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A methodological proposal to design climate shelter systems: The role of social infrastructure in climate adaptation strategies

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ABSTRACT

As climate change increasingly exposes urban populations to extreme weather events, adaptation strategies go beyond physical interventions to address social vulnerabilities. This paper proposes a methodological framework for designing climate shelter systems that integrate social infrastructure into climate-responsive planning. Grounded in the concept of community resilience, the approach combines top-down and bottom-up strategies to identify, evaluate, and adapt existing public and social spaces for use as climate shelters. The methodology is applied to a case study in the Bonfim parish of Porto, Portugal; an area characterised by socio-economic deprivation, aging infrastructure, and climate vulnerability. The framework consists of two phases: criteria-based site selection (combining indicators and spatial analysis using GIS software) and participatory engagement (interviews with residents and stakeholders) to assess suitability, perceptions, and behavioural responses to climate events. Specifically, 32 interviews were conducted as part of the case study. The outcome is a multi-layered shelter network encompassing outdoor, indoor, emergency, and vulnerable-group-specific spaces, tailored to the local context. The findings underscore the dual role of climate shelters as protective infrastructure and as catalysts for social cohesion, climate literacy and public engagement. The study emphasises the need to integrate climate adaptation into everyday urban practices and highlights the role of efficient governance, communication, and monitoring. By leveraging social infrastructure, climate shelters can evolve from emergency responses into long-term assets that strengthen adaptive capacity and promote climate justice. The proposed methodology is transferable across diverse urban contexts, with the necessary adjustments, offering practical guidance for cities aiming to operationalise equitable and inclusive climate adaptation strategies.

1. Introduction

As the climate crisis intensifies, cities are adopting a wide range of adaptation strategies, from regulatory measures to physical interventions. However, climate change affects the urban territories unevenly, amplifying pre-existing vulnerabilities (UN-Habitat, 2014), which can also be exacerbated by insufficient or poorly planned adaptation strategies (Amorim-Maia et al., 2023b). These inequalities in urban areas have fueled the climate justice discussion, which has become crucial in the overall planning process, emphasising the need to specifically address social vulnerability in climate-related policies.

This paper intends to contribute to the debate on climate adaptation strategies, responding to extreme weather events, by proposing systems of urban climate shelters. More specifically, it proposes a methodology to define a climate shelter system that embraces two interrelated objectives. First, the design of the climate shelter system (identifying categories of spaces, their characteristics, operating rules, etc) as part of the climate adaptation strategy. And second, take advantage of spaces within the social infrastructure to be part of the climate shelters network, enhancing community resilience and fostering collaborative dynamics. A case study in the city of Porto is presented to illustrate the implementation of the proposed methodology, which includes the application of criteria, spatial analysis using GIS and interviews. Like other cities, Porto has been experiencing significant extreme climate events, such as heatwaves, coldwaves, and urban flooding. These events pose significant risks to public health, especially for vulnerable groups.

In the context of the growing literature on climate adaptation, this paper emphasises the relevance of climate-responsive planning as a

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pivotal approach for building community resilience by incorporating climate issues into planning processes and policies.

1.1. Climate-responsive planning and the role of social infrastructure to enhance community resilience

Cities are facing increasing climate impacts, which demand urgent solutions that involve designing or reshaping urban spaces as part of climate adaptation efforts. These impacts affect communities unevenly, requiring context-sensitive and site-specific responses that address a wide range of local needs (Cruz et al., 2025). To be effective, climate adaptation strategies must aim to strengthen communities' resilience by focusing on the capacity of social systems (Sousa et al., 2024), while also enhancing individuals' abilities (Graça et al., 2022) to cope with climate-induced disruptions, particularly in light of unequal vulnerabilities (Carmen et al., 2022).

The IPCC (IPCC, 2022) defines climate resilience as the capacity to anticipate, prepare for, and respond to hazardous events or climate-related trends. Building on the need for locally tailored and community-focused strategies, the concepts of community resilience and climate resilience, while distinct, are closely interconnected. Community resilience is widely understood as the collective ability of communities to respond to diverse, multi-scalar changes, risks, and disruptions, and to adapt and thrive in contexts marked by uncertainty and unpredictability (Berkes & Ross, 2013; Maclean et al., 2013; Magis, 2010). In this regard, resilient communities are fundamental to achieving climate resilience (Haque et al., 2022; Lerch, 2017). To this end, participatory approaches that integrate place-based solutions tailored to the needs of low-income and vulnerable populations are recommended to foster both resilience and adaptive capacity (Roy et al., 2022).

Building on these concepts, climate-responsive planning has emerged aligned with community-based adaptation approaches, emphasizing the empowerment and engagement of local communities, the support of grassroots organizations, and the promotion of participatory governance processes (Patnaik, 2021; Roy et al., 2022). While communities are central to effective climate adaptation, their efforts must be supported by institutional and governmental frameworks operating across multiple levels (Bulkeley & Betsill, 2005; Care International, 2015; Rafael et al., 2015).

As several authors have noted, in fostering community resilience, particularly in the face of climate risks, adaptation strategies should prioritise the social dimensions of risk (Sanyal & Routray, 2016; Wilkin et al., 2019) and the adaptive capacity of communities (Shirleyana et al., 2023), rather than focusing solely on physical vulnerabilities, promoting the physical transformation of urban spaces (Lv et al., 2024; Mccann & Fünfgeld, 2016; Roy et al., 2022). This focus is critical to advancing a holistic, just, and inclusive approach to climate-responsive planning (Cutter, 2016). Strategies often described as climate-responsive design (Cortesão et al., 2020; Daniel et al., 2023), typically involve implementing nature-based solutions and alternative construction methods to address climate-related challenges such as heatwaves, cold spells, flooding, and sea-level rise (Brandsma et al., 2024; Kozlowski & Yusof, 2016; Liu et al., 2023; Tamminga et al., 2020).

Nevertheless, the complexity of responding to climate impacts calls for a more comprehensive and context-sensitive approach that goes beyond design interventions and the material or physical transformation of urban spaces (Wangchuk, 2023).

In this sense, climate-responsive planning approaches that emphasise the social dimensions of adaptation strategies (Tavares et al., 2020) tend to align with scholars who highlight the importance and the potential of communities' social infrastructure (Enneking et al, 2025). This concept encompasses the full range of physical and institutional infrastructures that support social life (Lathan & Layton, 2019), facilitating the establishment and maintenance of social networks and connections between people (Klinenberg, 2018; Lathan & Layton, 2022). Beyond serving as instrumental responses to collective needs, such as those arising during extreme climate events, social networks are increasingly recognised for their potential to foster social inclusion, mediate differences, reduce isolation, and encourage sociability (Klinenberg, 2018).

Building on the recognised potential of social infrastructure, several authors (Craig-Scheckman et al., 2024; Enneking et al., 2025; Latham & Layton, 2022; Shirleyana et al., 2023) highlight that such spaces generate a "social surplus" (Latham & Layton, 2019:8). This surplus manifests in the form of trust, cooperation, civility, civic engagement, improved access to information and health outcomes, encounter and a sense of shared purpose - elements that become especially crucial in times of crisis and environmental disasters. As Aldrich and Meyer (2014) argue, communities with strong social infrastructure are better equipped to anticipate and respond to changing conditions and uncertainties, and to recover more quickly and effectively from climate-related shocks, demonstrating high levels of adaptive capacity.

From an action-oriented perspective and considering the potential of social infrastructure to address collective challenges and related provisioning needs, Latham and Layton (2019, 2022) identify several key characteristics necessary for these spaces to support successful intervention strategies. These include abundance, diversity, ongoing maintenance, accessibility, and responsiveness to people's wants and needs. Crucially, they also highlight the importance of what they term 'an ethos of democratic living', underscoring the role of these spaces in fostering inclusive, participatory, and equitable social interactions.

1.2. Integrating climate shelters within the social infrastructure

Several cities have recently introduced climate shelters as part of their adaptation strategies, aiming to provide protection against extreme weather events, particularly heatwaves, for the most vulnerable populations. The concept of climate shelters emerged as a critical infrastructure component designed to safeguard communities during climatic catastrophes (The Sphere Project, 2011). These shelters are equipped to provide prolonged refuge, supplying essential resources such as food, water, fuel, bedding, and clothing (Bashawri et al., 2014). However, as extreme weather events become more frequent and widespread, cities must provide not only emergency shelters but also everyday refuges that enhance thermal, acoustic, and wind protection in both indoor and outdoor environments (Amorim-Maia, et al., 2023b; Montero-Gutiérrez et al., 2023).

Climate shelters are often embedded within public spaces and infrastructures, including parks, schools, civic centres, libraries, and transportation hubs (Campbell et al., 2022; Iglesias-Pascual et al., 2023; Williams-Eynon, 2023). To go beyond infrastructural adaptation demands to take advantage of the social infrastructure in this process (Latham & Layton, 2019). It means not only providing physical shelter but also offering community spaces for gathering, information dissemination, and the distribution of essential provisions such as food and medicine (Huddleston et al., 2022; McShane & Coffey, 2022; Tan, 2014). Climate shelters can, therefore, serve a dual purpose, providing immediate protection while fostering social inclusion and resilience within communities (Amorim-Maia et al., 2023a; Henshel & Ashby, 2023), ranging from private initiatives to public facilities managed at municipal, regional, or national levels (Amorim-Maia, et al., 2023a).

Despite their importance, research indicates that few cities have established comprehensive climate shelter systems, and the majority of such systems are primarily focused on mitigating heat exposure (Ayuntamiento de Bilbao, 2024; Florian, 2022; Sitzoglou, 2021; Ville de Paris, 2025). Moreover, many of these spaces operate under a top-down approach, often managed by civil protection agencies and primarily directed toward highly vulnerable populations, such as individuals experiencing homelessness (Amorim-Maia et al., 2023b; Wu et al., 2019). Additionally, the unequal distribution of public facilities within urban areas results in accessibility disparities, further exacerbating

social and spatial inequalities.

Thus, to enhance the effectiveness of climate shelters, four main issues must be addressed (Amorim-Maia et al., 2023a, 2023b; The Sphere Project, 2011; Wu et al., 2019):

- Providing a suitable quantity and variety of shelters to accommodate diverse community groups and address multiple climate risks, assuring flexibility and adaptability for future needs;
- Developing a systematic approach to shelter placement through coverage and impact analyses, ensuring accessibility for the most vulnerable populations and promoting climate justice;
- Providing valuable and useful information about available shelters, their locations, and their functions to ensure that individuals can access appropriate spaces during climate-related events and emergency situations;
- Expanding the function of shelters beyond emergency use and infrastructural adaptation, transforming them into spaces for social interaction and infrastructure reinforcement in urban areas.

Furthermore, the efficacy of the shelter system in enhancing community resilience must not be exclusively predicated on a risk-oriented framework (Amorim-Maia et al., 2023b). Developing affective relationships between communities and urban spaces is fundamental to strengthening adaptive capacities (Cruz et al., 2025; Nightingale et al., 2021), enabling residents not only to use formal shelters but also to repurpose informal spaces as climate refuges when needed. Therefore, understanding local behaviours, uses, and emotional connections to potential shelter spaces from the outset is crucial for ensuring their success as part of the broader social infrastructure (Huddleston et al., 2022; McShane & Coffey, 2022).

1.3. Cities with climate shelter networks

Several cities worldwide have initiated efforts to develop climate shelter networks, including Barcelona, Berlin, Bogotá, Buenos Aires, London, Madrid, Mexico City, New York, and Paris. Barcelona pioneered with a network of climate shelters as part of its Climate Plan in 2019, aiming to improve thermal comfort in buildings and public spaces, particularly for vulnerable populations. Since 2020, the city has established criteria to convert spaces to climate shelters (Ajuntament de Barcelona, 2024), which must maintain temperatures below 26°C in summer and above 19°C in winter, while ensuring accessibility, and providing seating areas and access to drinking and cooling water (Brandon, 2022; Florian, 2022). These shelters include schools, museums, libraries, and civic centres, as well as outdoor areas such as parks and gardens. Despite its innovative approach, challenges remain, such as insufficient staff training, limited operating hours during holidays coinciding with peak heat events, and low public awareness (Amorim-Maia et al., 2023a). Other Spanish cities have developed their shelter networks, like Bilbao, Madrid, Sevilla and Zaragoza.

Paris developed the “Paris s’adapte plan” in 2023, focusing on reducing asphalt coverage, planting trees, installing drinking fountains, and creating over 1,400 “cool islands” to provide refuge during heatwaves, not neglecting to protect the most vulnerable populations (Ville de Paris, 2025). The Paris Oasis Project repurposed schoolyards into climate-adaptive spaces through participatory design (Urban Innovative Actions, n.d.), with schools serving as community hubs outside school hours, further strengthening local social networks and resilience (Sitzoglou, 2021).

London’s “Cool spaces project” (2020) allows boroughs, community groups, and cultural organisations to propose sites for heat refuge, validated by local authorities based on accessibility and amenities criteria.

In Lisbon, since 2023, the municipality has promoted heat adaptation through the ‘Cool the City’ programme, increasing green areas, shade, and airflow while reducing heat emissions from vehicles and buildings (Raposo, 2023). Nevertheless, the city still lacks a comprehensive plan that defines a network of climate refuges or shelters (Raposo, 2025).

2. Materials and methods

2.1. Characterisation of the study area in the city of Porto

According to the climate scenarios, the city of Porto will face several climate-related risks in the future, including drought, heavy rainfall, extreme low temperatures and extreme high temperatures (CMP, 2016, 2025; Monteiro et al., 2018). Furthermore, the process of urbanisation since the mid-20th century, marked by a high percentage of channelled/tubed streams and soil sealing (75%) (Monteiro et al., 2022), is likely to compound climate impacts, such as the emergence of heat islands and urban flooding. Thus, it is anticipated that the magnitude of impacts will significantly increase. It is worth noting that the municipality of Porto has been adopting sustainable and resilient policies and strategies, and has recently implemented several adaptation initiatives and measures to prevent and mitigate the expected impacts. However, the municipality has not yet considered any climate shelter system.

In the central areas, temperatures are higher due to the built environment's characteristics, including high density, old building stock, consolidated urban tissue, few green areas and lack of tree canopy coverage. As green areas experience lower thermal load and areas with higher building density and soil sealing experience higher thermal load (Monteiro et al., 2022), the latter pose a higher risk of generating heat islands. Conversely, areas with lower thermal loads present a higher risk of cold temperatures during winter. Furthermore, the combination of high temperatures and minimal wind speed, particularly during the summer months, exacerbates the situation. Figs. 3 and 4 (Monteiro et al., 2018) evidence the criticality through the intersection of thermal load and ventilation potential data, respectively, for Summer and Winter. The maps indicate that several areas in the city centre exhibit extreme criticality due to low ventilation and high temperatures (Fig. 1), which can be mitigated by outdoor sheltering. Furthermore, during the winter season (Fig. 2), while ventilation levels vary from very low to moderate, lower temperatures can result in thermal discomfort, particularly in peripheral areas where ventilation potential is higher.

The study area encompasses the parish of Bonfim, situated in the central part of the city. This territory is of particular interest due to its unique urban characteristics, diverse climatic variables and its associated vulnerabilities. The parish continues to be characterised by the vestiges of its industrial past, as evidenced by the prevalence of medium to low-cost housing and the presence of brownfield sites. The low-cost housing often takes the form of "ilhas" (islands), a specific housing typology of Porto, which are sets of low-cost, working-class houses from the late 19th century, characterised by very poor living conditions. Of the 957 “ilhas” within the municipality, only 7% are in a good state of conservation with satisfactory living conditions (Vazquez & Conceição, 2015; CMP, 2021). The territory exhibits notable vulnerabilities in terms of socioeconomic deprivation (Monteiro et al., 2018), with the elderly constituting the most vulnerable population group. The elderly experienced an increase of 2.4% between 2011 and 2021, with an ageing ratio of approximately 2,3 (INE, 2021; Monteiro et al., 2018). Bonfim is also the parish with the highest proportion of elderly people living alone, which increases their vulnerability by limiting their capacity to prepare for and respond to extreme climatic events, as they are largely dependent on neighbours and family (CMP, 2021). Additionally, they have health weaknesses and risks, as well as mobility problems, which make them more susceptible to the adverse effects of extreme temperatures, both high and low.

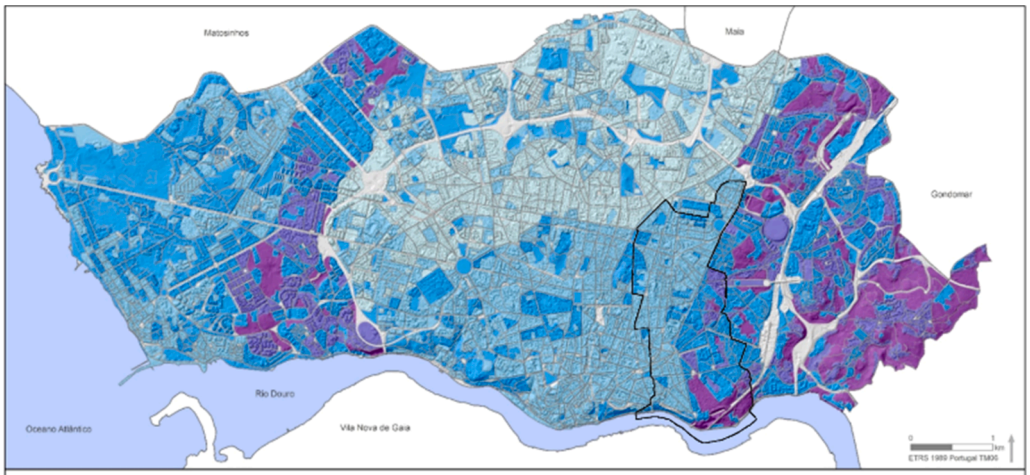
The area is affected by extremely high temperatures in the summer, as well as low temperatures and heavy rainfall in the winter, which occasionally causes urban flooding. As illustrated in Fig. 5, there is a high incidence of flooding in this area. In almost half of the area, there



Critical areas in Summer

Thermal load \ Ventilation potential	High to very high	Moderate	Very low to low
Low	Non critical	Low critical	Critical
Moderate	Low critical	Critical	Very critical
High	Critical	Very critical	Extremely critical

Fig. 1. Map of criticality in Summer (Source: Monteiro et al., 2022).



Critical areas in Winter

Thermal load \ Ventilation potential	Very low to low	Moderate	High to very high
High	Non critical	Low critical	Critical
Moderate	Low critical	Critical	Very critical
Low	Critical	Critical	Extremely critical

Fig. 2. Map of criticality in Winter (Source: Monteiro et al., 2022).

are extremely critical situations for high and low thermal loads (see Figs. 1 and 2). There is an overlay of areas with individuals over the age

of 64 (51 to 100%) (Fig. 4), which corresponds to areas classified as high priority regarding heat (Fig. 3).

In the central and eastern part of the city, socio-economic-environmental deprived areas are frequent. Due to the old building stock in Bonfim, most houses are not well prepared to provide thermal comfort, as corroborated by the fact that 31,2% of the housing stock (CMP, 2024a) has no heating. In the case of the referred "ilhas" - a typology of housing notably prevalent in the parish (Fig. 4) - it is expected that the populations may leave their houses during such extreme events.

During extreme events (e.g. extreme temperatures or heavy rains leading to flooding), the provision of shelters can ensure people have a safe haven, particularly in vulnerable areas where housing conditions may not provide adequate protection. The use of social infrastructure spaces for these purposes fosters a safer environment and strengthens interpersonal relationships among neighbours. The planning process for these shelters should consider locations already familiar to and trusted by the population, enhancing community resilience and promoting climate justice effectively.

2.2. Methodology

An innovative and replicable methodology is proposed for implementing urban climate shelters. The design of the climate shelter system is understood as processual, meaning it is a participative, iterative, and dynamic system. Three main novel contributions are proposed. First, a participatory approach enables the integration of citizens' and stakeholders' insights in identifying potential spaces, as well as in validating the final proposal. Second, the use of key criteria in selecting spaces involves combining quantitative and qualitative methods. A spatial analysis of the city, using statistical and GIS data, supports the identification of vulnerabilities, potentialities and other spatial synergies. Additionally, an analytical and empirical approach, based on observations and on-site data collection, enables a more comprehensive and detailed understanding of the potential spaces. Third, this process includes a monitoring component to assess the functioning and governance of the whole climate system. Ultimately, the entire process is expected to yield outcomes that extend beyond mere climate resilience, specifically by promoting and enhancing social infrastructure. The overall framework of the methodology is replicable, with reasonable adjustments attending to different contexts.

The methodology employs a two-phase approach (Fig. 5), combining both top-down and bottom-up strategies to ensure a participatory and inclusive planning process. The first phase involves preparation and data collection, while the second focuses on further analysis to ultimately obtain a climate shelter system.

2.2.1. Phase 1

Phase 1 encompasses the preparatory steps of the study, including the definition of criteria for selecting climate shelters, the identification of data sources, and the selection of population groups to be interviewed. The identification of criteria for selecting suitable spaces to serve as climate shelters considers the literature review, as well as a thorough understanding of the specific conditions that shelters should have. Each city may have very specific conditions and climate risks that determine the spaces to be selected. Therefore, these criteria are divided into four groups: thermal comfort (related to ambient temperature), accessibility (related to proximity and free access), safety (related to civil protection issues and urban insecurity) and availability of amenities (such as toilets, seating and free drinking water). It should be noted that these characteristics should be adjusted according to climate risks, such as flooding, cold waves and heat waves (Fig. 6). The first three criteria are related to immediate protection from climate event risks. On the one hand, by providing spaces that protect people from climatic impacts, thereby improving their well-being and safety; on the

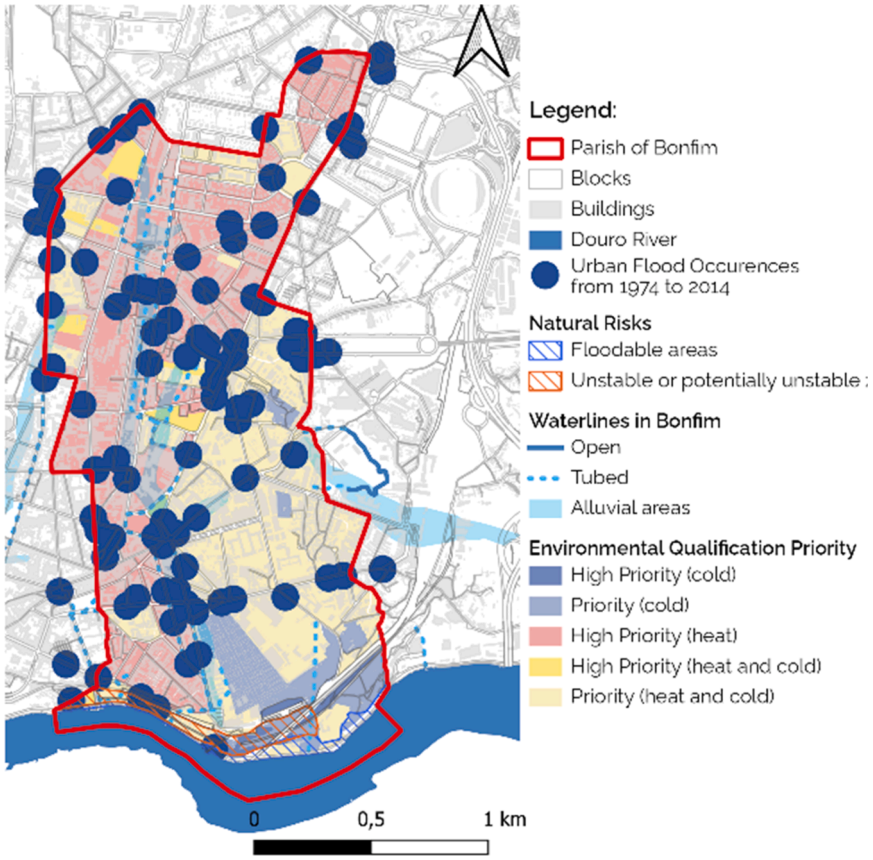


Fig. 3. Map of climatic and environmental risks in Bonfim Parish.

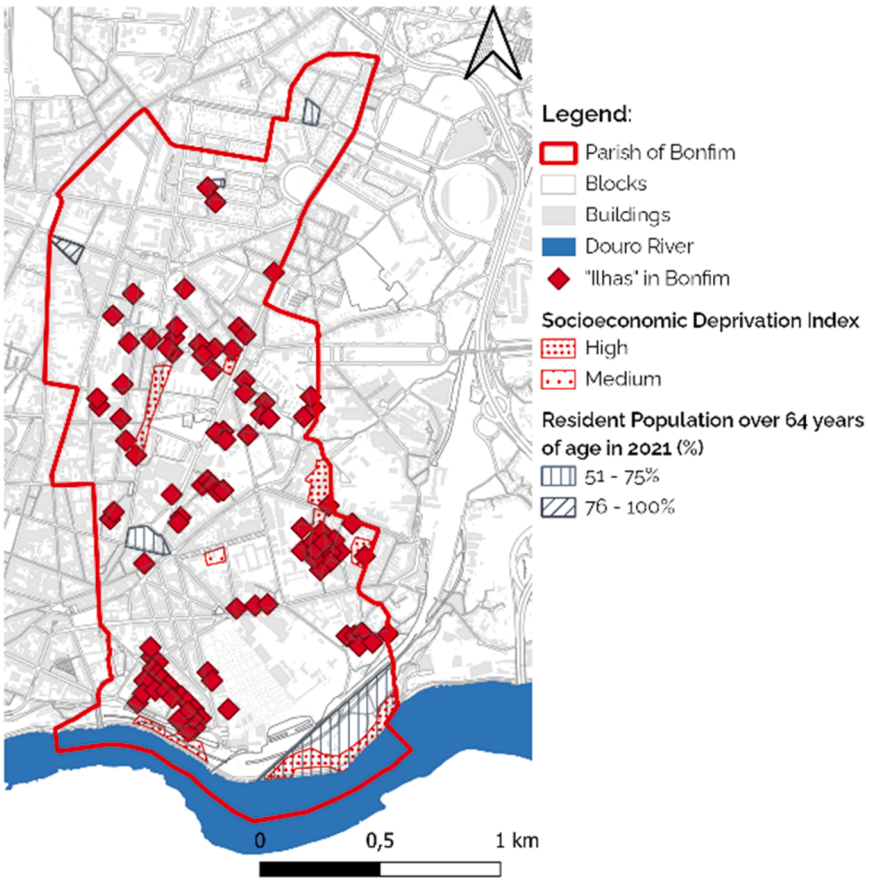


Fig. 4. Map of socioeconomic vulnerabilities in Bonfim Parish.

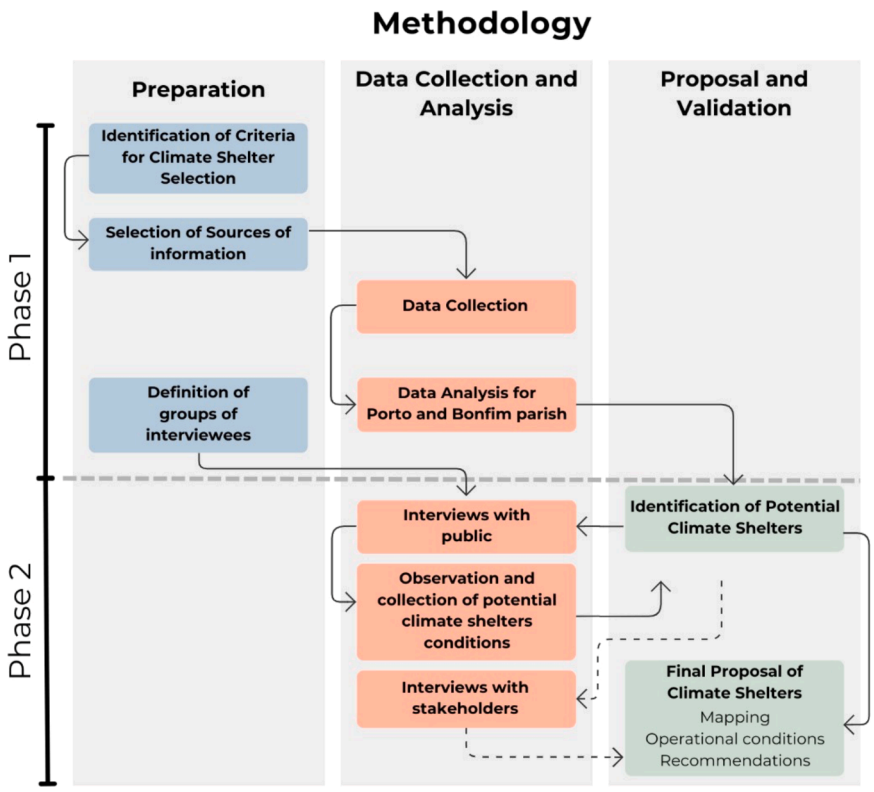


Fig. 5. Scheme of the methodology presenting all steps within each phase.

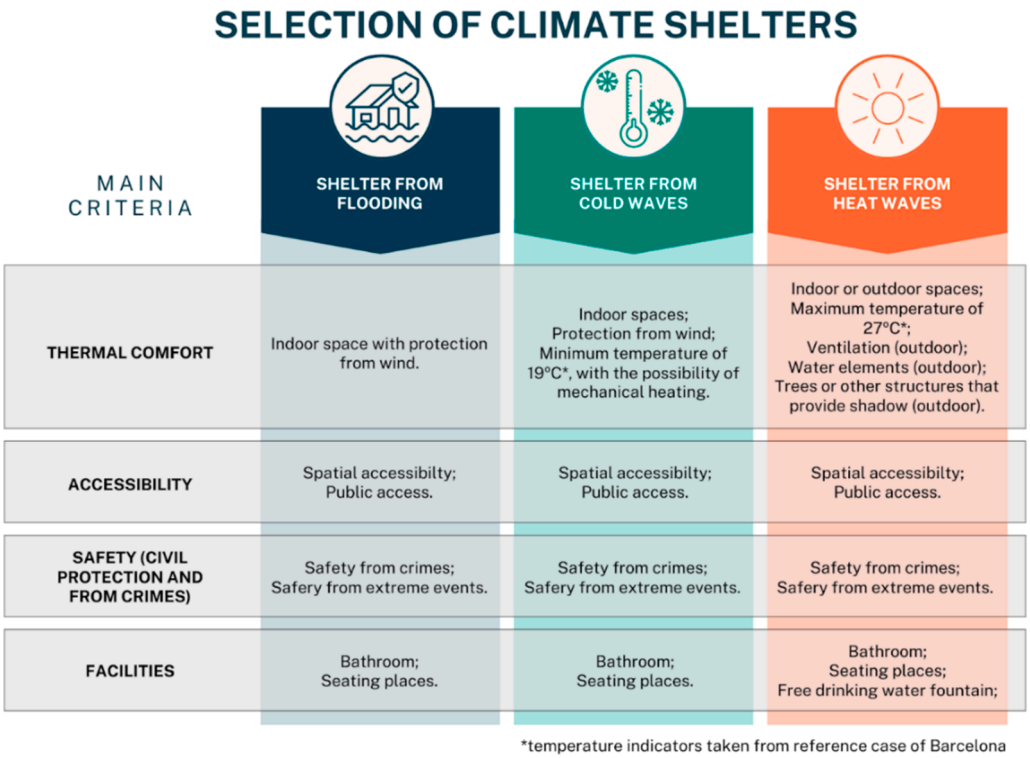


Fig. 6. Criteria for the selection of climate shelters.

other hand, by providing accessible and proximate spaces that are also unrestricted. The last criterion is related to providing goods and amenities, to ensure that the users' basic needs are satisfied.

The **selection of information sources** encompasses the identification of relevant documents, reports, legislation, and plans at both national and local levels, as well as statistics and spatial data. such as the Municipal Master Plan, Environmental and Territorial Characterisation Reports, and data from the National Statistical Institute's Census (INE, 2021). These sources provide pertinent data for analysing the territory and its vulnerabilities. Most of the collected information is mapped using QGIS software to support spatial analysis and cross-referencing of data. This approach enables the identification of areas where vulnerabilities and risks intersect, thereby highlighting where interventions are most needed.

Finally, as part of this preparatory phase, it is crucial to **identify the groups of interviewees**, including both the public and relevant stakeholders, to guarantee diversity and representativeness in the interviews.

2.2.2. *Phase2*

The second phase ultimately aims to define the climate shelter system. First, a preliminary version of the shelter system is prepared, incorporating the **identification of potential climate shelters**, in accordance with the criteria selected in Phase 1. This identification is obtained through a screening process of municipal facilities, either collective equipment (both existing and proposed) (CMP, 2021) or social facilities (CMP, 2024b). Furthermore, other institutions or spaces that fulfil this purpose are added. All these sites are geo-referenced using QGIS software, with details on whether they are open or closed, the source of the proposal, the name of the facility, and its regular use. All data is compiled in a table, facilitating subsequent analysis of the sites' real usefulness in the face of climate risks and the type of support they can provide to the population. This table lists potential mapped sites, further analysed after on-site visits and verification via Google Maps to determine their current usage and condition. At this stage, each site is assessed according to the shelter's selection criteria (Fig. 6). This assessment allows for determining the potential to comply with the function of a climate shelter, as well as to minimize impacts from extreme climate events.

Secondly, in-depth **interviews** are conducted with residents living in the surrounding areas and with stakeholders linked to potential locations, to explore community perceptions of climate change and assess behavioural changes during extreme climate events. These interviews comprise three main open-ended questions designed to gather perceptions and experiences: (i) participants' perceptions of climate change, (ii) behaviour changes during extreme climatic events and places most sought after as shelters, and (iii) participants' willingness to use formal shelters, if such shelters were available. In addition, on-site **observations and detailed conditions for potential climate shelters** should be compiled. The draft proposal should be validated through **interviews with relevant stakeholders**. Their knowledge regarding the utilisation of these spaces and their role within the city's social infrastructure is of most relevance to ultimately obtain the **final proposal for the climate shelter system**.

3. Results

3.1. *Potential climate shelters*

The preliminary mapping of potential shelters is developed based on the public and collective facilities. The map encompasses other public spaces, which are identified through a broader analysis of the study area. The list of potential shelters is extensive and inclusive, encompassing daycare centres, childcare centres, social institutions that provide food and aid to vulnerable communities, parks, sports centres, schools, cultural centres, museums, and libraries, among others. In all, 183 sites are mapped in Fig. 7 according to the type of risk.

3.2. *Interviews*

This stage of the research aims to explore community perceptions of climate change and assess behavioural changes during extreme climate events. A total of 32 interviews were conducted with potential users of

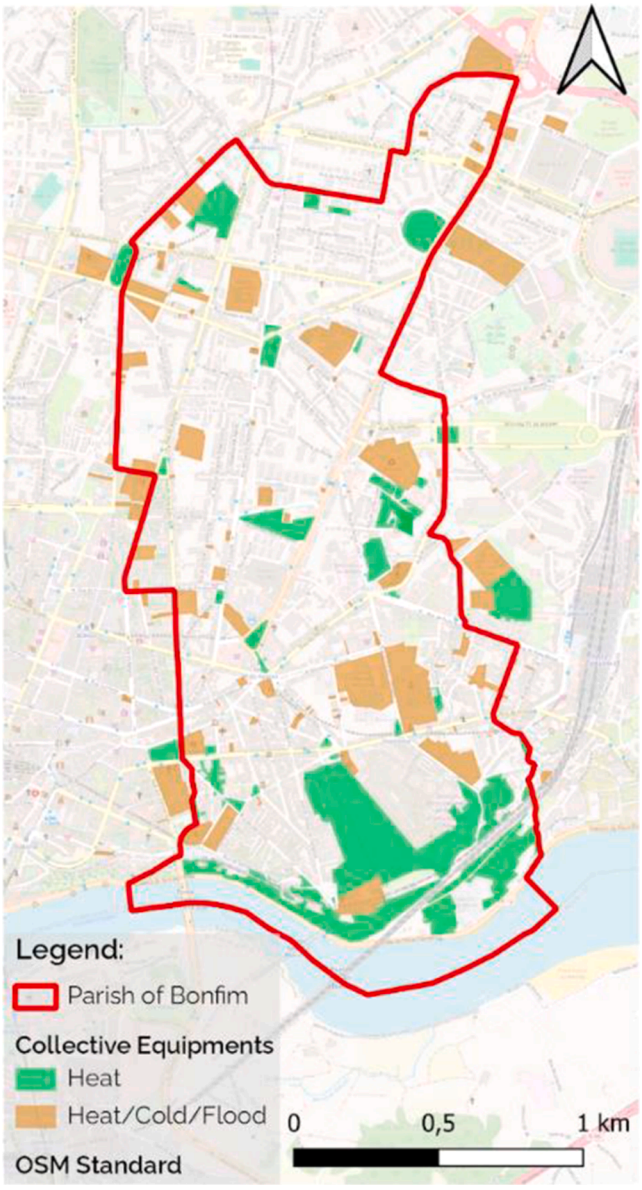


Fig. 7. Mapping of Infrastructures that could be used or adapted to climate shelters, classified by the type of risk they respond to. (Source: CMP, 2021; CMP, 2024b).

the climate shelters. Participants were recruited through a convenience sampling approach at potential shelter sites within the parish of Bonfim. Interviews were conducted on different days and times, including weekdays and weekends, to increase the likelihood of engaging a diverse range of individuals. The interview data were analysed using an inductive thematic analysis approach, enabling the full use of the relevant information provided by the interviewees and an overall understanding of the material. Initial codes were identified based on recurring ideas, expressions, and patterns across responses. These codes were subsequently grouped into broader themes related to (i) perceived impacts of climate change, (ii) seasonal behavioural patterns, and (iii) awareness and effective or potential use of public spaces during extreme weather events. Given the exploratory nature of the study and the limited sample size, the analysis was conducted by a single researcher, with themes refined iteratively through repeated comparison of responses. Percentages were calculated to summarise the frequency of key responses, while illustrative quotations were selected to support the thematic findings.

A notable challenge that emerges in the interviews is the difficulty respondents have in offering detailed reflections on climate change. Although many participants report feeling affected, few are able to explain why. When asked about their behaviours during extreme weather events, interviewers often have to clarify the types of events being referred to. Overall, there is limited awareness of seasonal behavioural changes, particularly regarding the choice of spaces in response to climate conditions.

Nevertheless, when asked about the impact of climate change, 78% of respondents report feeling affected, particularly by cold and rain in winter (‘*The winter is more uncomfortable*’). During this season, most tend to stay at home, with only 12.5% seeking alternative indoor spaces (‘*stay home, or going to shopping malls and museums*’). On the other hand, many engage in outdoor activities during high temperatures in the summer and tend to look for cooler places around the city (it should be noted that Porto is a city with a maritime coastline and a river crossing its urban core, both of which provide extensive and temperate waterfront areas), such as staying in parks, going to beaches and the riverbanks (‘*During heat, we go to the beach, parks, look for shadows*’; ‘*I enjoy going next to the river*’) and enjoying outdoor restaurants and cafes. Finally, when asked about the potential use of climate shelters, 84.375% highlight their relevance and indicate they would use them if available (‘*There could be more pleasant and healthy public spaces*’, ‘*There could be water features for people to get wet and cool off in*’).

In addition to the residents’ interviews, five interviews were conducted with owners of local food and beverage establishments (restaurants and cafés). They report an increase in the number of customers during the summer and, at times, serve as a temporary climate shelter during adverse weather conditions, such as rain or cold. When asked whether their establishment could be integrated into a formal climate shelters network – serving also as venues for public awareness and educational events - four out of five owners respond positively. Notably, many of these establishments foster a sense of community among their regular clients, which contributes to community resilience, even in informal or unstructured ways.

To comply with the methodology that involves interviews with stakeholders, additional interviews were conducted with managers and technical staff of sites identified as potential public or publicly accessible facilities. Efforts were made to include representatives from a diverse range of facilities, such as a library, a public administrative office and a museum, recognizing their distinct institutional characteristics and their varying public perceptions. They provide valuable perceptions and useful insights. Firstly, although the area has a significant vulnerable population and faces persistent energy poverty, residents generally do not rely on public facilities to cope with extreme weather events (‘*The location is not frequently used by locals to shelter from heat or cold/rain*’; ‘*residents and the elderly do not seek it out as a climate refuge*’). Exceptionally, the library experiences significant demand, especially from homeless individuals, besides residents and tourists (‘*Yes, it is used by residents, tourists, and homeless people to shelter from bad weather, mainly because it is freely accessible, offers thermal comfort, and has a quiet atmosphere that can be enjoyed inside*’). In this case, ‘*staff are aware and prepared to welcome those seeking shelter, as they regard this as part of the institution’s social role*’.

Considering recent events and projected climate scenarios, all interviewees recognize both the need for, and the potential benefits of, establishing a future climate shelter network for both residents and tourists. They suggested a range of possible venues, including schools, libraries, public gardens, metro stations and churches (‘*already traditionally recognised as protective spaces, given the historical role they’ve always had serving the community in this way*’). However, despite the number and variety of public facilities in the parish, interviewees note that several - including their own - ‘*face significant challenges in being integrated into such a network, primarily due to space constraints and safety issues*’. All interviewees emphasize the importance of educational initiatives and awareness-raising efforts targeting both institutions and

citizens, to strengthen the initiative' success and to promote climate literacy and community resilience. Many citizens remain largely unfamiliar with the idea of using certain public spaces for purposes beyond their conventional functions, particularly older and more socially isolated individuals, who often prefer to seek refuge at home, even when their living conditions are far from thermally adequate.

Finally, all interviewees stress the importance of frontline managers of institutions and public facilities recognizing the potential of their spaces to support the city's adaptation to climate change, particularly by fostering the resilience of local populations. As they noted: '*It is necessary to strengthen the awareness and accountability of decision-makers and to carry out educational work with public facility users and the community itself so they can recognize and use climate refuges*'; "*(…) coordination and alignment with the city council are also decisive factors*'.

3.3. Final climate shelter system

From the 183 sites mapped in Fig. 7, a two-phase filtering process is conducted. First, sites are subjected to remote verification using Google Maps and on-site inspections, to assess their current use, physical condition, and capacity to function as climate shelters. Several sites identified in the municipal master plan as collective facilities are currently inactive, including abandoned buildings and undeveloped areas; some equipment and facilities are already at the limit of its capacity; and others, on the other hand, are closed or have restricted-access, which lead to the prioritisation of spaces already open to the public where compliance with shelter criteria could be more readily verified.

In the second phase, on-site observations and the results of the interviews conducted enabled a deeper analysis of the potential spaces, particularly examining the spatial conditions in detail and the necessary requalification to meet the criteria for designation as a shelter. As the criteria differ depending on the shelter location (indoors for cold weather, indoors for natural disasters, and outdoors for heat), all these factors are taken into consideration. This filtering process allows for the identification of 68 potential spaces. Results are represented in Fig. 8 with spaces classified according to their need for requalification.

Consequently, spaces that have been categorised as high or very high in terms of need for requalification are not yet suitable for use as shelters. Those classified as medium can be utilised, though they may not meet all the necessary conditions, and spaces requiring low or very low intervention are ready for immediate use. It is worth noting that all potential climate shelters require certain modifications. Most outdoor shelters should provide at least toilet amenities or free drinking water, while indoor shelters need to extend their operating hours for longer periods.

Additionally, information from the fieldwork (observations and interviews) allows for a comprehensive selection of the final spaces, taking into consideration their inclusion in the social infrastructure of the urban area. Those are the spaces most used and recognised by the community as gathering and safe spaces, where people feel strongly supported.

The final climate shelter system, comprising 26 spaces, is divided into four distinct subsystems: outdoor shelters, indoor shelters, institutions that provide daily shelter for vulnerable groups, and shelters that offer better protection in the event of catastrophes (see Fig. 9):

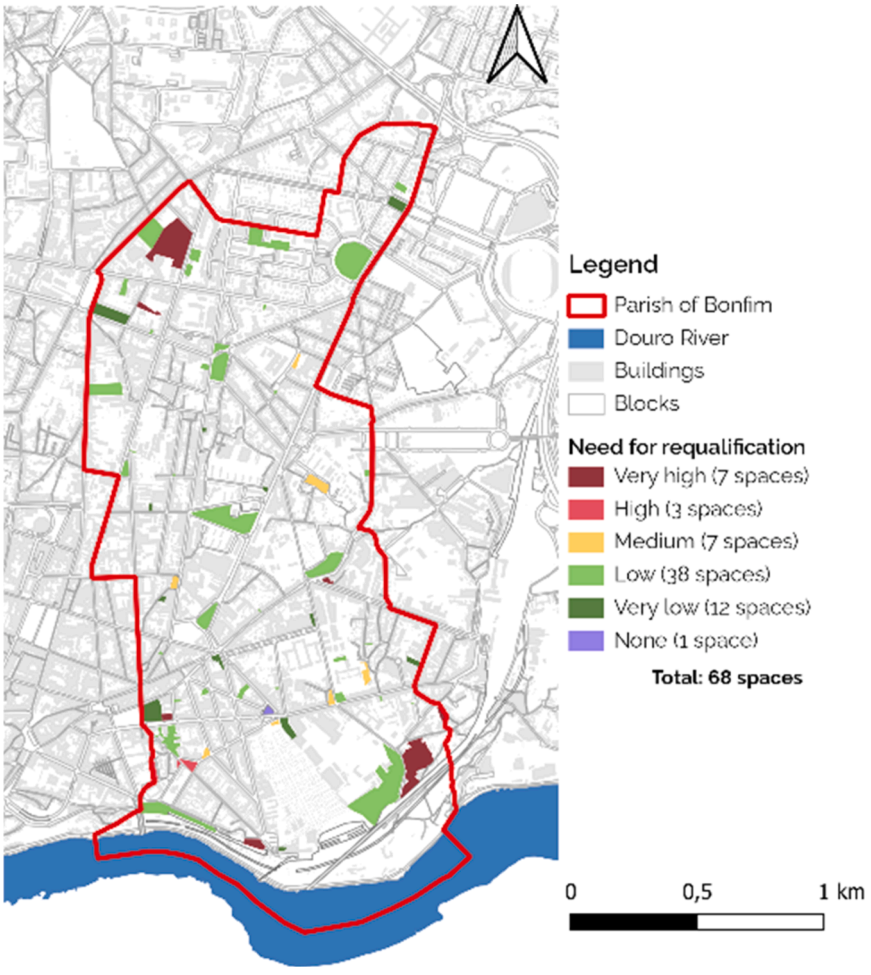


Fig. 8. Map presenting the need for requalification of each potential shelter.

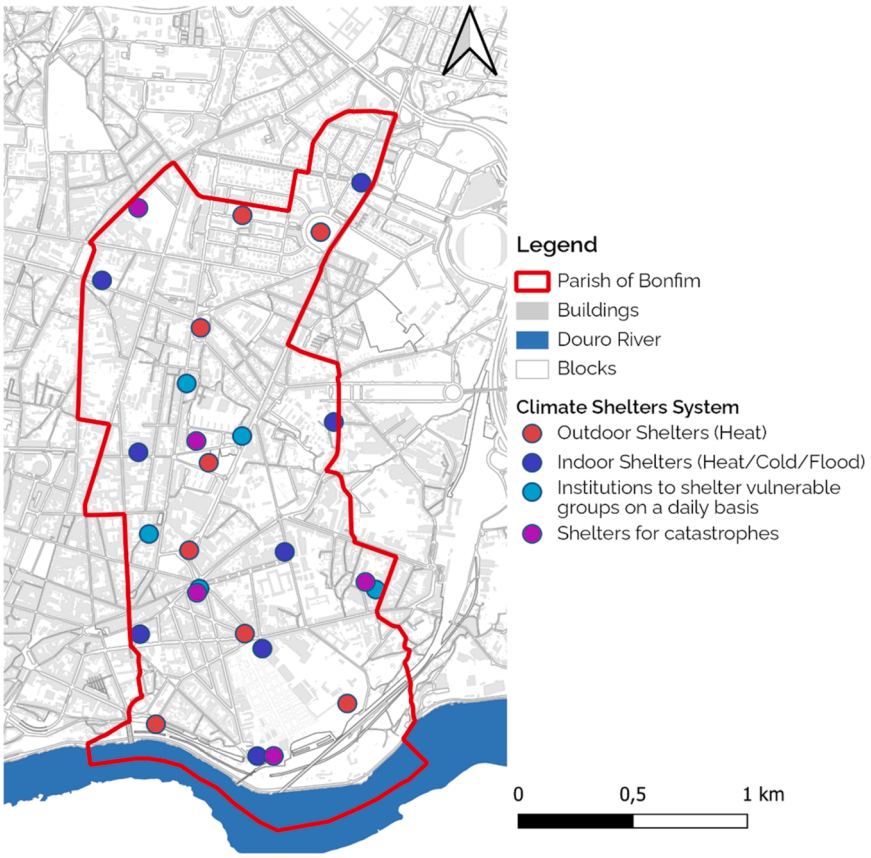


Fig. 9. Map of Final Climate Shelter System in Bonfim Parish.

- **Outdoor Shelters:** These encompass parks, squares, and other open-air public spaces where individuals can seek relief from extreme heat. Such shelters should provide adequate shade, natural ventilation, seating, and access to free drinking water. The inclusion of water features is beneficial, as they help to lower ambient temperatures and may offer opportunities for personal cooling. To enhance usability and support longer stays, outdoor shelters may also be equipped with public restrooms.
- **Indoor Shelters:** Designed to offer protection from a range of climatic events - including heatwaves, cold spells, heavy rainfall, and flooding - these shelters should maintain pleasant indoor temperatures. These spaces often serve cultural, commercial, or religious functions and typically operate during limited hours. Therefore, coordination with local authorities is essential to ensure extended opening times and guaranteed free public access during extreme weather events.
- **Shelters for Vulnerable Groups:** This category includes indoor spaces intended to support vulnerable individuals who may be unable to safely remain in their homes. These shelters must provide adequate conditions for prolonged stays during extreme events, though they are not designed for use in large-scale emergencies. They are often located within community centres or institutional facilities and serve a regular function in the community.
- **Shelters for Catastrophes:** These are large-scale indoor facilities, such as schools or sports complexes, intended for use during major emergencies, such as severe flooding that results in displacement. These shelters must be capable of accommodating large numbers of people for extended durations and providing essential services and support during crisis situations.

4. Discussion of results

The methodological proposal acknowledges the importance of considering both essential requirements for the spaces (thermal comfort, accessibility, safety and facilities) and site-specific climatic risks (flooding, cold and heat waves). Thus, more comprehensive criteria enable the selection of spaces that extend beyond those previously studied in the literature, which have fewer requirements and prioritise shelters for specific climatic phenomena, such as heatwaves (Amorin-Maia et al., 2023b). This goes in line with Wangchuck (2023), which highlights the importance of adaptation responses using more comprehensive and context-sensitive approaches.

Besides, the methodology adopts a dual perspective on climate adaptation. First, it responds to the urgent need for protection from current extreme climate events. Second, by enhancing existing social infrastructure (Enneking, et al., 2025), these shelters are positioned as spaces for social interaction and climate adaptation education, fostering their long-term sustainability as a service to the community and as a significant contribution to urban resilience (Faulkner et al., 2018). As noted by Dodman and Mitlin (2013), this kind of approach enables communities to identify and respond to specific climate risks, thereby reinforcing both community and climate resilience. These strategies should also incorporate ongoing risk management, monitoring, and learning mechanisms to support adaptability and ensure long-term effectiveness (Basel et al., 2020; Fry et al., 2023; Ikhlas & Ramadan, 2024).

The interviews reveal a consensus on the need to provide climate shelters, as they will be essential in the face of climate-related scenarios. In this regard, residents tend to seek out these places more frequently during high temperatures, due to climate comfort, urban safety and potential for social gathering. Therefore, they may play a crucial role in enhancing the quality of life by encouraging greater public use and

fostering a sense of ownership and shared purpose, generating the "social surplus" referred by Latham & Layton (2019). Nevertheless, stakeholders also highlighted that most facilities (indoor spaces) are not prepared to become climate shelters and will require improvements in terms of physical and human resources. Associated with these improvements, financial investment may also constitute a considerable obstacle.

The proposed climate shelter system aimed to position each shelter within a five-minute walking distance for most of the study area, strategically enhancing accessibility (in particular, for those with reduced mobility). Additionally, partnerships with local actors can facilitate the use of these spaces/shelters for climate-related awareness campaigns and educational workshops. This approach aligns with participatory governance processes that ensure the engagement and empowerment of local communities (Patnaik 2021; Roy et al., 2022).

The results in the Porto case (Bonfim parish) comprise a system of 26 climate shelters, categorized into four subsystems. This classification is essential not only for addressing the diverse climate risks but also for guiding their governance, monitoring, and maintenance. The first two categories of shelters, outdoor and indoor spaces, are essentially considered or designed as proximity shelter spaces of everyday life, whether public or semi-public, serving the general population, thereby coping with more frequent climatic impacts. In the case of shelters for vulnerable groups, the idea is to take advantage of certain institutions that already provide assistance to these groups of the population, extending their competencies and actions for climate resilience purposes. The last category is intended to address the extreme impacts that occur during catastrophic phenomena, resulting in disrupted situations in the everyday life of the city. These shelters are spaces located around the city with a higher capacity to accommodate a greater number of people, requiring exceptional and large-scale assistance. Unlike the other categories, in these critical cases, management competencies require higher levels of governance that extend beyond local actors.

From a governance perspective, the system is relatively straightforward to implement, as it primarily relies on existing facilities and infrastructures that are already familiar to the public. Yet, facilities should be continuously monitored and assessed to identify weaknesses and necessary improvements.

Overall, in order to achieve an efficient climate shelter system, several key factors must be ensured:

Firstly, **governance** must be prioritised from the beginning, ensuring that all stakeholders clearly understand the institutional framework and their responsibilities (Bulkeley & Betsill, 2005). This foundational element will be essential throughout all phases of the system's implementation and operation - particularly in terms of maintenance and monitoring - enabling adjustments within a dynamic social context that must continuously respond to evolving challenges. In the case of Porto, the governance model includes the municipal authority and the institutions responsible for the selected facilities, ensuring each actor complies with their roles and duties. However, the engagement of local actors and stakeholders may face some setbacks, as not all will be willing to participate. In this sense, the role of municipal entities is crucial in persuading them to participate in the process, which may involve offering incentives and implementing countermeasures. In this regard, the important role of institutional leaders in driving awareness-raising and capacity-building efforts is crucial, as noted in the interviews conducted.

Additionally, building on the importance of **social infrastructure** in designing a climate shelter system, the municipal authority must undertake preliminary efforts to assess the suitability of the sites identified as part of the city's social infrastructure. This process should actively involve the responsible entities to ensure their engagement. This step strengthens the establishment of a clear and transparent governance model by fostering collective and institutional awareness of the value of these sites, beyond their purely functional or instrumental roles, thereby ensuring their effective engagement during both the implementation phase and the long-term operation of the system.

A third recommendation points to the importance of valuing continuous **public participation** in the climate system design, integrating citizens' needs into a bottom-up structure to ensure effectiveness. Particular attention should be given to implementing an effective **communication plan** to inform the population about the shelter network, its location, and operation, while also raising awareness about the health impacts of extreme weather events and how to respond. This will enhance climate literacy and resilience in both public spaces and homes. The plan should use a variety of physical and digital media channels to reach diverse social groups, particularly those most vulnerable, such as the elderly, children, the homeless, and those facing energy poverty or low incomes. Early communication of extreme event warnings, along with shelter locations, should also be arranged across multiple media channels. In particular, stakeholders involved in the governance model must be actively involved in this communication plan, to be better prepared to respond accordingly. An entity responsible for coordinating the communication plan plays a pivotal role in ensuring its coherence, credibility, and effectiveness, facilitating the timely exchange of information among stakeholders and the community, ensuring the consistency and clarity of the climatic events information.

Fourth, **literacy** and awareness are essential for strengthening climate resilience and for ensuring citizens recognise the role of climate shelters. This can be achieved through campaigns and training programs that educate people on how to anticipate, prepare for, and respond to extreme events, particularly concerning personal and housing security and health. Within shelters, practical information on preventive and adaptive measures can be provided, including guidance on actions to take during these events.

Fifth, the climate shelter system should be supported by a robust **monitoring plan** with clearly defined responsibilities and timelines to achieve the effectiveness of the whole shelter network. Monitoring will provide insights into public awareness, usability, pleasurability, emerging needs, and vulnerabilities. Monitoring should combine top-down and bottom-up approaches, involving continuous analysis and active participation.

Finally, **collaboration with other cities** in implementing climate shelter systems and other adaptation strategies can provide valuable insights into best practices. This collaborative approach allows cities to exchange ideas and support one another in their climate adaptation efforts.

While the proposed system constitutes a significant advancement in adaptation planning, the shelter selection process alone is insufficient to achieve equitable and effective climate action. It must be complemented by broader strategies that prioritise community engagement and foster climate resilience and literacy. Moreover, the development of holistic community-based adaptation guidelines is essential to enable flexible and efficient replication across diverse local contexts (Breil et al., 2018; Markphol et al., 2021).

Implementing a climate shelter system faces several limitations rooted in political, institutional, and social challenges. A major barrier is the lack of political will, as climate adaptation measures often compete with more immediate urban priorities such as infrastructure, housing, or economic growth, leading to insufficient allocation of resources and attention. Besides, the usual adaptation measures considered in climate-responsive design, such as the use of nature-based solutions (Cortesão et al., 2020; Daniel et al., 2023), do not entirely incorporate the social dimension of climate adaptation. Additionally, disarticulation among governmental bodies (for example, poor coordination between levels of government and/or with stakeholders) can lead to fragmented planning, overlapping responsibilities, inefficient use of financial resources and, ultimately, ineffective risk management. The absence of meaningful stakeholder and community engagement further threatens the process, as the overall system relies on a multitude of components, where these actors are a critical piece. The research presented in this paper also faced limitations due to limited resources and time constraints. Thus, the case study was applied to only one parish in the city of Porto. Although the

parish of Bonfim was carefully selected as a parish that could illustrate the situation in the city, the study's results would have benefited from a broader scope. Moreover, applying the methodology to other cases would have proven its effective transferability. Additionally, the number of interviews was limited. The small sample size and limited number of questions do not allow for statistically significant findings. Future research should therefore incorporate a broader and more comprehensive survey to better assess public awareness of climate change, patterns of social infrastructure use across seasons, and socio-economic characteristics, thereby supporting a more robust bottom-up planning approach complemented by additional engagement strategies.

5. Conclusions

Studies on climate shelters designed for regular use during extreme weather events represent a recent topic of research in the literature. At the same time, many cities are beginning to adopt adaptation strategies that comprise a network of climate shelters, or punctual interventions with more disconnected spaces.

In this paper, a methodological proposal to design a climate shelter system is presented. The system should provide a diverse network of spaces that not only safeguards populations during extreme events but also fosters interpersonal connections and community engagement. This approach emphasises that enhancing individuals' awareness regarding the location and function of these shelters empowers them to make informed decisions and proactively engage in risk mitigation measures, thereby enhancing collective resilience.

The study highlights that proposals for climate shelters must address a wider range of risks and vulnerabilities. Each territory is unique, with its own risks and vulnerabilities varying from place to place. Most reference cases focus on heatwaves as the primary risk to be addressed by climate shelters, with only Bilbao and Barcelona also mentioning cold waves. Nevertheless, other risks (like floods, storm surge or strong winds) are still only mentioned in disaster situations, when climate shelters are used as critical infrastructure. Due to low levels of indoor climate comfort in Portugal, it is also relevant to consider cold waves, and to protect the vulnerable groups from extreme cold temperatures with indoor shelters.

Using spaces within the social infrastructure as shelters promotes social integration, enhances social capital and, consequently, community resilience. This reinforces the importance of the methodology proposed and its potential replicability in other cities, with necessary adjustments to local climate risks and city context. This methodology utilises existing spaces familiar to and used by communities to create protected areas from climate events.

Besides, the proposal's effectiveness relies on a methodology that combines bottom-up and top-down approaches. This enables the municipality to engage more effectively with communities while maintaining clear communication with stakeholders.

To provide effective and efficient governance, it is essential to distribute responsibilities among institutions and entities to facilitate the monitoring of societal and climate changes. Given that this subject is relatively new in the literature, there is limited research on the results of implementing climate shelter systems. Monitoring the spaces and their usage is crucial to understand whether and how they are being utilised. Additionally, these spaces play a key role in literacy and awareness initiatives, contributing to the overall functioning of the system and preparing the population for future hazards.

Finally, the selection and adaptation of spaces for climate shelters must be accompanied by effective governance, clear communication strategies, community engagement, climate literacy and continuous monitoring. Climate shelters, envisioned as integral elements of social infrastructure, represent a robust strategy for climate change adaptation. Beyond their protective function, these spaces play a vital role in fostering social capital and enhancing community resilience. By integrating into the fabric of daily life, climate shelters can contribute to local identity and social cohesion, both of which are essential for reducing vulnerabilities and strengthening adaptive capacity.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the author(s) used ChatGPT and Grammarly in order to improve the writing. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

CRediT authorship contribution statement

Sara Cruz: Writing – review & editing, Writing – original draft, Supervision, Methodology, Investigation, Funding acquisition, Conceptualization. **Maria Luísa Scharlau:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis. **Luísa Batista:** Writing – review & editing, Writing – original draft, Validation, Investigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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