetation overgrowth, or seismic activity. All these factors contribute to a comprehensive evaluated risk profile, based on a simplified matrix inspired by risk-assessment models commonly used in heritage conservation.

- Diagnostic Tools. The study documents the technologies used for assessing the structures, grouped into Non-Destructive Testing (NDT), Minor Destructive Testing (MDT), Destructive Testing (DT), and other forms of remote sensing (e.g., UAV photogrammetry, LiDAR, infrared thermography). This helps track the integration of emerging technologies and identify gaps in diagnostic methodology, especially in hard-to-access or roofless environments.

- Materials Affected. Observations on the types of materials (e.g., limestone, brick, mortar) and their condition are recorded to understand decay behaviours and material vulnerabilities across different typologies and climates.

- Environmental Factors. Special attention is given to climate- and water-related deterioration, such as capillary rise, rainfall penetration, biological growth, and freeze-thaw cycles. Climate change implications are also examined—particularly the role of increased precipitation, thermal stress, and extreme weather events in accelerating decay processes.

The corresponding visual schema (Fig 1) aligns these variables in a way that facilitates the scoring and comparative analysis of each case.

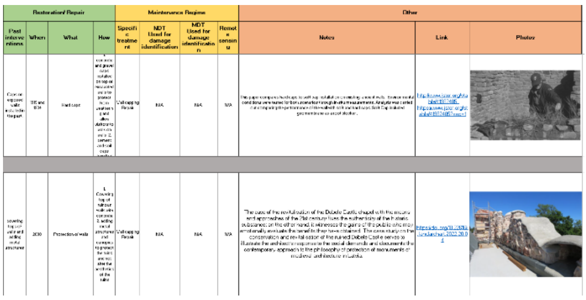

Fig. 1. Sample of spreadsheet comparison

The project was conducted over a three-month period, during which approximately 50 scholarly publications were systematically reviewed. From these sources, a total of 65 relevant case studies were identified and analysed. The case studies span 17 countries across Europe, Asia, and the Americas, representing a wide range of climatic zones—from temperate and maritime environments to arid and monsoon-prone regions. Although the research focus includes England, the broad geographic scope allowed for cross-regional comparison of environmental effects, material behaviours, and conservation practices. A significant proportion of the examined structures comprised city walls, fortifications, and other defensive architecture, which are often exposed and lack protective roofing elements.

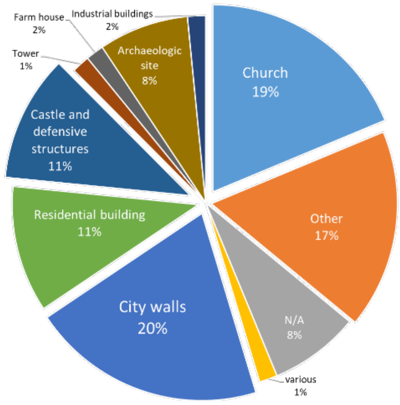

Fig. 2. Building typology statistic

The most affected structural components were external walls, which are typically the most vulnerable to weathering and environmental impacts due to their constant exposure.

In terms of diagnostic techniques, non-destructive methods (NDTs) were prevalent across most studies, underscoring the emphasis on minimal intervention in heritage contexts. Among these, visual observation (21%) and photogrammetry (14%) were the most frequently reported tools, likely due to their accessibility, cost-effectiveness, and applicability in both field and remote assessments.

Regarding materials, brick masonry (28%) and stone masonry (60%) were the most cited in the reviewed literature. These traditional materials exhibit distinct responses to environmental stressors, with stone often more durable but susceptible to biological growth and surface erosion, and brick more prone to salt crystallisation and moisture retention.
Overall, these findings reinforce the necessity of integrating environmental and material-specific considerations into conservation planning, while also demonstrating the utility of structured, comparative case study analysis for informing future research and policy.

IV. THE ROLE OF ENVIRONMENTAL FACTORS

The analysis of the 65 case studies found in Literature, with a specific focus on masonry heritage structures, revealed statistically significant patterns of decay, most notably related to environmental exposure, thus the role of water in causing environmental deterioration. Within the causes of water ingress, it is possible to identify heavy precipitation and direct ingress covering respectively the

35% and 26% of the causes (Fig. 3). The heavy precipitations are directly related to the role of climate change in increasing disaggregation of the mortar and lack of connections; vulnerabilities which are especially acute in structures without roofing systems.

Within this context, increasingly intense precipitation events—driven by climate change—are accelerating the disaggregation of mortar and weakening the bond between masonry units in historic structures. This process directly compromises the material cohesion and stability of roofless heritage buildings, heightening their vulnerability to progressive decay and eventual collapse.

The Met Office, national meteorological service office for the UK, emphasizes this emerging risk as follows:

- The winter half-year (October–March) in the UK has become approximately 16 % wetter during 2015–2024 compared to the 1961–1990 baseline.
- Climate models project that heavy summer rainfall events, which currently occur roughly seven days per year in England and Wales, will increase to nine to eleven days annually under scenarios of global warming between +2 °C and +4 °C Met Office.
- Under high-emissions scenarios (RCP 8.5), rainfall intensities exceeding 20 mm per hour—key thresholds for flash flooding and rapid saturation—could become four times more frequent by the 2070s compared to current levels.
- Furthermore, extreme rainfall events, such as an hour recording over 30 mm of rain, may become between 2.5 to 3.5 times more likely by the 2070s, especially in urban centres like London.

These intensified precipitation patterns serve as a catalyst for rapid moisture ingress into exposed masonry. Roofless structures, already deprived of protective top coverings, are particularly susceptible. Heavy downpours and prolonged wet periods not only expedite traditional decay mechanisms—such as salt crystallisation, freeze–thaw damage, and biological colonisation—but also magnify structural stress at wall heads and joints [4]

In addition to the above, roofless masonry structures are directly exposed to increasingly severe precipitation and flooding events—phenomena now widely associated with climate change. Indeed, around 50% of the analysed case studies explicitly cited climate-induced hazards such as prolonged rainfall, flash flooding, and debris flow as significant contributors to accelerated degradation. These trends are consistent with broader research that links climate change to an increased rate of heritage loss, particularly in fragile or abandoned structures [1] [2].

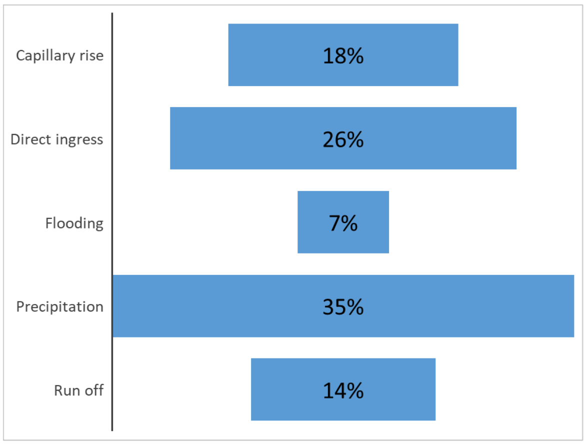

Fig. 3. Main water ingress causes

On the other hand, the direct ingress of water can be both associated to environmental effects but also anthropogenic actions that act as amplifiers of deterioration. These include neglect, insufficient maintenance, and in some cases, the complete abandonment of ruins—conditions that significantly increase exposure and reduce the capacity for early intervention. Human-induced changes to the landscape and soil, such as uncontrolled development, deforestation, and poorly managed drainage, were also observed to intensify water ingress and promote debris flow, often altering the hydrological balance of historic sites [5].

Once the ingress of water made its own path, it is hard to stop other environmental hazards which are consequences of the water source.
For example, moisture consistently emerged as the dominant and most damaging agent. This aligns with findings from existing literature that highlight the critical role of water in the degradation of porous construction materials such as brick and natural stone [6] [7].

In fact, moisture influences masonry deterioration through both direct and indirect pathways. Direct effects include capillary rise, which facilitates the transport and deposition of salts, leading to crystallisation-induced stresses, surface exfoliation, and mortar decay [8]. In addition, freeze–thaw cycles, prevalent in temperate climates, promote microcracking and eventual material disintegration due to the expansion of water as it freezes within the masonry pores [9].

Indirectly, moisture encourages the growth of vegetation, a process that poses a major threat to structural stability, particularly in roofless and exposed masonry walls. Vegetation growth was identified as the most recurrent and destabilising phenomenon affecting external elevations. In some isolated cases, root systems may temporarily stabilise deteriorated joints by occupying voids and binding displaced elements. However, in most cases, root infiltration exacerbates decay by disrupting the interlocking of masonry units, dislodging mortar, and generating internal pressures that can trigger partial or sudden collapses [10] [11]

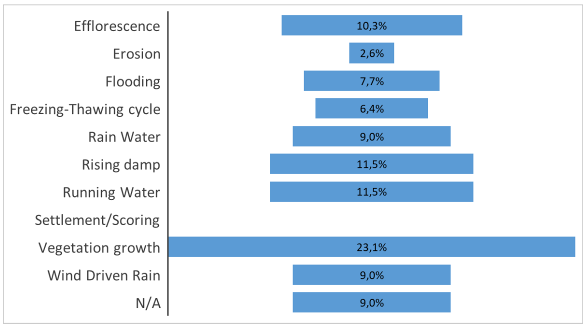

Fig. 3. Environmental factors affecting roofless structures within the statistics

In addition, once the vegetation roots are bonded with masonry, also the process of removals is dangerous and can compromise the overall stability of the structural element.

Indeed, this requires wide consolidation plan where the role of the roots must be evaluated before their removal from the masonry walls.

V. SUMMARY AND CONCLUSIONS

The project duration was approximately three months and during this period around 50 papers were examined from which about 65 case studies were extracted. The case studies were not only from England but from 17 different countries in Europe, Asia and America with varied climatic conditions. Most of these case studies included city walls and defensive structures and most damage was recorded on the external walls.

Damage identification and monitoring was recorded as using non-destructive methods, however visual observation (21%) and Photogrammetry (14%) were the most popular used.

The main agent of deterioration is relating to water and moisture ingress extending to vegetation growth that also tends to cause problems to structures. About half of the case studies indicate that changes are closely linked to effects of Climate Change, such as flooding, extensive rainfall and debris flow. Building materials mostly mentioned and affected are Brick (28%) and Stone masonry (60%).

Finally, it must be acknowledged that climate change itself is largely a consequence of cumulative anthropogenic activity, and its accelerating impacts pose one of the most urgent threats to the preservation of masonry heritage.
These findings emphasise the pressing need to integrate environmental resilience and risk-based planning into conservation strategies for roofless and ruinous masonry structures. Preventive measures, early diagnosis using appropriate tools, and site-specific climate adaptation approaches are essential for extending the life of these vulnerable cultural assets.

VI. FUTURE DEVELOPMENTS

The study revealed a notable gap in the representation of English case studies within the broader international literature on ruinous masonry heritage structures. Despite the presence of a significant number of roofless and partially collapsed historic buildings across England—many of which are of high cultural and architectural value—these assets remain understudied and insufficiently monitored. This lack of systematic documentation and analysis hinders both risk assessment and the development of long-term conservation strategies.

To address this gap, there is a clear need to prioritise studies focused on English heritage ruins, particularly those located in remote or rural settings, where conservation efforts often rely on limited funding and irregular site visits. These structures are frequently visited for tourism or educational purposes yet lack the maintenance regimes or technical assessments necessary for their sustainable preservation. An important avenue for improvement lies in the adoption of advanced non-destructive testing (NDT) and remote sensing technologies, which offer considerable potential for assessing material conditions, structural stability, and patterns of degradation. Satellite imagery can provide non-invasive, repeatable, and scalable diagnostics, helping to uncover hidden or emerging defects without physical intervention [12] [13]. These tools are particularly valuable in cases where visual inspections are constrained by limited accessibility or when traditional survey techniques are not feasible due to the scale or fragility of the site.

VII. CONCLUSION

The preservation of roofless, ruinous masonry heritage structures requires a multifaceted approach that addresses the various factors contributing to their deterioration. By improving our understanding of these factors and developing more effective assessment, monitoring and treatment techniques, longevity of these invaluable heritage assets can be ensured. More extensive implementation of advanced non-destructive testing techniques was seen as a future improvement.

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