Weathering the Storm: Climate Change and the Preservation of Bryggen's Wooden Heritage

Regan Reser
6301487

AR2A011: Architectural History Thesis
TU Delft 2024/2025

Figure 1 (Front Cover): Bryggen in Bergen
Visit Bryggen/Espen Bakketun, *Bryggen in Bergen*. https://en.visitbergen.com/things-to-do/bryggen-in-bergen-p878553

Contents

Figure 2: Bryggen in 1930s
Berit Wallenberg. *Tyskebryggen.* (1930), film negative, https://www.flickr.com/photos/swedish_heritage_board/

Figure 3: Bryggen in 2016
Lucy Dodsworth. *Bryggen, the Old Heart of Bergen.* (2016), https://www.ontheluce.com/in-pictures-bryggen-the-old-heart-of-bergen/

Introduction: Bryggen in Peril

Bryggen, a UNESCO World Heritage Site located in Bergen, Norway, is a remarkable example of late medieval wooden architecture that reflects the city's maritime and trading legacy. As one of Northern Europe's oldest port cities, Bergen has built timber-based harbour infrastructure since its foundation in the 12th century with archaeological findings revealing pier constructions dating back to around 1100 (1). The current site of Bryggen comprises of 62 timber buildings of historical significance (2). While many above-ground structures date from after 1702 due to a fire at that time, the cellars and foundational levels contain materials as early as the 15th century (3). What distinguishes Bryggen is its history of continual rebuilding. After any catastrophic event, each time construction has followed the same parcel divisions, floor plans, and construction techniques. The result is a remarkably consistent two- to three-story architectural appearance that has endured for centuries (4).

Beneath the surface lies an even more extraordinary layer of cultural heritage. The soil and groundwater at Bryggen have preserved centuries of archaeological deposits, offering insights into daily life and urban development during the Middle Ages (5). Though much of the visible architecture has been reconstructed, the site's combined above-ground structures and subterranean deposits embody a timber-building tradition once common throughout Northern Europe, making Bryggen invaluable to Norway's cultural and architectural legacy.

Yet Bryggen now faces an unprecedented threat: the global climate crisis. The increasing frequency of heavy rains, warmer temperatures, and especially rising sea levels pose a large risk to the integrity of both the wooden buildings and the archaeological layers beneath. Located adjacent to the harbour, Bryggen is particularly susceptible to flooding. Future sea-level rise could inundate the site, making traditional rebuilding impossible. Furthermore, rising temperatures accelerate timber decay by promoting fungal growth and increasing the moisture content in wood (6). If global temperatures rise 1.5°C above pre-industrial levels by 2030, as projected, rot rates may increase significantly, requiring more intensive conservation measures (7).

This thesis explores Bergen's identity as a city of weather where the climate has shaped the Bergenser way of life, how climate change is now threatening this living tradition and Bryggen's historic wooden structures and underground deposits, and what current and possible mitigation strategies can help protect them. Preservation responses at Bryggen are already underway ranging from drainage interventions and flood protection to advanced material conservation and groundwater stabilization. However, these efforts are often short-term.

By drawing on other UNESCO examples, including Venice's MOSE flood barriers, microbial coating techniques used in Poland's timber churches, and geotextile strategies proposed for sites like Hadrian's Wall, this thesis seeks to propose broader and more long-term approaches to safeguarding Bryggen. The goal is not only to protect a physical site but to preserve a living narrative of adaptation, resilience, and cultural continuity in the face of accelerating climate change.

(1) Jon C Day Bakke-Alisøy H, Hygen HO, Eriksen OS, Heron SF (2024) Application of the Climate Vulnerability Index (CVI): Bryggen World Heritage property. Bergen Municipality, Bergen; Riksantikvaren, Oslo; and Climate Vulnerability Index, Townsville. 978-0-6459516-8-4
(2) Ibid.
(3) Ibid.
(4) Ibid., 5.
(5) Jens Rytter and Iver Schonhowd, "Monitoring, Mitigation, Management – The Groundwater Project: Safeguarding the World Heritage Site of Bryggen in Bergen," (Norwegian Institute for Cultural Heritage Research, 2015), 8.
(6) Anne S. Kaslegard, "Climate Change and Cultural Heritage in the Nordic Countries" (Nordic Council of Ministers, 2011), 15.
(7) Ibid.

Literature Review

A growing body of literature analyses the impacts that climate change is having on UNESCO sites around the world. The following review synthesizes relevant work on Bryggen itself, broader preservation practices, and international parallels that inform this thesis's proposed strategies. These sources fall into three thematic categories: (I) Bergen's climate and local perceptions, (II) subsurface and groundwater-related threats to Bryggen, and (III) other UNESCO case studies offering potential models for further interventions.

I. Climate and Cultural Identity in Bergen

Bremer et al. provide a foundational understanding of Bergen's climate-conscious urban identity. Through local surveys and ethnographic analysis, the authors reveal how Bergen residents, or Bergensers, have long constructed their identity in relation to the city's distinctive weather conditions, particularly its rainfall and temperature patterns. The study finds a growing 'climate concern' among residents, who are increasingly aware that their environment is shifting, and that this change may erode both their cultural and physical landscape. These insights frame climate change not merely as a technical problem, but one that deeply affects local identity and lived experience in Bergen.

Day et al. expand on this work by outlining the city's emerging policy responses to climate risk, including early municipal planning efforts and public discussions on rising sea levels and rainfall. Their work helps position Bryggen within a broader cultural and governance context, emphasizing that preservation must account for both infrastructure and public perception.

II. Subsurface Archaeology and Groundwater Preservation

The preservation of Bryggen's subsurface cultural deposits is a key concern addressed in several technical studies. Rytter et al. offer an in-depth analysis of the site's groundwater and soil composition, documenting leakage from nearby structures and saltwater infiltration from the harbour. Their work confirms that groundwater saturation is essential to slowing decay and preventing the oxidation of archaeological material beneath the timber buildings. Elam et al. complements this study by examining how disturbances from nearby construction and climate-induced drying increases the rate of decay in buried timber, threatening long-term preservation.

Additionally, Matthiesen presents a chemical analysis of Bryggen's groundwater and its role in maintaining a low-oxygen environment essential for preservation. His study contributed directly to the development of the site's monitoring network, which today includes over 30 groundwater sensors. These works provide the foundation for Bryggen's current groundwater management strategy.

Kaslegard, writing more broadly about Scandinavian timber heritage, identifies the major climate stressors for historic wood: temperature fluctuations, increased rainfall, and rising humidity. Her research confirms that Bryggen's challenges are part of a larger regional pattern, and that adaptation strategies must consider long-term shifts in atmospheric and soil moisture levels.

III. UNESCO Case Studies and Adaptive Models

While much of the literature on Bryggen focuses on existing risks and management efforts, other sources present adaptive preservation models that could be transferred to Bryggen's context. Taylor and Birley document the preservation challenges at Hadrian's Wall in the UK, where archaeological peat deposits are deteriorating due to climate change. Their study discusses potential mitigation techniques such as soil rehydration and the use of geotextile membranes which are strategies that could be adapted for Bryggen's subterranean layers.

Umgiesser et al. provide an analysis of Venice's MOSE system, a large-scale flood defence mechanism designed to protect the city from tidal surges. Their evaluation of MOSE's impact, cost, and technical performance offers useful insights into how a scaled-down version might be applied to Bergen's harbour to protect Bryggen from sea-level rise.

Lastly, Hu explores the vulnerability of Poland's timber churches in Małopolska and reviews innovative interventions such as microbial coatings and lime-based moisture barriers. These case studies offer low-impact, climate-responsive strategies that can help extend the life of historic wooden structures and reduce the need for invasive restoration.

IV. Conclusion

The literature reviewed reveals that while Bryggen is already the focus of extensive monitoring and localized conservation efforts, gaps remain, especially in long-term adaptation planning. Climate change is not a static challenge; it requires forward-looking strategies that integrate physical, cultural, and environmental knowledge. To preserve Bryggen, an integrated understanding of preservation beyond the traditional should be utilised.

Figure 4: View over Bergen Harbour and Bryggen
Taylor Mcintyre/Tripsavy. *Weather in Bergen.* (2020). https://www.tripsavvy.com/weather-in-bergen-1626874

Chapter 1: Weathered Resilience. Bergen's Identity, Climate, and the Rising Tide of Change

Bergen, often referred to as the 'city of weather', has long been shaped by its climatic conditions. Located along Norway's western fjords, it lies in an oceanic climate zone marked by cold, rainy winters and cool, damp summers (8). The city's rainy season can last up to seven months, earning it the title of the rainiest and least sunny city in Europe (9). Despite this, Bergen's residents—known as Bergensers—have not merely endured their environment; they have embraced it, cultivating a local identity rooted in weather resilience.

This ethos is reflected in everyday life and cultural expression. Outdoor activity is integral to the Bergen lifestyle as residents regularly hike, fish, ski, or walk in the rain. Public narratives emphasize this tenacity. One local rainwear company, BRGN, writes: "We live in one of the rainiest cities in the world... This is Bergen. This is who we are. We won't let the weather dictate: what to do, where to go, when to go..." (10). In Bergen, adaptability is a point of pride. Interviews reveal that locals consider it "embarrassing" to struggle with the rain which implies that tolerance for weather is not just practical, but essential to being a true Bergenser (11).

However, in recent decades, this historically stable climate is changing in ways that challenge both Bergen's infrastructure and its identity. Older residents have noted seasonal shifts: winters are milder, spring arrives earlier, and rainfall patterns are increasingly unpredictable (12). These changes affect daily life: from altering ski seasons and agricultural cycles to destabilizing the long-standing cultural narrative of resilience (13).

Public concern has grown alongside these environmental shifts. In the 1990s, only 10% of Norwegians reported being worried about climate change (14). By 2016, 96% acknowledged its reality, and two-thirds believed it was already affecting their lives (15). Climate anxiety is no longer theoretical; it's experienced daily by people whose identity is closely tied to the elements. The question now facing the city is whether cultural resilience can evolve quickly enough to meet the escalating pace of environmental change.

Among the most vulnerable and symbolically significant elements of Bergen's urban landscape is Bryggen. Designated as a UNESCO World Heritage Site, Bryggen includes historic timber buildings situated directly along the Bergen harbour. UNESCO lists "climate change" as a key hazard for Bryggen on their website, citing risks from rising sea levels, increased precipitation, and warming temperatures (16). These factors threaten both the architectural integrity of the site and its deeper cultural meaning.

(8) "Climate – Bergen," Climates to Travel, accessed March 2025, https://www.climatestotravel.com/climate/norway/bergen.
(9) Ibid.
(10) Scott Bremer et al., "Portrait of a Climate City: How Climate Change is Emerging as a Risk in Bergen, Norway," Climate Risk Management 29 (2020): 6.
(11) Ibid., 6–7.
(12) Ibid., 7.
(13) Ibid.
(14) K. Steentjes et al., "European Perceptions of Climate Change: Topline Findings of a Survey Conducted in Four European Countries in 2016" (Cardiff: Cardiff University, 2017).
(15) Ibid.
(16) K. N. Nguyen and S. Baker, "Climate Change and UNESCO World Heritage-Listed Cultural Properties: A Systematic Review, 2008–2021," Heritage 6, no. 3 (2023): 2394–2420.

I. Location and Environmental Exposure

The first and most immediate risk to Bryggen lies in its geographical location. The site is elevated only 1.5 meters above sea level and is directly adjacent to the harbour (17). With sea levels proposed to rise along Norway's coast between 0.12 m to 0.46 m by 2100, rising water is a serious problem (18). In a 100-year storm surge/flooding scenario, simulations show flooding would reach farther inland than previously recorded, impacting Bryggen and surrounding infrastructure as seen in figure 5 (19). Climate change is also predicted to increase storm frequency and intensity, especially due to rising wind speeds, further exacerbating the risk of storm surge (20). Salt-water intrusion, particularly during flood events, threatens to compromise the timber's structural integrity.

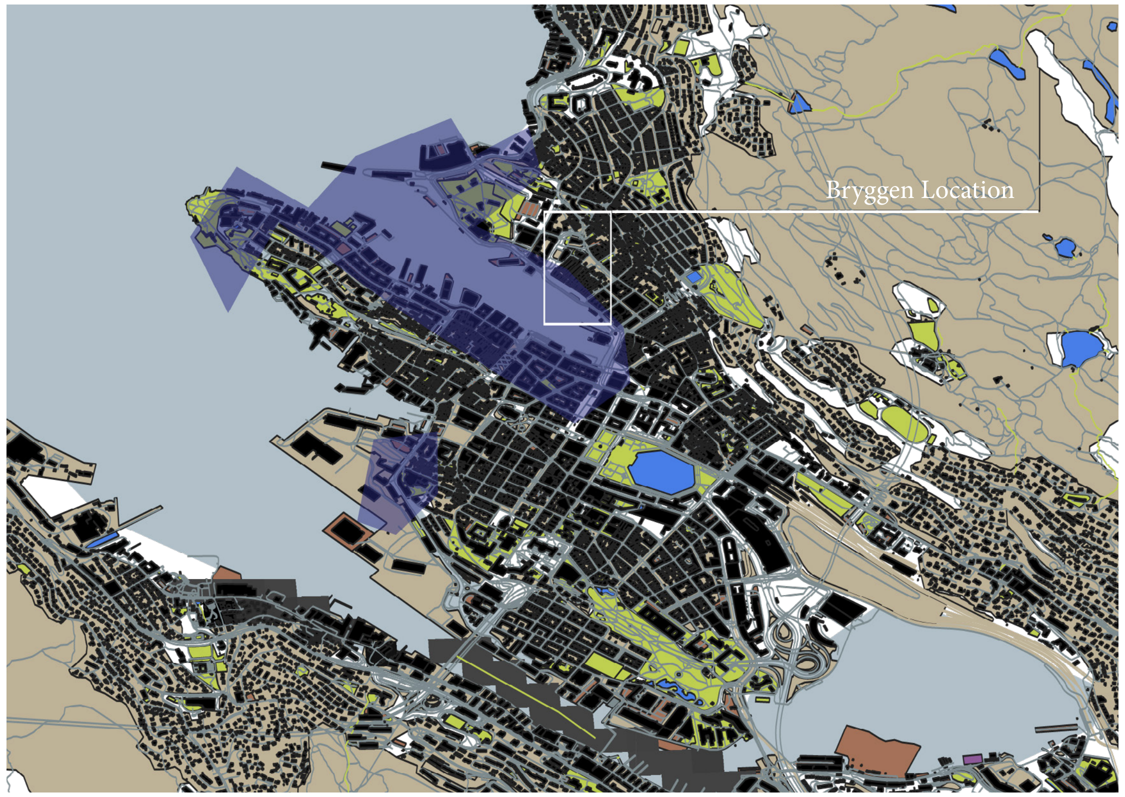


Figure 5: Bergen Flooding Scenario 100 year flood
Map by Regan Reser using QGIS 3.34, based on CORINE Land Cover and Coastal 2018 data. Bergen Flooding Map. 2025.

Flooding coverage in 100 year flooding event

(17) Guri Venvik & Ane Bang-Kittilsen & Boogaard, Floris. (2019). "Risk assessment for areas prone to flooding and subsidence: a concept model with case study from Bergen", Western Norway. Hydrology Research. 51. 10.2166/nh.2019.030.
(18) Norwegian Mapping Authority, "Future Sea Level along the Norwegian Coast," last modifed April 26, 2024, https://www.kartverket.no/en/at-sea/se-havniva/sea-level/future-sea-level-along-the-norwegian-coast.
(19) Map by Regan Reser using QGIS 3.34, based on CORINE Land Cover and Coastal 2018 data. Bergen Flooding Map. 2025.
(20) Day et al., 27.

II. Vulnerability of Material and Subsurface Deposits

Bryggen's timber structures are particularly vulnerable to climatic changes. While wood has historically been an abundant and durable building material in Scandinavia, rising temperatures and increased rainfall in Bergen create conditions that accelerate wood decay (21). Humidity promotes water ingress into the timber and weakens its structural capacity over time (22). The result is a heightened need for frequent and invasive maintenance, further straining conservation resources.

Equally concerning is what lies beneath the surface. Bryggen sits atop archaeological deposits that reach up to ten meters in depth and contain highly organic material (23). These deposits are preserved only under specific groundwater conditions that maintain low oxygen levels. If the groundwater is contaminated or depleted, either by over-drainage or saltwater infiltration, organic decay accelerates, leading to possible subsidence and loss of critical heritage material (24).

Figure 6: Section of Bryggen with Deposits
T. Sponga. *Section Showing Buildings, Archaeological Deposits, and Groundwater.* Riksantikvaren

III. Infrastructure Limitations

Bergen's integrated drainage system—which combines sewage and storm water—poses a third major challenge. This system, including at Bryggen, is currently capable of handling standard rainfall. But as climate change increases the frequency and intensity of storms, the system risks being overwhelmed. During high rainfall events, surface flooding can occur, leading to both structural and subsurface damage. A simulation using a rainfall rate of 20 mm/h predicted significant pluvial flooding around the harbour, with direct implications for Bryggen (25). The overflow of untreated storm water and sewage can contaminate the groundwater, compromising the preservation of subsurface archaeological materials (26).

(21) Day et al., 28.
(22) Ibid.
(23) Ibid., 7.
(24) Ibid.
(25) Venvik et al., 5.
(26) Rytter et al., 8.

IV. Conclusion

Bergen's historical relationship with weather is central to its identity and built environment. But as climate patterns shift and intensify, the city faces an unprecedented challenge; one that tests both its cultural resilience and technical infrastructure. Bryggen stands at the intersection of these pressures: a historic site deeply tied to Bergen's past and extremely vulnerable to its environmental future. As the following chapters will show, while Bergen has already implemented various preservation strategies, the scope and scale of the climate crisis may demand more radical interventions to safeguard this heritage site.

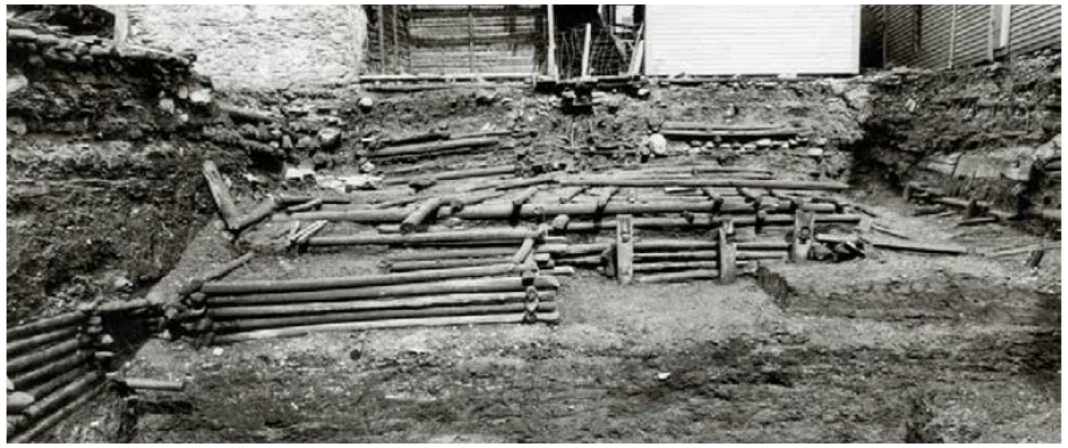


Figure 7: Buildings erected after 1702 fire on top of metres-thick organic archaelogical deposits
Universitetsmuseet i Bergen. *Building with exposed deposit.* Riksantikvaren.

Figure 8: Archaelogical deposits with monitoring devices
J. Rytter.(2017). *Piles drilled through archaeological deposits.* Riksantikvaren.

Chapter 2: Preserving Bryggen. Current Challenges and Strategies in the Face of Climate Change

Bryggen represents more than historic architecture. It embodies Bergen's cultural legacy, timber-building heritage, and deeply rooted relationship with climate. Yet, the increasingly unpredictable environmental conditions associated with climate change pose serious threats to the site. Preservation is no longer a matter of protecting wooden façades alone; it requires safeguarding a network of subterranean conditions, especially the groundwater and archaeological deposits beneath the surface that are essential to the site's integrity.

This chapter shifts from examining identity and vulnerability to analysing the active preservation strategies now in place at Bryggen. These include interventions to stabilize groundwater levels, manage drainage and flooding, and protect the site from structural decay caused by increased precipitation and temperature fluctuations. While these methods reflect significant progress and interdisciplinary coordination, many remain temporary or reactive, constrained by cost, infrastructure, and climatic uncertainties.

I. Groundwater Management and Archaeological Preservation

Much of the current conservation work at Bryggen focuses on the cultural deposits beneath the timber buildings, which are rich in organic material and require specific environmental conditions to remain stable. These deposits are preserved through constant water saturation, which limits oxygen exposure and slows microbial decay (27). As climate shifts cause both increased rainfall and drier intervals, managing this balance has become increasingly complex.

In response to accelerated decay, the Norwegian Directorate for Cultural Heritage (Riksantikvaren) launched a major groundwater monitoring and management project in the early 2010s. Studies revealed that approximately 30 cubic meters of organic material were being lost each year due to oxidation and drainage-related issues (28). In response, 35 monitoring devices were installed throughout the site to track subsidence, groundwater levels, and oxygen content (29).

One of the most effective early interventions was raising the groundwater level by 70 centimetres in a key zone where a nearby hotel's drainage system had caused significant groundwater loss (30). This rise had an immediate stabilizing effect, as increased water saturation limited the rate at which oxygen could penetrate and accelerate decay. Oxygen diffuses roughly 1,000 times faster in air than in water, making even small fluctuations critical (31).

To maintain this delicate balance, Bryggen now employs an integrated groundwater management system that includes passive and active methods. A rainwater garden, the largest of its kind in Norway, collects and filters runoff to replenish groundwater, and during extended dry periods, the system is supplemented with municipal drinking water (32). These strategies have helped reduce the rate of decay in the archaeological layers, but their long-term success depends on consistent rainfall and climate stability which are both increasingly uncertain.

(27) Ibid., 46.
(28) Ibid.
(29) H. Matthiesen, "Detailed Chemical Analyses of Groundwater as a Tool for Monitoring Urban Archaeological Deposits: Results from Bryggen in Bergen," Journal of Archaeological Science 35, no. 5 (2008): 1378–88.
(30) Day et al., 89.
(31) Johanna Elam, Charlotte Björdal, " A review and case studies of factors affecting the stability of wooden foundation piles in urban environments exposed to construction work," International Biodeterioration & Biodegradation, Volume 148, 2020, 104913, ISSN 0964-8305, https://doi.org/10.1016/j.ibiod.2020.104913.
(32) Day et al., 128.

II. Salt-water Intrusion and the Threat of Sea-Level Rise

While groundwater loss from urban drainage has been partially addressed, salt-water intrusion from the adjacent harbour remains a growing concern. Sea-level rise, storm surges, and tidal pressure increasingly threaten to introduce saline water into the soil, which can alter pH levels, promote osmosis, and distort wooden structures (33). Salt-water exposure also accelerates the degradation of organic material in the archaeological deposits and compromises the mechanical properties of submerged wood (34).

Although large-scale flood barriers have been proposed, none have yet been implemented due to high costs and logistical challenges. Current solutions focus on smaller interventions: sewage pipes near the harbour have been retrofitted with non-return valves to limit back flow during high tides (35). Despite this, monitoring data already shows evidence of seawater infiltration near Bryggen's edge, with organic decay estimated to be increasing by approximately 1% annually in these zones (36).

The absence of a permanent flood barrier leaves Bryggen vulnerable to future surge events. Three potential options have been proposed: an outer sea wall, an interior harbour gate, or a hybrid system. But political hesitation and financial constraints have stalled progress (37). Without action, the risk to the site from extreme weather events will continue to escalate.

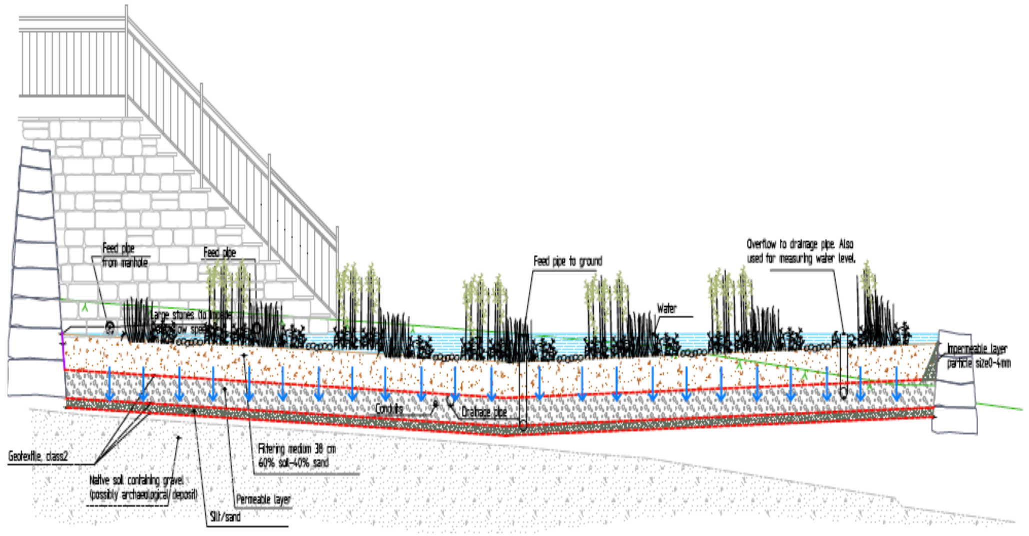
III. Surface Water Management and Drainage Limitations

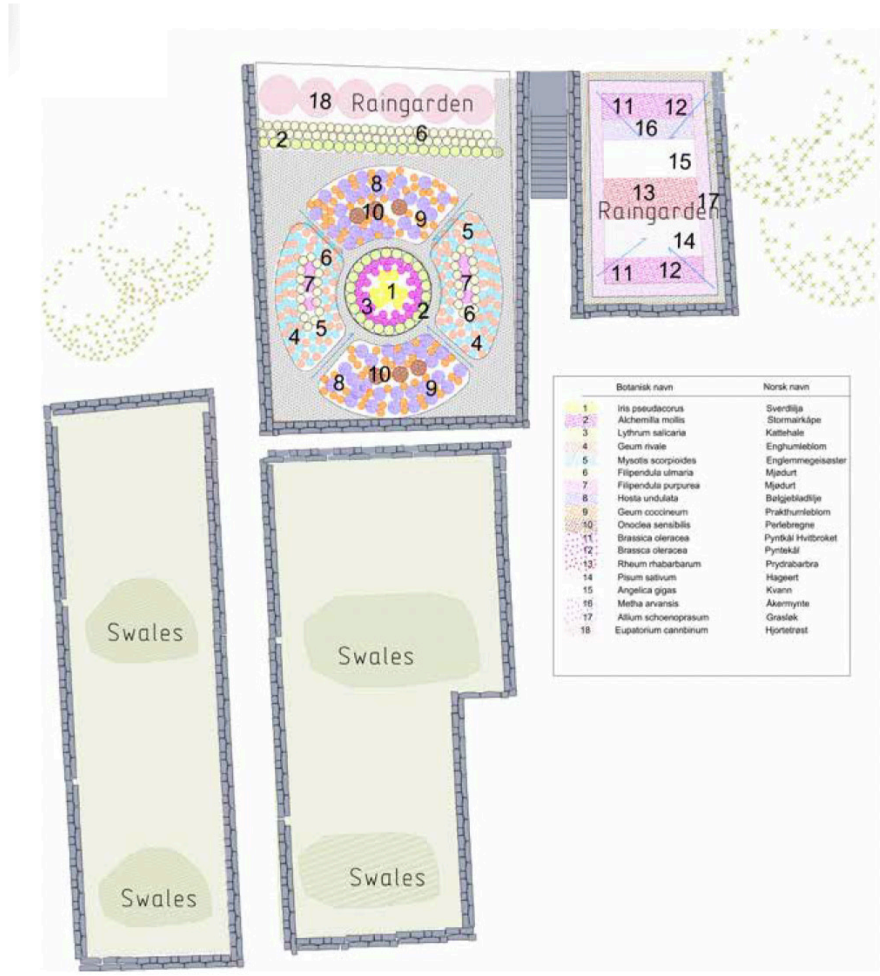
Beyond sea-level threats, Bergen's increasingly heavy rainfall has overwhelmed its existing urban drainage infrastructure. The city uses an integrated sewer-storm water system, which, under extreme precipitation, struggles to manage runoff. Bryggen's location in a low-lying coastal zone makes it especially susceptible to surface flooding. A recent flood simulation using a rainfall rate of 20 mm/h identified the harbour as one of the city's most vulnerable areas (38).

Surface flooding introduces additional water into the soil, which may carry contaminants and disrupt the chemical equilibrium necessary for archaeological preservation (39). Flood-waters can also cause physical damage to the above-ground timber buildings, particularly in lower structural members that absorb moisture readily and are more prone to rot.

To address these problems, the city has implemented a Sustainable Urban Drainage System (SUDS) framework at Bryggen (figures 9-10). In addition to the rainwater garden, the site includes permeable pavement to increase infiltration, swales to retain water and raise humidity levels, and safety valves to control overflow (40). These features aim to reduce both surface flooding and groundwater oxidation, which together threaten the stability of the site. However, these systems have not yet been tested under extreme climate scenarios, leaving their future efficiency uncertain.

(33) Roman K. et al., "Effect of Seawater with Average Salinity on the Moisture Content, Ash Content and Tensile Strength of Some Coniferous Wood," Materials 16, no. 8 (2023): 2984.
(34) Ibid.
(35) Day et al., 91.
(36) Ibid., 89.
(37) Peter Guttorp, Thordis L. Thorarinsdottir, How to Save Bergen from the Sea? Decisions under Uncertainty, Significance, Volume 15, Issue 2, April 2018, Pages 14–18, https://doi.org/10.1111/j.1740-9713.2018.01125.x
(38) Venvik et al., 5.
(39) Day et al., 28.
(40) Ibid., 143–144





Figures 9-10: SUDS Strategy Drawings of Current Interventions
Multiconsult AS. (2017). *Cross Section and Schematic of Rainwater Garden*. Riksantikvaren.

IV. Climate Impact on Timber Structures

The visible timber architecture of Bryggen is also under increasing threat. Moisture content is a primary factor affecting wood's mechanical properties, decay rate, and susceptibility to mold. Under projected climate conditions, Northern Europe is expected to see a 50% increase in outdoor wood rot over the next century (41). Bergen's forecast for warmer and wetter conditions will place substantial stress on both restored and original timber elements.

The buildings at Bryggen already undergo regular damp-proofing and structural reinforcement, but these methods are maintenance-heavy and do not prevent cumulative deterioration. Additionally, subterranean heating from surrounding buildings and energy systems is raising the temperature of the soil and groundwater, further accelerating the decomposition of buried organic material (42).

Mold also poses a serious risk to the structural integrity of the site as it can 'eat' at the wood. Studies show that mold growth becomes active in wood when moisture content exceeds 35% and temperatures rise to around 23–25°C, and these conditions that are becoming more common during Bergen's warmer seasons (43). Currently, no extensive climate-proofing program exists for the above-ground buildings beyond routine maintenance and monitoring.

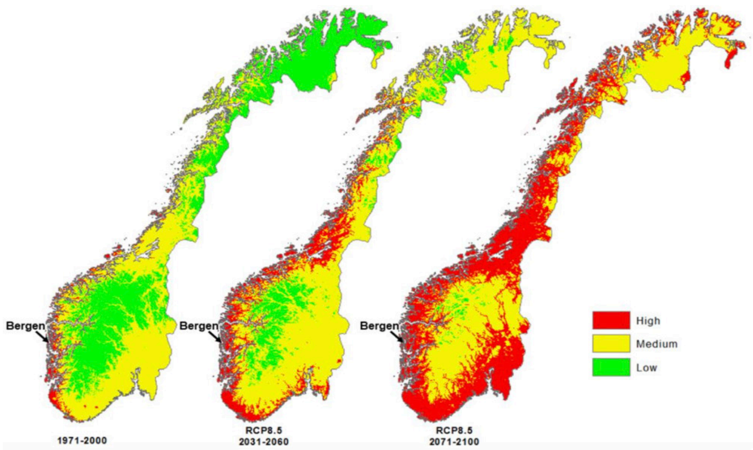


Figure 11: Estimated rot risk historically and projected in Norway
Riksantikvaren. *Rot Risk diagrams RCP.* (2024), chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://riksantikvaren.no/content/uploads/2024/12/Application-of-the-CVI-to-Bryggen_final.pdf

V. Conclusion

While Norway has taken significant steps to monitor and mitigate the effects of climate change on the site, current strategies remain largely reactive and dependent on stable environmental conditions. Groundwater stabilization, salt-water intrusion prevention, urban drainage reforms, and timber maintenance are all essential, but they are not sufficient in the face of long-term climatic shifts.

These findings point to the urgent need for more durable, adaptive strategies, drawing from other UNESCO precedents, and what lessons they can provide that might inform future interventions at Bryggen.

(41) Anne S. Kaslegard, "Climate Change and Cultural Heritage in the Nordic Countries (Nordic Council of Ministers", (2011), 15.
(42) Ibid., 89.
(43) Ibid., 143.

Chapter 3: Integrating Innovation. UNESCO Interventions for Local Heritage

While current preservation efforts at Bryggen focus on mitigating the immediate threats of climate change, the evolving nature of these risks demands more forward-thinking and adaptive strategies. To ensure Bryggen's survival through the next century, it is necessary to look beyond localized solutions and draw from various heritage conservation efforts of the UNESCO community.

This chapter evaluates innovative interventions from other UNESCO World Heritage sites that face comparable climate challenges. Namely Hadrian's Wall in the UK, Venice's MOSE flood barrier system in Italy, and the wooden churches of Malopolska in Poland. These case studies provide conceptual and technical frameworks that could be adapted to the specific environmental, cultural, and spatial context of Bryggen.

I. Subsurface Preservation and Ground Stabilization: Lessons from Hadrian's Wall

Like Bryggen, Hadrian's Wall contains fragile archaeological deposits, many of which are buried in peat-rich, waterlogged soils. As the marshy ground begins to dry out due to rising temperatures and land-use changes, these deposits are increasingly exposed to oxygen, accelerating their degradation (44). This is very similar scenario to Bryggen which faces a similar break down of archaeological deposits due to oxidation.

Figure 12: View of Hadrian's Wall
English Heritage. *History of Hadrian's Wall.* https://www.english-heritage.org.uk/visit/places/hadrians-wall/hadrians-wall-history-and-stories/history/

(44) G., Taylor & Birley, B. (2022). KEYNOTE: Revealing Magna and the threat of climate change to archaeological sites. Paper presented at Roman Finds Conference 2022, Carlisle.

In response, preservationists at Hadrian's Wall have implemented intensive groundwater monitoring and soil sampling strategies like those at Bryggen (45). One of the more radical proposals has been the deliberate reburial of key sections of the site using peat or geotextiles to simulate the original moisture-retaining environment (46). This keeps the wall from further deterioration as the soil deposits help it to reach equilibrium once more.

To translate this to Bergen, burying Bryggen's above-ground structures is not feasible, but this method could be adapted for subsurface preservation. For instance, introducing geotextile membranes into the soil beneath Bryggen could help regulate water content, stabilize temperature, and control gas exchange which would mitigate the oxidation process without extensive excavation (47). In order to understand how geotextiles react with water, another precedent had to be found as Hadrian's Wall does not have the same delicate groundwater balance as Bryggen. It was unexpectedly found in shipwreck conservation, where waterlogged wood is wrapped in geotextiles to prevent accelerated decay (48). Geotextiles could be gently wrapped around the timber deposits at Bryggen before being covered with soil once more which can help it to remain in a preserved state. And given the long-lasting material life of polypropylene geotextiles in water conditions, it would provide a long-term solution to oxidation and water contamination effecting the archaeological deposits (49).

Given that Bryggen already has extensive monitoring infrastructure, integrating geotextiles in select zones could offer an efficient, low-impact enhancement to the site's current groundwater strategy with regards to the deposits. Potential risks with geotextiles involve possible alteration to the soil composition or introduction of negative bacteria to the deposits, but if monitored with the current system at the site, these risks can be easily mitigated.

Figure 13: Geotextile wrapped timber ship beam
Anastasia Pournou.The Mermaid Project. (2013). https://www.researchgate.net/figure/Condition-of-geotextile-after-12-years-as-a-physical-barrier_fig6_308887197

(45) Ibid.
(46) Ibid.
(47) A. Pournou, "Assessing the Long-Term Efficacy of Geotextiles in Preserving Archaeological Wooden Shipwrecks in the Marine Environment". J Mari Arch 13, 1–14 (2018). https://doi.org/10.1007/s11457-017-9176-9
(48) Ibid.
(49) Ibid.

II. Coastal Flood Protection: The MOSE Barrier System in Venice

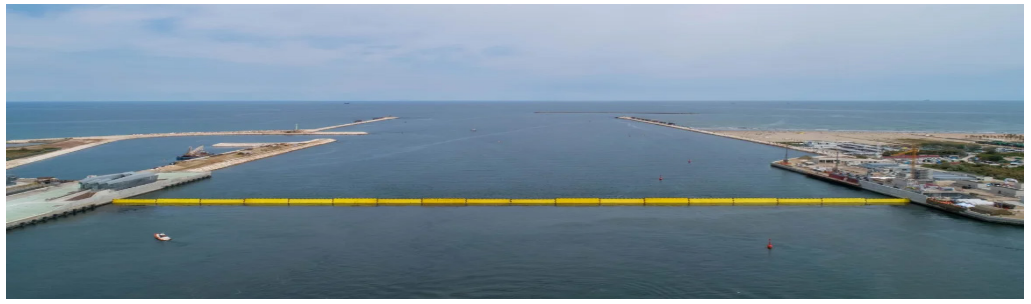


Figure 14: View of MOSE fully engaged
Consorzio Venezia Nuova. *Barriers of Treporti Inlet.* https://mosevenezia.eu/

Perhaps the most ambitious heritage protection effort in recent memory is Venice's MOSE (Modulo Sperimentale Elettromeccanico) system. Developed in response to increasingly devastating floods, MOSE consists of 78 mobile floodgates anchored to the seabed and designed to rise during storm surge events, temporarily sealing off the Venetian lagoon from the Adriatic Sea (50). Operational since 2020, the system uses predictive weather modelling to determine deployment and has successfully protected the city from major tidal flooding since its implementation (51).

While Bergen's geography differs significantly from Venice, the harbour at Bryggen shares the fundamental challenge of proximity to rising sea levels. A similar system, though smaller in scale, could be employed at the mouth of Bergen's harbour. Unlike Venice, which requires protection across multiple entry points and a vast lagoon, Bryggen's vulnerability is concentrated in a smaller zone that could be secured with two to three strategically placed mobile gates. These would remain submerged and invisible during normal conditions but could be raised during storm surges to prevent seawater from reaching the site (52).

The primary barrier to such a system is cost. Sea gate interventions have been proposed in the past to the Bergen city council, but none have been successfully passed. However, when considered as a long-term investment in both cultural preservation and urban flood protection, the potential value is significant. Therefore, I think a model like MOSE should be implemented in Bergen to protect the UNESCO site as well as the city itself from store surge. It can be closed during predicted storm surge events, sealing the harbour off from high chance of flooding which would protect Bryggen as well as Bergen's industrial fishing infrastructure located near the harbour. Therefore, protecting not just the UNESCO site from flooding but also the fishing industry which has been significant to the economy and local life of Bergen since its founding.

(50) Engineering World, "MOSE Project Explained – How Venice Is Fighting Rising Seas," YouTube video, 7:45, October 14, 2021, https://www.youtube.com/watch?v=ntncs8QCkLw.
(51) Georg Umgiesser, et al., "The Prediction of Floods in Venice: Methods, Models and Uncertainty," Natural Hazards and Earth System Sciences 21, no. 8 (2021): 2679–91.
(52) Ibid.

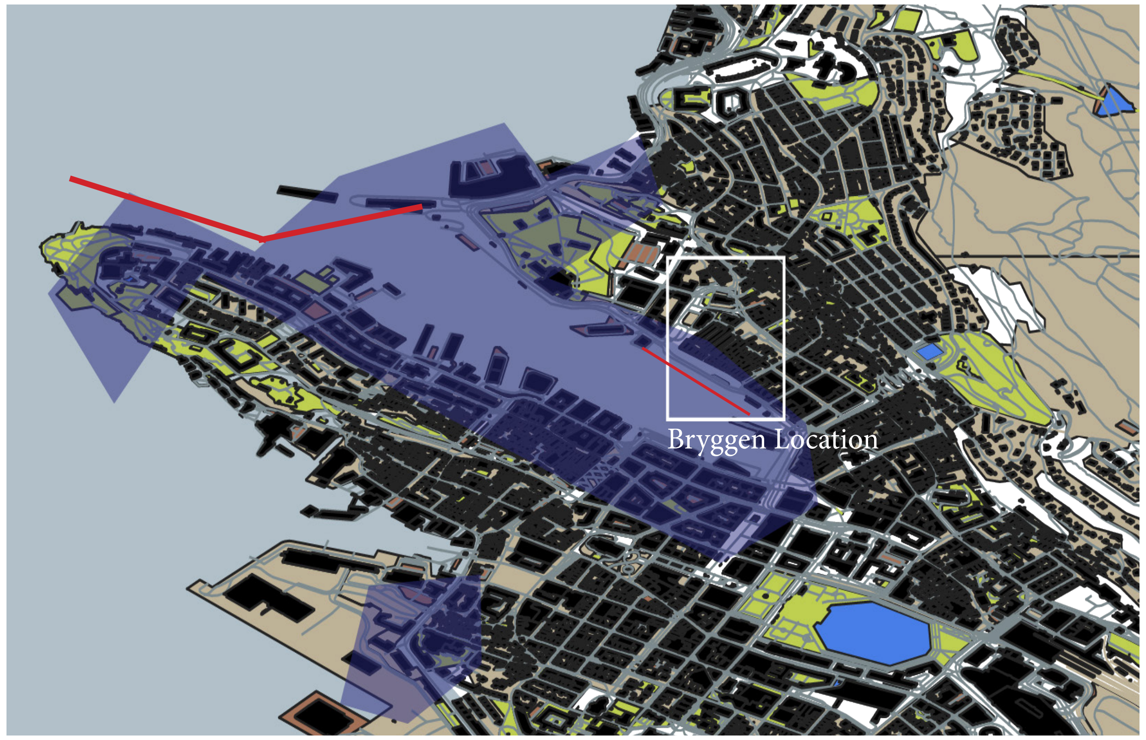


Figure 15: Bergen flooding prone zones with flood gate possible positions in red
Map by Regan Reser using QGIS 3.34, based on CORINE Land Cover and Coastal 2018 data. Bergen Flooding Map. 2025.

III. Timber Structure Resilience: Insights from the Malopolska Wooden Churches

The UNESCO-listed wooden churches of southern Małopolska in Poland face many of the same climatic pressures as Bryggen. Namely increased humidity, rainfall, and rising temperatures that elevate the risk of rot and mold. In response, preservation scientists have explored low-impact, climate-adaptive interventions such as lime mortar coatings and plant-based microbial treatments (53).

Lime mortar, applied at the foundations and exterior walls, helps deflect water while allowing timber to breathe, preventing internal moisture buildup (54). Meanwhile, microbial control methods introduce naturally occurring compounds, such as essential oil-based microcides, to timber surfaces to prevent mold and fungal growth (55). These treatments have proven effective in reducing the decay rate without relying on aggressive chemical preservatives, making them especially suitable for heritage sites that must balance conservation with authenticity (56).

Applying similar approaches at Bryggen could reduce maintenance frequency while extending the life of structural timber. Targeted microbial treatments could also reduce reliance on invasive restorations, preserving more of the original material over time. This would help to preserve the iconic timber façades for future generations as these strategies can be utilised long term, with minimal impact to the existing timber, and could slow the accelerated rot rate that climate change is predicted to cause in Norway. Risks with the proposal of microbial treatment often focus around staining, but this can be considered minor in the context to the complete preservation of the site.

(53) Haisheng Hu, "Impact of climatic-meteorological conditions on Polish wooden cultural heritage: an example of world heritage sites featuring wooden churches near Krakow. Humanities and Social Sciences Communications" (2024). 11. 10.1057/s41599-024-03854-0.
(54) Ibid.
(55) A.M. Omar et al. "Spectroscopic and molecular investigation of Cheopswooden boat for microbial degradation applying proper" (2022). Sci Cult 8(1):1–9
(56) Ibid.

Figure 16: Church of St. Philip in Malopolska
Albertine Slotboom. *World Heritage Photos*. https://www.werelderfgoedfotos.nl/en/photos/66-wooden-churches-of-southern-malopolska.html

IV. Conclusion

Each of the precedents discussed presents not just technical solutions but broader conceptual shifts in how heritage sites adapt to climate change. Bryggen's preservation strategy should evolve toward a hybrid model by combining immediate maintenance and monitoring with long-term adaptation and resilience. Geotextiles and microbial treatments offer low-cost enhancements to existing systems, while harbour floodgates, though expensive, represent a vital line of defence as sea levels continue to rise.

The proposed interventions should be considered within a broader planning framework, one that includes city officials, climate scientists, archaeologists, and local communities. Cultural heritage preservation in the climate era must be understood as an ecological and infrastructural effort, not merely an aesthetic or historical one. The other UNESCO examples of Hadrian's Wall, Venice, and Malopolska show that preservation is not about resisting change but managing it. With thoughtful adaptation and innovation on top of the existing measures conducted, Bryggen can become a model for sustainable heritage preservation in the face of the current global environmental crisis.

Conclusion

Bryggen stands today as both a physical artefact and a living symbol of resilience. For centuries, this historic area has withstood fires, urban change, and environmental wear, emerging each time with its architectural character and cultural significance intact. Yet, the accelerating climate crisis presents a fundamentally different kind of threat. One that not only endangers Bryggen's material survival but also challenges the very identity the city of Bergen itself.

This thesis has explored the vulnerability of Bryggen in the face of climate change, beginning with Bergen's deep cultural ties to its climate. This city of weather's population has historically defined itself through endurance and adaptation to natural forces. However, the city's long-established weather patterns are changing. Rising sea levels, intensified rainfall, and shifting temperatures are destabilizing both the community's sense of place and the fragile balance that has preserved Bryggen's wooden structures and subterranean archaeological deposits for centuries.

The increasing unpredictability of weather systems, paired with projected sea-level rise, means that current interventions may soon prove insufficient. But there is hope to be found as Bryggen is not alone in meeting the challenges that the climate crisis poses to architectural heritage site. UNESCO sites around the world are adapting as well. From the geotextile-based subsurface stabilization methods seen at Hadrian's Wall, to the large-scale but scalable MOSE flood barrier system in Venice, to microbial coatings and lime mortars protecting Poland's timber churches, each site provides insights that could help future-proof Bryggen, and they collectively emphasize the need for hybrid solutions. Ones that combine technological innovation with ecological sensitivity and cultural guardianship.

In conclusion, the preservation of Bryggen in the era of climate change must go beyond technical fixes. It demands a broader shift in how we value and care for vulnerable heritage in a warming world. To do this, Bergen must continue to re-imagine its relationship with the sea, the weather, and its historic core, bringing the 'city of weather' into the next century with its most precious district still in tact for future generations of Bergensers to enjoy.

Notes

(1) Jon C Day Bakke-Alisøy H, Hygen HO, Eriksen OS, Heron SF (2024) Application of the Climate Vulnerability Index (CVI): Bryggen World Heritage property. Bergen Municipality, Bergen; Riksantikvaren, Oslo; and Climate Vulnerability Index, Townsville. 978-0-6459516-8-4
(2) Ibid.
(3) Ibid.
(4) Ibid., 5.
(5) Jens Rytter and Iver Schonhowd, "Monitoring, Mitigation, Management – The Groundwater Project: Safeguarding the World Heritage Site of Bryggen in Bergen," (Norwegian Institute for Cultural Heritage Research, 2015), 8.
(6) Anne S. Kaslegard, "Climate Change and Cultural Heritage in the Nordic Countries" (Nordic Council of Ministers, 2011), 15.
(7) Ibid.
(8) "Climate – Bergen," Climates to Travel, accessed March 2025, https://www.climatestotravel.com/climate/norway/bergen.
(9) Ibid.
(10) Scott Bremer et al., "Portrait of a Climate City: How Climate Change is Emerging as a Risk in Bergen, Norway," Climate Risk Management 29 (2020): 6.
(11) Ibid., 6–7.
(12) Ibid., 7.
(13) Ibid.
(14) K. Steentjes et al., "European Perceptions of Climate Change: Topline Findings of a Survey Conducted in Four European Countries in 2016" (Cardiff: Cardiff University, 2017).
(15) Ibid.
(16) K. N. Nguyen and S. Baker, "Climate Change and UNESCO World Heritage-Listed Cultural Properties: A Systematic Review, 2008–2021," Heritage 6, no. 3 (2023): 2394–2420.
(17) Guri Venvik & Ane Bang-Kittilsen & Boogaard, Floris. (2019). "Risk assessment for areas prone to flooding and subsidence: a concept model with case study from Bergen", Western Norway. Hydrology Research. 51. 10.2166/nh.2019.030.
(18) Norwegian Mapping Authority, "Future Sea Level along the Norwegian Coast," last modifed April 26, 2024, https://www.kartverket.no/en/at-sea/se-havniva/sea-level/future-sea-level-along-the-norwegian-coast.
(19) Map by Regan Reser using QGIS 3.34, based on CORINE Land Cover and Coastal 2018 data. Bergen Flooding Map. 2025.
(20) Day et al., 27.
(21) Ibid, 28.
(22) Ibid.
(23) Ibid., 7.
(24) Ibid.
(25) Venvik et al., 5.
(26) Rytter et al., 8.
(27) Ibid., 46.
(28) Ibid.
(29) H. Matthiesen, "Detailed Chemical Analyses of Groundwater as a Tool for Monitoring Urban Archaeological Deposits: Results from Bryggen in Bergen," Journal of Archaeological Science 35, no. 5 (2008): 1378–88.
(30) Day et al., 89.
(31) Johanna Elam, Charlotte Björdal, " A review and case studies of factors affecting the stability of wooden foundation piles in urban environments exposed to construction work," International Biodeterioration & Biodegradation, Volume 148, 2020, 104913, ISSN 0964-8305, https://doi.org/10.1016/j.ibiod.2020.104913.
(32) Day et al., 128.
(33) Roman K. et al., "Effect of Seawater with Average Salinity on the Moisture Content, Ash Content and Tensile Strength of Some Coniferous Wood," Materials 16, no. 8 (2023): 2984.
(34) Ibid.
(35) Day et al. 91.
(36) Ibid., 89.
(37) Peter Guttorp, Thordis L. Thorarinsdottir, How to Save Bergen from the Sea? Decisions under Uncertainty, Significance, Volume 15, Issue 2, April 2018, Pages 14–18, https://doi.org/10.1111/j.1740-9713.2018.01125.x
(38) Venvik et al., 5.

(39) Day et al, 28.
(40) Ibid., 143–144
(41) Anne S. Kaslegard, Climate Change and Cultural Heritage in the Nordic Countries (Nordic Council of Ministers, 2011), 15.
(42) Ibid., 89.
(43) Ibid., 143.
(44) G., Taylor & Birley, B. KEYNOTE: Revealing Magna and the threat of climate change to archaeological sites. Paper presented at Roman Finds Conference 2022, Carlisle.
(45) Ibid.
(46) Ibid.
(47) A. Pournou, "Assessing the Long-Term Efficacy of Geotextiles in Preserving Archaeological Wooden Shipwrecks in the Marine Environment". J Mari Arch 13, 1–14 (2018). https://doi.org/10.1007/s11457-017-9176-9
(48) Ibid.
(49) Ibid.
(50) Engineering World, "MOSE Project Explained – How Venice Is Fighting Rising Seas," YouTube video, 7:45, October 14, 2021, https://www.youtube.com/watch?v=ntncs8QCkLw.
(51) Georg Umgiesser, et al., "The Prediction of Floods in Venice: Methods, Models and Uncertainty," Natural Hazards and Earth System Sciences 21, no. 8 (2021): 2679–91.
(52) Ibid.
(53) Haisheng Hu, "Impact of climatic-meteorological conditions on Polish wooden cultural heritage: an example of world heritage sites featuring wooden churches near Krakow. Humanities and Social Sciences Communications" (2024). 11. 10.1057/s41599-024-03854-0.
(54) Ibid.
(55) A.M. Omar et al. "Spectroscopic and molecular investigation of Cheopswooden boat for microbial degradation applying proper" (2022). Sci Cult 8(1):1–9
(56) Ibid.

Bibliography

Bremer, Scott, Eleanor Johnson, Kjersti Fløttum, Kyrre Kverndokk, Arjan Wardekker, and Werner Krauß. "Portrait of a Climate City: How Climate Change is Emerging as a Risk in Bergen, Norway." Climate Risk Management 29 (2020): 100236. https://doi.org/10.1016/j.crm.2020.100236.

Day Jon C, Bakke-Alisøy H, Hygen HO, Eriksen OS, Heron SF (2024) "Application of the Climate Vulnerability Index (CVI): Bryggen World Heritage property". Bergen Municipality, Bergen; Riksantikvaren, Oslo; and Climate Vulnerability Index, Townsville. 978-0-6459516-8-4

Elam, Johanna, and Charlotte Björdal. "A Review and Case Studies of Factors Affecting the Stability of Wooden Foundation Piles in Urban Environments Exposed to Construction Work." International Biodeterioration & Biodegradation 148 (2020): 104913. https://doi.org/10.1016/j.ibiod.2020.104913.

Engineering World, "MOSE Project Explained – How Venice Is Fighting Rising Seas," YouTube video, 7:45, October 14, 2021, https://www.youtube.com/watch?v=ntncs8QCkLw.

Guttorp, Peter and Thordis L. Thorarinsdottir, "How to Save Bergen from the Sea? Decisions under Uncertainty," Significance, Volume 15, Issue 2, April 2018, Pages 14–18, https://doi.org/10.1111/j.1740-9713.2018.01125.x

Hu, Haisheng. "Impact of climatic-meteorological conditions on Polish wooden cultural heritage: an example of world heritage sites featuring wooden churches near Krakow". Humanities and Social Sciences Communications. 11. (2024). 10.1057/s41599-024-03854-0.

Kaslegard, Anne S. "Climate Change and Cultural Heritage in the Nordic Countries". Copenhagen: Nordic Council of Ministers, 2011.

Matthiesen, Henning. "Detailed Chemical Analyses of Groundwater as a Tool for Monitoring Urban Archaeological Deposits: Results from Bryggen in Bergen." Journal of Archaeological Science 35, no. 5 (2008): 1378–1388. https://doi.org/10.1016/j.jas.2007.10.010.

Nguyen, Kim N., and Sarah Baker. "Climate Change and UNESCO World Heritage-Listed Cultural Properties: A Systematic Review, 2008–2021." Heritage 6, no. 3 (2023): 2394–2420. https://doi.org/10.3390/heritage6030120.

Norwegian Mapping Authority, "Future Sea Level along the Norwegian Coast," last modifed April 26, 2024, https://www.kartverket.no/en/at-sea/se-havniva/sea-level/future-sea-level-along-the-norwegian-coast.

Omar, A.M. et al. "Spectroscopic and molecular investigation of Cheopswooden boat for microbial degradation applying proper". Sci Cult 8(1):1–9 (2022).

Pournou, A. "Assessing the Long-Term Efficacy of Geotextiles in Preserving Archaeological Wooden Shipwrecks in the Marine Environment". J Mari Arch 13, 1–14 (2018). https://doi.org/10.1007/s11457-017-9176-9

Roman K, Grzegorzewska E, Leszczyński M, Pycka S, Barwicki J, Golisz E, Zatoń P. "Effect of Seawater with Average Salinity on the Moisture Content, Ash Content and Tensile Strength of Some Coniferous Wood". Materials (Basel). 2023 Apr 9;16(8):2984. doi: 10.3390/ma16082984. PMID: 37109820; PMCID: PMC10144292.

Rytter, Jens, and Iver Schonhowd. "Monitoring, Mitigation, Management – The Groundwater Project: Safeguarding the World Heritage Site of Bryggen in Bergen". Oslo: Norwegian Institute for Cultural Heritage Research, 2015.dom.

Steentjes, K., et al. "European Perceptions of Climate Change: Topline Findings of a Survey Conducted in Four European Countries in 2016". Cardiff: Cardiff University, 2017.

Taylor, G., & Birley, B. (2022). "Revealing Magna and the threat of climate change to archaeological sites". Paper presented at Roman Finds Conference 2022, Carlisle.

Umgiesser, Georg, et al. "The Prediction of Floods in Venice: Methods, Models and Uncertainty." Natural Hazards and Earth System Sciences 21, no. 8 (2021): 2679–2691. https://doi.org/10.5194/nhess-21-2679-2021.

Venvik, Guri, Ane Bang-Kittilsen, and Floris Boogaard. "Risk Assessment for Areas Prone to Flooding and Subsidence: A Concept Model with Case Study from Bergen, Western Norway." Hydrology Research 51 (2019): 10.2166/nh.2019.030.