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A Geospatial Approach to Urban Project Management and Resilience:
Promoting Climate Shelters in the Municipality of Braga (Portugal)

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ABSTRACT

The escalating impacts of climate change necessitate innovative urban planning and management strategies to safeguard communities against extreme weather events. This study explores the creation of climate shelters areas with the use of technologies, namely a mobile application, within the urban center of Braga, Portugal. Utilizing Geographic Information Systems (GIS) project, we mapped areas of extreme heat risk, assessed urban vulnerabilities, and proposed adaptive strategies to enhance resilience through of a climate shelters mobile application. This paper sets out to explore the importance of creating climate shelters in the urban center of the city of Braga, namely within the city's ring road, assessing both the challenges posed by climate change and the opportunities that arise from implementing adaptive solutions. This type of study aims to adopt innovative and sustainable approaches in the city of Braga and other territorial areas, as well as more resilient in the face of the climate challenges of the 21st century.

KEYWORDS

Geotechnologies, Internet of Things (IoT), Geographic Information Systems (GIS), Climate Shelters, Extreme Heat, Cities Management, Resilience, Sustainability

1. INTRODUCTION

Climate Change (CC) represents a growing challenge for urban environments, where extreme weather events, particularly heatwaves, increasingly impact public health, infrastructure, and societal resilience (Khan et al., 2023; Kumar, 2021; Pinto et al., 2024; Vidal et al., 2024). Urban Heat Island (UHI), driven by dense infrastructure and limited green spaces, amplify these effects, disproportionately affecting vulnerable populations (Lopes et al., 2024; Pinto et al., 2024).

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This study therefore proposes the implementation of climate shelters in the urban center of Braga (Portugal), based on the extreme heat risk mapping used in the methodology proposed by Lopes et al. (2023). Braga, a city located in the northern region of Portugal, faces these challenges head-on due to its unique combination of urban density, historical buildings, and climatic conditions.

Climate shelters are designated spaces designed to offer relief from extreme heat while contributing to urban resilience. These areas are physical safe zones but also critical components of a comprehensive urban climate adaptation strategy. By addressing both immediate thermal comfort and long-term resilience, climate shelters align with global efforts to create sustainable and livable cities in the face of climate uncertainties (Lopes, Silva, et al., 2025).

Inspired by international examples, namely the case of Barcelona (Spain), where more than 300 public spaces have been designated as climate shelters (Amorim-Maia et al., 2023; Martín-Vide & García, 2024), the aim is to promote solutions for adapting to extreme weather conditions in the city of Braga, namely by creating a Geographic Information Systems (GIS) application to provide citizens with information on places where they can take shelter during episodes of extreme heat.

By applying an intersectional climate justice perspective and mixed approaches, the specific needs of the most vulnerable populations (namely the young and the elderly) will be identified. This study reveals that social and climate vulnerabilities, such as energy poverty and inadequate housing, exacerbate climate risks for lower-income residents, and seeks to structure the network of shelters in areas close to these places, which can be accessible to those who are in the city every day or who visit the urban space.

The results highlight the need for climate shelters, structured at different levels of priority, which offer shelter during extreme weather events but also address underlying structural inequalities. Such shelters include the creation/identification of inclusive and culturally appropriate spaces, as well as the development of adaptive capacities for the most vulnerable populations. This integrated approach aims to promote more resilient and equitable cities in the face of growing challenges related to Urban Heat Stress (UHS).

Through the application of Geographic Information Systems (GIS) and technologies, this study provides a robust methodology for assessing risk, integrating multi-layered data, and deriving actionable insights for management of public spaces. This study can be replicated in other territorial areas, benefiting from the notes in this proposal, the application of which can be readapted.

2. LITERATURE REVIEW

The repercussions of the contemporary CC process are manifest in numerous regions worldwide, exerting substantial influence on diverse economic sectors (Carleton & Hsiang, 2016). The urban climate adaptation strategy underscores the multifaceted nature of the risks posed by extreme heat (Hussain et al., 2024; Lopes et al., 2023; Parihar & Birman, 2024). A recurring theme in the literature is the role of Urban Heat Island (UHI), which is exacerbated by factors such as surface albedo, lack of vegetation, and anthropogenic heat sources. Research has underscored the significance of green, blue, and gray infrastructures in mitigating these risks by reducing Land Surface Temperature (LST) and enhancing microclimatic conditions (Lemus-Canovas et al., 2020; Lopes et al., 2024; Lopes, Remoaldo, Ribeiro, & Martin-Vide, 2022; Lopes, Remoaldo, Ribeiro, & Martín-Vide, 2022; Lopes, Vidal, et al., 2025; Pinto et al., 2024). Green infrastructure, comprising elements such as urban parks and tree canopies, offers shading and evapotranspiration benefits, while blue infrastructure, including rivers and fountains, facilitates cooling through water evaporation. Infrastructures of a gray classification include facilities designed to provide maintenance during the hottest days, such as libraries or museums, with free access for those who need it. Pinto et al. (2024) Pinto et al. (2024) proposed a four-tiered system of protection for varying degrees of severity in urban areas, ranging from temporary infrastructure to more substantial precautionary measures.

The notion of climate shelters has emerged as a critical concept in urban planning, particularly in cities experiencing frequent heatwaves (Amorim-Maia et al., 2023; Lopes, Remoaldo, Ribeiro, & Martín-Vide, 2022). A case study of Barcelona reveals the implementation of municipal networks of climate shelters, designed to safeguard vulnerable populations. Different cities have adopted varied strategies to overcome the barriers in implementing climate shelters. In Barcelona, the municipal administration secured public funding and private partnerships to establish over 200 designated spaces for heatwaves (Amorim-Maia et al., 2023). In contrast, New York and Paris have invested heavily in public engagement and awareness campaigns. These experiences offer valuable lessons for Braga, particularly in financing and fostering community participation. These shelters, incorporating both natural and artificial cooling strategies, emphasize accessibility, equity, and community engagement (Amorim-Maia et al., 2023).

Indeed, the integration of climate shelters within urban environments has come to be regarded as a pivotal strategy for enhancing thermal comfort in locales, particularly in metropolitan areas encountering extreme weather phenomena (Roaf et al., 2009; Sharifi & Khavarian-Garmsir, 2022). The presence of weather shelters has been demonstrated to exert a substantial influence on the attractiveness and competitiveness of urban areas (Amorim-Maia et al., 2023; Plazas et al., 2023; Vasconcelos et al., 2024). These shelters, situated in strategic locations within urban environments, provide both residents and visitors with protected and accessible locations during heat waves and other extreme weather events, thereby contributing to the general satisfaction and well-being of the population (Martín-Vide & García, 2024).

Recent advancements on the Internet of Things (IoT) and geospatial technologies have profoundly impacted the realm of urban resilience assessment and planning (Nagavi et al., 2024; Peldon et al., 2024). These technological innovations have facilitated the integration of diverse components, thereby enabling the dissemination of critical information to citizens. GIS-based methodologies facilitate detailed spatial analyses, integrating data on temperature patterns, demographic vulnerabilities, and urban infrastructure (Ali et al., 2024; Safavi, 2024). This methodological approach facilitates the identification of high-risk zones and the subsequent prioritization of interventions, informed by empirical evidence (Safavi, 2024).

The integration of geospatial technologies and Internet of Things (IoT) platforms into urban planning has revolutionized the management of urban spaces, particularly in facilitating the sustainable use and accessibility of blue, green, and grey spaces for residents and tourists (Berigüete et al., 2024; Wang et al., 2021). These technologies provide real-time data and insights that enhance urban experiences, ensure environmental preservation, and improve overall city functionality (Berigüete et al., 2024).

IoT platforms play a pivotal role in monitoring and managing urban spaces. Blue spaces, such as rivers, lakes, and coastal areas, benefit greatly from IoT-enabled sensors that monitor water quality, temperature, and biodiversity levels (Wang et al., 2021). These systems ensure that aquatic environments remain healthy while providing accessible and safe recreational areas for the population. For instance, cities can use IoT applications to inform the public about safe swimming zones or areas affected by pollutants in real-time. This proactive management promotes both environmental conservation and public safety (Santamouris, 2013).

Green spaces, including parks, urban forests, and botanical gardens, are essential for the ecological and social health of cities. IoT devices can track foot traffic, air quality, and soil conditions, ensuring that these areas are maintained effectively and sustainably. For example, sensors placed in urban parks can measure soil moisture levels, allowing for optimized irrigation practices that conserve water resources. Additionally, IoT platforms can provide users with interactive maps highlighting park amenities, biodiversity trails, and real-time crowd density, enhancing the experience for both residents and tourists (Blackstock & Lea, 2014; Florido-Benítez, 2024). These applications make it easier for visitors to explore and enjoy green spaces while supporting their sustainable management.

Grey spaces, such as streets, buildings, and urban infrastructure, also benefit from IoT integration. Smart urban planning tools use real-time data to manage pedestrian flows, monitor infrastructure health, and optimize energy usage (Alahi et al., 2023; Hui et al., 2023). Applications focused on urban mobility can provide tourists and residents with updated information on public transportation, bike-sharing stations, and walking routes. For example, apps that integrate real-time data from IoT sensors can guide users through city landmarks while suggesting sustainable transport options, such as electric buses or bicycle paths. These tools not only improve urban accessibility but also reduce the environmental footprint of city exploration (Habitat, 2022).

Online applications serve as essential interfaces between IoT platforms and the public, facilitating informed decision-making and seamless interaction with urban spaces (Fadhel et al., 2024; Tao, 2013). These applications allow users to access tailored information about city spaces, including weather conditions, event schedules, and safety updates. For instance, a mobile application designed for tourists might combine IoT data with augmented reality to provide immersive guides to historical landmarks, integrating cultural insights with practical navigation tools. Similarly, apps can alert users to temporary closures or maintenance work in urban parks, helping them plan their visits effectively.

Furthermore, these platforms enable inclusive participation in urban management. Residents can report issues such as damaged infrastructure, unclean spaces, or safety concerns directly through mobile applications. This feedback loop ensures that city managers can respond swiftly, fostering a sense of community involvement and shared responsibility for urban well-being. For tourists, such platforms offer enhanced engagement, allowing them to discover hidden gems in the city while adhering to sustainable practices promoted by local governments (Berigüete et al., 2024; Hui et al., 2023)

The integration of the IoT with online applications has been demonstrated to support urban resilience in the face of CC. As cities continue to experience the repercussions of extreme weather events, these technologies offer critical data for adaptive management. For instance, smart systems can monitor flood-prone blue spaces and issue warnings to residents and tourists, thereby minimizing risks during heavy rainfall. Green spaces that have been equipped with sensors can track the impact of heatwaves on vegetation, enabling targeted interventions to preserve urban greenery (Santamouris, 2013; Santamouris, 2015). Conversely, gray spaces leverage the IoT to facilitate structural health monitoring, ensuring the safety and functionality of infrastructure during adverse conditions

Ethical considerations and data governance are paramount in deploying these technologies. Transparent policies regarding data collection, storage, and usage must be in place to protect user privacy and build public trust. Additionally, platforms must be designed to be accessible and user-friendly for diverse demographics, ensuring that technological advancements benefit all sections of the population (Blackstock & Lea, 2014).

The integration of IoT technologies and online applications within the framework of urban management signifies a transformative approach to enhancing the functionality and sustainability of blue, green, and grey spaces. By providing real-time data, fostering public engagement, and supporting adaptive strategies, these tools ensure that urban spaces remain vibrant, accessible, and resilient. As cities continue to evolve, the strategic deployment of these technologies will be essential in meeting the needs of residents and tourists while promoting sustainable urban development (Citaristi, 2022).

3. METHODS AND DATA

3.1. Study Area

This study employs a comprehensive methodology, integrating geospatial analysis with demographic and infrastructural data to assess Urban Heat Stress (UHS) in Braga. The analysis focuses on the inner-ring road of Braga, encompassing diverse urban typologies, from densely populated historical areas to open green spaces.

The municipality of Braga has 193,324 inhabitants across an area of 183 km^2 and experienced a population growth of 6.5% between 2011 and 2021, resulting in a population density of 989.6

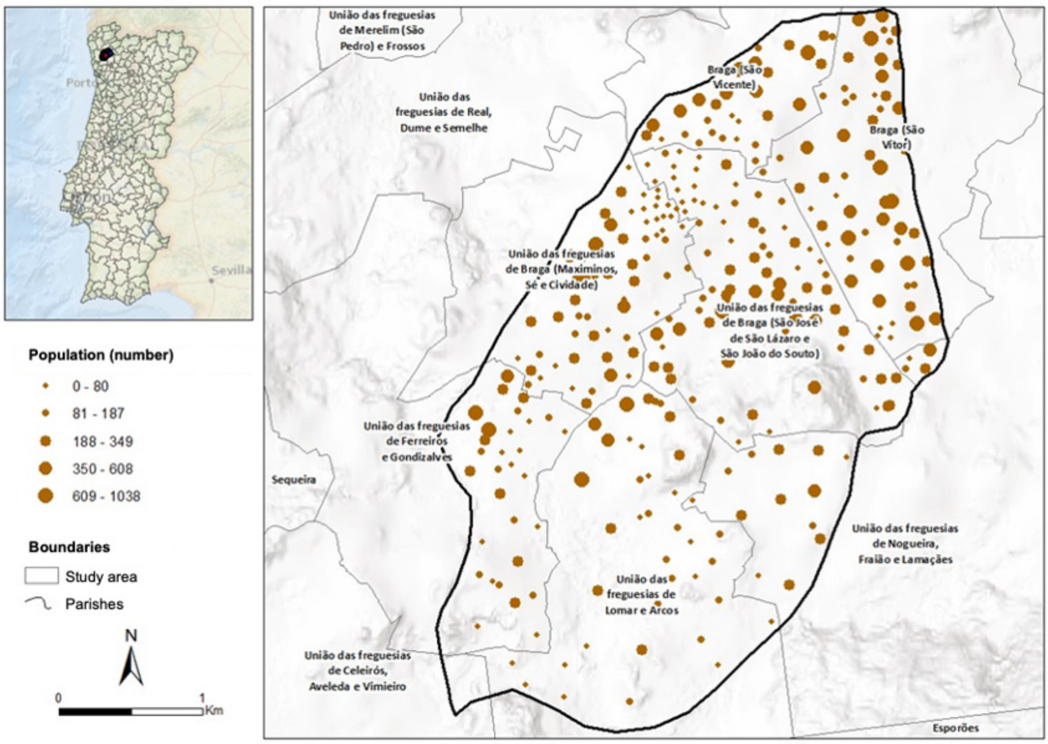
inhabitants per km^2 (INE, 2022; 2023). This growth is largely attributed to the presence of prominent higher education institutions, such as the University of Minho, and research facilities, including the International Iberian Nanotechnology Laboratory (INL), which attract a youthful and dynamic demographic. The city of Braga is situated in a region characterized by a temperate Atlantic climate, marked by mild, rainy winters and influenced by nearby mountain ranges and the Atlantic Ocean. Data from the IPMA reference station reveal an average of 12 days per year with minimum temperatures below 0°C and 90 days with maximum temperatures exceeding 25°C, including 30 days surpassing 30°C. The region's average temperatures are estimated to range from 13ºC to 28ºC (IPMA, 2024).

Specifically, the area delineated in Figures 1 and 2 (within Braga's inner-ring road) demonstrates a heightened pressure from the resident population, constituting 33.2% of the municipality's total population. Conversely, the area to the north, encompassing the city center, the Historic Center, and functional areas linked to services and commerce, exhibits a higher population density and is experiencing an influx of residents. In contrast, the southern region is distinguished by its transition from rural to urban characteristics. This area exhibits a lower population density, attributable to the presence of cultivated fields and dispersed housing structures.

Figure 1. Location of Braga inner-ring road, municipality of Braga

Source: Authors' own elaboration.

Figure 2. Population (number) along inner-ring road in the municipality of Braga



Source: Authors' own elaboration.

3.2. Main Procedures to Calculate the Urban Heat Risk (UHS)

The Urban Heat Stress (UHS) assessment employed the Heat Risk Index (HRI) model developed by Lopes et al. (2023), incorporating hazard, exposure, and vulnerability dimensions (Figure 3), as initially proposed by Faugères (1991).

Hazard analysis was conducted using mean Land Surface Temperature (LST) data from the LANDSAT 8-OLI satellite, a common variable in studies examining the impacts of LST on thermal comfort and health (Estoque et al., 2020; Lopes et al., 2023; Lopes et al., 2024; Pinto et al., 2024). Additionally, an Environmental Criticality Index (ECI) was calculated by combining LST and NDVI, classified into five quintile-based categories (Senanayake et al., 2013). The population density (inhabitants/km^2) was employed to measure exposure, aligning with previous research on heat-related risks (Buscail et al., 2012; Lopes et al., 2023; Lopes, Vidal, et al., 2025). The concept of vulnerability was divided into two components: sensitivity and adaptive capacity. These components were informed by studies on heat risks (Aminipouri et al., 2016) Census data from 2011 was utilized, as equivalent data for 2021 was not available. The concept of adaptive capacity encompassed various aspects, including green spaces, shelter areas, health services, and education levels, with a particular focus on the percentage of residents who had obtained a higher education. The data concerning green spaces was derived from the Normalized Difference Vegetation Index (NDVI) analysis and Fractional Vegetation Cover (FVC) for the period 2013–2022. The data underwent a process of normalization using ArcGIS PRO 3.3, and the HRI map was developed using the Analytical Hierarchical Process (AHP) to assign variable weights, as proposed by Lopes et al. (2023), with the following variables (Table 1).

Table 1. Indicators used to evaluate the urban heat risk in the municipality of Braga

Risk domain	Indicator	Unit of measurement
Hazard	Land Surface Temperature (LST)	ºC
Exposure	Population Density	Inhabitants/km^2
Vulnerability Sensitivity (Buildings)	Buildings with 5 or more floors	%
	Old buildings (constructions pre-1960)	%
	Buildings without masonry plates	%
Vulnerability Sensitivity (economic status)	Young (≤15 years) and elderly people (≥65 years)	%
	Retired	%
	Unemployed	%
Vulnerability Coping and Adaptive capacity	Population with higher education	%
	Shelters (cafes, metro and train stations, shopping)	% (service area of at least one shelter less than 5 minutes away)
	Health services (HS)	% (service area with at least one HS less than 5 minutes on foot and 15 minutes by emergency vehicle)
	Fractional Vegetation Cover (FVC)	%

Source: Authors' own elaboration.

The following primary data sources were included in this study:

1. Satellite Imagery, based on Landsat 8-OLI data for surface temperature mapping.
2. Portugal's 2021 Census for demographic analysis. And
3. Urban Infrastructure Maps, with GIS layers detailing green spaces, water bodies, and building characteristics.

3.3. The Use of Geotechnologies and the Construction of an Application to Promote Climate Shelters

The development of the GIS-based mobile application for identifying climate shelters during extreme heat events involved a series of adaptations to the methodology and key procedures.

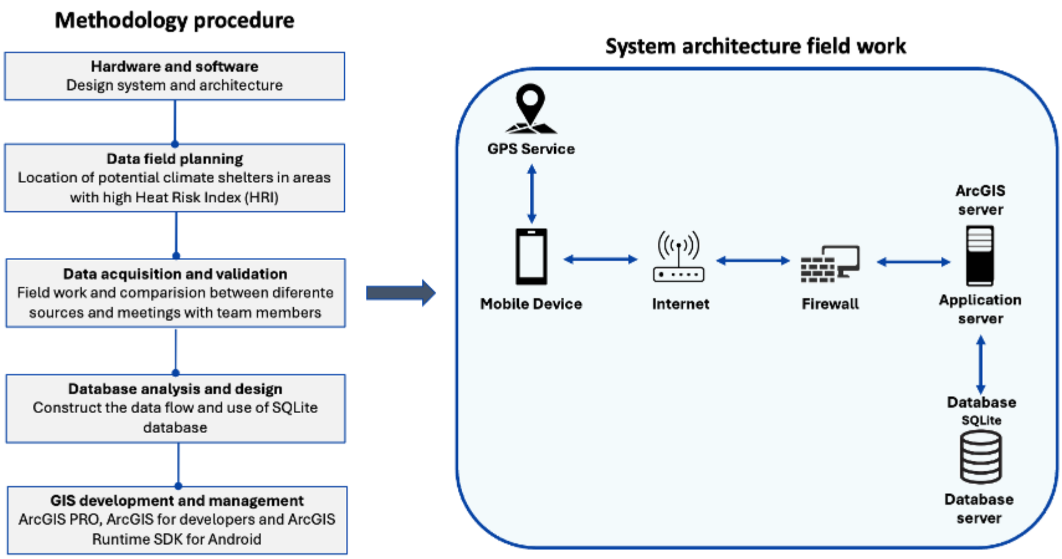
In the data planning phase, the needs of potential users were identified, with a focus on mapping and classifying climate shelter locations. These shelters are then categorized into several distinct classes, including public spaces such as libraries and malls, green areas such as parks and gardens, water-related spaces such as lakes and pools, and emergency cooling stations. Each category corresponds to a distinct map layer, thereby enabling the formulation of targeted recommendations.

The geographic locations of the shelters are identified using latitude and longitude, enabling precise placement on a map. Furthermore, unique attributes, including accessibility, operational hours, and capacity, are systematically catalogued for each location.

The implementation of the GIS-based application faced financial and technological challenges, like those reported in cities like Barcelona, where initial resistance from both users and municipal managers posed an obstacle (Plazas et al., 2023). To mitigate these challenges, strategies such as municipal incentives and partnerships with universities and technology companies have been fundamental.

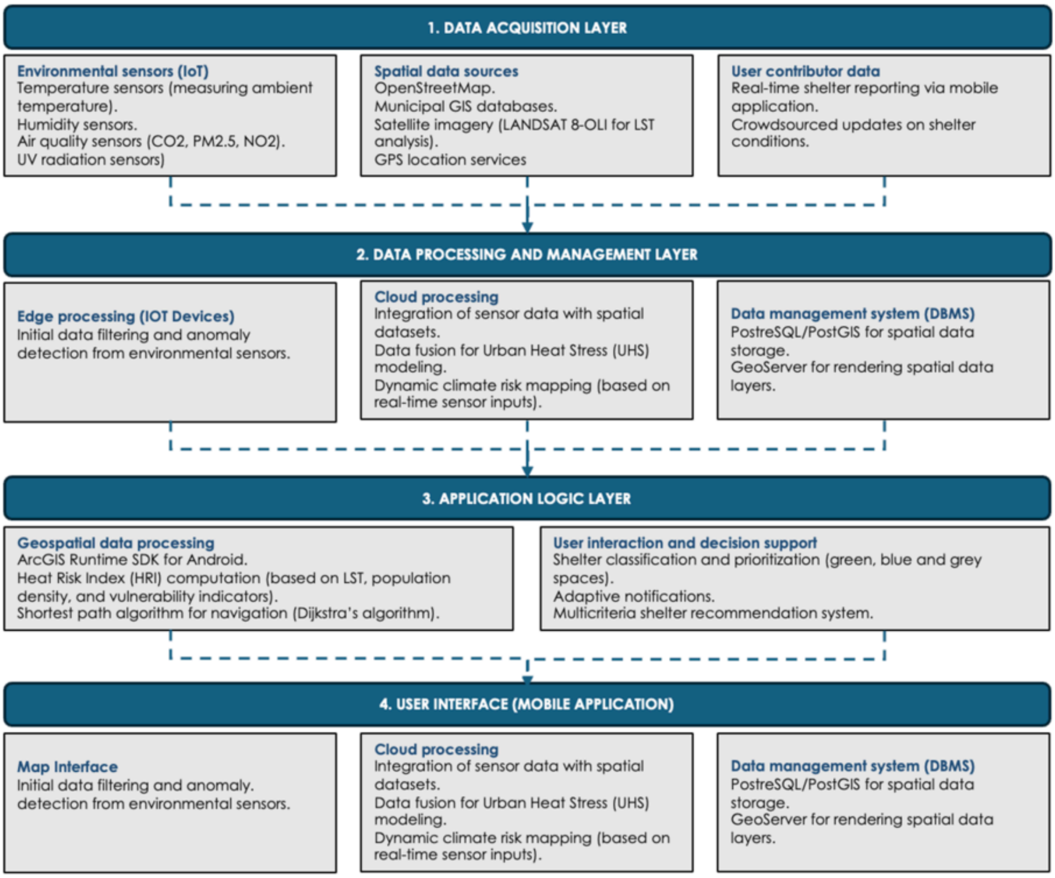
For GIS processing, ArcGIS was selected due to its advanced capabilities in managing spatial data; its cloud-based functionalities; and the use in both institutions: University and Municipality of Braga. The application employs the ArcGIS Runtime SDK for Android to facilitate the creation and integration of maps, thereby enabling the delivery of real-time location-based services. The development of the mobile application was carried out using Android Studio, a practice that ensured compatibility with Android devices. Laptops were employed for facilitating software execution, while smartphones were utilized for testing the app's functionality. Figure 3 synthetizes the methodology procedure and system architecture used during the research.

Figure 3. Methodological procedure and system architecture used in the case study



Source: Authors' own elaboration.

Figure 4. System architecture diagram used in the case study: Data acquisition, data processing and management, application and user interface



Source: Authors' own elaboration.

The system architecture used in the case study considers data acquisition, data processing and management, application and user interface. Figure 4 shows the structure of this system.

Two data types were collected:

1. Spatial data, which includes coordinates and boundary information for climate shelter locations.
2. Non-spatial data, encompassing details such as shelter type, capacity, amenities (e.g., air conditioning, water availability), and accessibility.

The data sources encompass a variety of repositories, including but not limited to online platforms such as OpenStreetMap, municipal databases, and official websites of public and private climate shelter providers. Spatial data acquisition employed GPS services to facilitate real-time location detection of users, thereby enabling the application to suggest proximate shelters.

This project also integrates dynamic data acquisition methods, enabling users to report or validate locations, thereby ensuring the application remains up to date and responsive to user needs.

To ensure the accuracy and reliability of the spatial and non-spatial data, a validation process was implemented.

- Data from multiple official sources were cross-checked to eliminate discrepancies.
- Meetings with stakeholders, including local governments and emergency planners, ensured correct classification and usage of climate shelters.
- Field surveys verified data for high-priority shelters through 123 survey.

The database design is predicated on six primary categories of climate shelters: public spaces, green areas, water-related spaces, emergency cooling stations, healthcare facilities, and transit hubs. These data were grouped in climate shelter geodatabase with important information by public as ID, name, level, typology, hours/weekdays and access (Table 2).

The shortest path to a shelter is calculated with unit measure, leveraging spatial data for efficient route optimization.

The Geographic Information System (GIS) module integrates ArcGIS for data visualization and analysis. The application utilizes the ArcGIS Runtime SDK for Android to:

(1) Display a base map styled for urban heat management.
(2) Add feature layers representing climate shelter locations.
(3) Highlight critical information, such as shelter categories and real-time occupancy.

The map enables users to ascertain their current location, search for proximate shelters, and receive directions to the selected location. Internet access and GPS services are indispensable for the acquisition of real-time updates and navigation.

Shelter markers are distinguished by category and are characterized by distinct visual markers, such as trees for green spaces or snowflakes for cooling stations. This enhances usability during heat events. The objective of this proposal is to facilitate the adoption of these markers by the Braga municipality, with the aim of providing its population with essential information and safeguarding them from the potential dangers associated with extreme heat. The objective of this proposal is to be implemented by the Braga municipality to provide its population with the necessary information and protection regarding the potential risks associated with UHS.

4. RESULTS

The geospatial analysis revealed distinct patterns of UHS across Braga. The LST map indicated elevated risks in densely built-up areas, particularly within the historic city center. These zones demonstrated low albedo and limited vegetation, thereby exacerbating the urban heat island effect. Conversely, peripheral areas characterized by higher vegetation density exhibited relatively lower surface temperatures. In the southernmost regions, the presence of green areas such as Monte do Picoto and areas of urban-rural transition, characterized by the presence of cultivated fields and sporadic housing, resulted in lower LST compared to other areas.

The central region exhibits a substantial population agglomeration, characterized by a high density of 34,000 individuals per square kilometer in certain subsections. A similar trend is observed in the towns situated to the north of Braga's historic center, which also exhibit a high population density compared to the surrounding regions.

These demographic analyses indicated significant vulnerabilities among elderly populations and residents in older buildings. The grouping of pre-1945 constructions, distinguished by inadequate thermal insulation, corresponded to regions exhibiting elevated UHS. In contrast, modern buildings, equipped with advanced cooling systems, exhibited superior adaptive capacity. Figure 5 shows a summary of the variables used in this study to measure the UHS.

The study identified 33 potential climate shelter sites within the inner-ring road. These sites were subsequently categorized into three distinct types:

1. Green spaces and urban parks, including Monte do Picoto and Parque da Ponte.
2. Blue spaces, areas adjacent to the Rio Este and other water bodies.
3. Air-conditioned buildings, with public facilities offering indoor cooling, including libraries and community centers.

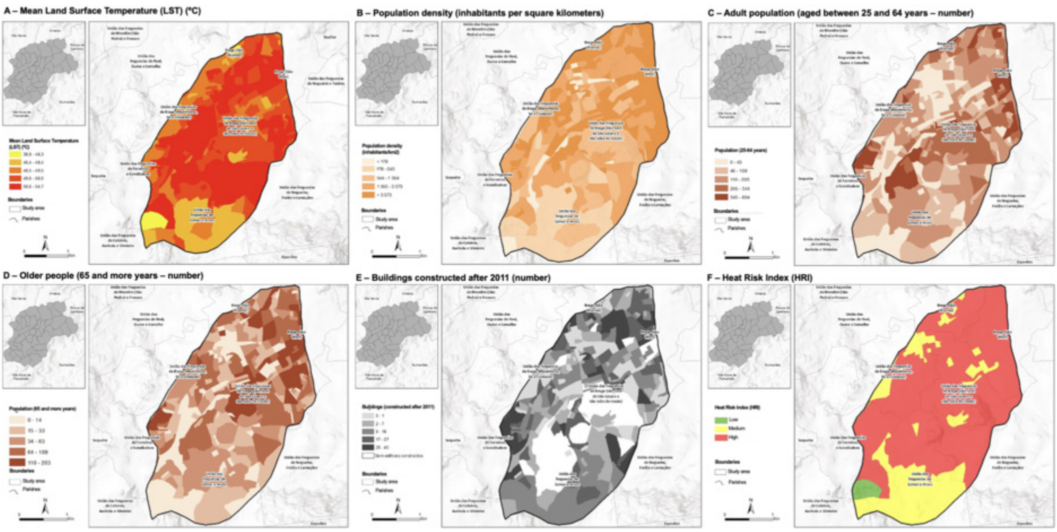
To enhance accessibility and usability, a mobile application was developed. This tool enables residents to identify the nearest climate shelter, access comprehensive information regarding facilities, and plan their routes. The incorporation of features such as distance measurement and real-time updates renders this application a vital resource during heatwaves.

Table 2. Construction of the climate shelter geodatabase in Braga inner-ring road

ID	Name	Level	Typology	Hours/Weekdays	Access
The identifier in question comprises the digital identification number that was assigned during the selection process in ArcGIS Pro.	The designation will be assigned to all locations to ensure their identification and facilitate adherence to the protocol.	Each tier of the shelter level possesses distinct characteristics that facilitate its identification, thereby enabling the user to assess its suitability in each context. The first level of shelter is characterized by its constant availability and proximity to the community, making it easily accessible to all members. Shelter Level 2 is characterized by designated operational hours and the implementation of mobility restrictions, which renders it inaccessible to the broader community. Shelter Level 3 indicates availability during specific times and in designated spaces with functions.	The typology is predicated on the disclosure of the intrinsic characteristics of the localities, i.e., whether it is made up of: The first category is designated as “Green Space,” which encompasses gardens and green areas. The second category is blue spaces (water bodies and rivers). The third category is designated as “Grey Space,” which is characterized by its association with public buildings (libraries, museums).	The availability of hours and days of the week is contingent upon the level of each shelter. The operational hours of these facilities vary which in turn impacts the user's selection of a climate shelter.	The accesses encompass mobility and the conditions of the shelters to reach it, such as: - Parking; - How to get around (on foot or by car); - Conditions for people who need special care, such as people with reduced mobility or blindness.

Source: Authors’ own elaboration.

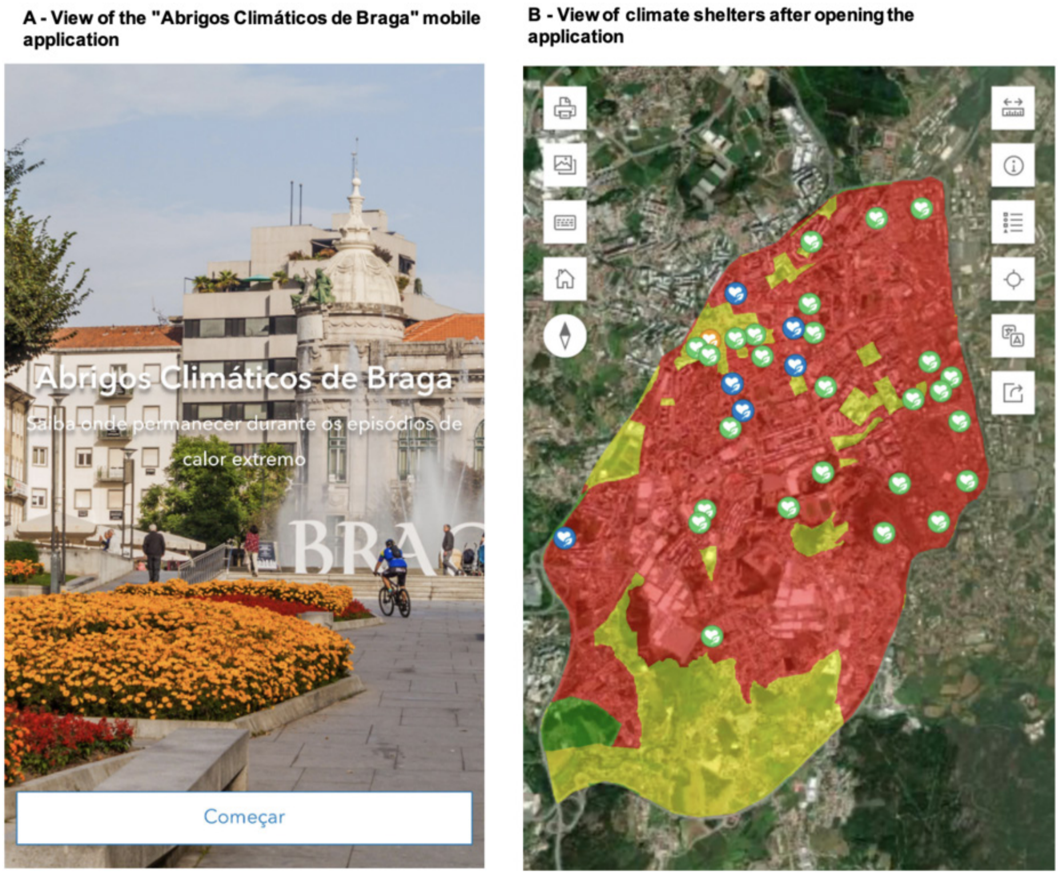
Figure 5. Some indicators used in the sociodemographic and environment conditions in Braga inner-ring road



Source: Authors' own elaboration.

The GIS application developed for the purpose of identifying climate shelters during extreme heat events integrates key features. These features include an interactive map module that displays and allows for exploration of shelter locations and an analysis module that recommends nearby shelters based on the user's location in the city of Braga (Figure 6).

Figure 6. Mobile application of climate shelters in Braga inner-ring road



Source: Authors' own elaboration.

The implementation of the map module entailed the integration of the ArcGIS Runtime SDK within the Android Studio development environment. A base map style, such as the World Navigation Map, was selected and incorporated into the application using the *setMap()* function. The initial view of the map was configured using *setInitialViewpoint()* to focus on the designated region of interest, such as urban areas prone to heat stress, ensuring users could immediately engage with relevant information. Location data for climate shelters was incorporated into a feature layer created with tools provided by the ArcGIS for Developers subscription account. The data visualization was then refined further using the ArcGIS Online Map Viewer, where shelter categories such as public spaces, green areas, water-related areas, and emergency cooling stations were assigned distinct symbols for easy identification (see the example in Figure 7). These customizations ensure that the map interface is user-friendly and visually intuitive. After the finalization of the feature layer, it was incorporated into the base map and displayed within the application, thereby enabling users to explore the identified locations interactively.

Figure 7. Data visualization in mobile application of climate shelters in Braga inner-ring road

A - Legend of the climate shelters available in the application

B - Details of the information when you click on the climate shelter symbol

Climate shelters

Access	Parking; Walkable; Open for all.
Time	Always available.
ID	1
Level	Level 1
Name	Parque de Lazer de Lomar
Type	Green Infrastructure

Source: Authors' own elaboration.

The map module incorporates interactive buttons, thereby enhancing its usability. A “Home” button facilitates the redirection of the view to the initial map focus through the use of the *setViewPointAsync()* function, thereby ensuring the accessibility of the full regional overview.

A “Location” button utilizes the *setAutoPanMode()* function to display the user's current location on a map. This process requires user permission to access location services. These features facilitate seamless navigation and interaction with the application. To enhance the appeal of the map, a callout is triggered when a shelter location is selected. This callout comprises two components: the shelter name and an image.

By clicking on the image, users can access a detailed bottom sheet that displays further information about the shelter. The description encompasses the following:

- Shelter type and capacity.
- Availability of facilities like air conditioning, water supply, and shaded areas.
- Emergency contact details.
- Directions and access information.

The analysis module enhances the application's functionality by capitalizing on the advanced capabilities offered by the ArcGIS Runtime SDK. Users can search for specific shelter types or filter locations based on categories such as emergency cooling stations or green areas. The results of these queries are updated dynamically and displayed as a customized layer on the map.

The application incorporates route planning and direction-finding capabilities, enabled through the ArcGIS Route Planner. The application integrates real-time traffic and walking distance analyses to calculate the shortest path to selected shelters using Dijkstra's algorithm, thereby optimizing navigation for users. The proximity recommendation system further enhances the user experience by evaluating the user's current location and identifying the five closest shelters, with the shelters being ranked based on accessibility and proximity.

The ArcGIS Runtime SDK has demonstrated its efficacy as a robust and versatile platform for implementing GIS-based applications in the context of climate adaptation. Its scalability allows for seamless handling of large datasets, while its flexibility enables developers to tailor the application's functionality and visual interface to meet specific user needs. The availability of detailed documentation and development resources from ArcGIS has facilitated the application's design and deployment, ensuring a smooth and efficient process. While the current implementation offers a range of valuable features, further enhancements could be introduced. These enhancements may include enabling offline functionality for use in areas with limited internet access, integrating real-time updates on shelter occupancy and environmental conditions via IoT sensors, and incorporating a feedback mechanism for users to report inaccuracies or suggest new shelter locations. It is imperative to note that the application is currently undergoing finalization. Following the completion of the testing phase, the application will be made available to the citizens of Braga. A preliminary evaluation of the application has been conducted, involving a small sample of users (n=78).

The main results of applying this methodology are summarized in Table 3, which identifies the main differentiating solutions of the technology used in this study.

Table 3. Key success factors of Braga’s climate shelter model

Key Factors	Advantages of the proposal
Technological Integration	GIS-based mobile application with real-time IoT data.
Shelter Typology	Green spaces, blue spaces, grey spaces, emergency cooling stations.
Citizen Engagement	User-reporting and validation of shelter locations.
Real-Time Data	IoT sensors for temperature, air quality, and occupancy monitoring.
Accessibility & Equity	Prioritization of vulnerable populations (elderly, low-income areas).
Policy & Governance	Collaboration between local government, researchers, and emergency planners.
Scalability & Adaptability	Can be replicated in other cities with similar climate risks.

Source: Authors’ own elaboration.

5. DISCUSSION AND CONCLUSIONS

The objective of the investigation was to ascertain the area’s most susceptible to the risk of extreme heat. The investigation focused on Braga's Ring Road. Within the scope, two primary observations were made: the identification of the area’s most vulnerable to extreme heat and the insufficiency of suitable shelters to deal with this risk. It was determined that, in addition to the vulnerable areas, the city faces a significant challenge in cataloging and publicizing existing shelters, which exacerbates the situation of exposure to extreme heat for the population. Consequently, it is imperative to implement measures to efficiently map and communicate the location of shelters, in addition to developing mitigation strategies for the areas identified as most susceptible. The research also sought to formulate a proposal for classifying climate shelters within the Braga study area. The study identified three levels of climate shelters, categorized based on the adequacy of the shelters to the needs of the population.

A total of 33 shelters were identified and integrated into a GIS-based mobile application, enabling real-time shelter mapping and improving public access to cooling spaces.

To overcome the main identified barriers, Braga can adopt successful approaches from other cities. In particular:

- Financial constraints. For example, Barcelona leveraged European funds for climate resilience programs, while New York involved the private sector in co-financing urban cooling infrastructure.
- Resistance to technology adoption. In Barcelona, Plaza et al. (2023) have used gamification strategies and incentives to encourage the use of mobile applications for climate shelter location tracking.

- Public awareness. Staricco et al. (2024) refers the implemented media campaigns and direct community engagement through workshops on climate risks and how to use available shelters.

By adopting a multi-faceted approach, Braga can enhance the effectiveness of its climate shelters and foster greater acceptance among both the population and policymakers.The findings underscore the significance of integrating climate shelters into urban planning frameworks as other studies in the literature (Amorim-Maia et al., 2023; Martín-Vide & García, 2024; Pinto et al., 2024). By addressing both physical and social vulnerabilities, these shelters contribute to a holistic approach to climate adaptation. The case of Braga, and the case study in particular, illustrates how geospatial technologies can inform targeted interventions, ensuring that resources are allocated efficiently and equitably in case of UHS.

Despite the robustness of the methodology, the study presents some limitations that should be addressed in future research. Some identified shelters may not maintain adequate cooling levels, as reported in other studies, and certain shelters, such as public buildings, may have restricted access during weekends or holiday periods. Additionally, the current classification relies on predefined locations, requiring periodic updates to reflect new shelter opportunities and infrastructure changes.

To further enhance the effectiveness of climate shelters and their integration into urban planning, future studies should incorporate dynamic climate models, integrating real-time environmental data to refine heat risk assessments and improve shelter recommendations. Community engagement should be enhanced, with citizen participation in shelter identification and validation to improve spatial equity and usability. Expanding IoT integration, including real-time temperature and humidity sensors in shelter locations, would enhance decision-making for both users and policymakers. Further studies should also evaluate the effectiveness of shelters, assessing their performance during heatwaves to ensure thermal comfort and accessibility. This initiative constitutes an inaugural endeavor to integrate GIS to promote climate shelters within urban environments. Subsequent studies must be conducted to ameliorate the primary limitations of the present research. In fact, a recent study by Martín-Vide & Moreno-García (2024) stated that several climate shelters do not have the right thermal conditions, with some parks maintaining temperatures that are clearly higher than recommended during heat waves. In other cases, it is necessary to improve the access structure, considering that on festive days or vacation weeks some covered facilities close, and it is necessary to check the suitability of these spaces in terms of maintaining conditions to protect the population during excessive heat.

To further enhance the effectiveness of climate shelters and their integration into urban planning, future studies should:

- *Incorporate dynamic climate models* – Real-time environmental data should be integrated to refine heat risk assessments and improve shelter recommendations.
- *Enhance community engagement* – Citizen participation in shelter identification and validation can improve spatial equity and usability.
- *Expand IoT integration* – The inclusion of real-time temperature and humidity sensors in shelter locations would enhance decision-making for both users and policymakers.
- *Evaluate the effectiveness of shelters* – Future studies should assess shelter performance during heatwaves, ensuring their thermal comfort and accessibility.

Despite this, the implementation of climate shelters in Braga represents an innovative and replicable model for urban heat adaptation. By leveraging GIS technologies, real-time data, and participatory planning, cities can enhance their resilience to CC. As extreme heat events intensify, multi-stakeholder collaboration will be essential to ensure that climate shelters become a fundamental component of sustainable urban development.

CONFLICTS OF INTEREST

We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

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