Final Report - The Hill District
Go2Change Annual Training School 2026

Bahareh Kheyrkhah[1], Elif Nur Sarı[2], Lailly Vaz de Miranda[3], Tuncay Narin[4], Giulia Boccacci[5], Emre Kishali[6], Emine Çiğdem Asrav[7]

[1]*Department of Preventive Conservation for Built Heritage,Otto-friedrich-universität, Bamberg, Germany;*
[2]*Department of Landscape Architecture, Istanbul University - Cerrahpasa, Türkiye;*
[3]*Institute of Landscape Architecture, RWTH University - Aachen, Germany;*
[4]*Department of Sociology, Sakarya University, Türkiye;*
[5]*Department of Physics, Sapienza University of Rome, Italy;*
[6]*Department of Architecture, Kocaeli Üniversitesi, Türkiye;*
[7]*Department of Architecture, Bilkent University, Türkiye.*

Introduction

This report presents the project developed by Team Hill District in the context of the Go2CHANGE Training School held in Bamberg, Germany. The project addresses the impacts of climate change on cultural heritage, with a focus on assessing climate-related risks and identifying appropriate response strategies.

The key objective is to explore how climate hazards impact heritage values and to support the development of adaptive actions for their long-term preservation and sustainable management (Figure 1). The approach combines climate risk assessment with a value-based understanding of the heritage site, ensuring that both tangible and intangible aspects are considered.

The project was developed by an interdisciplinary team, with members contributing complementary expertise. Roles were organized across key areas, including case study analysis, climate risk assessment, solution development, and implementation planning, ensuring a coordinated and efficient workflow.

Figure 1. Conceptual framework of the study.

Introduction to the Case Area: the Hill District

The selected case area corresponds to the historic religious and political core of Bamberg (Figure 2), a key component of its UNESCO World Heritage designation. Bamberg is recognized for its Outstanding Universal Value (OUV) as “an outstanding and representative example of an early medieval town in Central Europe”, reflecting the preservation of its urban structure and historical character over time.

The area is characterized by a dense concentration of monumental architecture, including the cathedral, churches, and monastic complexes, which define its historical and symbolic significance. These built elements are complemented by a system of open spaces, among them Domplatz and the Rose Garden, that directly shape the spatial organization and public use of the area.

Situated on a series of hills, the site presents a distinctive monumental skyline, often referred to as the “Franconian Rome.” This topographical configuration enhances both its visual identity and its cultural value. A key heritage attribute of the area lies in its well-preserved medieval urban layout, expressed through the relationships between built structures, open public spaces, and the overall spatial configuration.

In terms of current conditions, the site remains well preserved and actively used, with high levels of accessibility and tourism pressure. However, increasing environmental stressors are becoming more evident, particularly related to extreme weather events. The exposure of built heritage materials to rising temperatures and intensified precipitation patterns, represents a growing concern for the long-term conservation of both structural and surface materials.

Figure 2. The Hill District of Bamberg (Germany).

Methodology

Figure 3 illustrates the step-by-step workflow of the methodology adopted by the Hill District group during the Bamberg Training School, ranging from vulnerability identification and climate risk formulation to the development of mitigation and adaptation strategies and the final implementation plan. A structured methodology aligned with the training school's sequence of discussions, lectures, and applied tools was followed. The process began with the exploration of key concepts of hazard identification and vulnerability assessment. According to the IPCC (2007), vulnerability is defined as the degree to which a system is susceptible to, and unable to cope with, the adverse effects of climate change, including climate variability and extremes. It is further noted that vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, as well as its sensitivity and adaptive capacity.

Within this framework, rising temperatures were identified as the primary climate-related hazard, and the focal area was designated as Bamberg Cathedral (Domplatz) and the open spaces surrounding this medieval architectural heritage site. The sensitivity, exposure and adaptive capacity notions were discussed in the context of the case area.

The second phase involved formulating a climate risk statement, drawing on lectures, publications, site visits, and mapping exercises provided by the trainers, as well as simulation tools and published climate data. The area was then analysed by adapting the European standard EN 16883:2017 – originally developed for historic buildings – to the context of open urban spaces, complemented by geospatial analysis in QGIS and microclimatic simulations using GSV2SVF and RayMan.

Subsequently, mitigation and adaptation strategies were developed through the design of nature-based solutions, encompassing both temporary and permanent interventions to the open space areas adjacent to the monument.

Finally, an operationalisation framework was established through stakeholder mapping based on impact–interest levels, governance structures, and policy considerations, culminating in a concrete implementation plan. Each phase was treated as interconnected, with iterative revisions carried out throughout the analytical process to ensure a holistic and coherent overall approach.

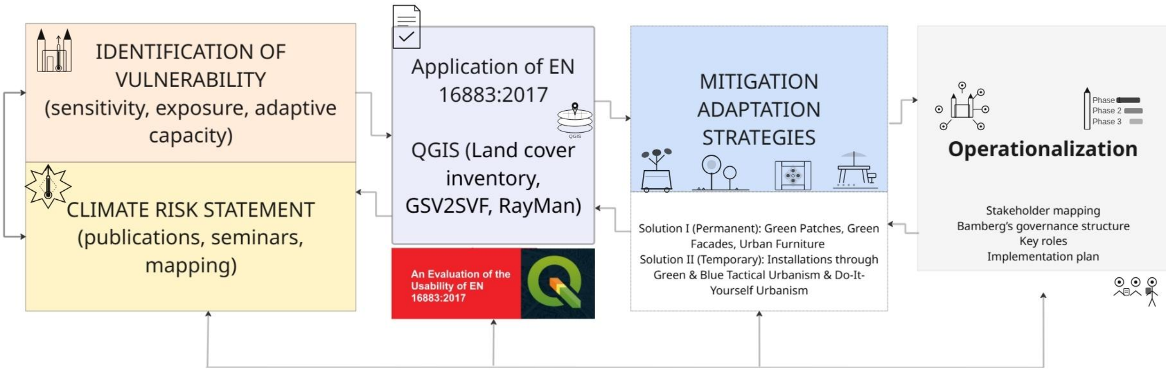

Figure 3. Step-by-step methodological framework.

Climate Risk Statement

The hills of Bamberg, including culturally significant open spaces around landmarks such as Bamberg Cathedral, Neue Residenz, Rosengarten, and surrounding urban areas, are increasingly exposed to climate change risks, particularly **rising temperatures** and more frequent heatwaves, alongside hazards such as heavy rainfall and strong winds. These spaces play a key role in the city's historic urban landscape, contributing to visual integrity, cultural significance, and social life (Alberth et al., 2019).

Climate projections indicate a steady increase in temperatures and prolonged heat periods, intensifying surface heating and reducing thermal comfort (Legg, 2021; Foken, 2025), as reported in Figures 4-7. Vulnerability is driven by high exposure due to elevated topography and south-/west-facing orientation, as well as by urban morphology that can either trap heat (in narrow streets) or increase solar gain (in open spaces). Sensitivity is amplified by heat-absorbing materials, limited vegetation, and insufficient shading. At the same time, adaptive capacity is constrained by heritage conservation requirements, strongly limiting physical interventions.

In the short term, these conditions reduce thermal comfort, increase surface temperatures, and negatively affect visitor experience. In the long term, they contribute to material degradation, vegetation loss, reduced accessibility and social use, and increased maintenance needs (Coletti, 2024). As a result, key **heritage values**—authenticity, integrity, and social function—are at risk, with potential impacts on Bamberg's Outstanding Universal Value as an early medieval urban landscape.

The combined evidence from historical temperature records and future climate projections (Figure 4) clearly indicates a pronounced and progressive increase in temperature extremes. The observed rise in the number of hot days ($T_{max} \geq 30$°C) is consistent with model projections, which indicate a further intensification under future scenarios—particularly under higher emission pathways. Together, these trends highlight a significant and ongoing amplification of climate-related heat hazards in Bamberg. (Foken, 2025; Stocker 201) (Figure 4).

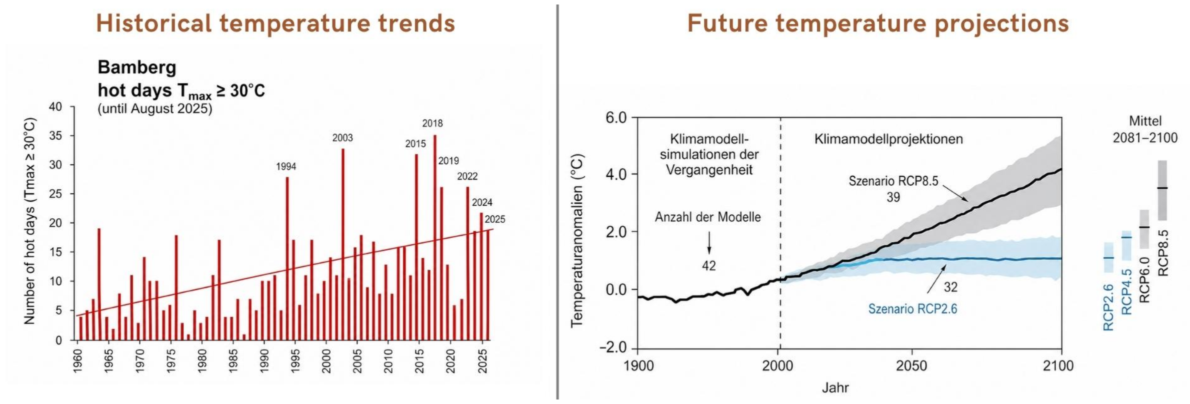

Figure 4. Historical temperature trends and future projections for Bamberg (Sources: Foken, 2025; Stocker 2013).

Urban open spaces characterised by low Sky View Factor (SVF: 0.2) as shown in Figure 5, exhibit high exposure to direct solar radiation. This condition increases heat flux and contributes to increased thermal stress for both visitors and local users, particularly in areas with limited shading and sparse vegetation.

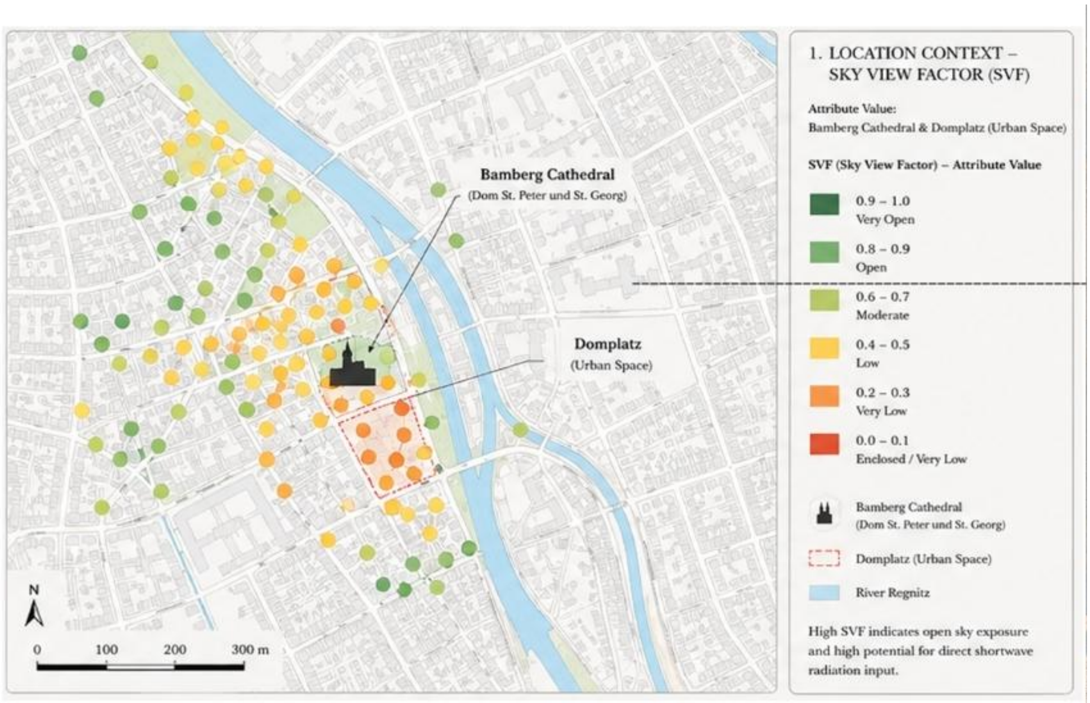

*Figure 5. S*ky View Factor (SVF) level of the Hill District area.

Urban surfaces directly receive incoming shortwave solar radiation and, depending on their physical and thermal properties such as albedo, emissivity, and heat storage capacity, absorb a significant portion of this energy. This absorbed energy is subsequently re-emitted as longwave radiation, particularly during the later hours of the day. As a result, in urban open spaces, radiative heat loads can increase significantly, leading to elevated levels of heat stress for pedestrians depending on the intensity and duration of radiation exposure (Figure 6).

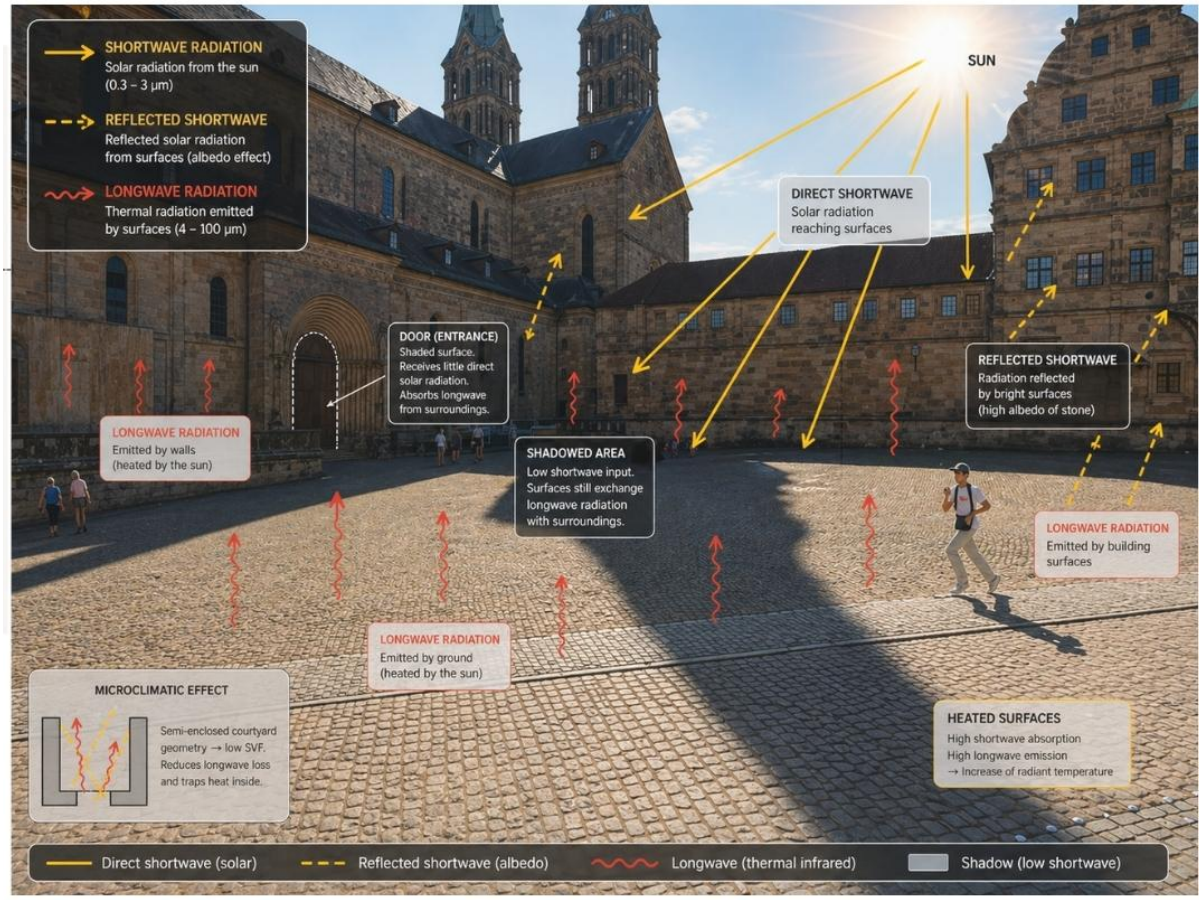

Figure 6. Microclimatic radiation processes in Domplatz (generated with ChatGPT).

In 2023, 807,294 overnight stays were recorded in Bamberg (Bamberg Tourism & Congress Service, 2024), and approximately 65.8% of visitors also visit Bamberg Cathedral (Triphobo, n.d.) 2.5 million visitors for a year (Birgit Kastner, Archdiocese of Bamberg). During the peak summer period, when tourist demand is highest, visitors may be exposed to extreme thermal stress conditions reaching up to 47 °C PET (Physiological Equivalent Temperature), indicating a significant heat stress risk (Figure 7).

August/2025

Day/Time	213	214	215	216	217	218	219	220	221	222	223	224	225	226	227	228
00:00	13	8,9	12	9	12	6,6	4,7	6,6	11	11	6,4	6,4	9,3	12	15	18
01:00	13	8,9	11	9	12	4	4,9	6,5	11	10	5,5	5,8	8,6	12	13	19
02:00	12	9,5	11	9,5	13	3,2	3,9	5,9	12	9,8	5,5	5	8,8	11	12	17
03:00	12	9,2	11	9	12	2,3	3,1	6,2	12	9,1	4,8	4,4	8,2	11	12	17
04:00	12	11	10	9,4	12	1,5	3,5	6,5	12	9,1	4,8	4	7,6	9,8	12	16
05:00	11	11	11	9,5	12	3,3	3,7	8,5	13	9,3	6	4,4	8,3	10	11	16
06:00	12	10	12	9,2	13	6,6	7,7	11	15	13	8,5	9,7	12	14	15	16
07:00	13	12	13	9,8	16	12	12	16	17	17	14	17	19	21	21	18
08:00	16	17	15	9,1	21	17	18	22	22	20	20	27	28	29	29	21
09:00	19	20	17	11	25	23	20	29	27	25	26	31	33	36	33	25
10:00	22	23	19	13	27	23	26	31	32	27	28	33	37	42	39	31
11:00	23	26	20	19	27	27	28	33	36	31	32	33	41	43	41	34
12:00	25	24	16	24	25	26	30	36	39	32	34	35	42	44	47	32
13:00	23	25	17	24	27	28	30	38	40	33	35	37	42	44	47	35
14:00	26	24	20	26	20	29	32	35	41	32	35	38	42	44	41	34
15:00	26	25	19	26	22	28	32	35	43	33	35	38	43	45	43	32
16:00	24	25	16	23	21	27	31	35	41	31	34	38	42	43	42	33
17:00	25	24	17	21	21	26	30	32	37	30	34	36	41	41	38	29
18:00	19	20	18	19	21	23	24	27	32	26	31	31	35	34	32	24
19:00	14	17	13	17	17	17	19	21	24	21	21	23	26	26	29	20
20:00	11	15	12	14	11	9	14	15	16	13	13	14	18	19	25	16
21:00	10	9,7	11	14	8	5,8	10	11	14	10	9,7	12	16	17	22	15
22:00	10	13	11	13	7,3	4,7	8,1	12	12	9,1	8,6	11	14	19	21	13
23:00	9,5	12	9,2	11	8,2	3,6	6,9	12	11	7,4	7,7	9,8	13	17	20	12

Day/Time	229	230	231	232	233	234	235	236	237	238	239	240	241	242	243
00:00	12	5,8	7,9	6,5	15	9,2	4,4	2,8	0,7	2,7	12	15	13	9,9	4,8
01:00	10	4,9	8,2	5,8	14	7,9	3,5	3,5	-1	2,1	13	12	12	11	3,8
02:00	9,3	4,3	5,6	5,2	11	5,9	4,6	2,2	1,5	2,2	12	14	14	9,5	3,7
03:00	8,9	3	4,3	4,7	12	8,2	5,6	3	0	-0	13	13	15	11	3,4
04:00	11	2,6	3,5	4,1	12	7,6	6,2	3,6	-2	1	14	13	13	10	3,1
05:00	12	3	3,6	4,3	12	6,2	6,8	4,9	-3	-2	13	15	13	6,4	2,9
06:00	11	6,6	7,6	9,8	13	8,7	7	5,3	1,6	1,5	14	13	12	11	5,6
07:00	13	10	15	15	15	8,8	7,7	7,4	6,8	8	17	14	14	12	9,6
08:00	17	18	22	19	20	13	14	12	15	16	20	18	17	15	15
09:00	19	21	25	29	24	16	18	22	22	19	23	21	17	18	20
10:00	21	24	31	35	25	18	17	22	25	28	28	24	19	22	25
11:00	26	28	33	37	28	21	17	22	25	31	30	20	22	19	26
12:00	27	29	33	39	29	21	18	23	28	30	32	19	27	22	28
13:00	27	31	34	37	30	21	18	23	27	32	33	25	27	25	27
14:00	27	32	36	36	30	22	16	25	28	33	34	25	27	29	29
15:00	28	30	35	34	30	22	18	22	29	31	34	18	25	20	30
16:00	27	30	37	33	26	20	16	22	27	31	32	21	26	25	30
17:00	20	30	35	31	24	18	16	21	25	30	29	22	25	23	26
18:00	18	26	31	25	21	14	14	17	20	25	26	16	20	19	20
19:00	15	21	20	22	19	12	12	12	15	16	23	15	14	9,3	15
20:00	13	12	12	19	16	8,9	6,3	8,7	8,5	9,1	18	15	10	7,7	9,9
21:00	12	9,9	9,5	18	12	7,3	4	7,3	7,5	11	17	14	9,9	6,5	8,6
22:00	7,7	9,6	8,5	17	9,7	5,4	2,6	2,7	6,3	12	15	14	9,5	5,5	7,4
23:00	7	8,3	7,3	16	10	4,4	1,3	1,9	2,9	12	15	14	10	4,7	7,1

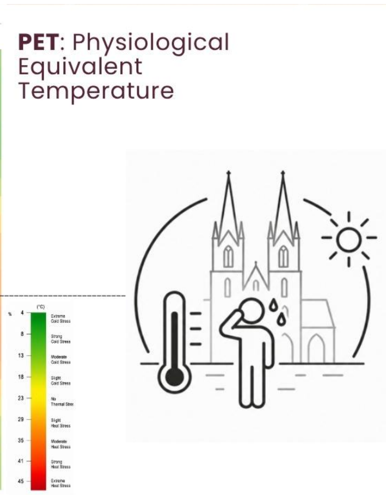

Figure 7. Variation of PET (Physiological Equivalent Temperature) values throughout August 2025.

Figure 8 illustrates the relationship between environmental factors such as temperature, humidity, and precipitation, which cause material stress leading to stone decay. It integrates architectural mapping and close-range material analysis to identify weathering patterns and highlights the potential application of IoT-based weather stations for site-specific microclimatic monitoring.

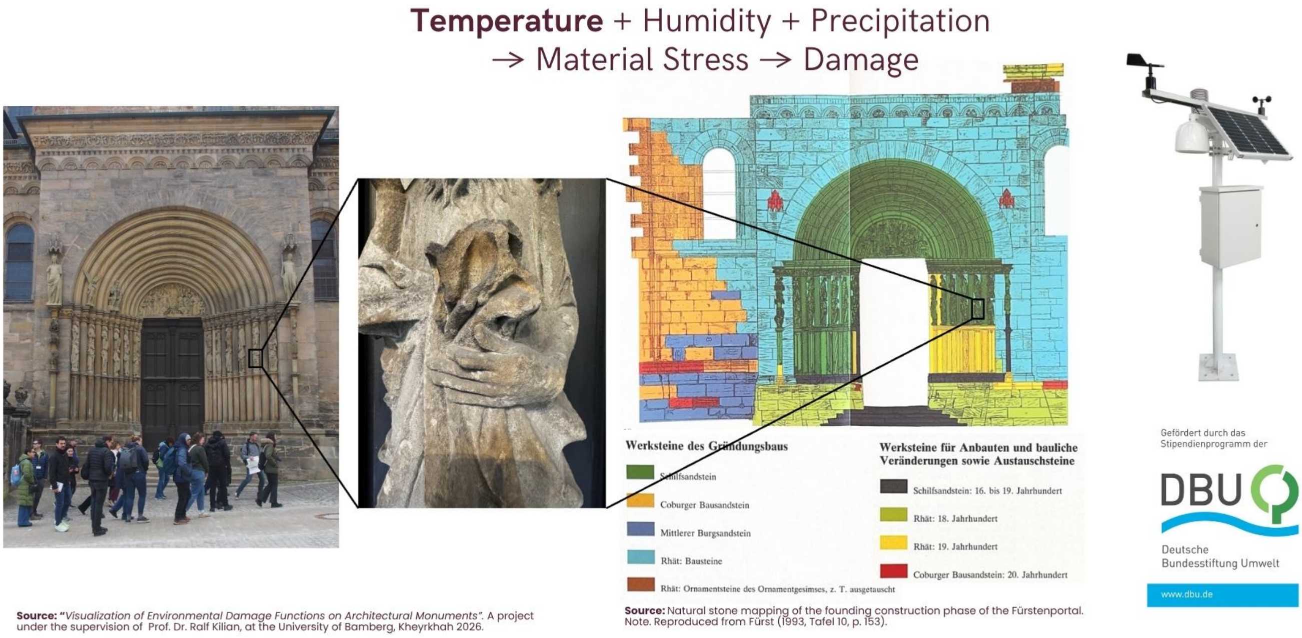

Figure 8. Climate-induced deterioration of Schilfsandstein at the Fürstenportal of Bamberg Cathedral (Domplatz, Bamberg).

Note. Includes natural stone mapping of the founding construction phase of the Fürstenportal. Reproduced from Das Fürstenportal des Bamberger Domes (Tafel 10, p. 153), by M. Schuller, 1993, Bayerische Verlagsanstalt. Additional content adapted from the ongoing research project "Visualization of Environmental Damage Functions on Architectural Monuments," supervised by Prof. Dr. Ralf Kilian, University of Bamberg, funded by DBU (Deutsche Bundesstiftung Umwelt).

Solutions to Climate Change Impacts to the Case Area

The primary climate risk identified in the case area relates to direct solar radiation exposure in urban open spaces, resulting in elevated surface and air temperatures and increased levels of thermal stress for users. These conditions are further exacerbated by projected increases in ambient temperatures associated with climate change. In parallel, the heritage attributes and values of the area play a defining role in defining the appropriate intervention strategies for addressing climate risks.

The setting of Bamberg Cathedral constitutes a site of high cultural and historical significance, drawing visitors continuously. The open expanse of Domplatz, flanked by the Alte Hofhaltung and the Neue Residenz, forms the immediate forecourt of the cathedral. Its spatial character is defined as much by what it withholds as by what it offers: the Bavarian State Office for Monument Protection (Bayerisches Landesamt für Denkmalpflege) prohibits physical additions to the paved square, including seating, on the grounds that the space was not used as a public gathering area in medieval times and that any such intervention would compromise its historical integrity. Visitor activity therefore concentrates in the spaces adjacent to the square, namely the inner courtyard of the Alte Hofhaltung and the Baroque Rosengarten behind the Neue Residenz. The site's enduring function as a space of passage rather than extended use is embedded in both its medieval origins and its current conservation regime, a condition that directly shapes the constraints and opportunities for improving outdoor thermal comfort.

Proposed interventions operate across two scales: the open spaces surrounding the cathedral and the cathedral building itself. The radiative load at Domplatz works in two distinct ways: incoming shortwave solar radiation reaches the sandstone surfaces of the cathedral directly, driving the thermal cycling that accelerates material fatigue and surface degradation, as documented in Figure 8. The paved surfaces of the square simultaneously absorb solar radiation during the day and re-emit it as longwave radiation, raising the mean radiant temperature (MRT) across the space. Interventions must address both pathways.

The proposed solutions are structured according to the land ownership and heritage protection regime of each area (Figure 9). In addition, green re-routing strategies and transitional green areas are introduced to redistribute visitor flows and broaden the spatial extent of pedestrian movement, improving walkability and encouraging use of cooler, vegetated paths. The zone adjacent to the cathedral, including the courtyard of the Alte Hofhaltung and the area around the Diözesanmuseum, falls under municipal ownership and accommodates permanent nature-based interventions. Temporary and reversible installations are deployed across both the state-protected Domplatz and the Archdiocese-owned Domkranz terrace, the latter having already received comparable temporary greening in 2025 through the "Grüne Oase am Dom" initiative, which introduced trees, shrubs, shading elements, and seating for a three-week period under the coordination of the Archdiocese of Bamberg (Erzbistum Bamberg, 2025). A third set of interventions targets the cathedral's exterior fabric directly.

In the municipality-owned zone, permanent nature-based solutions provide long-term microclimatic benefits. These include permeable paving with integrated green patches (A), pocket parks (B), and green facades on structurally suitable secondary buildings within the courtyard precinct (C). Vegetation intercepts incoming shortwave solar radiation before it reaches surrounding masonry, reducing peak surface temperatures and dampening daily thermal amplitude. Microclimate simulations of heritage urban contexts have established that nature-based solutions combining tree canopy and urban vegetation achieve greater reductions in PET than non-vegetative measures alone (Arrar et al., 2024).

Temporary installations apply to both the state-protected Domplatz and the Archdiocese-owned Domkranz, where reversibility is non-negotiable. These are coordinated by the municipality and organised in two sub-categories. Tactical Urbanism interventions are deployed seasonally across the full summer period, covering the months of peak thermal stress and maximum visitor pressure. They include portable trees (D), temporary gardens organised by the municipality (E), misting poles (F), interactive cooling art organised by the municipality (G), and urban furniture (H). Field measurements and simulations of shading devices in outdoor urban spaces have shown reductions in PET of up to 12°C (Lam et al., 2023). Misting poles complement shading through evaporative cooling: field measurements show that evaporative misters reduce MRT by an average of 7.6°C, with the greatest improvements occurring when mist is combined with shade, achieving PET reductions of 15.5°C (Vanos et al., 2020). DIY Urbanism interventions, also coordinated and controlled by the municipality but focused on community participation, take the form of cooling art installations that residents and visitors design and build themselves. These remain in place for shorter periods of a few days or weeks and include a portable garden (I) and interactive cooling art from the community (J).

The cathedral's exterior sandstone requires direct intervention, as the outdoor cooling measures are too distant from the building to shade its surfaces. Experimental studies on sandstone used in cultural heritage buildings have demonstrated that repeated temperature cycles generate new microcracks at mineral boundaries and reduce surface hardness, with damage accumulating progressively with each cycle (Waragai, 2023). Surface consolidation using alkoxysilane-based products (K) counteracts this process by penetrating the stone's pore network through a sol-gel reaction and forming silicon-oxygen bonds chemically compatible with quartz-based sandstone, re-establishing cohesion between loosened grains before microcracking propagates further (Xu et al., 2018). Hydrophobic surface protection (L) complements consolidation by reducing moisture ingress, which limits the salt crystallisation cycles that further widen existing cracks. Both treatments must preserve vapour permeability and remain retreatable.

Figure 9. Proposed green re-routing strategy and temporary/permanent intervention areas in Domplatz, Bamberg.

These approaches collectively address both adaptation (reducing vulnerability to heat stress) and mitigation (supporting urban cooling and ecological performance), while ensuring compatibility with the heritage values and spatial dynamics of the site. The strategies respond to clearly identified climate risks and heritage attributes, and are structured in alignment with the European Standard EN 16883:2017 Conservation of Cultural Heritage – Guidelines for Improving the Energy Performance of Historic Buildings, here adapted to the context of open urban spaces (Figure 10).

To support a systematic evaluation, the "assessment table" provided in Annex B of EN 16883:2017 was used to assess each proposed measure (A-L). The criteria were adapted to reflect the specific conditions of open public spaces and include: technical compatibility, heritage significance of the building and its setting, economic viability, impact on the outdoor environment, and aspects of use. The "indoor environmental quality" category was not considered in this assessment, with the exception of the aspect related to the emission of harmful substances. The "energy" category was also excluded from the evaluation and is therefore not reported in Figure 10, due to the lack of accessible and reliable data required to perform a consistent assessment within the timeframe of this study.

The measures considered and evaluated through this method are listed below:

- **A:** Permeable pavement (green patches)
- **B:** Pocket parks
- **C:** Green façades on suitable buildings
- **D:** Portable trees
- **E:** Temporary gardens (organised by the municipality)
- **F:** Misting poles
- **G:** Interactive cooling art (organised by the municipality)
- **H:** Urban furniture
- **I:** Portable garden
- **J:** Interactive cooling art (from the community)
- **K:** Surface consolidation (alkoxysilane-based treatment)
- **L:** Hydrophobic surface protection

Assessment category	Assessment criteria	A	B	C	D	E	F	G	H	I	J	K	L
Technical Compatibility	Hygrothermal risks	1	2	-1	1	2	0	1	0	2	1	1	2
	Structural risks	0	0	-1	0	0	0	0	0	0	0	2	1
	Corrosion risks	0	0	-2	0	0	0	0	0	0	0	0	0
	Salt reaction risks	0	0	-1	0	0	0	0	0	0	0	1	1
	Biological risks	-1	-1	-1	0	-1	0	0	0	-1	0	0	0
	Reversibility	-2	-2	-1	2	2	2	2	2	2	2	-1	-1
Heritage Significance	Risk of material impact	0	1	-1	1	1	0	0	0	1	0	-1	0
	Risk of visual impact	-1	-1	-2	-1	-1	-1	-2	0	-1	-1	0	0
	Risk of spatial impact	0	-1	0	-1	-1	0	-2	-1	-1	-1	0	0
Economic Viability	Capital costs	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
	Operating / maintenance costs						-1					-1	-1
	Economic return	0	0	-1	0	0	0	0	0	0	0	0	0
	Economic savings	1	1	0	1	1	1	0	0	1	0	1	1
Indoor Environmental Quality	Indoor env. cond. – building content	x	x	x	x	x	x	x	x	x	x	x	x
	Indoor env. cond. – building fabric	x	x	1	x	x	x	x	x	x	x	1	2
	Occupant comfort	x	x	x	x	x	x	x	x	x	x	x	x
	Emission harmful substances (indoor)	x	x	x	x	x	x	x	x	x	x	x	x
	Emission other harmful substances	x	1	2	1	1	1	0	0	1	0	0	0
Impact on the Outdoor Env.	Emission harmful substances (outdoor)	1	2	2	1	1	1	0	0	1	0	0	0
	Natural resources	1	2	2	2	2	0	0	0	2	0	0	0
Aspects of Use	Influence on use & users of building	1	1	1	2	2	2	2	2	2	2	0	0
	Consequences of change of use	1	1	1	2	2	2	2	2	2	2	0	0
	Consequences – new technical room	x	x	x	x	x	x	x	x	x	x	x	x
	Final sum	1	5	-3	10	10	6	2	4	10	4	2	4

Legend: -2 High risk; -1 Low risk; 0 Neutral; 1 Low benefit; 2 High benefit; x Not applicable; Not assessed

Figure 10. Adapted application of EN16883:2017 principles to open public spaces.

According to the applied assessment method, portable trees (D), temporary gardens (organised by the municipality) (E), and portable gardens (I) emerged as the most suitable and context-appropriate options.

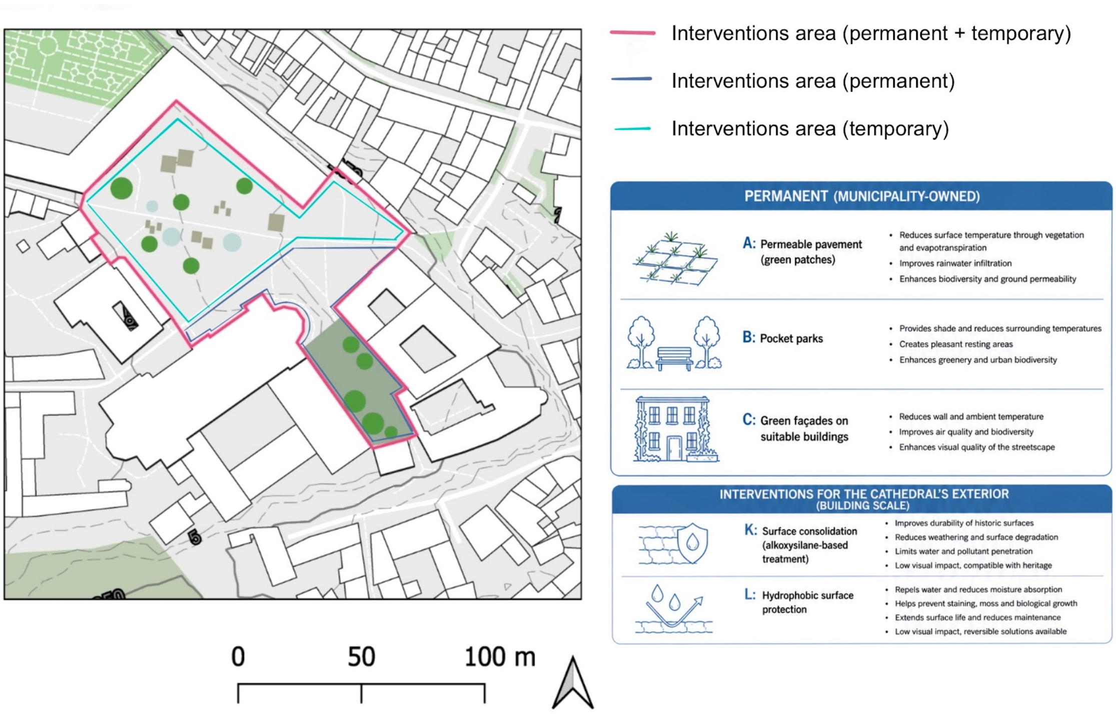

Figure 11. Permanent solutions proposed in the plan

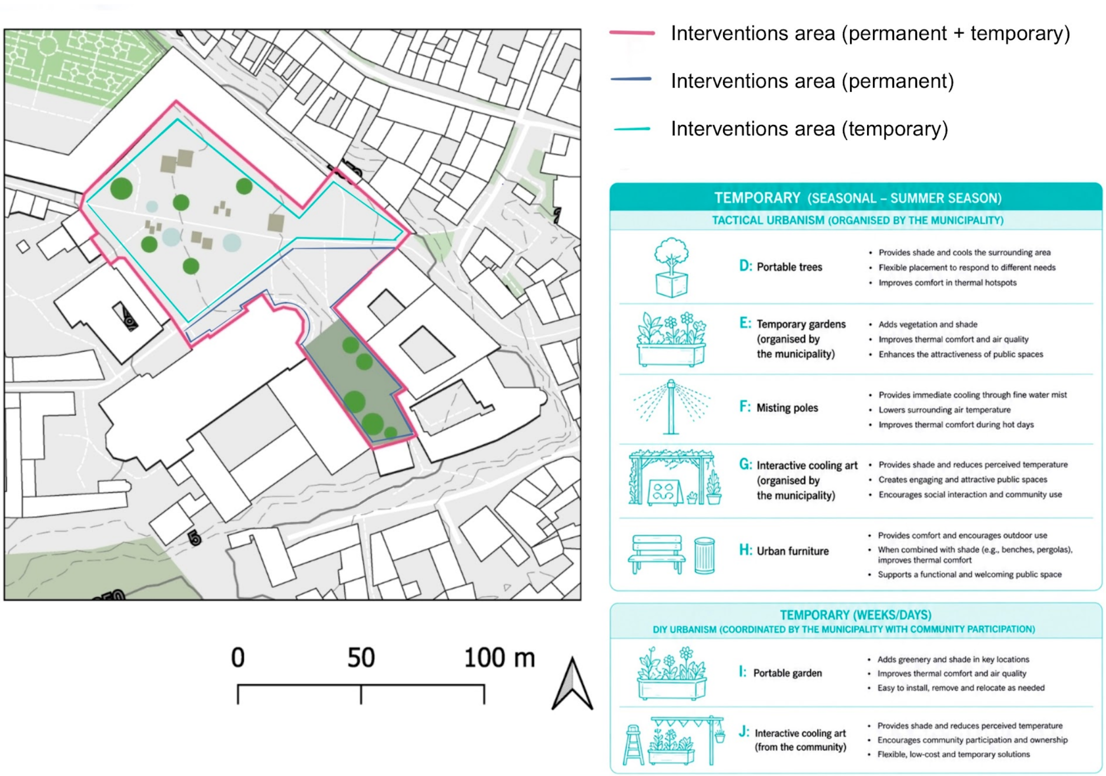

Figure 12. Temporary solutions proposed in the plan

Considering the climate projections and the outcomes of the analysis, rising temperatures will lead to increased surface temperatures across the monument and its surrounding. This will directly affect the architectural features that constitute the cathedral's OUV, its use, and its long-term conservation management. Rising temperatures present a three challenges in the Hill district which affects:

- the interior (including thermal comfort and the artefacts, ornaments such as the pipe organ instrument);
- the building envelope (comprising architecturally and historically significant elements such as the gate of Domplatz, sculptures, and decorative stonework);
- the surrounding open spaces.

While this phase of the Hill District group work focused primarily on open space mitigation strategies, general approaches for the building envelope and interior have also been identified. In contrast to the detailed analysis carried out for open spaces, the following proposals are presented here as general recommendations for the interior as well as for the building envelope.

Monitoring the building envelope is essential for understanding the impacts of climate change and for developing informed adaptation strategies (Figure 8). In this context, non-destructive testing (NDT) methods are recommended. Infrared Thermography (IRT) can be used to map surface temperature distribution and identify areas of moisture accumulation on both exterior and interior surfaces, helping to detect thermally vulnerable zones and support targeted conservation interventions. Ultrasonic Pulse Velocity (UPV) Testing is further suggested to assess material performance, structural integrity, void distribution, crack morphology, and the progression of deterioration processes within the fabric of the monument.

For the interior, continuous and discrete monitoring campaigns of temperature (T) and relative humidity (RH) are necessary to produce comprehensive hygrothermal distribution profiles as well as to track the temporal evolution of the microclimate over time. These assessments must account for indoor air movement and should be conducted across all seasons to capture the full range of environmental fluctuations. Understanding how RH levels distribute within different zones of the Bamberg’s cathedral is critical for anticipating condensation risks and biological deterioration.

To support this, instruments such as anemometers and thermohygrometers deployed in a grid pattern (as 1x1 m etc.) are recommended to measure ambient air temperature, relative humidity, and air flow velocities throughout the interior of the monument. Simultaneously, external climate conditions (air temperature and humidity) should be recorded to enable correlation with indoor microclimate variations, and to better understand the interactions between outdoor drivers, indoor conditions, and user experience. This integrated monitoring framework together with the surface diagnostics, structural material assessment, and interior microclimate mapping and open space adaptation proposals form the basis for a responsive, evidence-led conservation and adaptation strategy for Bamberg Cathedral in the context of climate change.

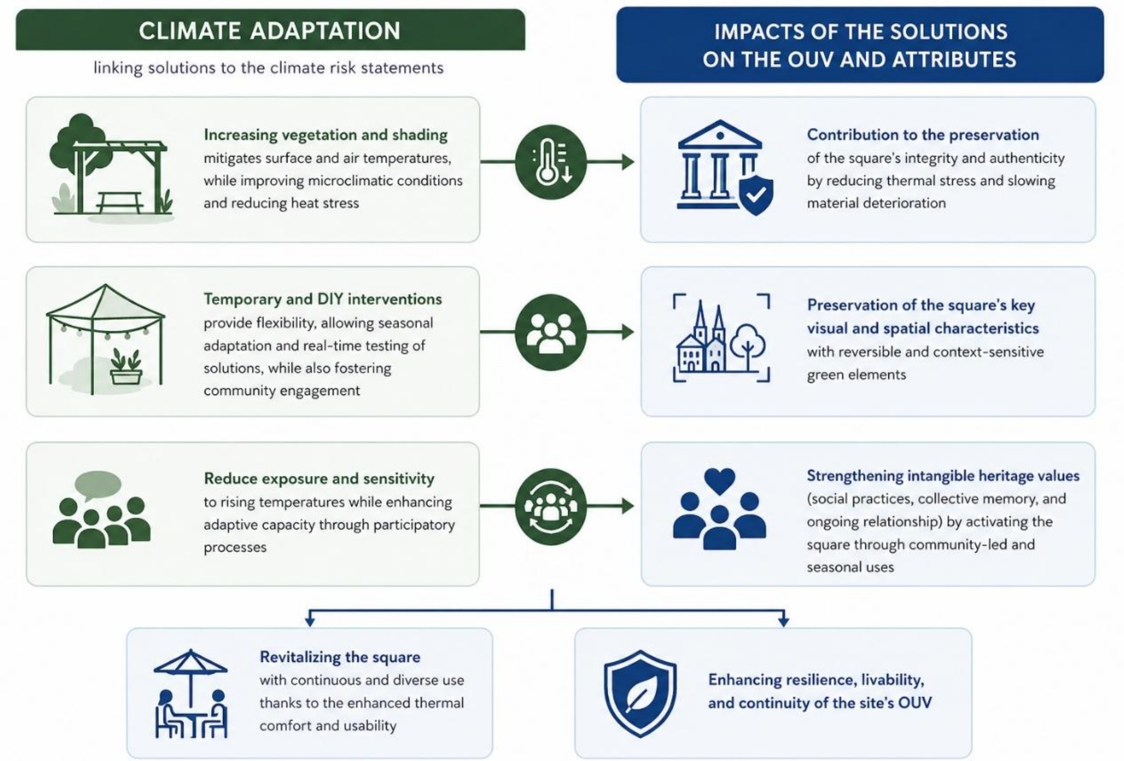

Figure 13. Diagram illustrating the proposed climate adaptation solutions and their impacts on the OUV and their attributes.

Pathway to Operationalisation of the Solutions

The proposed framework moves across two participation levels (Figure 14):

- The first focuses on structured engagement with decision-makers, aiming to build shared awareness and commitment among high-influence stakeholders through meetings, structured workshops, formal approvals, pilot co-design sessions, bilateral meetings, and visual simulations.
- The second centres on community-led action and social awareness, fostering participation among both high- and low-influence stakeholders through participatory workshops, interactive sessions, participatory workshops that make climate action visible and collectively owned. Its impact elucidated by do-it-yourself urbanism both on reducing thermal stress and community engagement.

<table>
<tr><th>ACTIONS</th><th>stakeholders</th><th>potential funding</th><th>Project implementation Procedure
Negotiate / Convince / Design / Plan / Act</th><th>Timeline</th></tr>
<tr><td>Action I: Permanent Urban Greening
green patches
green facade
urban furniture</td><td>Municipality Environmental Office
Municipality Building Division
Municipal Parks Department
Municipal Planning Department
Bavarian State Conservation Office
Archdiocese of Bamberg
Bavarian Administration of Palaces & Gardens</td><td rowspan="3">International
National
Academic & Research Support
Other Public Funding (indirect)
Local Core Funders
Private & Philanthropic Funders
(Supplementary)

plus

Sponsors
Fund raising</td><td rowspan="3">1. Preparatory Phase: Site Analysis and Stakeholder Engagement
- detailed microclimatic and spatial analysis of the square to identify priority areas for intervention (i.e. heat hotspots, low-airflow zones)
- engagement of key stakeholders (local authority, heritage experts, community groups, local businesses, and residents)
- meetings and workshops

2. Co-design and Planning Phase
- design with stakeholders and community members
- design guidelines will be developed by the municipality to ensure the compatibility with the historic context, material sensitivity, and reversibility
- technical planning with installation requirements, maintenance strategies, and seasonal adaptability

3. Pilot Implementation: Temporary and Tactical Interventions
- initiating seasonal tactical urbanism and DIY
- testing solutions in real conditions, raising awareness, and fostering a sense of ownership

4. Monitoring and Evaluation (during the pilot phase)
- environmental data collection (temperature reduction, shading effectiveness)
- social data collection (use patterns, community participation)
- experiential data collection (thermal comfort, user satisfaction)
- systematic evaluation of the feedback to assess performance and identify necessary adjustments

5. Permanent Implementation Phase
- successful strategies will be scaled up into permanent interventions
- designs for durability, low maintenance, and long-term climate adaptation while respecting the heritage character

6. Long-Term Management and Adaptation
- flexible management framework with continuous monitoring, seasonal adjustments, and iterative improvements
- temporary interventions to be periodically modifies, allowing dynamic and responsive climatic conditions and community needs</td><td>permanent</td></tr>
<tr><td>Action II: Tactical Urbanism
green & blue infrastructure</td><td>plus
Cultural Event Organizations
community
related & potential NGOs</td><td>seasonal
(spring-summer-autumn)</td></tr>
<tr><td>Action III: Do-It-Yourself Urbanism
interactive installations</td><td>plus
Cultural Event Organizations
community
related & potential NGOs</td><td>any time during the year
day/days/weeks</td></tr>
</table>

Figure 14. Action plan outlining key stakeholders, funding mechanisms, timelines for each action, and the overall project implementation process.

A stakeholder influence–interest grid was developed to identify key actors involved in the implementation process, categorized according to their level of influence and interest (Figure 15).

- At the international level, UNESCO was identified as a key stakeholder, characterized by high interest and moderate influence.
- At the national level, the Bavarian State Office of Monument Protection was positioned within the high influence–high interest category, reflecting its critical role in the implementation of the proposed solutions. In addition, the Bavarian Administration of State-Owned Palaces, Gardens and Lakes was identified as having high influence but relatively low interest. At the local level, stakeholders such as Academic and Research institutions, the Environmental Office, the Department of Art and Culture, Tourism Boards, and Local Businesses were categorized as having high interest but low influence in relation to the proposed interventions.
- Key local actors including the World Heritage Office, the Municipality of Bamberg, the City Council, the Archdiocese of Bamberg, and the German Federal Environmental Foundation were classified within the high influence–high interest category, indicating their central role in decision-making and implementation processes. Other stakeholder groups, such as public schools, educational institutions, and residents, were identified as having low interest and low influence. Finally, the Bürgerverein Bergstadt and private property owners were categorized as stakeholders with high influence but low interest.
- Within the collaborative stakeholder group, visitors were identified and categorized as having low interest and low influence.

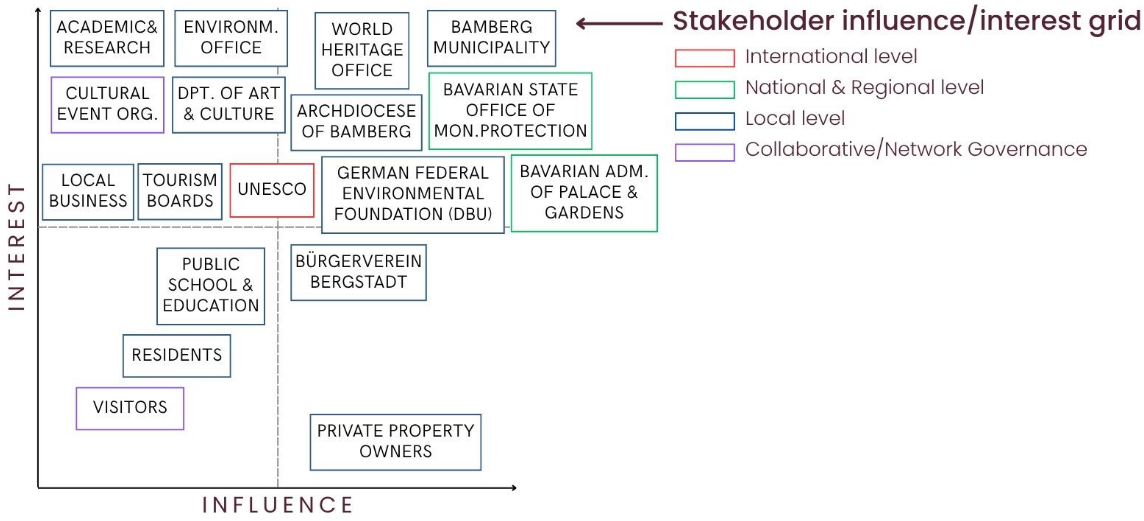

Figure 15. Stakeholder analysis based on the influence–interest matrix.

Identified as a potential funding source, the German Federal Environmental Foundation demonstrates its capacity to support environmental and heritage-related initiatives through a project carried out between 2025 and 2028 (Figure 16).

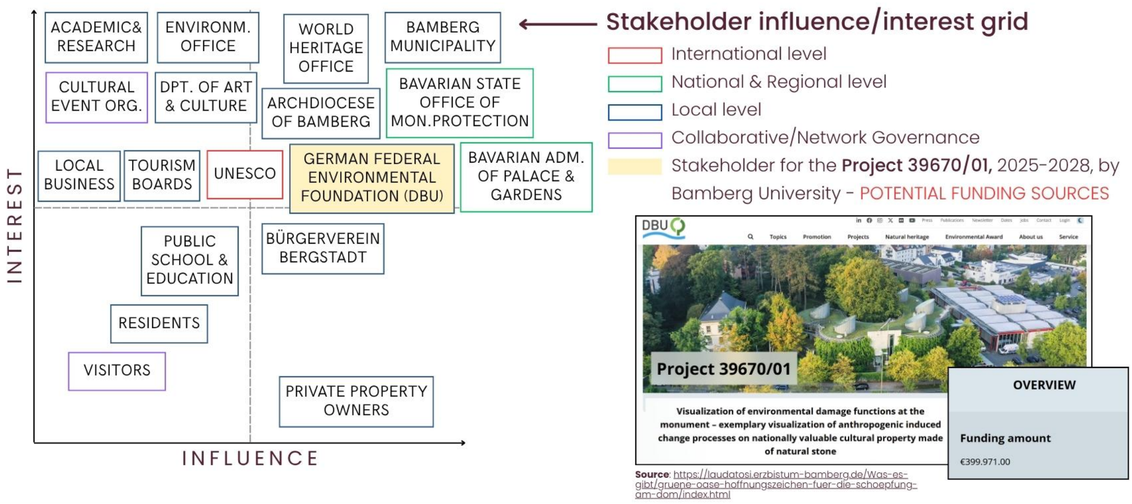

Figure 16. Stakeholder analysis based on the influence–interest matrix (Example of the Project-I).

Another potential funding source was identified through the project "Green Oasis – A Sign of Hope for Creation", carried out in 2025 by the environmental office, Cultural Event Organizations, the Department of Art and Culture, and the Archdiocese of Bamberg. As these actors have already implemented such a project, they were identified as a strong reference for supporting future temporary solutions (Figure 17).

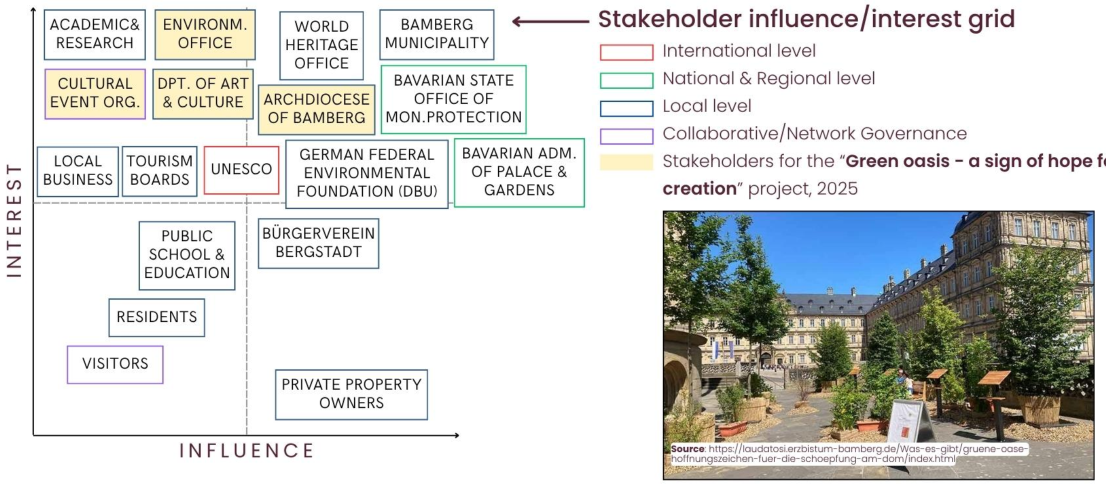

Figure 17. Stakeholder analysis based on the influence–interest matrix (Example of the Project-II)

Finally, a multi-level funding framework was developed to support the implementation of the proposed solutions (Figure 18). This framework identifies potential funding sources across international, national, regional, and local levels including public institutions, research programs, and private or philanthropic actors emphasizing that successful operationalisation depends on combining diverse financial resources and fostering cross-sector collaboration.

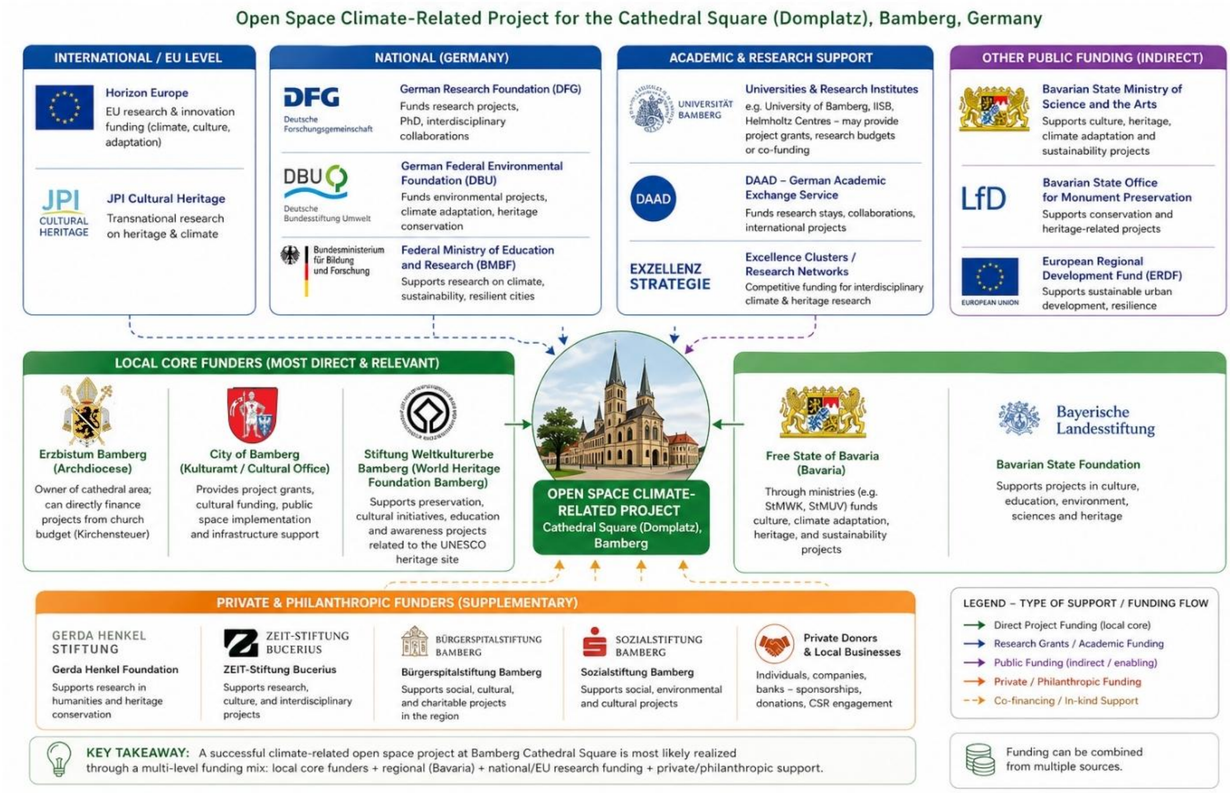

Figure 18. Stakeholders with potential funding.

Conclusions and Summary

Rising temperatures have been identified as the primary climate hazard threatening Bamberg's hill district. Given the site's UNESCO Outstanding Universal Value as "*an outstanding and representative example of an early medieval town in central Europe*" rising temperatures at Domplatz, pose **critical risks** to the cathedral and surrounding historic fabric. This not only has an **impact on visitors and local people** but also will **accelerate the deterioration of building façades**, particularly affecting the historic materials and architectural elements that define these structures' significance.

To address these thermal impacts while safeguarding the site's heritage significance, a combination of reversible and low-impact adaptive interventions is proposed. In the Domplatz, these include nature-based and tactical measures such as portable trees, temporary gardens, and modular green installations. Together, these interventions aim not only to reduce ambient temperatures through shading and evapotranspiration, but also to enhance public awareness of climate risks affecting cultural heritage.

In addition to these solutions in the Domplatz, interventions will follow conservation-sensitive principles within the cathedral, prioritizing minimal intervention and reversibility. Proposed measures include passive climate control strategies (e.g., improved natural ventilation and solar shading where appropriate), alongside carefully integrated environmental management systems such as non-invasive cooling and humidity regulation. These solutions are designed to enhance thermal comfort and protect the building fabric without compromising its material integrity or OUV.

Building on these strategies, and in recognition of the site's OUV, meaningful and inclusive stakeholder engagement is essential for guiding any interventions within the historic core. This process should involve heritage authorities, conservation experts, local communities, religious representatives, and visitors, ensuring that proposed measures are collaboratively developed, context-sensitive, and aligned with conservation principles. Such an approach not only strengthens the legitimacy and acceptance of interventions but also supports the long-term safeguarding of the site's values and attributes.

References

- Alberth, P., Röhlen, H., & Büttner, D. (Eds.). (2019). *Managementplan UNESCO-Welterbe "Altstadt von Bamberg"*. Stadt Bamberg, Zentrum Welterbe Bamberg.
- Arrar, H. F., Kaoula, D., Santamouris, M., Foufa-Abdessemed, A., Emmanuel, R., Matallah, M. E., Ahriz, A., & Attia, S. (2024). Coupling of different nature-based solutions for pedestrian thermal comfort in a Mediterranean climate. Building and Environment, 256, 111480. https://doi.org/10.1016/j.buildenv.2024.111480.
- Coletti, C. (2024). Climate change threats to stone cultural heritage: State of the art of quantitative damage functions and new challenges for a sustainable future. *Heritage, 7*(6), 3276–3290.
- EN 16883:2017. (2017). *Conservation of cultural heritage—Guidelines for improving the energy performance of historic buildings*.
- Foken, T. (2025). *Bamberg im Klimawandel* (2nd ed.). BoD–Books on Demand.
- Intergovernmental Panel on Climate Change (IPCC). (2007). *Climate change 2007: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden, & C. E. Hanson, Eds.). Cambridge University Press. https://www.ipcc.ch/site/assets/uploads/2018/03/ar4_wg2_full_report.pdf

- Kilian, R. & Kheyrkhah, B. (ongoing). *Visualization of environmental damage functions on architectural monuments: Exemplary visualization of anthropogenic induced change processes on nationally valuable cultural assets made of natural stone*. University of Bamberg. DBU-funded research project.
- Lam, C. K. C., Weng, J., Liu, K., & Hang, J. (2023). The effects of shading devices on outdoor thermal and visual comfort in Southern China during summer. Building and Environment, 228, 109743. https://www.sciencedirect.com/science/article/abs/pii/S0360132322009738
- Legg, S. (2021). IPCC, 2021: Climate change 2021—The physical science basis. *Interaction, 49*(4), 44–45.
- Management Plan for the UNESCO World Heritage Site "Town of Bamberg." (n.d.). World Heritage Office.
- Schuller, M. (1993). *Das Fürstenportal des Bamberger Domes: Veröffentlichungen des Diözesanmuseums Bamberg* (Band 6). Bayerische Verlagsanstalt.
- Stocker, T. F., Qin, D., Plattner, G. K., Alexander, L. V., Allen, S. K., Bindoff, N. L., & Xie, S. P. (2013). Technical summary. In *Climate change 2013: The physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 33–115). Cambridge University Press.
- Vanos, J. K., Wright, M. K., Kaiser, A., Middel, A., Ambrose, H., & Hondula, D. M. (2020). Evaporative misters for urban cooling and comfort: effectiveness and motivations for use. International Journal of Biometeorology, 65, 55–65. https://link.springer.com/article/10.1007/s00484-020-02056-y
- Waragai, T. et al. (2023). Influence of thermal cycling in the mild temperature range on the physical properties of cultural stones. Journal of Cultural Heritage, 59, 171–180. https://www.sciencedirect.com/science/article/abs/pii/S129620742200214X
- Xu, F., Zeng, W., & Li, D. (2018). Recent advance in alkoxysilane-based consolidants for stone. Progress in Organic Coatings, 124, 140–154. https://www.sciencedirect.com/science/article/abs/pii/S0300944018305241

Web Resources

- Bamberg Tourism & Congress Service. (2024). *Jahresbericht 2023*. https://blog.bamberg.info/2024/03/jahresbericht-2023-des-bamberg-tourismus-kongress-service/
- Deutsche Bundesstiftung Umwelt (DBU). (n.d.). *Projekt 39670-01*. https://www.dbu.de/projektdatenbank/39670-01/
- Erzbistum Bamberg. (n.d.). *Grüne Oase – Hoffnungszeichen für die Schöpfung am Dom*. https://laudatosi.erzbistum-bamberg.de/Was-es-gibt/gruene-oase-hoffnungszeichen-fuer-die-schoepfung-am-dom/index.html
- Triphobo. (n.d.). *Bamberg Cathedral*. https://www.triphobo.com/places/bamberg-germany/bamberg-cathedral