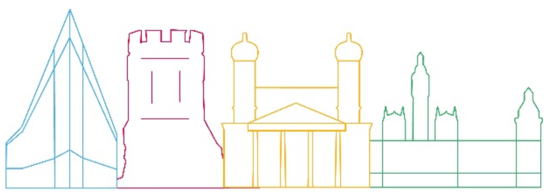
ARCH

ARCH D6.2

Assessment of long-term implementation options



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Executive Summary

This deliverable has been prepared for the European Commission-funded research project *ARCH: Advancing Resilience of historic areas against Climate-related and other Hazards*. It is the key output of task 6.2 *Assessment of long-term implementation options* within work package (WP) 6 *Resilience measures & Pathways.* The aim of task 6.2 is to assess the long-term performance of resilience measures identified in T6.1 around three main spheres of knowledge: environmental effectiveness, economic efficiency, and socio-institutional acceptance. At the same time, the outputs of task 6.2 are inputs for task 6.4.2 *Developing a resilience pathway visualization tool*.

The work embedded in task 6.2 comprehends an extensive desk-study in the above-mentioned spheres. The information collected to describe environmental effectiveness is mainly focused on the performance of resilience measures towards extreme temperatures and heat waves, floods, and earthquakes for urban/building and heritage structures. On the other hand, the economic efficiency of the implementation of resilience measures is addressed by the benefit-cost analysis for the above-mentioned hazards for urban/building and heritage structures while it addresses a multi-hazard perspective for agricultural heritage. Furthermore, this deliverable describes a preliminary exercise to characterise the institutional acceptability of a broad range of resilience measures for historic areas.

The desk study resulted in 322 consulted references which covered 536 case studies. These case studies have provided performance information about selected metrics. By hazard:

- Earthquake: 172 effectiveness entries for the following indicators
    - Physical damage reduction (%)
    - Annualized collapse probability reduction (%)
    - Risk index (IS-V / %NBS) increase (%)
    - Expected Annual Loss (EAL) reduction (%)
    - Resistance Increase (%)
    - Reduction of observed minor damage (%)
    - Reduction of observed moderate damage (%)
    - Reduction of observed severe/heavy damage (%)
    - Reduction of observed collapse (%)
- Flood: 166 effectiveness entries for the following indicators
    - Flooded area reduction (%)
    - Runoff reduction (% or cm)
    - Infiltration rate (mm/l)
- Heat: 446 effectiveness entries for the following indicators
    - Air Temperature Reduction (ºC)
    - Indoor air temperature reduction (ºC)
    - Physiologically equivalent temperature (ºC)
- Cost (multi-hazard): 1000 economic performance entries for the following indicators
    - Benefit-Cost Ratio

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Table of abbreviations

Acronym	Explanation
AOL	Adaptation Option Library
BBB	Building Back Better
BCR	Benefit Cost Ratio
CBA	Cost Benefit Analysis
BCR	Benefit Cost Ratio
CH	Cultural Heritage
CLS	Collapse Limit State
DLLS	Damage Limitation Limit State
EAL	Expected Annual Losses
EMS-98	European Macroseismic Scale
EWS	Early Warning Systems
MI	Macroseismic Intensity
IRR	Internal rate of return
IS-V	Safety Index
GIS	Geographic Information System
LSLS	Life Safety Limit States
MEMI	Munich Energy-balance Model for Individuals
NBS	Nature Based Solution
NBS%	% of New Building Standard
NPV	Net Present Value
OLS	Operational Limit States

PBEE	Performance Based Earthquake Engineering
PET	Physiological Equivalent Temperature
PGA	Peak Ground Acceleration
RC	Reconstruction Cost
RMI	Resilience Measure Inventory
RPVT	Resilience Pathway Visualization Tool
SA	Spectral Acceleration
SotA	State-of-the-Art
SuDs	Sustainable Drainage systems
WP	Work package

1. Introduction

This deliverable has been prepared for the European Commission-funded research project *ARCH: Advancing Resilience of historic areas against Climate-related and other Hazards*. ARCH aims to enhance the resilience of areas of historic and cultural value to climate change-related and other hazards. In order to achieve this goal, a range of models, methods and tools such as the Resilience Measure Inventory (RMI) and Resilience Pathway Visualization Tool (RPVT) have been developed to support decision-making at appropriate stages of the resilience management cycle.

As a result of task 6.1 *Inventory of preparation, safeguarding, conservation & management, and response & recovery measures,* the Resilience Measure Inventory was developed which lists 261 measures. The RMI also describes general information about the resilience measures such as the typology of the measure, the feasible implementation scale, and the disaster risk management phase at which they can be applied. While the RMI provides a long list of resilience measures this task further continues to characterise the resilience measures by investigating their economic, socio-institutional, and environmental performance. Thus, task 6.2 *Assessment of long-term implementation measures* deepens on their characterisation at case study level mainly via a desk-study of the effectiveness and economic performance of the resilience measures. In order to gather all the information and allow the development of standardised approaches to help city administrators in the fields of heritage, climate change and risk management, a database was developed. The information gathered from the above-mentioned sources has been analysed, processed, and synthesised into measures corresponding to the objectives that ARCH is tackling. This document's objective is to describe the content, structure of the gathered information, and conclusions of the task, being the main outcome of task 6.2. This deliverable will allow understanding what data-driven information is available as input for the RPVT and what gaps have been found.

1.1. Gender statement

This deliverable has been developed taking into consideration the guidance on gender in research provided in the Project Handbook (D1.2), as well as State-of-the-Art (SotA) report number 5 of deliverable D7.1 *Mainstreaming gender in building cultural heritage resilience*.

Following these guidelines, the work carried out within this deliverable has been built under the gender perspective to conduct a gender mainstreaming in the work carried out as follows:

- Working towards gender balance when considering the researchers who carried out the development of the resilience measure assessment in the framework of the task 6.2 and the reviewers.
- Providing equal opportunity to all members of the consortium and external participants when involved in the meetings and workshops carried out in the framework of the task 6.2. for the development of the socio-institutional acceptability assessment.
- Reflecting non-binary gender perspective when asking for the participants details

1.2. Relation to other deliverables

This deliverable, *D6.2 Assessment of long-term implementation options*, builds on the previous deliverable *D6.1 Inventory of resilience measures.* This deliverable assesses the performance of all the gathered resilience measures included in D6.1. However, it has to be highlighted that performance of all measures may not be available for all type of assessments (environmental, economic or socio-institutional) or all type of metrics. Part of the work carried out under task 6.2 feeds the RPVT, which is intended to support the evidence-based planning and decision making, among other things.

1.3. Structure of this report

The report is divided into 6 sections. Following this introduction, section 2 describes the used methodology for the data gathering of the environmental, economic, and socio-institutional performance. Section 3 presents how the information has been gathered, that is, the structure of the database which will be served as an input for Task 6.4.2 *Developing a resilience pathway visualisation tool*. This section also describes the content – what information is available – of the database from different angles, *e.g*. by the type of analysed hazard or by resilience measure. Finally, sections 4, 5 and 6 focuses on a summary of the results and conclusions of the environmental, economic, and socio-institutional content of the database, respectively.

2. Methodology

WP 6 is dedicated to developing resilience pathways for historic areas. In order to support this objective task *6.2 Assessment of long-term implementation options* aims to assess the long-term implementation measures identified in the Resilience Measures Inventory (RMI, developed in task 6.1) according to different performance criteria such as:

- Environmental effectiveness, based on literature and modelling
- Economic efficiency (benefit-cost analysis), based on literature
- Socio-Institutional parameters, including:

  1) willingness of staff working for local, regional or national authorities to implement a measure (“institutional acceptance“) and

  2) barriers to implementation

An assessment of each measure’s performance against these criteria will be considered for task 6.4.2 *Developing a resilience pathway visualisation tool*.

2.1. Literature review for environmental effectiveness

2.1.1. Heat & Flood

A literature review was conducted in English and Spanish (native language of the authors) to find case studies where the impact of hazardous events such as extreme heat and flooding due to key climatic factors could inform behaviour (validation) in implementing the measures identified in the RMI, developed in task 6.1.

The searches have been carried out using the following types of resources:

- Nonspecific search engines as *Google*, *Bing* and *DuckDuckGo*
- Scientific papers databases as *Science Direct*, *Scopus* and *Google Scholar*
- Websites devoted to climate change and disaster risks as *PreventionWeb* and *ClimateADAPT*

The search strategy began with the combinations of the following keywords:

- “Cultural heritage”
- “Heatwave mitigation”
- “Flood mitigation”

The search was then narrowed down by adding selected climatic variables and key words combinations from each group of measures as shown in Table 1.

Table 1. Keywords list for the literature search for heat and floods

Resilience measure GROUP	NEW KEYWORDS USED (non-exhaustive list)
Building cooling system	Runoff reduction, infiltration rate, flooding area reduction, air, temperature, reduction, PET reduction, indoor, heat, cooling, green roof, air conditioning, cooling-roof, humidity maintenance, passive cooling strategies, shading, natural ventilation,
Building walled areas	Runoff reduction, infiltration rate, flooding area reduction, walls, below sea level,
Dry proofing	Runoff reduction, infiltration rate, flooding area reduction, drainage, waterproofing...
Green and foresting solutions	Runoff reduction, infiltration rate, flooding area reduction, air, temperature, reduction, PET reduction, indoor, heat, cooling, grass, trees, park, foresting plan, permeable container, retention pond, slope
Infiltration techniques	Runoff reduction, infiltration rate, flooding area reduction, bioretention basin, permeable pavement, infiltration trenches
Surface and underground water storage solutions	Runoff reduction, infiltration rate, flooding area reduction, Rainwater harvesting system, water storage, underground,
Temporary protection systems	Runoff reduction, infiltration rate, flooding area reduction, container systems, free-standing and frame barriers, sandbags
Urban planning regulations	Runoff reduction, infiltration rate, flooding area reduction, green area, pervious surface,
Water contention system against floods	Runoff reduction, infiltration rate, flooding area reduction, flood gate, dike, dam, water containing, evacuation, dry proofing structure, protection, barrier, impermeable container, freestanding,
Thermal management strategy	Air, temperature, reduction, PET reduction, indoor, pavement-watering, heat, cooling
Urban cooling system strategy	Air, temperature, reduction, PET reduction, indoor, heat, cooling traffic calming, reduction, morphology, cool pavement, water spraying, district heating
Urban planning regulations	Air, temperature, reduction, PET reduction, indoor, heat, cooling, green area, pervious surfaces

The research on cultural heritage was not limited to a typology of cultural heritage, but on the other hand, it was limited to open access publications.

In addition to the above-mentioned information sources the following EU projects data bases have been identified as key for reviewing climate adaptation strategies and measures, covering climate risks, including flooding and heat stress, and their prioritisation:

- **RESIN** Adaptation Option Library[1]
- **IGNITION** Project Nature-Based Solutions (NBS)_ evidence database[2]

RESIN EU project's Adaptation Option Library (AOL) includes the evaluation of climate adaptation measures addressing risk such as heat and floods based on their effectiveness among other criteria. Although the measures do not specifically apply to cultural heritage, their effectiveness may also be valid evaluating their impact on cultural heritage of different typologies.

IGNITION EU project's NBS evidence base is built on academic research and demonstration projects and compiles a catalogue of benefits for green roofs, walls, trees and spaces and Sustainable Drainage Systems (SuDS).

2.1.2. Earthquakes

A literature review has been conducted in English to identify case studies in which the benefits of the resilience measures identified in the Resilience Measures Inventory (RMI, developed in task 6.1) to reduce earthquake-induced impacts are quantitatively measured.

The searches have been carried out based on the expertise of the UNICAM and ENEA teams, who are subject matter experts in the field of seismic risk mitigation and resilience of the built environment (and who have been directly involved in the design and implementation of resilience measures following major earthquakes in Italy and overseas). The focus is on measures which improve the seismic resilience of the built environment in historic areas.

The following scientific databases were searched: *Science Direct*, *Scopus*, *Google Scholar*, and *Research Gate*. Key words combinations used for carrying out the literature review are reported in the following table (Table **2**) for each group of measures.

[1] https://resin-aol.tecnalia.com/apps/adaptation/v4/#!/app/summary
[2] https://www.greatermanchester-ca.gov.uk/what-we-do/environment/natural-environment/ignition/

Table 2. Key words used for the literature review search on the resilience measures identified from the ARCH RMI tool for earthquake hazard

Resilience Measure GROUP	NEW KEYWORDS USED (non-exhaustive list)
Risk and vulnerability assessment methods	Damage assessment form; emergency management tool; decision support systems; vulnerability curves; seismic vulnerability assessment; fragility curves; damage scenarios; seismic risk analysis; Geographic Information System (GIS) mapping
Tie rods and hoops system	Vulnerability assessment; seismic performance, 2016 central Italy earthquake, masonry buildings, unreinforced masonry churches and palaces; strengthening techniques
Structural reinforcement to better withstand seismic actions	Ordinary buildings; reinforced concrete buildings; retrofitting techniques; seismic retrofit policies; effectiveness of structural-strengthening policies and practices
Traditional skills (i.e. conservation of structural authenticity and use of original constructive material and techniques) and periodic maintenance (before-event	Conservation principles; historic area; cultural heritage; exposure assessment; hazard assessment; seismic vulnerability assessment; damage assessment; impact assessment; resilience assessment

The search covered different cultural heritage typologies and different seismic vulnerability levels for both residential and cultural heritage buildings included in historic areas.

In addition to the above-mentioned scientific sources the following EU projects databases have been identified as key sources:

- NIKER *New Integrated Knowledge Based Approaches to the Protection of Cultural Heritage from Earthquake-Induced Risk* EU funded project[3]: NIKER project database.
- RESCULT, *Increasing Resilience of Cultural heritage: a supporting decision tool for the safeguarding of cultural assets,* EU funded project*:* European Interoperable Database (EID)[4] a composite tool designed to support emergency operators, authorities and decision-makers in protecting cultural heritage against natural hazards.

[3] FP7 ENV.2009.3.2.1.1 - Technologies for protecting cultural heritage assets from risks and damages resulting from extreme events, especially in the case of earthquakes. https://cordis.europa.eu/project/id/244123

[4] https://www.rescult-project.eu/european-interoperable-database/

2.2. Literature review for Benefit Cost Ratio (BCR)

The economic impact of the implementation of resilience measures was analysed in a desk study as a benefit-cost analysis. The aim was to collect information to characterize each case study and the parameters considered in the cost-benefit analysis (*i.e*. costs incurred, benefits obtained, benefit-cost ratios, ...).

The searches have been carried out using different types of resources:

- Nonspecific search engines as *Google*, *Bing* and *DuckDuckGo*
- Scientific papers databases as *Science Direct* and *Google Scholar*
- Websites devoted to climate change and disaster risks, such as *PreventionWeb* and *ClimateADAPT*.

From the initial exploration, a collection of documents about “risk management”, “climate change adaptation” and “cost benefit analysis” have been identified. The search strategies resulted from combinations of the following keywords:

- “Climate change”
- “Adaptation”
- “Disaster risk management”
- “Cost benefit analysis”
- “CBA”
- “Cost benefit ratio”
- “CBR”

Each selected report or paper was read to identify specific benefit-cost ratios, and these ratios assigned to one of the measure groups.

From the results of this phase, it was immediately apparent that the distribution of BCRs was greatly irregular. Therefore, a second searches phase was conducted in which the strategy aimed at identifying the benefit-cost ratio of specific measures, especially for groups for which results were not obtained in the previous stage.

Table 3 shows other specific terms used, for each group of measures that, were combined with the above-mentioned keywords during the literature search.

Table 3. Keyword list for the literature search for cost benefit analysis (multi-hazard)

Resilience Measure GROUP	NEW KEYWORDS USED (non-exhaustive list)
Administrative instruments…	Capacity building, governance, local labour, insurance, economic instruments
Building codes…	Building code, standards, energy performance of buildings
Crop adaptation...	Crop, sowing, agriculture, biological control, precision farming

Resilience Measure GROUP	NEW KEYWORDS USED (non-exhaustive list)
Damage evaluation	Damage evaluation, damage assessment, post-disaster damage
Resilient communities	Resilient communities, co-creation, education, cooperative work
Emergency planning...	Emergency planning, evacuation planning, emergency plan, evacuation plan
Emergency security...	Emergency security, back-up system, stabilization techniques, protection techniques
Forecasting...	Forecasting, early warning systems, EWS
Research & Development...	Adaptation indicators, climate indices, adaptative measures improvement
Rehabilitation...in buildings	Building rehabilitation, passive cooling, green roofs, reinforcement, flood resistant materials
Relocation or removal	Relocation, removal
Risk assessment	Risk assessment, hazard risk map, seismic risk map, flood risk map, heat risk map, exposure mapping
Soil management	Soil management, crops, fertilization, cropping
Spatial planning	Spatial planning, urban plan, land use, zoning
Water management	Water management, infiltration systems, irrigation, rainwater collection
Traditional knowledge	Traditional knowledge, indigenous knowledge
Urban interventions	Urban, rainwater, traffic, rain garden, green plans

As a result of this process, 202 references were identified, of which 130 (64.3%) were classified as particularly relevant based on their abstracts. Referable information was found in 88 of them (the 67.7% of the reviewed references), mainly in reports (48.8%) and scientific articles (47.7%), and occasionally in other documents such as dissertations and other types of references.

The literature review faced some difficulties. On the one hand, the second phase of the search yielded very few significant results, probably due to the high level of granularity of the measures. On the other hand, a significant amount of references provides benefit-cost ratios at what it has been defined as “Strategy” level. This implies that the cost-benefit analysis integrated a mix of measures to address a hazard, thus providing economic performance (BCR) at an aggregate level. Despite it is not possible to assign a specific value of BCR to each individual resilience measure, it was decided not to exclude this information and use it separately as an input to the RPVT.

2.3. Stakeholder's acceptability perception

This subtask aims at:

(i) benchmarking the willingness of cities and local stakeholders ('institutional acceptance') to implement the resilience measures considered in the Resilience Measure Inventory (RMI) to identify preferences and trends
(ii) understanding how context or discipline of a potential decision-maker/implementer may influence the acceptability of these resilience measures
(iii) identifying barriers, limiting factors and requirements associated with implementation.

In order to conduct the assessment of socio-institutional parameters an excel-based tool was designed to acquire the *´Perceived institutional acceptance for the implementation of the resilience measures (covered in the RMI) in the context of historic areas‘* and their barriers for implementation. It is important to note that the likely acceptability of and barriers to the use of a particular measure may vary depending on the location of implementation and its context. Given that the ARCH project focuses on historic areas, this is of particular importance as each historic area is characterised by its own assembly of heritage values. Thus, given the qualitative and perceptions-based nature of these parameters, which are likely to be strongly influenced by disciplinary backgrounds and professional experience, the inclusion of a range of staff from each city administration (and other stakeholders where city partners deemed relevant) was sought to improve the validity and robustness of the results.

2.3.1. Sought target stakeholders

The assessment process targets the involvement of several stakeholders from city administrations (and beyond, where city partner deemed relevant) in the fields of emergency, cultural heritage, climate adaptation or environment, planning and any other relevant stakeholders (*e.g*. economic department) as well as local social organisations (where relevant & possible).

> This is especially important to empower different departments within the decision-making process of resilience building and to help inform decisions for the long-term sustainability of resilience plans.

The workshop participants were 11 stakeholders (7 men and 4 women) who participated directly as ARCH partner projects or as ARCH Local stakeholders with different backgrounds (Figure 1).

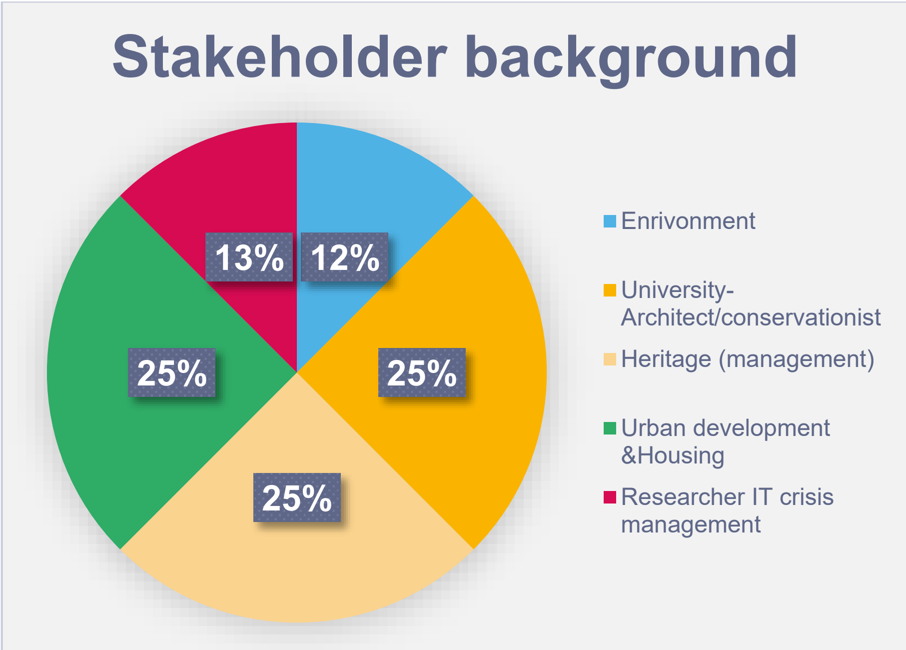


Figure 1. Participant's background for the urban/ building & structures heritage session

2.3.2. Assessed resilience measures

The RMI comprises not only structural or physical tools and measures to build resilience on historic areas, but also management, economic or social measures. The RMI includes 216 resilience measures, classified according to their objectives in 71 subgroups which are gathered in 17 groups. As a detailed socio-institutional performance assessment of all 216 measures would impose an unrealistic time burden on participants, the assessment was done at subgroup level for Urban/Built & structures heritage and at subgroup level and measure level for Agricultural Heritage.

2.3.3. Metric

In common language ***Acceptance*** is defined as "a general agreement that something is satisfactory or right"[5] or as "If there is acceptance of a new product, people start to like it and get used to it"[6]. However, it is not a trivial matter as there are nuances on how acceptance is defined across different theoretical models and thus, how it is assessed. There is a lack of evidence regarding the most suitable tool to measure Acceptance [1]. Most often questionnaires are used, but other methodologies such as interviews, focus groups and system use have been applied [2].

Within the ARCH project, we sought to understand the *perceived institutional acceptance* for the implementation of each resilience measures or subgroup of measures (covered in the RMI) in the context of historic areas' by asking participants the following question: *"To which extend*

[5] https://dictionary.cambridge.org/es/diccionario/ingles/acceptance
[6] https://www.collinsdictionary.com/es/diccionario/ingles/acceptance

do you think these subgroups of resilience measures are accepted at your department for their implementation in historic areas?" (Figure 3).

The scale to assess the perceived acceptance is represented in Figure 2.

Widely accepted	5
Moderately well accepted	4
Neutral	3
Little acceptance	2
Unaccepted	1

Figure 2. Selected scale for perceived acceptance measurement

Apart from the acceptance of resilience measures the exercise also aimed at identifying the most common ***barriers*** for the implementation of the structural or physical resilience measures. A barrier is commonly understood as *something that prevents something else from happening or makes it more difficult*[7]*.* The stakeholders were asked to identify, among the barriers indicated (Table 4), those that apply to each resilience subgroup/measure in their context.

Table 4. Barrier classes and definition considered in the exercise

Barrier type	Barrier's definition
Financial	when high costs make a certain resilience measure difficult to afford
Technical	when technical specificity, technical regulation/standard, technical requirement and/or technical knowledge/capacity may prevent the use or implementation of the resilience measures
Political	when a policy instrument avoids or limits the deployment of a resilience measure
Spatial	when spatial requirements for the deployment of a measure limit its applicability
Social	when the differences and inequalities associated with population limit the deployment of a resilience measure
Cultural	when differences based on behaviour, communication and/or beliefs hinder the deployment of a resilience measure

[7] https://dictionary.cambridge.org/es/diccionario/ingles/barrier

Barrier type	Barrier’s definition
Awareness	when there is a lack of knowledge or understanding of the existence of a resilience measure or of the details that characterize the measure

2.3.4. Methodology: Workshop with excel based exercise

Prior to the workshop an e-mail was sent to participants to present the task and its purpose. At the workshop (Table 5), a high-level screening exercise for acceptability (an example can be seen in Figure 3) was explained using an excel tool. Then time for individual completion of the exercise was given. The exercise was adjusted to agricultural heritage as well as for urban, structures and building heritage. Representatives from Valencia Foundation City assessed the agricultural heritage in Spanish while representatives from Bratislava, Camerino and Hamburg Foundation Cities assessed the urban, structures and building heritage in English (Bratislava and Hamburg) and Italian (Camerino).

Table 5. Agenda of the workshop dedicated to assessing perceived acceptance and barriers of resilience measures

Time	Duration	What (and where)
12:00	15’	Welcome, introduction to the session, the ARCH project, and warm-up poll (plenary)
12:15	10’	**Session 1: Assessing institutional and social measures: presentation** (3 x breakout rooms in English, Spanish or Italian)
12:25	20’	Individual work (breakout rooms)
12:45	15’	Discussion (breakout rooms)
13:00	10’	**Session 2: Assessing structural measures: presentation** (breakout rooms)
13:10	20’	Individual work (breakout rooms)
13:30	20’	Discussion (breakout rooms)
13:50	10’	Post-workshop poll, close, and next steps (plenary)

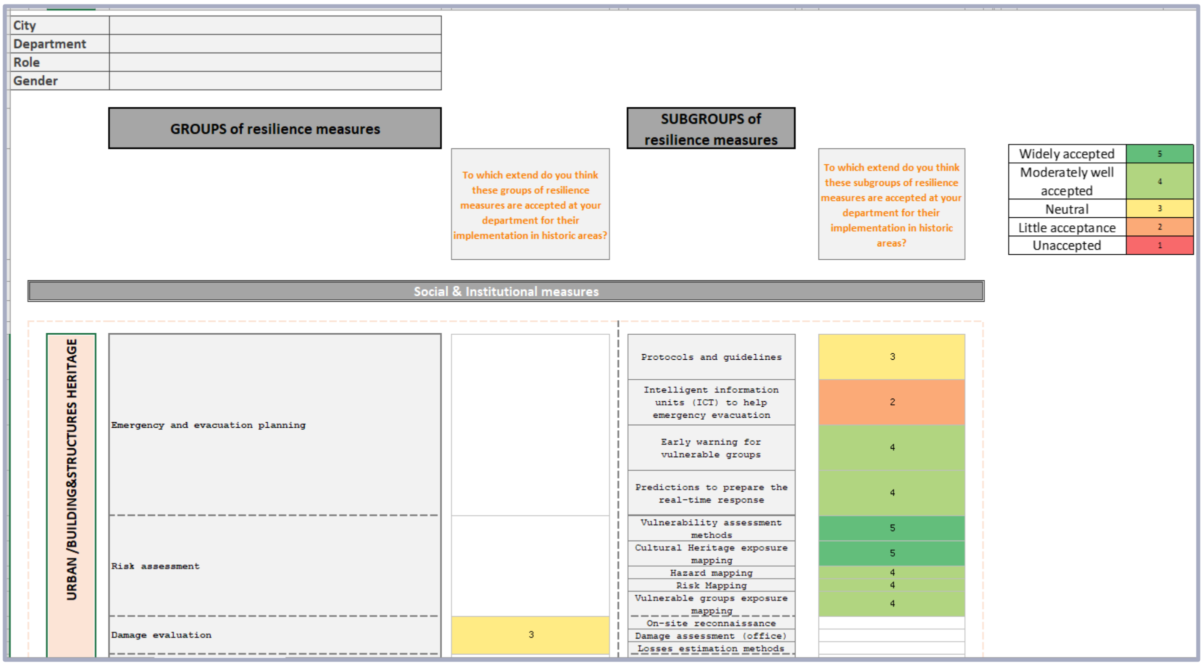


Figure 3. Example of the excel based screening exercise

2.3.5. Considerations

To our knowledge, this is the first exercise to characterize the institutional acceptability of a broad range of resilience measures for historic areas. This innovative exercise created a great opportunity to provide further evidence-based characterization of resilience measures, thus, supporting decision-making. However, there were two major challenges that could not be addressed:

1. It is desirable to gather responses from a diverse group of participants in order to have a solid basis for assessing acceptability. A limited number of responses (<20) and/or just from one or two disciplines may result in biased conclusions, e.g. if all partner city representatives participate, but without colleagues from other departments. Therefore, it is unlikely that the results are directly transferable to other cities/contexts, but they can be used as lessons learned.
2. Context-specific acceptability and barriers: as historic areas are defined by particular physical, aesthetic and intangible qualities, it may be difficult for respondents to assess the likely willingness to implement resilience measures or implementation barriers, which are independent of a specific site. However, the work intends to identify those types of measures or groups of measures (social, institutional, physical) that have a high weight for the specificity of the site.

Unfortunately, the failure to engage a larger sample, even if the workshop was held in English, Italian and Spanish to avoid language barriers, impedes a robust analysis but can be considered as a first attempt to approach the question.

Nevertheless, this work reveals general trends in the acceptability of and barriers to the implementation of resilience measure, described in Section 6, and the degree of coherence. In other words, the study allowed to benchmark the willingness of cities and local stakeholders to implement resilience cities as well as their barriers.

3. Elements

This section describes the structure of the database, type of content stored and identified gaps in data gathering. Data is stored following a relational model in which the tables, and the relationships among them (Figure 4) form the core group of elements. The database will not be publicly accessible, but the processed data will be available through the RPVT. Socio-institutional performance was not integrated in the database as the study is an exploratory action to deepen on this topic and it is believed that the local context can play a vital role.

In the diagram showed in Figure 4 ,each box represents an entity of the model and the lines connecting those entities represent the relationship among them and their cardinality (one to one, one to many or many to many). At the same time, every entity has a set of elements or attributes that characterize it.

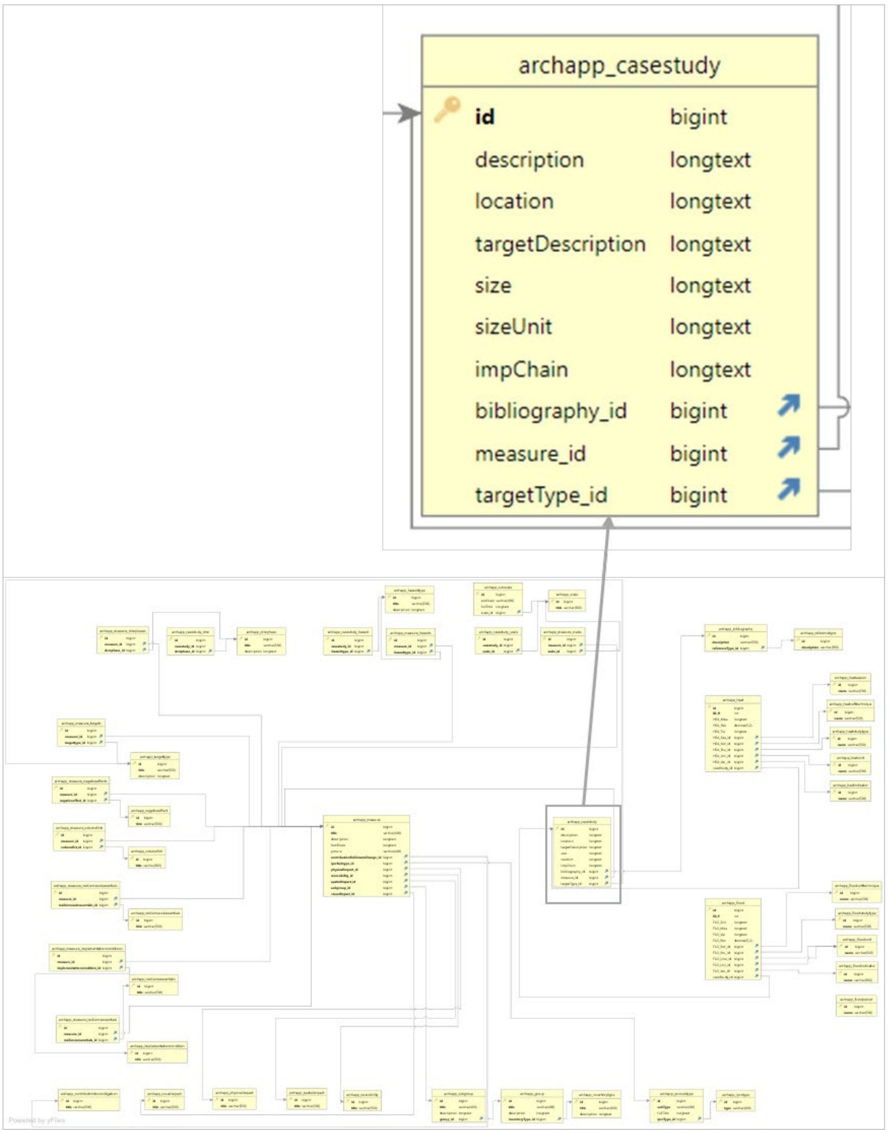


Figure 4. Schematic overview of the entity-relationship model (or the structure and links) of the database with highlight on the type of information gathered to describe the case studies

3.1. General elements

The database is organized in 3 domains:

(1) general information about the resilience measures (information provided by RMI), bibliography and case study
(2) raw performance information regarding the environmental effectiveness and cost-efficiency
(3) processed performance information. Every domain has several elements and sub-elements.

3.1.1. General and case study information

The elements under the general domain aim to give the basic information for each resilience measure, the information of the source of the information for future traceability purposes and a description of the case study. The information collected in this domain is listed below:

- Bibliography type and reference
- Resilience measure title: name of the resilience measure based on the RMI
- Description of the implementation of the measure in the case study: it will describe the aim of the implementation of the measure, functioning, context, and any other relevant information
- Location of the case study: it names de city and country where the study takes place.
- Heritage type and characteristics. Resilience measure performance can be assessed in different environments; thus, this element intends to identify if the measure has specifically been applied to heritage and a description of the heritage
- Size of the study or size of the implemented measure
- Impact chain that the reference refers to
- Disaster risk management phase in which the resilience measure has been applied
- The scale and subscale at which the resilience measure has been implemented: it refers to any of the spatial scales on which it is possible to implement resilience measures, ranging from the element to territorial scale. Different subscales have been considered (e.g. buildings, infrastructures, groups of buildings, towns, cultural landscapes etc.)
- The hazard(s) that is addressed by the measure

In the case of the earthquake related case studies some further information was collected (Figure 5):

- Typology of the exposed element: the characteristics of the building
- The vulnerability class of the exposed element

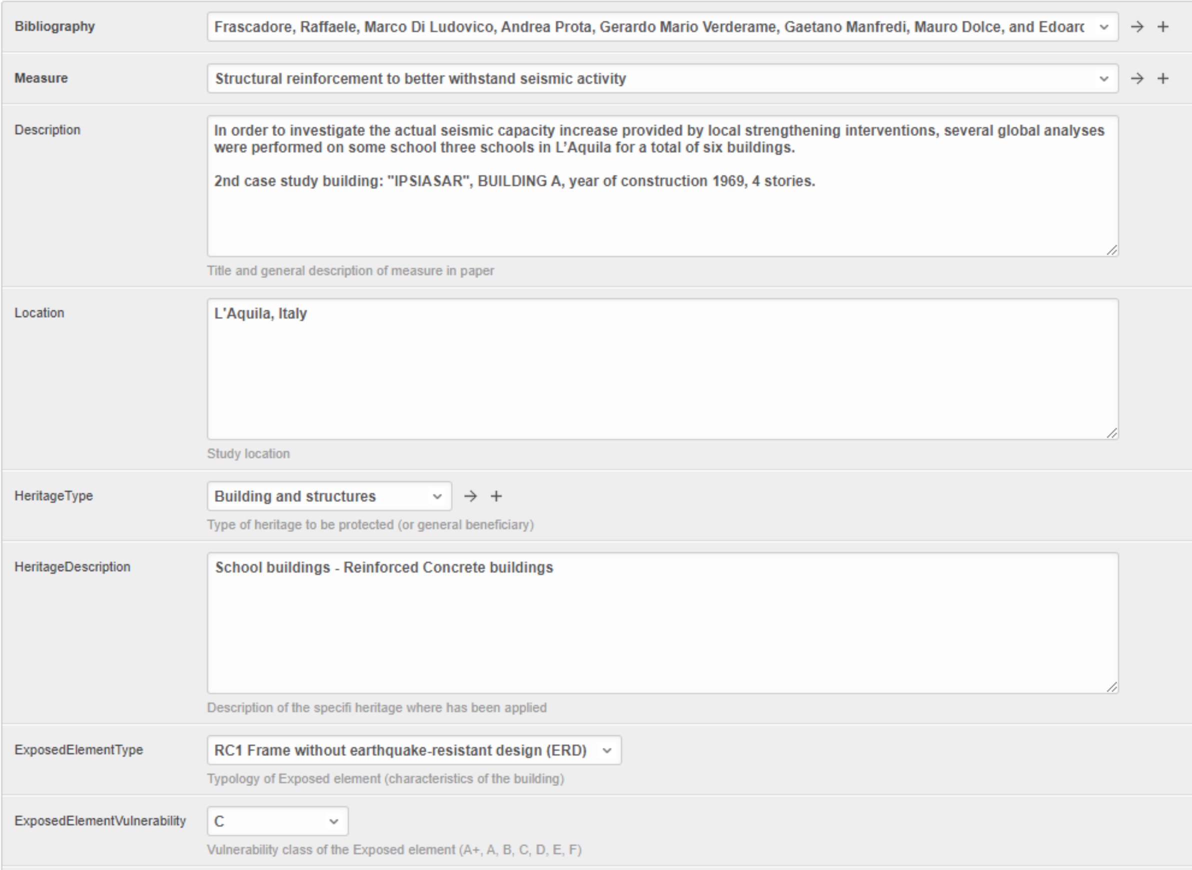


Figure 5. Image of the web-portal with all the elements from the case study table for earthquakes

3.1.2. Effectiveness and cost-efficiency

The effectiveness refers to the magnitude reduction of a hazard and/or the vulnerability components due to the deployment of resilience measures. Resilience measures can contribute in different ways in the adaptation and disaster risk management. For example, by:

- Reducing the magnitude of the impact: increasing the shadow by planting trees in a square and thus improving the thermal comfort of the place
- reducing the exposure, by changing the use of vulnerable building to earthquakes
- improving the vulnerability
    - Reducing the sensitivity: number of buildings with improved building strengthening
    - Improving the adaptive capacity: by co-creating with the community a disaster preparation plan

This variety in the nature of resilience measures and hazards implies a need for different metrics, which are further developed in Section 3.2. Each of these metrics requires a specific element to better describe the performance.

Apart from the metric, other relevant information is gathered to characterize the effectiveness values.

- Complementary information to heat metric data:
    - Investment direct costs: investment expenditure, annual operating and maintenance, cost of administrative implementation, time horizon, value of the discount rate
    - Investment indirect costs: costs, time horizon, value of the discount rate
    - Benefits: Overall benefits, time horizon
    - Cost effectiveness analysis: BCR

- Complementary information to heat metric data:
    - Scenario description: negative scenario vs positive scenario, that is, what it has changed to address heat risk
    - Software simulator/technique of the measurement
    - Season in with the measurement was taken
    - Time range the measurement was taken

- Complementary information to flood metric data:
    - Software simulator/technique of the measurement
    - Simulation period
    - Scenario description: negative scenario vs positive scenario, that is, what it has changed to address flood risk
    - Intensity of rainfall or fluvial flooding (value & unit)

- Complementary information to earthquake metric data:
    - Software simulator/technique of the measurement
    - Scenario description: negative scenario vs positive scenario, that is, what it has changed to address earthquake
    - Intensity of the seism (Table 6)
    - Exposed element (Table 7)
    - Vulnerability of exposed element (Table 8)

Table 6 reports definitions for the three selected earthquake intensity measures that have been used for this work, namely: Peak Ground Acceleration, *PGA* [m/s^2]; Spectral Acceleration, *Sa* [m/s^2]; and Macroseismic Intensity, *I*.

Table 6. Selected earthquake hazard metrics

Earthquake Intensity Measure	Acronym and Unit	Definition
Peak Ground Acceleration	PGA [m/s^2]	Amplitude of the largest absolute acceleration recorded on an accelerogram at a site during a particular earthquake (quantitative measure).
Spectral Acceleration	Sa [m/s^2]	Largest acceleration induced by the earthquake on a building or structure having a particular natural vibration period

Earthquake Intensity Measure	Acronym and Unit	Definition
Macroseismic Intensity	MI	A qualitative measure of the effects of the earthquake on the built environment.

As far as the classification of the exposed buildings included in historic areas is concerned reference has been made to a selection of the classification proposed by the EMS-98 [3] as reported in Table 7. For cultural heritage buildings, reference has been made to the classification proposed in [4] and included in D7.2 *Mapping and characterization of good practices in cultural heritage resilience* [5] and in particular to a sub-set of it including: Churches, Palaces, Towers and Chapels.

Table 7. Types of historic areas' buildings exposed to the earthquake hazard

Exposed Element Type		
Masonry (M)	M1	Rubble Stones
	M2	Adobe (Earth Bricks)
	M3	Simple stone
	M4	Massive stone
	M5	Unreinforced Masonry (old bricks)
	M6	Unreinforced Masonry with RC floors
	M7	Reinforced or Confined Masonry
Reinforced Concrete (RC)	RC1	Frame without earthquake-resistant design
	RC2	Frame with moderate level of earthquake-resistant design

For classifying the vulnerability of the exposed elements reference has been made to the energy efficiency classes (EU Directive 92/75/EC[8]) that are adopted nowadays in Italy for classifying the seismic vulnerability of both existing and new built buildings. The vulnerability classes go from *A+, i.e.* great building performance under earthquake loads (or in other words very low seismic vulnerability) to *F*, i.e. very poor building performance of under earthquake loads (or in other words very high seismic vulnerability). These adopted classes reported in Table 8 are inverse to the ones adopted by the EMS98. Table 8 also reports the qualitative attribution of the building types reported in Table 7 to the vulnerability classes according to EMS-98 [3].

[8] "Council Directive 92/75/EEC of 22 September 1992 on the indication by labelling and standard product information of the consumption of energy and other resources by household appliances". EU web portal Retrieved 24 April 2011.

Table 8. Matching the "Exposed Element Vulnerability" assumed taxonomy with the vulnerability classes and with the building types identified in EMS-98 (3)

Exposed Element Vulnerability	EMS-98 Vulnerability classes	Building Types in Historic Areas (reported in Table 7)
A+	F	-
A	E	-
B	D	M7, RC2
C	C	M4, M6, RC1
D	B	M3, M5
E	A	M2
F	A-	M1

Starting from the case studies selected from the international literature search, the attribution of both the building types and of the vulnerability classes has required to make some inferences through expert judgements, as for the examples reported in Table 9.

Table 9. Matching the "Exposed Element Type" as for the assumed taxonomy (Table 7) with the descriptions provided in the analysed case studies.

Exposed Element Type		Real case study	Inferences for the Attribution of the building type
RC2	Frame with moderate level of earthquake-resistant design	6-storey RC frame building built in New Zealand before 1970 [6]	Based on the construction period and information given in the paper
RC1	Frame without earthquake-resistant design	pre-1970s 3-storey RC frame building built in L'Aquila (Italy) [7]	Based on the construction period and information given in the paper
RC1	Frame without earthquake-resistant design	3-storey RC frame building built in Cosenza (Italy) [8]	Based on the construction period and information given in the paper
RC1	Frame without earthquake-resistant design	3-storey RC frame building built in L'Aquila (Italy) in 1961 [9]	Based on the construction period and information given in the paper

Exposed Element Type		Real case study	Inferences for the Attribution of the building type
RC1	Frame without earthquake-resistant design	4-storey RC frame building built in L'Aquila (Italy) in 1969 [9]	Based on the construction period and information given in the paper
RC1	Frame without earthquake-resistant design	2-storey RC frame building built in L'Aquila (Italy) in 1969 [9]	Based on the construction period and information given in the paper
RC2	Frame with moderate level of earthquake-resistant design	2-storey RC frame building built in L'Aquila (Italy) in 1999 [9]	Based on the construction period and information given in the paper
RC2	Frame with moderate level of earthquake-resistant design	4-storey RC frame building built in L'Aquila (Italy) in 1982 [9]	Based on the construction period and information given in the paper
RC2	Frame with moderate level of earthquake-resistant design	4-storey RC frame building built in L'Aquila (Italy) in 1982 [9]	Based on the construction period and information given in the paper

3.2. Metrics

Metrics allow the assessment of the impact of the implemented measures to tackle specific challenges or hazards. Indicators and units are both essential pieces of the performance metrics. Thus, the ARCH project defined different metrics linked to the different hazards as a fundamental piece to measure effectiveness.

Metrics to assess the environmental effectiveness have been selected to quantify the reduction of the impact of the hazard. Floods, heat and earthquakes could be characterized in this manner. However, it has not been feasible to address other hazards affecting agricultural heritage such as drought via a hazard-related indicator[9]. The cost-efficiency metric as BCR, on the other hand, not only allows to address all types of hazards (multi-hazard indicator), but also enables the benchmarking of resilience measures of a structural, social, and institutional nature. Measures that impact on *e.g.* adaptation capacity are often more difficult to assess

[9] Indicators, which are used to describe drought conditions, are often related to precipitation, reservoir water levels and soil moisture. Resilience measures could be assessed based on water consumption; however, it was not possible to address it in a meaningful way within this project due to information gaps and due to limitations in the harmonisation of information

using only hazard or impact related indicators. It is therefore advantageous to use the BCR as a primary indicator or as a supplement to hazard-related indicators. The following subsection describes the metrics.

3.2.1. Heat

There are different parameters that can be used to measure the effectiveness of resilience measures linked to heat. These parameters are influenced by the receptor of the measures and the specific challenges to be addressed such as the improvement of the human comfort.

Air Temperature Reduction, Indoor air temperature reduction and Physiologically equivalent temperature (PET) have been selected to assess the measures' performance and impact for Extreme heat and Heatwaves hazard mitigation considering the expected outcomes. The selected measurement unit to quantify these three parameters is ºC, based on the available data in the case studies.

The **Air temperature Reduction** and **Indoor Air Temperature Reduction**, based on changes in air temperature, measure the cooling effect of a heat wave mitigation measure usually through shading and/or evapotranspiration. Thus, both indicators are ambient metrics of an area assessed through monitoring of temperature before and after the implementation of a mitigation solution or predicted by models, through dynamic simulation tools for microclimate analysis. Depending on the size of the area to be assessed, temperature quantification is recorded by thermometers/thermocouples in combination with dataloggers, climatic data drawn from meteorological/weather stations which regularly collect air temperature records, and other parameters such as windspeed and humidity, thermal imaging cameras, or satellite images in combination with thermal infrared data.

The robustness of evidence would depend on the precision of the equipment, the spatial design of the monitoring and the duration of temperature recording.

PET measures the human comfort, enabling a layperson to compare the integral effects of complex thermal conditions outside with his or her own experience indoors. As it is expressed in ºC, it makes results more comprehensible than other human-biometeorological terminology. It is calculated as follows [10]:

1. Determine the thermal conditions of the body using the Munich Energy-balance Model for Individuals, MEMI, [1] for a given set of climatic parameters. MEMI is based on the energy balance equation of the human body and is related to the *Gagge* two-node model [11]. The MEMI equation is as follows:

   $$(1)\ M + W + R + C + E_D + E_{Re} + E_{Sw} = 0$$

   where, *M* is the metabolic rate (internal energy production by oxidation of food); *W* is the physical work output; *R* is the net radiation of the body; *C* is the convective heat flow; E_D is the latent heat flow to evaporate water into water vapor diffusing through the skin; E_{Re} is the sum of heat flows for heating and humidifying the inspired air; E_{Sw} is the heat flow due to evaporation of sweat; and, *S* is the storage heat flow for heating or cooling the body mass.

   As a first step, the mean surface temperature of the clothing (T_{cl}), the mean skin temperature (T_{sk}) and the core temperature (T_c) must be evaluated. These three parameters provide the basis for calculation of E_{Sw}. Two equations are necessary to describe the heat flows from the body core to the skin surface (F_{cs}) as shown in (2), and heat flows from the skin surface through the clothing layer to the clothing surface (F_{sc}) as shown in [3,10]:

$$(2)\ F_{CS=v_b} \times \rho_b \times c_b \times (T_c - T_{sk})$$

where, v_b is blood flow from body core to skin (L/s/m^2); ρ_b is blood density (kg/L); and, c_b is the specific heat (W/sK/kg).

$$(3)\ F_{cs} = \left(\frac{1}{I_{cl}}\right) \times (T_{sk} - T_{cl})$$

where, I_{cl} is the heat resistance of the clothing (K/m2/W).

2. Insert calculated values for mean skin temperature (T_{sk}) and core temperature (T_c) into the MEMI equation [1] and solve the three equations for air temperature, Ta (v□= 0.1 m/s; water vapor pressure = 12 hPa; $T_{mrt} = T_a$). This temperature is equivalent to PET.

3.2.2. Flood

Flood mitigation structural measures' performance is assessed by the extent of (i) flooded area reduction, (ii) runoff reduction and (iii) infiltration rate. Flood protection and/or flood mitigation strategies usually rely on water retention, water storage and water absorption by the soil surface.

Flooded area reduction expressed in % is an evaluation of the water reduction in a delineated area affected by flood water and after the implementation of the flood mitigation measure. Geographic Information Systems (GIS) and remote sensing technology provide historical flood events information to support the monitoring and assessment of the implemented mitigation measures.

Runoff occurs when the intensity of rainfall exceeds the infiltration rate at the ground surface and/or when the soil surface is saturated and due to the rainfall intensity, there is a surface flow; precipitation arrives more quickly than soil can absorb it. In terms of runoff quantity associated to rainfall management assessment it can be performed by in situ measurements before and after implementing a flood management mitigation measure and the parameter used is the Runoff reduction expressed in cm or % enables the comparison.

Infiltration rate refers to the speed at which water moves into and through the soil profile; therefore, it is related to the soil or ground's ability to allow water movement within the soil profile, to the storage of water in the soil, the water available to plants, and the generation of runoff. It is expressed as mm/h which is equivalent to L/h*m^2, the volume of water (measured in terms of water column) infiltrating within a given soil area per unit of time.

3.2.3. Earthquake

Table 10 reports the metrics used for quantifying the effectiveness of the selected resilience measures to reduce impacts, and thus, enhancing resilience. A definition for each one of the resilience metrics is provided along with their main use within this work.

Table 10. Selected resilience metrics for quantifying the effectiveness of the selected resilience measures

<table>
<tr><th>Resilience Metric</th><th>Definition</th><th>Description of Use (for what is used)</th></tr>
<tr><td>IS-V</td><td>Safety-Index, measured as Capacity/demand ratio at CLS</td><td rowspan="4">Manly used for RC buildings and simulation-based studies</td></tr>
<tr><td>EAL</td><td>Expected Annual Losses</td></tr>
<tr><td>Risk Index</td><td>Seismic risk classification based on IS-V and EAL</td></tr>
<tr><td>Annualized collapse probability</td><td>annual probability of incurring in collapse</td></tr>
<tr><td>Reduced D2 [%]</td><td>Reduction of observed minor damage</td><td rowspan="4">Mainly used for Masonry building and CH types and for observed based damage studies</td></tr>
<tr><td>Reduced D3 [%]</td><td>Reduction of observed moderate damage</td></tr>
<tr><td>Reduced D4 [%]</td><td>Reduction of observed severe damage</td></tr>
<tr><td>Reduced D4 [%]</td><td>Reduction of observed collapse</td></tr>
<tr><td>Resistance Increase</td><td>Increment of building capacity or structural element resistance due to improvements, referred to the pre-intervention resistance</td><td>Used for all kind of building types (both masonry and RC) mainly for laboratory test measures</td></tr>
</table>

The *IS-V*, *EAL*, and *Risk Index* (assigned as a function of *IS-V* and *EAL)* metrics reported in Table 10 rely on *Performance Based Earthquake Engineering* (PBEE) concepts and framework [12], that are currently adopted in many modern seismic design codes worldwide. Therefore, they can be easily collected from most seismic assessment/retrofit studies available in literature.

Both life safety and the expected (direct and indirect) economic losses are considered key parameters to quantify and compare the performances of different building in their reference life; this to identify the buildings that might cause higher impacts, in term of either consequences to people or economic losses or both of them, thus allowing prioritising interventions on them. Several methodologies, as well as computer tools (e.g. PACT, [13]), were recently proposed for the implementation of loss-assessment in the current design practice. In Task 6.2 as far as earthquakes are concerned, reference has been made to the Italian “*Guidelines for the seismic risk classification of constructions*” [14, p. 65], [15] where a simplified methodology to evaluate Expected Annual Losses (EAL) is proposed.

The *EAL* class depends on the curve of the expected losses, which considers the performances at different Limit States (LSs): Operational (OLS), Damage Limitation (DLLS), Life Safety (LSLS), and Collapse (CLS). A repair cost, expressed as a fraction of the

Reconstruction Cost (%RC), is thus associated with each LSs (Figure 6). The EAL index is defined as the area under the curve of the expected losses.

The *IS-V* (or %NBS) index is defined as the capacity/demand ratio at Life Safety limit state. In other words, it represents the seismic performance of the building when compared to the performance of a new structure.

The *EAL class* is identified as the minimum class for life safety performance, related to a safety index *IS-V* (equivalent to the %New Building Standard, %NBS, used in the NZSEE 2017 guidelines [16]), and to the *EAL* class.

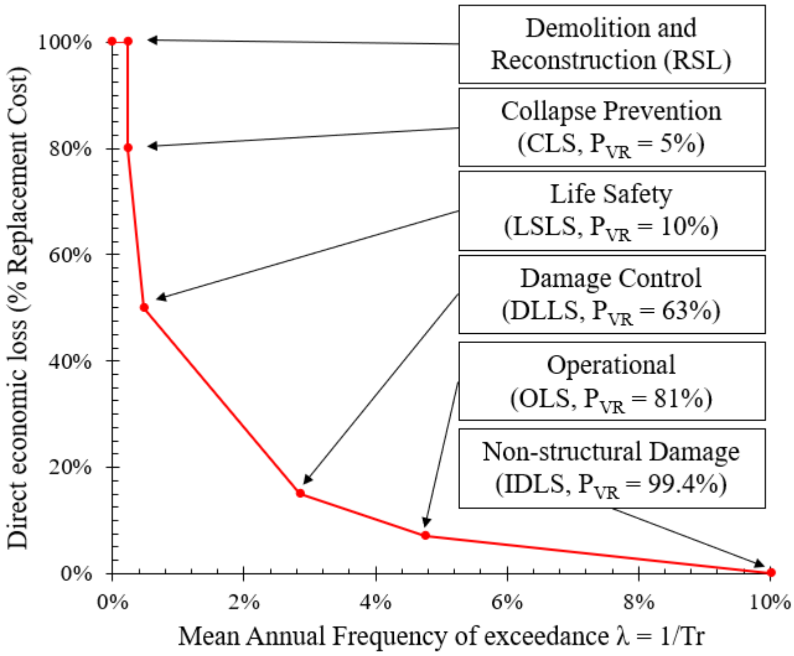
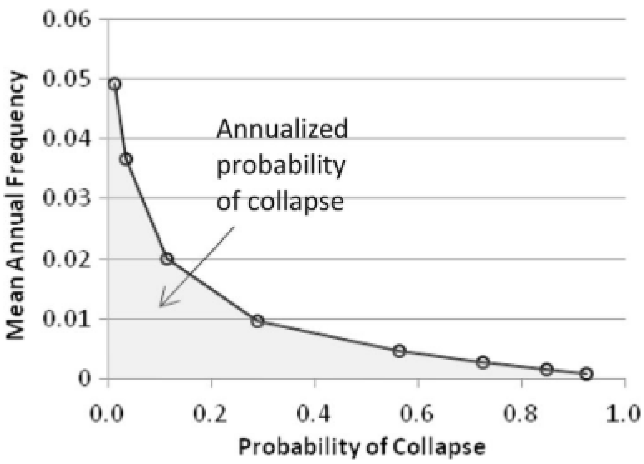


Figure 6. EAL curve as defined in the SismaBonus guidelines [14]

The *Annualized collapse probability* is defined as the annual probability of incurring in collapse for a building. As an example, Figure 7 (left) shows the relationship between the probability of incurring in structural failure and the associated mean annual frequencies for a structure. The area enclosed by the graph represents the annualized probability of collapse.



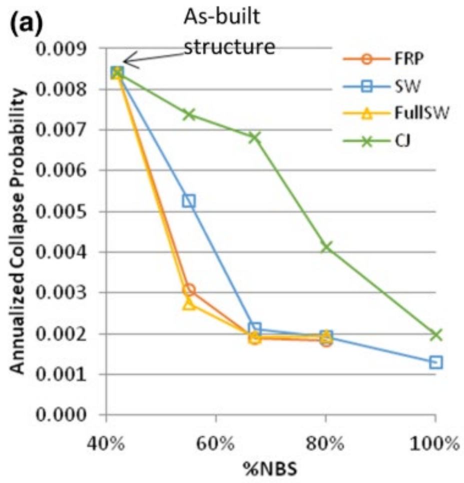


Figure 7. Evaluation of the annualized probability of collapse (left) and annualized probabilities of collapse as a function of the targeted % NBS for alternative retrofit strategies (right; FRP: Fiber Reinforced Polymers; (FULL)SW: (Full)Selective Weakening; CJ: Columns Jacketing) [6]

While the IS-V (or %NBS) index is a deterministic metric, the annualized collapse probability is a probabilistic metric. Therefore, buildings characterised by same IS-V/%NBS index may have different annualized collapse probability. The relationship between the seismic performance measure obtained in a deterministically (IS-V/%NBS) and in a probabilistic manner (the annualized probability of collapse) has been investigated in [6] (Figure 7).

Further to engineering-based metrics, other metrics were considered to quantify post-earthquake damage observation (apparent damage, i.e. what can be observed on the structural components during a post-earthquake damage survey). For this purpose, reference has been made to the discrete damage measure defined by the European Macroseismic Scale, EMS98, *i.e.* 5 damage grades (Dk k=1-5). Therefore, metrics were included, as reported in Table 11 for measuring the percentage reduction of different level of damage, namely: D2=minor damage; D3=moderate damage; D4=severe damage; D5=destruction/collapse.

Inferences had to been made to go from the damage descriptions and damage measures included within the case studies, selected after the literature search, to the quantification of the % reduction of the different damage grades as for the proposed metrics (Table 11). Two different approaches were taken to this end, namely:

- the use of vulnerability and fragility curves as for the examples reported in Figure 8;
- the ad-hoc adapted use of the AeDES, approach adopted in Italy, by law, and officially recognised by the European Commission[10] for post-earthquake damage and safety assessment and for the identification of short-term countermeasures (Figure 9) as reported in Table 11.

[10] https://op.europa.eu/en/publication-detail/-/publication/61df5d26-abe6-4efd-93ce-c2a90e415c13

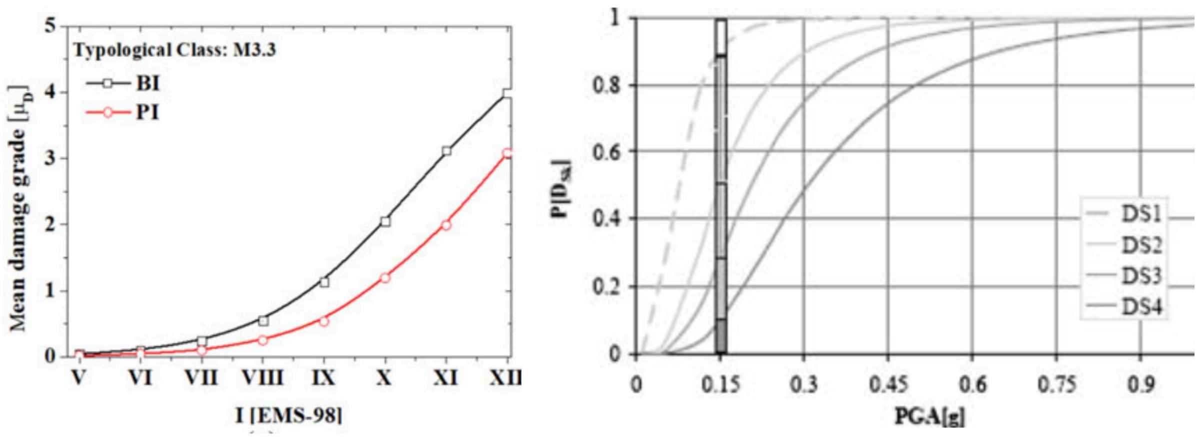


Figure 8. Representing damage reduction before and after the implementation of resilience measures: a) vulnerability curves for before BI and post PI seismic retrofitting interventions for M3 building types [17]; fragility curves for M6 typology [18]

	Level - extension Structural component Pre-existing damage	DAMAGE									
		D4-D5 Very heavy			D2-D3 Medium-severe			D1 Slight			Null
		> 2/3	1/3 - 2/3	< 1/3	> 2/3	1/3 - 2/3	< 1/3	> 2/3	1/3 - 2/3	< 1/3	
		A	B	C	D	E	F	G	H	I	L
1	Vertical structures	☐	☐	☐	☐	☐	☐	☐	☐	☐	○
2	Floors	☐	☐	☐	☐	☐	☐	☐	☐	☐	○
3	Stairs	☐	☐	☐	☐	☐	☐	☐	☐	☐	○
4	Roof	☐	☐	☐	☐	☐	☐	☐	☐	☐	○
5	Infills-partitions	☐	☐	☐	☐	☐	☐	☐	☐	☐	○
6	Pre-existing damage	☐	☐	☐	☐	☐	☐	☐	☐	☐	○

Figure 9. Grade and extension of damage to the structural components according to the AeDES, approach adopted in Italy, by law, and officially recognised by the European Commision[5] for post-earthquake damage and safety assessment and for the identification of short-term countermeasures

Table 11. % of Damage reduction associated to the three damage extension classes adopted by the AeDES approach[5]

Damage Levels	Damage Extension	Associated Damage %
D5, D4, D3, D2	>2/3	83%
	1/3÷2/3	50%
	<1/3	17%

Finally, the Resistance Increase [%] metric has been defined as following:

$$\text{Resistance Increase [\%]} = \left[\frac{Resistance\ As\ Built - Resistance\ after\ Retrofitting}{Resistance\ As\ Built}\right] 100$$

3.2.4. Multi-hazards

In order to help decision-making on investments whose benefits are not evident (due to externalities, difficulties to capture them through market mechanisms, long time periods, etc.), instruments have been developed for evaluating investment projects to decide whether it makes sense to spent at this time, given the expected future revenues, and to direct resources to those that provide the greatest net benefit. One of these instruments is the Cost-Benefit Analysis (CBA).

CBA is a methodology to comprehensively assessing costs and benefits of a project (a programme, intervention or policy measure) with the aim of determining if a project is desirable and, if so, to what extent, while also allowing for a comparison between alternative projects. It can be used ex ante, to evaluate the most convenience project, or ex post, to evaluate previously executed projects. In all cases, monetary values must be attached to the environmental impacts, both desired and undesired. This way, they are considered together with ordinary inputs and outputs of the project (capital, raw materials, goods, and services, etc.).

CBA is an application of welfare economics which is intended to select projects according to efficiency criteria. This method allows to determine economic efficiency of adaptation strategies by comparing net present value of the costs associated with them against benefits, calculating the net benefit. Results can be expressed in a single metric to allow the comparison of adaptation strategies and choose those which maximise social welfare. Three decision criteria or metrics are prioritized:

- **Net Present Value** (NPV) is defined as the difference between the present values of benefits and costs over a period of time. In a cost-efficient project, the NPV is greater than 0.
- **Internal Rate of Return** (IRR) is defined as the rate at which net cash flow of a project must be discounted to produce a NPV equal to 0. In a cost-efficient project, the IRR is greater than the interest rate.
- **Benefit/Cost Ratio** (BCR) is defined as the ratio between the present values of benefits and total project costs over a period of time and provides an estimate of the expected level of benefits per unit cost. In a cost-efficient project, the BCR is greater than 1.

The BCR was considered the most appropriate metric to represent the best value for money or the most cost-efficient option in this case, as it provides a more simplistic scale of measure through which to rank options as well as the least biased metric for comparison between different studies. For this reason, it is useful for comparing different investment alternatives, even though BCR does not allow for evaluating liquidity aspects of the compared options (the amount of investment, time needed for obtaining benefits, etc.).

In order to decide, the preferred projects are the ones with the highest BCR, taking into account that only BCR > 1 can be considered cost-efficient:

Table 12. Description of the BCR values implications in terms of investments

BCR > 1	means that each euro invested in the project yields more than 1 euro in benefits. The benefits of the investment outweigh its costs, making it cost-efficient. It is important to note that this rate cannot be considered sufficient to accept an investment when funds are limited. In these cases, BCRs greater than 2 or even higher would be needed to take the decision
BCR < 1	means that costs supersede benefits created by the project, considering the investment inefficient
BCR = 1	means than costs are determined to be exactly the same as benefits, considering the investment "At Cost Efficiency".

The BCR is nearly always positive, but negative ratios can also be obtained. Negative values indicate that the investment could generate greater disbenefits than benefits and may worsen site conditions instead of improving them.

Once discount rate is applied in the BCR estimation, projects with more immediate benefits obtain higher rates, being considered more cost-efficient than projects with distant benefits (other things being equal).

An important drawback of this process is the need for quantitative and monetized data on adaptation costs and benefits, as well as the difficulty of selecting an appropriate discount rate and considering the timing and scale of the strategies to be compared. The available studies use a diverse set of methods, socio-economic assumptions, cost metrics and benefit categories, as well as discount rates, making inter-comparison difficult. For this reason, care should be taken in reporting and compiling estimates.

3.3. Considered resilience measures and gaps

In this work, various types of resilience measures are considered, which can be classified as structural, social, and institutional measures. These measures are included in the Resilience Measure Inventory - RMI (ARCH D6.1). These resilience measures aim at adapting, preparing, safeguarding, managing, and recovering historical areas from heat, flood, earthquake, drought/water scarcity, soil erosion and biological hazards. However, not all covered RMI measures can address these hazards. Table 13 presents the portfolio of measures considered (for which performance information has been gathered) for each hazard.

For earthquake hazards, only measures from Urban /Building & structures heritage inventory type are considered, while for drought & water scarcity, soil erosion and biological hazard only measures from Agricultural heritage inventory type are considered. It is also worth highlighting that information on Europe's case studies represent almost 41%, followed by 37% case studies from Asia and 15% from USA.

Table 13. Relation of the performance information and the resilience measures measure

Subgroup	Measure	Heat	Flood	Earthquake	Drought	Soil erosion	Biological
Adaptation strategies	Adapt the design of the built environment to the changing climate conditions		€	€			
Awareness raising	Public education for good response against hazards				€		
Back-up systems	Identification of temporary alternatives to key physical infrastructure and basic services		€				
Building cooling system	Passive cooling strategies: natural ventilation.	✓					
	Passive cooling strategies: suitable insulation	✓					
	Cooling-roofs to reduce near-surface temperature	✓					
	Air conditioning	€, ✓					
	Green roofs to reduce near-surface temperature	€, ✓	✓				
Building strengthening	Resistance reinforcement of walls			€			
	Structural reinforcement to better withstand seismic activity			€, ✓			
	Structural reinforcement to roof		€				
Building walled areas	Building walled areas to maintain Heritage sites below sea level		€				
Buildings and structures construction codes and standards	Implementation of building code requirements for buildings at risk from flooding		€				
Built Cultural Heritage codes	Preventative maintenance		€				
Capacity building for institutions	Capacity building programme for staff engaged in disaster preparedness, response and recovery			€			

Subgroup	Measure	Heat	Flood	Earthquake	Drought	Soil erosion	Biological
	Capacity Building. Providing training for emergency preparedness for scientific bodies, administrative, and technical staff		€				
Crop management strategies	Crop diversification	€			€		
	Crop rotation	€			€		€
	Introduction of crops and varieties resistant to drought, salinity and emerging pests and diseases	€	€		€		€
	Long-cycle variety for *e.g.* dry cereals	€			€		
Crop protection measures	Promoting biological control of pests and diseases				€		€
Disaster Risk Management tools	Improvement of risk and crisis management tools		€	€			
Dry proofing	Elevating mechanical and utility equipment		€				
	Raising the interior floor above likely flood level		€				
	Waterproofing		€				
Early warning for vulnerable groups	Early warning systems for vulnerable groups		€				
Early Warning Systems	Early Warning Systems		€	€	€		
	Establishment of early warning systems for high temperatures	€					
	Flood Early Warning Systems		€				
Ecosystem-friendly drainage	Improved infiltration systems				€	€	
	Increase water retention in the soil through small drainage channels				€	€	
Efficient water conveyance (channels)	Replacement of open channels with low pressure piping systems to reduce evaporation and filtration losses				€		
Emergency stabilization (buildings)	Tie rods and hoops system				✓		

Subgroup	Measure	Heat	Flood	Earthquake	Drought	Soil erosion	Biological
Farming techniques adaptation	Encourage the use of cultivation techniques for the reduction of heat stress	€			€		
	Planting date changes	€			€		
Green and foresting solutions	Ditches to divert ground water and avoid erosion		€				
	Grass	✓	✓				
	Retention Pond	✓	€				
	Slope protection measures		€				
	Parks	✓	✓				
	Trees	✓	€, ✓		€		
Historic areas regulations	Zoning and statutory planning regulations for historic areas		€				
Improvement of irrigation efficiency	Automation and remote control of gravity irrigation				€		
	Design and planning of irrigation based on water and energy efficiency criteria	€			€		
	Efficient irrigation technology (e.g. drip)				€		
Increase of freshwater availability	Creating new systems for collecting and storing rainwater		€		€		
	Establishment of small ponds in rainwater collection areas		€		€		
	Use of other alternative water sources				€		
	(other)				€		
Increase of soil organic carbon and nutrients content	Cover crops	€	€		€	€	
	Optimized fertilization and organic matter application management				€	€	
Infiltration techniques	Bioretention basin		✓				
	Infiltration trenches		✓				

Subgroup	Measure	Heat	Flood	Earthquake	Drought	Soil erosion	Biological
	Permeable pavement		€, ✓				
	Rain garden		€				
Innovative governance models	Awareness-raising campaign to the community on hazards and risks	€	€				
	Community recovery programme		€			€	
Modelling	(Applicable to all measures)	€	€	€	€	€	€
Monitoring Systems	Establish protocols for the identification and monitoring of new pests, diseases, and invasive species		€		€		
Moving the built Heritage (partially or totally)	Moving the built Heritage (partially or totally)		€				
Public and private economic instruments for agriculture	Agricultural insurance that takes into account climate change		€		€		
Public and private economic instruments for urban	Economic instruments that enable institutions reducing vulnerability		€		€		€
	Incentive and supportive activities		€	€	€		
	Insurance allocation for emergencies		€		€		
R+D+I in adaptive measures	Research on species and varieties more adapted to climate change (Breeding, agricultural variety and seed bank etc.)				€		
Reduction of soil erosion and compaction	Contour cropping		€		€	€	
	Ground cover with mulching and plastic padding		€		€	€	
	Implementing multifunctional margins					€	
	Minimise bare ground periods		€			€	
	Minimum or zero tillage		€		€	€	
	Plant covers between rows of trees	€	€		€	€	€
	Planting hedges on the land boundaries		€			€	

Subgroup	Measure	Heat	Flood	Earthquake	Drought	Soil erosion	Biological
	Terrace construction or conservation		€		€	€	
Relocation	Wrapping, relocating and reporting		€				
Securing measures	Anchoring of moveable objects to avoid damages			€			
Surface and underground water storage solutions	Rainwater harvesting system		✓		€		
	Surface water storage				€		
	Underground water storage		€				
Temporary protection systems	Free-standing and frame barriers		€				
	Container systems		✓				
	Sandbags		€				
Territorial planning	Territorial urban plans		€				
Thermal management strategy	Apply pavement-watering method during heat wave	✓					
Urban cooling system strategy	Outdoor Water spraying	✓					
	Traffic calming/reduction interventions	✓					
	Urban morphological interventions for cooling	✓					
	Cool pavements	✓					
Urban planning regulations	Creation of green areas and pervious surfaces		€				
Vernacular resilient technical solutions	Traditional skills and techniques in building construction and periodic maintenance			€, ✓			
Vulnerability assessment methods	Risk and vulnerability assessment methods				✓		
Water contention system against floods	Dike or dams for water containing and evacuation		€				
	Dry proofing structures or protections		€				
	Flood gates		€, ✓				

Subgroup	Measure	Heat	Flood	Earthquake	Drought	Soil erosion	Biological
	Floodplain rehabilitation		€, ✓				
	Re-naturalisation of river and surrounds for improved flood management		€			€	
	Rigid freestanding barrier		€				
Wet proofing	Flood resistant materials below flood level		€				
	New drains adequate to cope with flooding		€				

The outputs of the desktop study showed that the information gap regarding the performance of resilience measures is significant. Around 54% of the resilience measures (117 in total) could not be assigned to any of the identified economic and environmental performance metrics. Resilience measures targeting floods are those that were better characterized in terms of economic performance (55 measure in total) and environmental effectiveness (11 measures in total) followed by resilience measures targeting heat risks, of which 14 measures in total had economic performance and environmental effectiveness. Environmental effectiveness based on the selected metrics apply mainly to structural measures, thus, it is logical that less resilience measures are characterised by environmental metrics.

The work shows that there is still a large gap in evidence-based performance information for many resilience measures. Therefore, promoting assessment, monitoring, and learning on the performance of resilience measures to generate evidence-based information should be a priority.

4. Results and conclusions from environmental performance of resilience measures

This section is intended to present the analysis of the performance data to identify the criteria of climate adaptation and risk management which can be relevant to consider when benchmarking the resilience measures for historic areas. This information is supported from existing databases, scientific reports, and policy documents in these fields. Furthermore, whenever possible, data trends and correlation factors have been identified.

4.1. Effectiveness assessment analysis of resilience measures against heat

The bases for this effectiveness assessment analysis of resilience measures against heat was done based on a bibliography review to collect specific indicators, metrics and other key variables to characterize the effectiveness of the measure. For the heat analysis, a total of 74 bibliography references were evaluated, resulting in a total 115 case studies from which a total of 428 effectiveness entries were gathered.

This chapter focuses on the 13 heat-related resilience measures that belong to four specific subgroups of RMI measures. As it can be observed that green infrastructure and foresting solutions, such as planting trees or establishing parks, are the most common measures covered in the literature (72% of the effectiveness entries), followed by building cooling systems such as green roofs, cooling roofs or other building insulation solutions (18.3% of the entries). The urban cooling system and thermal management strategies are less considered in the literature, representing 8.5% and 1.2% of the entries, respectively.

Table 14 presents a summary of references, cases, and entries per resilience measure for each option. The representativeness of this information (total number of entries, case studies, and papers considered) is important as the final effectiveness values linked to a measure and its robustness directly depends on the amount of total information considered.

As it can be observed that green infrastructure and foresting solutions, such as planting trees or establishing parks, are the most common measures covered in the literature (72% of the effectiveness entries), followed by building cooling systems such as green roofs, cooling roofs or other building insulation solutions (18.3% of the entries). The urban cooling system and thermal management strategies are less considered in the literature, representing 8.5% and 1.2% of the entries, respectively.

Table 14. List of resilience measures collected for this report and the number of entries, cases and references

Subgroups	Measure	Entries	Cases	References
Building cooling system	Passive cooling strategies: suitable insulation	14	5	5

Subgroups	Measure	Entries	Cases	References
	Air conditioning	1	1	1
	Cooling-roofs to reduce near-surface temperature	6	3	3
	Green roofs to reduce near-surface temperature	57	6	6
Urban cooling system strategy	Outdoor Water spraying	1	1	1
	Traffic calming/reduction interventions	20	2	2
	Urban morphological interventions for cooling	12	3	3
	Cool pavements	2	2	2
Green and foresting solutions	Grass	10	5	5
	Trees	147	46	16
	Park	134	60	35
	Retention Pond	8	1	1
Thermal management strategy	Apply pavement-watering method during heat wave	16	3	3

Another aspect considered in the literature review refers to the considered approach or method to assess the effectiveness. Table 15 and Figure 10 summarize the case studies and entries for each approach. Around 35% (153 entries) of the total amount of reported entries are linked to the effectiveness based on observations of their performance in practice, that is due to ad-hoc sensors or weather station data. On the other hand, 129 entries corresponding to 29% are related to modelling or simulations results using historical data. There are also another proportion of entries 22% (96 entries) that combine observations of the performance with models to analyse the performance of the measures under different scenarios. Less percentage is linked to some laboratory test studies or not specified.

Table 15. Representativeness of the approaches to measure the heat effectiveness

Approach	Entries	Cases
Observations (Measures)	153	50
Modelling (Simulations)	129	27
Simulation and measures	96	16
Laboratory Test	11	5
Not specified	54	25

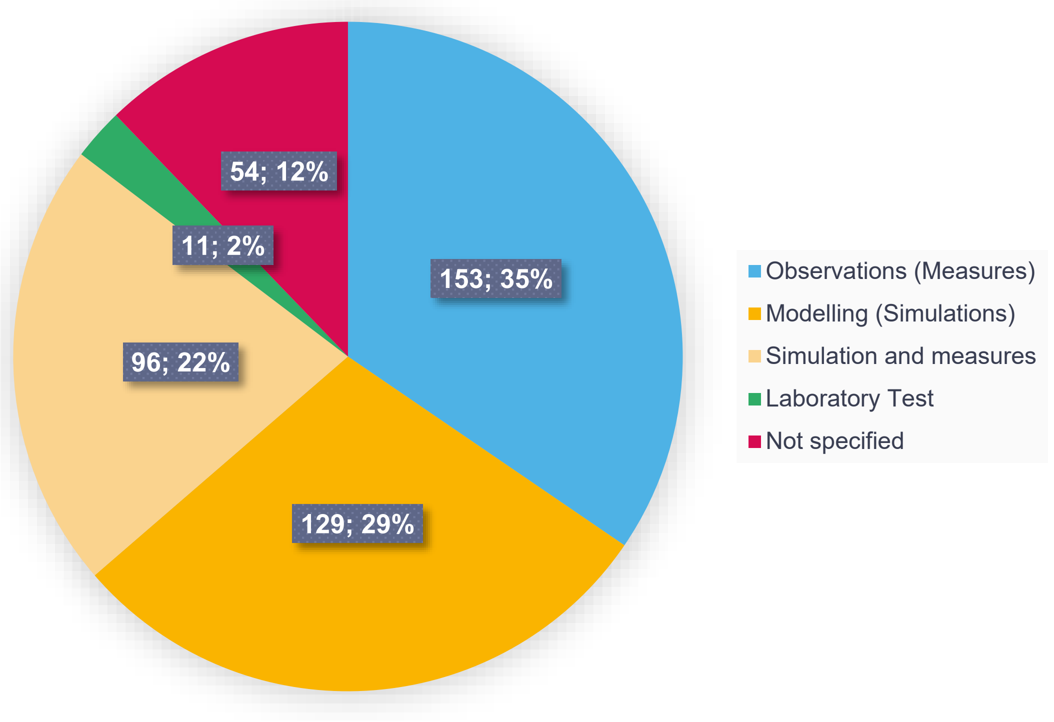


Figure 10. Study types Representativeness for Heat

Another important aspect to consider is the representativeness of each measure in relation to the different indicators considered to measure the effectiveness of the different resilient measure against heat. Table 16 shows the representativeness of each indicator by listing the total number of effectiveness entries gathered for each indicator, together with the number of case studies from which this effectiveness is originated and the number of bibliography references considered. As mentioned above, Air Temperature reduction was the most common indicator addressed in the literature, representing the 83.2% of the effectiveness entries considered.

Table 16. Representativeness of the heat indicators considered

Heat Indicator	Entries	Cases	References
Air T Reduction	356	102	63
PET reduction	56	11	8
Indoor air Tº Reduction	16	5	5

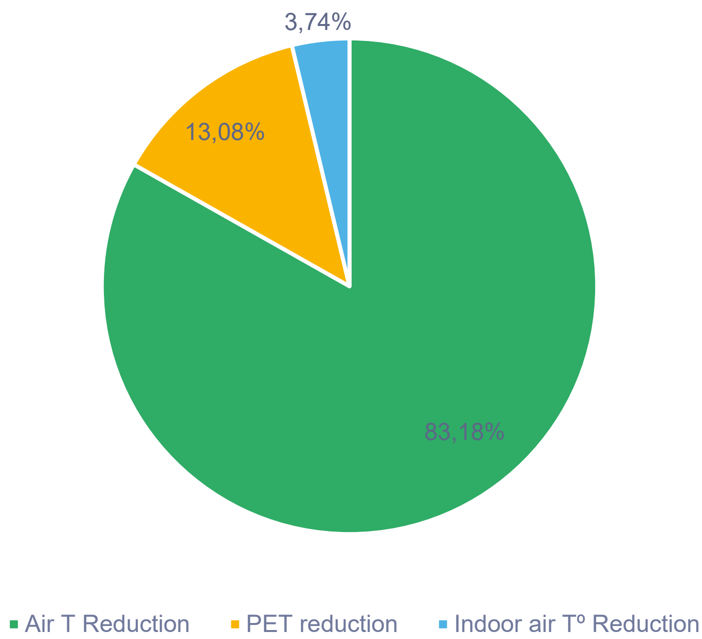


Figure 11. Representativeness of heat indicators

Furthermore, Table 17 is focused on visualizing how these indicators represent the effectivity for each measure. Parks and trees are the only two resilience measures for which more than 5 references have been found for *Air T reduction* indicator. This is probably the case as shading and evapotranspiration effect by these measures makes them especially attractive for implementation and thus for monitoring and assessment purposes.

Table 17. Representativeness of each heat indicator per measure

Measure	Indicator	Entries	Cases	References
Passive cooling strategies: natural ventilation	Indoor air T Reduction	2	1	1
Passive cooling strategies: suitable insulation	Air T Reduction	2	1	1
	Indoor air T Reduction	10	3	3
Air conditioning	Air T Reduction	1	1	1
Cooling-roofs to reduce near-surface temperature	Air T Reduction	2	2	2

Measure	Indicator	Entries	Cases	References
	Indoor air T Reduction	4	1	1
Green roofs to reduce near-surface temperature	Air T Reduction	51	4	4
	PET reduction	6	2	2
Outdoor Water spraying	Air T Reduction	1	1	1
Traffic calming/reduction interventions	Air T Reduction	14	1	1
	PET reduction	6	1	1
Urban morphological interventions for cooling	Air T Reduction	6	2	2
	PET reduction	6	1	1
Cool pavements	Air T Reduction	2	2	2
Grass	Air T Reduction	4	3	3
	PET reduction	6	2	2
Trees	Air T Reduction	137	24	14
	PET reduction	10	2	2
Park	Air T Reduction	120	58	33
	PET reduction	14	2	2
Retention Pond	PET reduction	8	1	1
Apply pavement-watering method during heat wave.	Air T Reduction	16	3	3

4.1.1. Harmonization of metrics

The lack of common metrics makes it difficult to harmonize and compare amongst resilience measures. This section summarizes the post-processing of data done for the harmonization of metrics regarding heat related information, based on the following elements:

- Detect the most used effectiveness parameter (e.g. PET, air Tº, etc.)
- Detect the most used unit by which the results are represented (ºC, K, %, etc.)
- Analyse the relationship between effectiveness and indicator (parameter, unit).

As stated before, during the literature review and based on RESIN AOL data, several parameters were identified, but 3 were selected as they were the most commonly used to measure heat effectiveness.

- Air Temperature Reduction (the most recurrent category)
- PET Reduction
- Indoor Air Temperature Reduction

There are also different units to express the parameter, developing common units of measure (e.g. degrees of Celsius/Fahrenheit, Kelvin, %) to express the parameter is also needed to compare between different adaptation options. During the literature review it was observed that the most recurrent category was ºC followed by %, so, as some studies give the effectiveness in % of reduction. When possible, the % unit was transformed into ºC to have a better amount of effectiveness in the same unit. The next table shows the final set of metrics used to measure the heat effectiveness.

Table 18. Metrics used for heat indicators

Parameter	Unit
Air T Reduction	ºC / %
PET reduction	ºC
Indoor air Tº Reduction	ºC

4.1.2. Harmonization of the values (overall ranges)

To help end-users understand the effectiveness of the resilience measures to tackle heat a qualitative performance scale has been developed. These ranges of effectiveness are calculated based on literature information and considering the information gathered for each measure and indicator. Additionally, considering the values of effectiveness gathered per indicator, several harmonization tables were created for each indicator to rank the effectiveness of the measures from Not effective, Low, Medium and High Performance.

Table 19. Air T reduction ranges of effectiveness

Threshold range	Performance
Air T Reduction > 2 ºC	High
1ºC < Air T Reduction< 2ºC	Medium
0ºC < Air T Reduction< 1ºC	Low
Air T Reduction <0	Not effective

Table 20. PET Reduction ranges of effectiveness

Threshold range	Performance
PET Reduction > 3.5 ºC	High
0.75 ºC < PET Reduction < 3.5ºC	Medium

Threshold range	Performance
0ºC < PET Reduction < 0.75 ºC	Low
PET Reduction <.0	Not effective

Table 21. Indoor T Reduction ranges of effectiveness

Threshold range	Performance
Indoor T reduction > 4 ºC	High
2 ºC < Indoor T reduction < 4ºC	Medium
0ºC < Indoor T reduction < 2 ºC	Low
Indoor T reduction <0	Not effective

Considering the above ranges for measuring the effectiveness over each indicator, and considering the average values of effectiveness entries gathered from this literature review, it can be concluded that the effectiveness of the different measures for reducing air temperature is highest in parks, outdoor water spraying, and green roofs, followed by those achieved through the implementation of trees, grass or other urban morphological interventions (Table 19). The performance of parks and trees with a higher number of entries can be considered more robust as it is based on a larger number of studies and factors such as geographical location dependence may have less weight.

Table 22. Effectiveness of the measures for the Air T Reduction

Measure	Performance
Green roofs to reduce near-surface temperature	HIGH
Traffic calming/reduction interventions	LOW
Cool pavements	LOW
Grass	MEDIUM
Apply pavement-watering method during heat wave	LOW
Cooling-roofs to reduce near-surface temperature	LOW
Outdoor Water spraying	HIGH
Urban morphological interventions for cooling.	MEDIUM
Trees	MEDIUM
Park	HIGH
Air conditioning	NOT EFFECTIVE

Considering the PET temperature reduction effectiveness of the different measures (Table 20), trees and parks rank the highest effectiveness, ranging from an average effectiveness above

3.5 ºC. This effectiveness is followed by the ones achieved by implementing grass and retention pond, with average effectiveness that vary between 1 ºC and 3 ºC.

Table 23. Effectiveness of the measures for the PET Reduction

Measure	Effectiveness
Trees	HIGH
Park	HIGH
Green roofs to reduce near-surface temperature	LOW
Traffic calming/reduction interventions	MEDIUM
Urban morphological interventions for cooling...	LOW
Grass	MEDIUM
Retention Pond	MEDIUM

Considering the indoor temperature reduction effectiveness (Table 24), there are only three available measures from which effectiveness is gathered, all ranging from medium to high effectiveness, with appropriate insulation strategies for cooling the most effective ones.

Table 24. Effectiveness of the measures for the Indoor T Reduction

Measure	Effectiveness
Passive cooling strategies: natural ventilation	MEDIUM
Passive cooling strategies: suitable insulation	HIGH
Cooling-roofs to reduce near-surface temperature	MEDIUM

Regarding the above tables, it is also important to stage that the effectiveness values are obtained considering different entries. Table 25 shows the number of entries and references considered to obtain the average effectiveness of the resilience measures for each indicator. As it can be observed, there are measures for which a more representativity of bibliography sources were gathered and others for which there were less sources. Another issue is the variability of the values, which sometimes varies greatly. In these cases, a more detailed analysis is needed to determine the reasons for each value and to detect any possible outliers and select the more appropriate ones.

Table 25. Ranges of effectiveness for each resilience options and variable of measurement

Measure	Indicator	Effectiveness	Entries	References
Passive cooling strategies: natural ventilation ...	Indoor air Tº Reduction	MEDIUM	2	1
Passive cooling strategies: suitable insulation …	Indoor air Tº Reduction	HIGH	10	3
Cooling-roofs to reduce near-surface temperature	Indoor air Tº Reduction	MEDIUM	4	1

Measure	Indicator	Effectiveness	Entries	References
Green roofs to reduce near-surface temperature	Air T Reduction	HIGH	51	4
Trees	PET reduction	HIGH	10	2
Park	PET reduction	HIGH	14	2
Green roofs to reduce near-surface temperature	PET reduction	LOW	6	2
Traffic calming/reduction interventions	Air T Reduction	LOW	14	1
Traffic calming/reduction interventions	PET reduction	MEDIUM	6	1
Urban morphological interventions for cooling	PET reduction	LOW	6	1
Cool pavements	Air T Reduction	LOW	2	2
Grass	Air T Reduction	MEDIUM	4	3
Apply pavement-watering method during heat wave	Air T Reduction	LOW	16	3
Cooling-roofs to reduce near-surface temperature	Air T Reduction	LOW	2	2
Outdoor Water spraying	Air T Reduction	HIGH	1	1
Urban morphological interventions for cooling	Air T Reduction	MEDIUM	2	1
Grass	PET reduction	MEDIUM	6	2
Trees	Air T Reduction	MEDIUM	137	14
Park	Air T Reduction	HIGH	120	33
Retention Pond	PET reduction	MEDIUM	8	1

Measure	Indicator	Effectiveness	Entries	References
Air conditioning	Air T Reduction	Not Effective	1	1

4.1.3. Harmonization based on determining factors

Each resilience measure has a different effectiveness, depending on the specific context, circumstances, and assumptions. This means that the way in which effectiveness is evaluated, the so-called value, also needs to be harmonized, or at least specific factors that may affect the final value of effectiveness need to be considered. This section briefly describes the factors that may be relevant and how the harmonization criteria for each factor can be considered. It is known that the climatic zone, scope of analysis, the extent of the implementation and the time span of the measurement may affect the evaluation of the effectiveness.

The micro-scale is a convenient **scale of analysis** when one wants to analyse pedestrian thermal comfort. The most common scale is usually the neighbourhood scale (between 1 and 2 kilometres) and the block and street scale (canyon type streets; less than 100 metres). The meso-scale refers to the whole municipality, which allows the benefits to be assessed. The grid typically used at this scale varies from regional (from 100 to 200 kilometres) to city (from 10 to 20 kilometres) using a moderate spatial resolution (about 100 metres) [19]. The effectiveness of the resilience measures is often blurred at this scale by the effect of other factors and because the effectiveness of solutions is site-specific and decreases as we move away from it. The scale of analysis is often related to the **scale of the implementation** of solutions. In ARCH it was considered tree implementation scales: element, district, or territory. However, most of the analysed case studies focus at district scale and few of them target element scale and no territory scale. Therefore, at this stage, no conclusions could be drawn from the scale of implementation.

The **time-range** at which the temperature or indicator measurement is collected has also been found an important parameter to consider. The time window most used in the literature for the calculation of effectiveness is generally from 13:00 to 15:00 CET as it is when the daily temperature reaches its maximum. It is also when the cooling effect by resilience measures reaches its maximum potential. However, depending on the adaptation objective, it could be considered to analyse the effectiveness in different time slots (*e.g.* if the objective is to avoid sleep disturbance, the night time slot should be chosen) [20]. It is important to highlight that the analysed references gather the effectiveness for a variety of time scales, ranging from one hour, three hours or even peak values[11]. Therefore, the collected data was post-processed and clustered in different time-ranges (Table 26) to compare the different effectiveness of the measures at different time ranges.

[11] Peak value is also known as maximum value. It is often referred to the effectiveness at the hottest time of the day

Table 26. Time clusters considered for the time frame analysis

Time clusters	Time frame
Morning	8:00-11:00
Mid-day	11:00-15:00
Afternoon	15:00-19:00
Night	20:00 -7:00
Peak value	-
All day	From 8:00-19:00

Figure 12 and Figure 13 represent the temperature reduction at the above defined time frames for air temperature and PET, respectively. As it can be observed, the highest effectiveness is gathered at peak time, which probably is around midday, that is, the different measures are more effective when the highest temperatures are happening, therefore one trying to adapt to extreme whether events these effective values should be considered. However, this cluster of values present the highest dispersion. The time range from 15:00-19:00 is when the highest temperature reduction is observed followed by the peak time for air temperature reduction. PET follows a similar trend.

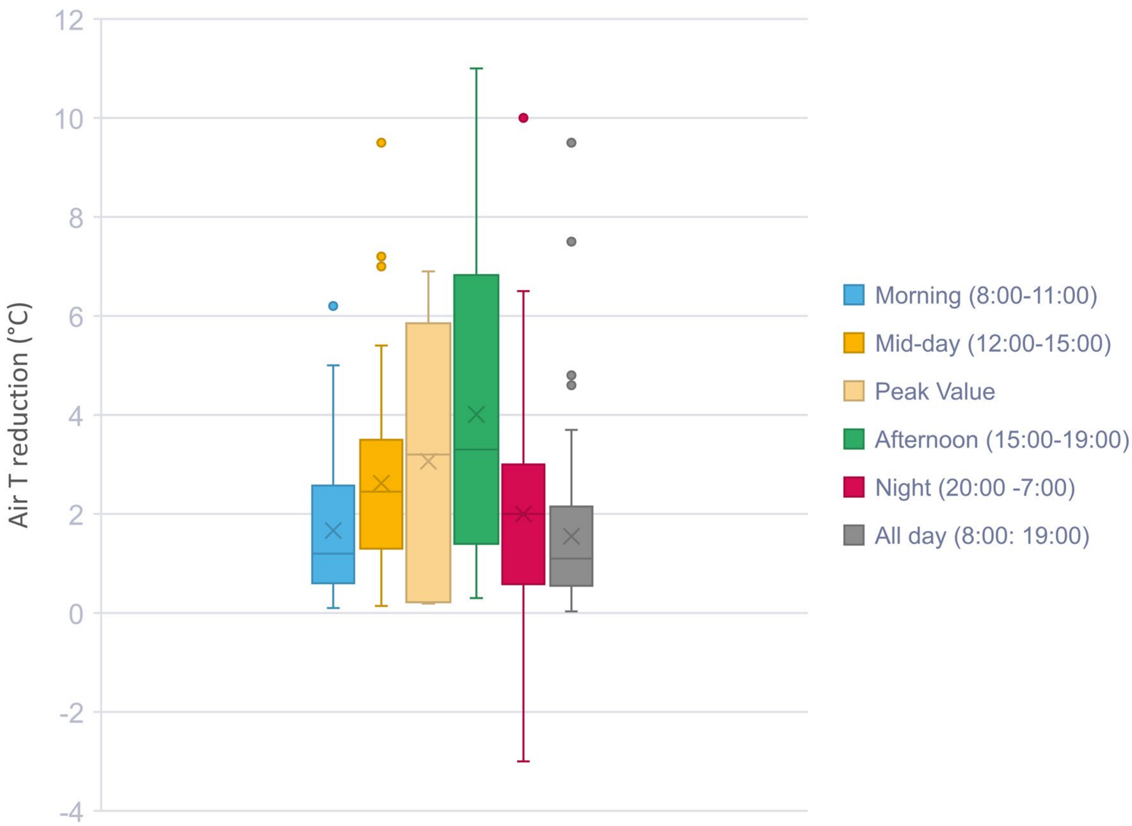


Figure 12. Air temperature reduction (°C) per timeframe

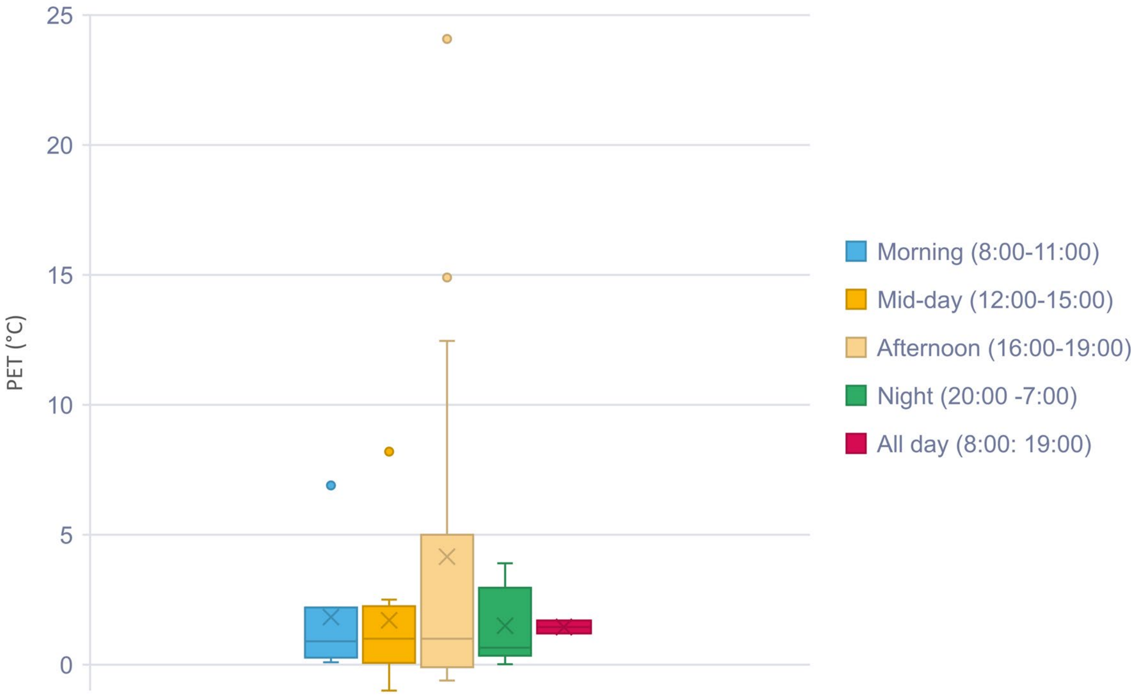


Figure 13. PET reduction values (°C) per timeframe

4.2. Effectiveness assessment analysis of resilience measures against flooding

Following the same approach explained for heat, the bases for this effectiveness assessment analysis of resilience measures against flooding has been done based on a bibliography review to gather specific indicators, metrics, and other variables interesting for characterizing the effectiveness of each measure. In this case, a total of 44 bibliography references were analysed, from which a total 55 case studies were extracted with a total of 165 effectiveness entries.

This subchapter focuses on the 11 flooding related resilience measures, which belong to 6 specific subgroups of the RMI. For each option, As it can be observed that green infrastructure and foresting solutions, such as planting trees or establishing parks, are the most common measures covered in the literature (72% of the effectiveness entries), followed by building cooling systems such as green roofs, cooling roofs or other building insulation solutions (18.3% of the entries). The urban cooling system and thermal management strategies are less considered in the literature, representing 8.5% and 1.2% of the entries, respectively.

Table 14 shows the subgroup to which this measure belongs, the number of case studies entries and the effectiveness "entries" that were gathered as well as the number of references from which these case studies were selected.

The representativeness of this information (total number of entries, case studies, and papers considered) is very important, as the final effectiveness values linked to a measure are directly dependent on the individual effectiveness entries and amount of total information considered.

As it can be observed in Table 27, the measure of implementing green roofs (which have been assigned to the building cooling system subgroup), and others infiltration techniques, such as infiltration trenches, permeable pavement or bioretention basin measures are the most common measures addressed within the literature containing the 60,24% of the effectiveness entries. Followed by green and foresting solutions, such as planting trees, grass, and parks, being the 18.7% of the entries.

Less considered in the literature are the temporary protection systems and the surface and underground water storage solutions, representing the 7.2% and 9.0% of the entries respectively.

Table 27. List of resilience measures collected against flooding and the subgroup they belong to. The number of effectiveness entries gathered, case studies and papers analysed.

Subgroup	Measure	Entries	Cases	Papers
Temporary protection systems	Container systems	12	4	2
Building cooling system	Green roofs	53	17	17
Water contention system against floods	Flood gates	1	1	1
	Floodplain rehabilitation	7	1	1
Green and foresting solutions	Grass	2	2	2
	Trees	9	6	5
	Park	20	10	8
Infiltration techniques	Infiltration trenches	2	1	1
	Permeable pavement	11	2	2
	Bioretention basin	34	7	6
Surface and underground water storage solutions	Rainwater harvesting system	15	2	2

Similar to what was analysed for heat, the approach considered to measure the effectiveness against flooding. Table 28 and Figure 14 show that 54% of the entries reported on the effectiveness of measures based on observations and another 40% of the entries presented modelling results or simulations.

Table 28. Representativeness of the approaches considered to measure the flooding effectiveness

Approach	Entries	Cases
Observations (Measures)	81	17
Modelling (Simulations)	60	24
Simulation and measures	2	2

Other	7	4

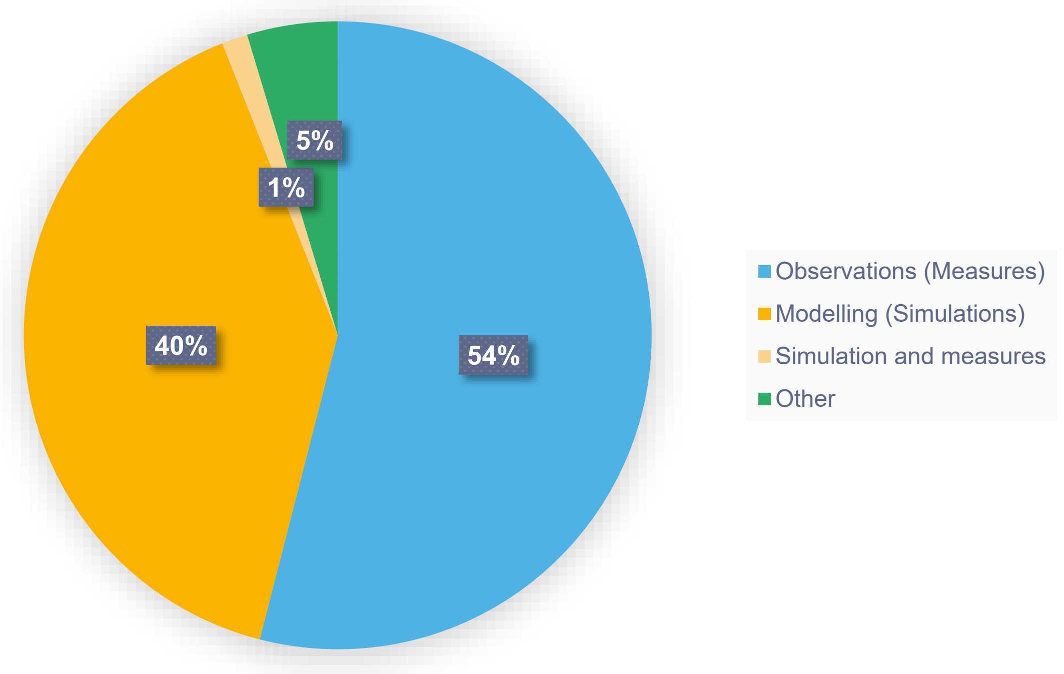


Figure 14. Percentage of approaches considered to measure the flooding effectiveness

Another important aspect to be considered is the representativeness of each measure with regard to the different indicators considered to measure the effectiveness of the different resilient measure against flooding. Table 29 shows the representativeness of each indicator by listing the total number of effectiveness entries per indicator, together with the number of case studies and the number of bibliography references (papers) considered. **Runoff reduction** was the most common indicator addressed within the literature, representing the 77.2% of the effectiveness entries considered.

Table 29. Representativeness of the heat indicators considered

Flooding Indicator	Entries	Cases	References
Flooded area reduction	23	5	4
Runoff reduction	118	38	34
Infiltration rate	12	5	3

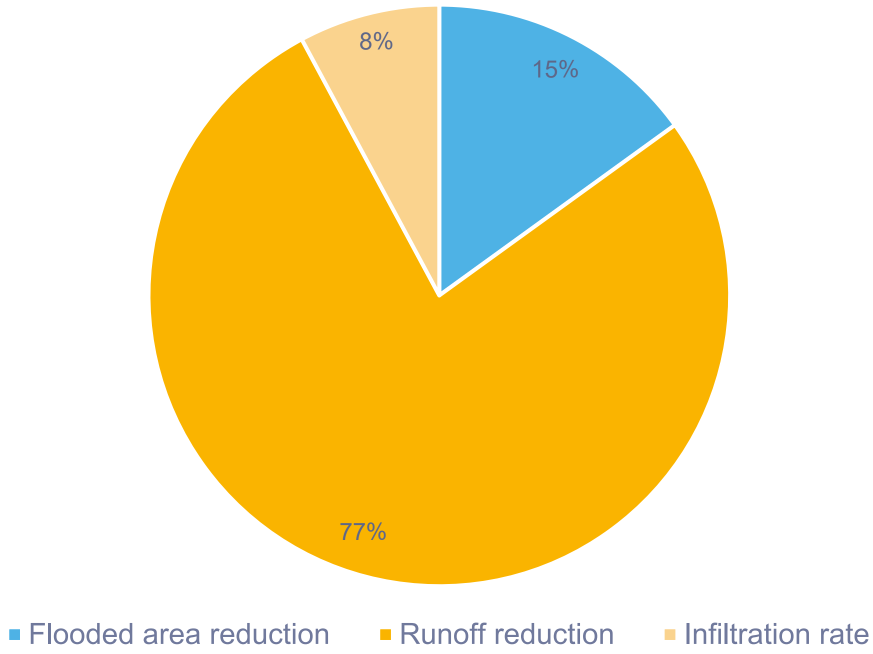


Figure 15. Representativeness of the flooding indicators

The next step is focused on visualizing how these indicators represent the effectivity for each measure. Table 30 shows the representativeness of these indicators per measure.

Table 30. Representativeness of each flood indicator per measure

Measure	Indicator	Entries	Cases	References
Container systems	Infiltration rate	10	3	1
Green roofs	Flooded area reduction	1	1	1
	Runoff reduction	52	16	16
Flood gates	Flooded area reduction	1	1	1
Floodplain rehabilitation	Flood height reduction	7	1	1
Grass	Runoff reduction	2	2	2
Trees	Runoff reduction	8	5	4
	Infiltration rate	1	1	1
Park	Runoff reduction	16	7	6

Measure	Indicator	Entries	Cases	References
Infiltration trenches	Runoff reduction	2	1	1
Permeable pavement	Flooded area reduction	10	1	1
	Infiltration rate	1	1	1
Bioretention basin	Flooded area reduction	11	2	2
	Runoff reduction	23	5	4
Rainwater harvesting system	Runoff reduction	15	2	2

As mentioned, and observed in the previous table, runoff reduction is the indicator most frequently addressed in the literature, representing 73.8% of the effectiveness entries. However, not all measures contain information on this indicator. As it can be observed in Table 30, there are some measures for which there is only information on one specific indicator, while others have information on two flood indicators. The following three tables provide the representativity of the different indicators by listing the measures for which effectiveness entries are available for each indicator.

4.2.1. Harmonization of metrics

Regarding the parameters to measure the effectiveness of flooding measures, the same approach as before was followed. Several parameters were identified during the literature review, but finally 3 were selected as they are the most used to measure flood effectiveness.

- Flooding area reduction
- Runoff reduction
- Infiltration rate

The literature review identified different units (%, cm, m, hm, inches, etc) for theses parameters. However, to ensure comparability between options, the units linked to each parameter were simplified and clearly defined in the following way:

Table 31. Indicators and units

Parameter	Unit
Flooding area reduction	%
Runoff Reduction	% or cm
Infiltration rate	mm/h or l/h.m^2

4.2.2. Harmonization of the values (overall ranges)

With the collected information for each measure and flooding indicator, effectiveness ranges are calculated. Additionally, considering the values of effectiveness gathered per indicator, Table 32-34 were created for each indicator to categorise the effectiveness of the measures from Not effective, Low, Medium and High. The next three tables provide information on the ranges of effectiveness linked to each indicator.

Table 32. Flooding area reduction ranges of effectiveness

Threshold range	Performance
Flooding area reduction > 50%	High
20% < Flooding area reduction < 50%	Medium
0% < Flooding area reduction < 20%	Low
Flooding area reduction< 0%	Not effective

Table 33. Runoff Reduction ranges of effectiveness

Threshold range	Performance
Runoff Reduction> 30%	High
10% < Runoff Reduction < 30	Medium
0% < Runoff Reduction < 10%	Low
Runoff Reduction< 0%	Not effective

Table 34. Infiltration rate ranges of effectiveness

Threshold range	Performance
Infiltration rate > 35 mm/h	High
10 mm/h < Infiltration rate < 35 mm/h	Medium
0,5 mm/h < Infiltration rate < 10 mm/h	Low
Infiltration rate < 0.5 mm/h	Not effective

Taken into account the above-mentioned ranges to measure the effectiveness of each indicator, and considering the average values of the effectiveness entries gathered from this literature review, it can be staged (see Table 35) that high run off reduction can be achieved by several measures, such as green roofs, infiltration trenches, bioretention basin, rainwater harvesting system and/or parks (achieving a reduction of more than 30%), infiltration trenches being the measure that achieves the highest percentage of reduction. On the other hand, tree planting is also a good measure as it achieves a reduction of almost 30% (marked MEDIUM-HIGH in the table). Finally, the planting of grass is another medium effective measure, but it is only half as effective than bioretention basins or infiltration trenches.

Table 35. Effectiveness of the measures considering the runoff reduction

Measure	Effectiveness	Entries	Papers
Green roofs to reduce near-surface temperature	HIGH	21	15
Grass	MEDIUM	2	2
Trees	MEDIUM-HIGH	8	4
Parks	HIGH	15	5
Infiltration trenches	HIGH	2	1
Bioretention basin	HIGH	23	4
Rainwater harvesting system	HIGH	15	2

Considering the flooding area reduction (Table 36) achieved by implementing different measures, flood gates, permeable pavements and bioretention basins are the most effective measures, with flood gates being the most effective of all measures.

Table 36. Effectiveness of the measures for the flooding area reduction

Measure	Effectiveness	Entries	Papers
Green roofs to reduce near-surface temperature	MEDIUM	1	1
Flood gates	HIGH	1	1
Permeable pavement	HIGH	10	1
Bioretention basin	HIGH	11	2

Finally, for the infiltration rate achieved by the different measures, there are only two measures with information regarding their effectiveness. Trees showed to be effective in increasing infiltration rate while the permeable pavements did not show high performance. It has to be noted that higher number of entries would allow a more robust analysis of these resilience measures.

Table 37. Number of entries per type of the measures for the infiltration rate indicator

Measure	Entries	Papers
Trees	1	1
Permeable pavement	1	1

Regarding the above tables, it is also important to emphasise that the effectiveness values were obtained considering different entries. The last two columns of the Table 35, Table 36,

Table 37 show the number of entries and papers that were considered to determine the average effectiveness of the resilience measures for each indicator. This means that there are measures for which a greater representativity of bibliography sources was collected and others for which less sources were gathered, which we call the representativity of the effectiveness values. Additionally, there is another issue regarding the variability of the values, namely the differences between the maximum average value, average value, and minimum value. In these cases, a more detailed analysis is needed to detect the reason for each variability.

4.2.3. Harmonization based on determining factors

Each resilience measure has a different effectiveness depending on the specific context, circumstances, and assumptions. This means that the way effectiveness is evaluated, the so-called value, also needs to be harmonized. This section describes relevant factors that could be used to harmonize the data.

The scale of implementation is an important component that affects the evaluation of effectiveness. For example, most studies evaluate the effectiveness of green roofs at the building scale (green roofs retain on average 41% of rainwater (extracted from Table 38)). However, further studies are needed to determine their effectiveness at the meso-scale (city or catchment). Nevertheless, green roofs, with their water retention capacity, can be a useful measure to reduce stormwater flooding at city or even catchment scale. Another important factor is intensity of precipitation that falls at the time of the effectiveness analysis. The lower the amount of rainfall during an event, the greater the proportion of rainfall retained by natural solutions. During the most intense rainfall events, most measures are saturated and therefore cannot retain all the rain that falls on them.

As an example of the above, Table 38 shows how the effectiveness of green roofs depends on the amount of precipitation. From this table it can be deducted how important it is to provide effectiveness values together with rain intensity for to better assess the performance of resilience measures.

Table 38. Green roof retention values for different events based on their rainfall values

Reference	Small events		Medium events		Large events	
	Rainwater volume	Retention	Rainwater volume	Retention	Rainwater volume	Retention
Carter and Rasmussen (2006)[21]	<25,4 mm	88%	25.4-76.2 mm	>54%	>76.2 mm	48%
Simmons et al. (2008)[22]	<10mm	100%	12 mm	26-88%	28 mm 49 mm	8-43% 13-44%
Teemusk and Mander (2007) [23]	<21mm	86%			>21 mm	Not significant
Lee et al. (2013) [24]	<20mm	60%			>20 mm	Not significant
Speak et al. (2013)[25]	<2mm	68%	2-10 mm	70%	>10 mm	

Hakimdavar et al. (2014) [26]	<20mm	97%	20-40 mm	45%	>40 mm	37%

4.3. Effectiveness assessment analysis of resilience measures against earthquakes

After the literature search, 26 paper were selected and analysed for inclusion in the database. These included 42 cases and corresponded to 164 entries (Table 39) for the selected resilience metrics related to earthquakes.

Table 39. Entries, cases, and references by Resilience Measures

Resilience Measures	Entries	Cases	References
Risk and vulnerability assessment methods	4	2	1
Tie rods and hoops system	43	1	1
Structural reinforcement to better withstand seismic actions	79	31	20
Traditional skills (i.e. conservation of structural authenticity and use of original constructive material and techniques) and periodic maintenance (before-event)	39	8	4

Table 40 reports the number of entries, cases, and references for each specific earthquake indicators, described in Section 3, which quantifies the effectiveness of resilience measures.

Table 40. Entries, cases, and Papers by Earthquakes Indicators

Earthquake Indicators	Entries	Cases	References
Physical damage reduction (%)	9	5	2
Annualized collapse probability reduction (%)	14	1	1
Risk index (IS-V / %NBS) increase (%)	22	10	4
Expected Annual Loss (EAL) reduction (%)	14	2	2
Resistance Increase (%)	5	2	2
Reduction of observed minor damage (%)	109	7	4
Reduction of observed moderate damage (%)	109	7	4
Reduction of observed severe/heavy damage (%)	99	4	3
Reduction of observed collapse (%)	106	7	6

Table 41 reports the results of analysing the resilience effectiveness after processing and aggregating the data entries.

It can be observed from the Table 41 how the effectiveness of "*tie rods and hoops system*" (ID RM=34) applied to masonry building types has proved great effectiveness to reduce damages at all the different observed damage levels analysed (i.e. minor, ID EI=8; moderate ID EI=9, severe ID EI=10 and collapses ID EI=11). The effectiveness is maximum in reducing moderate damages (*i.e.* Max=20% moderate damage decrease and decrease as far as the reduction of collapses is concerned (Max=14%)).

This trend is confirmed for the resilience measure "*Structural reinforcement to better withstand seismic actions*" (ID RM=69), which has a higher effectiveness compared to "tie rods and hoops system" (*i.e*. Max=83% moderate damage decrease, Max=24% collapse decrease).

"*Traditional Skill along with good maintenance*" (ID RM=191) applied to masonry building types, although not comparable to above-mentioned structural interventions, which have a non-negligible effectiveness (Max damage decrease from 7 to 9 %), that actually "*Structural reinforcement to better withstand seismic actions*" proved high effectiveness also when implemented in reinforce concrete building types. The Risk index (IS-V / %NBS, ID EI=3) Max increase 68%; the Expected Annual Loss (EAL) reduction, ID EI=4, Max increase 66%; Resistance Increase, ID EI=5 (Max =171%).

Table 41. Entries, cases, and Papers by Earthquakes Indicators.

Resilience Measure	Earthquake Indicator	Min	Mean	Max	Entries	Cases	References
Tie rods and hoops system	Reduction of observed moderate damage (%)	1.0	9.30	19.00	43	1	1
	Reduction of observed moderate damage (%)	1.0	8.91	20.00	43	1	1
	Reduction of observed severe/heavy damage (%)	1.0	8.17	18.00	43	1	1
	Reduction of observed collapse (%)	1.0	8.20	14.00	43	1	1
Structural reinforcement	Annualized collapse	12.00	62.86	86.00	14	1	1

Resilience Measure	Earthquake Indicator	Min	Mean	Max	Entries	Cases	References
to better withstand seismic actions	probability reduction (%)						
	Risk index (IS-V / %NBS) increase (%)	9.00	31.40	68.00	22	10	4
	Expected Annual Loss (EAL) reduction (%)	16.00	38.57	66.00	14	2	2
	Resistance Increase (%)	41.00	103.00	171.00	5	2	2
	Reduction of observed moderate damage (%)	2.0	23.900	83.00	28	4	2
	Reduction of observed moderate damage (%)	1.0	29.67	50.00	28	4	2
	Reduction of observed severe/heavy damage (%)	1.0	19.50	38.00	18	1	1
	Reduction of observed collapse (%)	1.0	10.80	24.00	25	4	4
Traditional skills (i.e. conservation of structural authenticity and use of original constructive material and techniques) and periodic maintenance	Reduction of observed moderate damage (%)	1.0	4.80	9.0	38	2	1
	Reduction of observed moderate damage (%)	1.0	5.0	9.0	38	2	1
	Reduction of observed severe/heavy damage (%)	1.0	4.90	9.0	38	2	1

Resilience Measure	Earthquake Indicator	Min	Mean	Max	Entries	Cases	References
(before-event)	Reduction of observed collapse (%)	1.0	4.88	7.0	38	2	1

5. Results and conclusions from economic performance of resilience measures

This section summarizes the main outputs and conclusions that can be drawn from the reviewed literature for assessing economic performance of resilience measures. About the 21% of the presented case studies do not refer to ‘individual measures’, but to adaptation ‘strategies’ that combine and implement different types of measures at the same time to face hazards. Most of the strategies collected were designed to deal with flooding, drought, and earthquakes, with percentages of 66%, 20% and 12%, respectively.

Next subchapters are focused on the description of the information and conclusions obtained for individual measures.

Regarding locations of the cost-benefit analyses contemplated by the reviewed references, most of them were sited in USA, India and Pakistan (Figure 16). However, if the number of cases studies and scenarios is taken in mind, most of the cases were located in Greece, Fiji and USA (Figure 17).

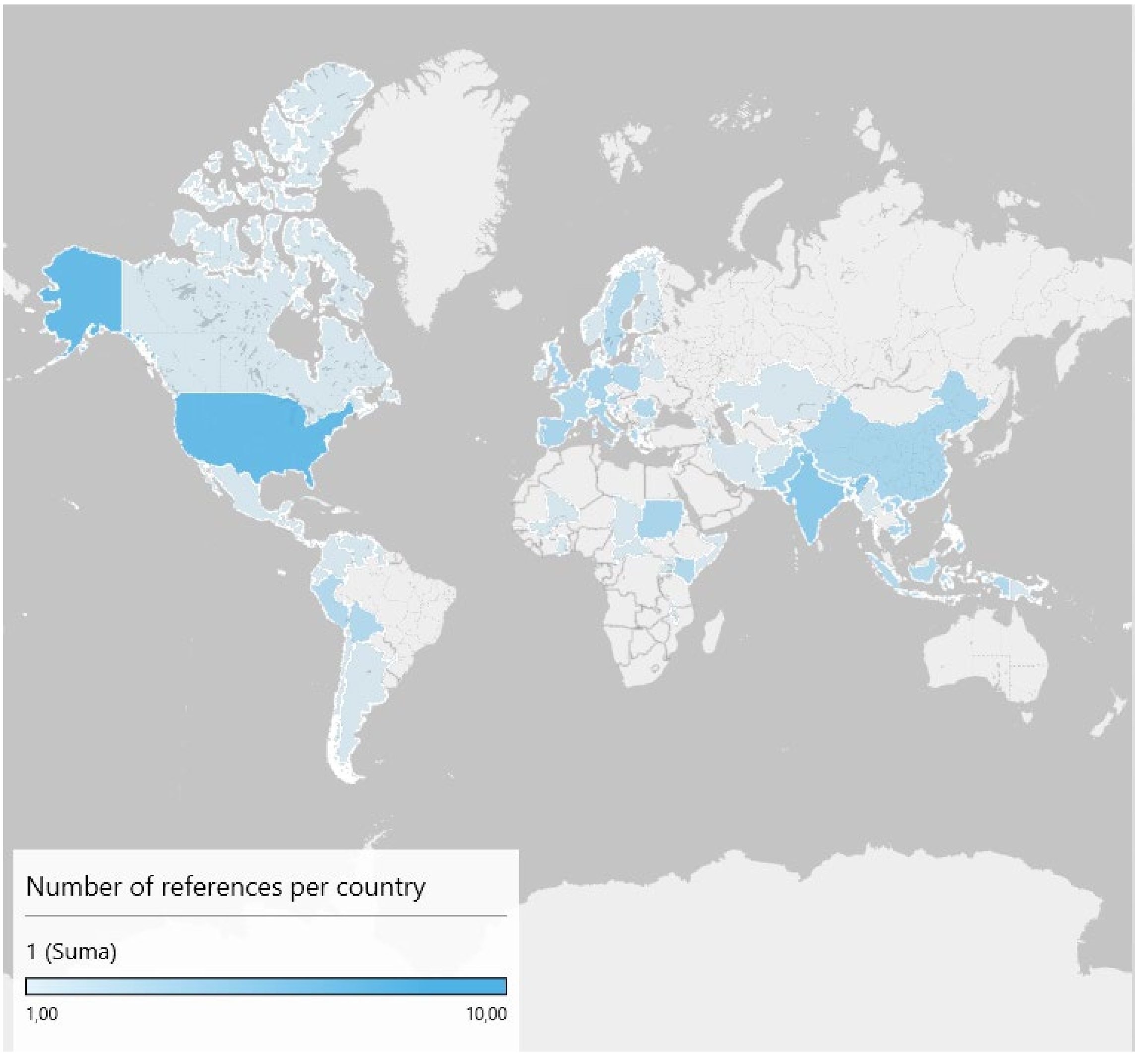


Figure 16. Number of references per country

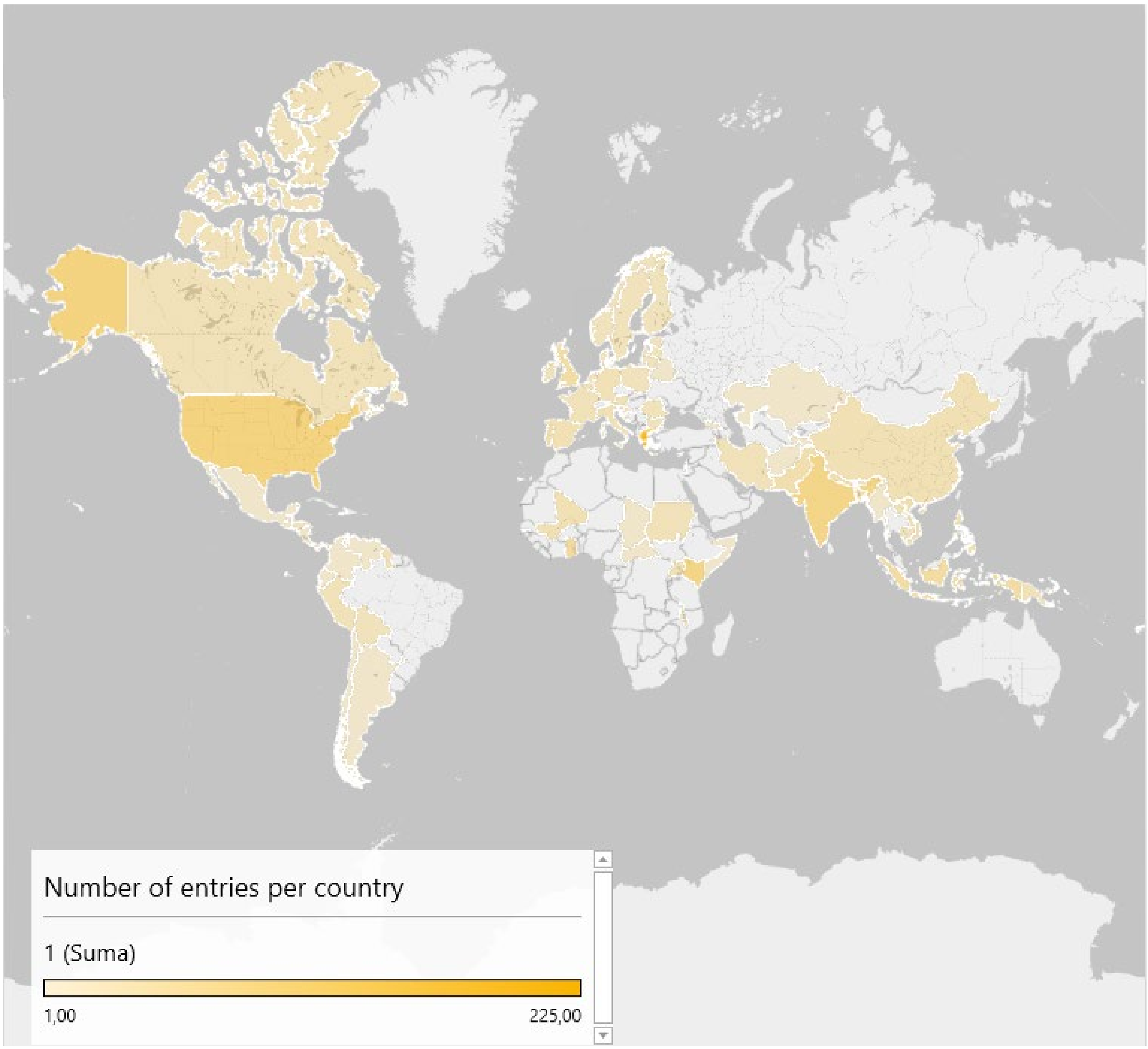


Figure 17. Number of entries per country

Most of the considered references (60%), analyse resilience measures implemented to face flooding, most of them covering fluvial and pluvial flooding (Figure 18). Drought is studied by 14% of the references. The remaining 25% consider measures regarding soil erosion, earthquakes, biological hazard, heatwaves, and landslides.

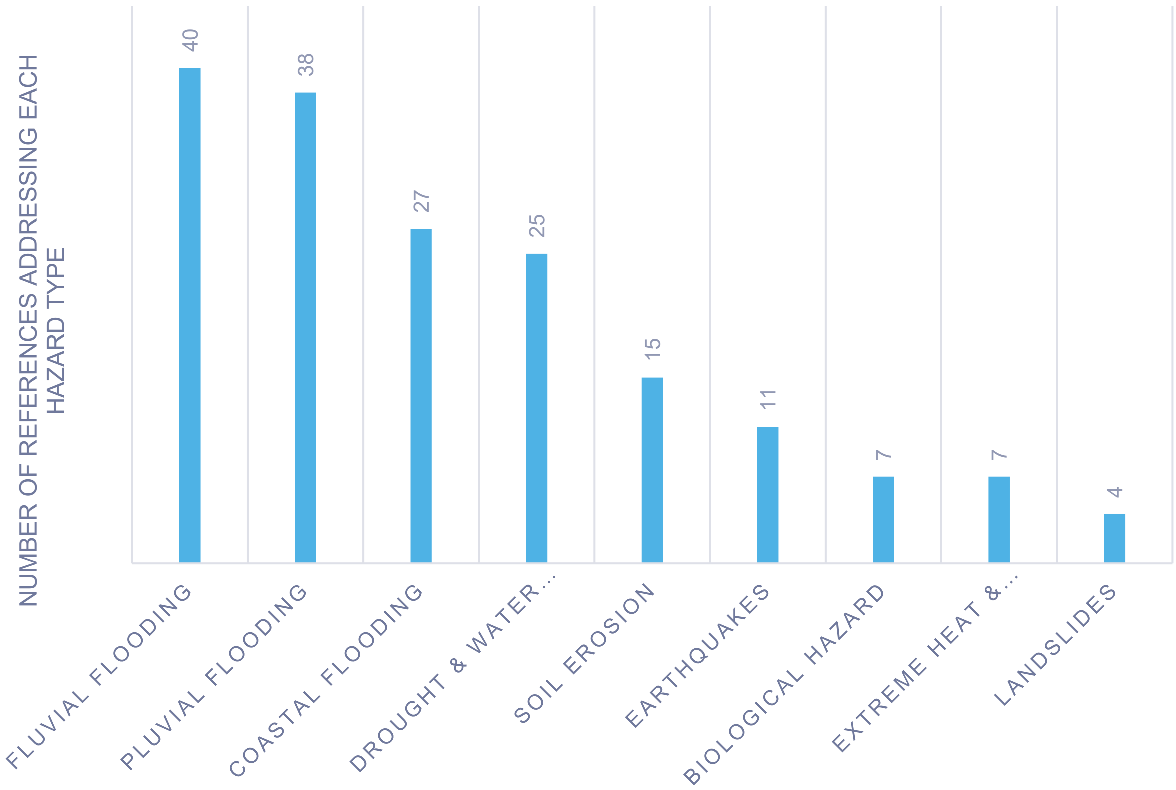


Figure 18. Number of references per hazard type

Regarding case studies presented in the considered references, measures to face flooding represent 56% of the entries and drought is considered in 23% of the entries (Figure 19). The remaining 21% consider measures in relation to soil erosion, earthquakes, biological hazard, heatwaves, and landslides.

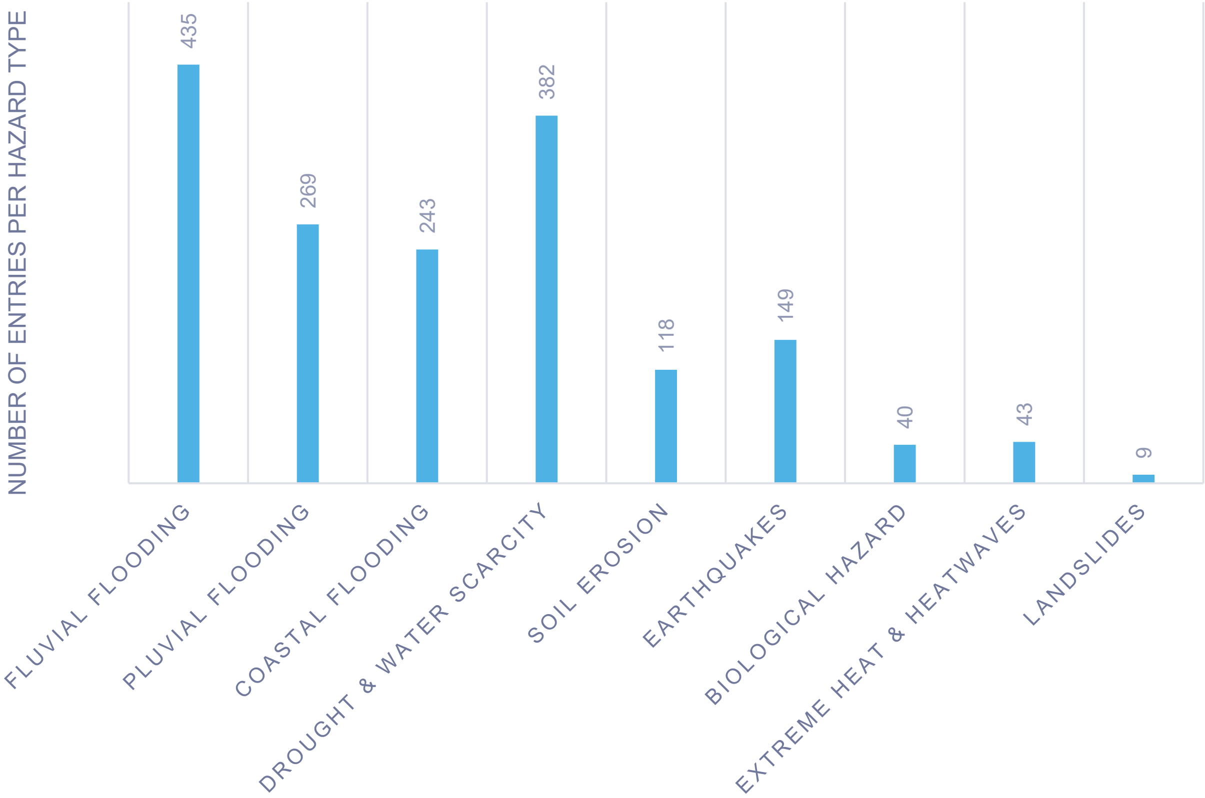


Figure 19. Number of entries per hazard type

Table 42. shows the list of groups of resilience measures covered by the considered references.

Table 42.Summary of references and entries per group of resilience measures

Group of resilience measure	Number of references per group	Number of entries per group
Administrative instruments and management strategies (European, national, or regional)	9	66
Buildings codes and regulations	2	12
Crop adaptation and sowing	8	204
Developing resilient communities	2	2
Economic instruments that enable a government being prepared to answer to the risks and damages that a hazard may cause	2	3
Emergency and evacuation planning	1	1
Emergency security, stabilization, and protection techniques	3	9
Forecasting, monitoring and Early Warning Systems	9	80

Group of resilience measure	Number of references per group	Number of entries per group
R&D&I measures and knowledge generation	1	1
Rehabilitation, restoration and conservation interventions in buildings	11	210
Relocation or removal	1	7
Soil management	12	175
Spatial planning	5	33
Sustainable and efficient water management	11	85
Traditional knowledge systems for disaster mitigation	1	1
Urban interventions	23	291
Total	**58**	**1180**

On the one hand, 16 groups are covered in the reviewed literature. As it can be seen, measures included in group “urban interventions” are the most common ones addressed withing the considered literature (40%), followed by the ones grouped as “soil management” (21%), “rehabilitation, restoration and conservation interventions in buildings” (19%) and “sustainable and efficient water management” (19%). Attending the number of case studies provided by the reviewed literature, measures included in “urban interventions” category are again the most common ones (25%), followed by the ones grouped as “rehabilitation, restoration and conservation interventions in buildings” (18%) and “crop adaptation and sowing” (17%).

On the other hand, no BCRs information could be found for the groups of measures: “damage evaluation” and “risk assessment”.

In relation to measures specifically aimed at natural and cultural heritage, it should be noted that in almost all the BCR analysed cases, they are not considered. Although in specific cases heritage and/or landscape are mentioned when considering social and economic costs, only one case was found in Italy, in which the earthquake mitigation measures are specifically aimed at the built heritage [27].

5.1. General conclusions for individual measures

As mentioned in previous chapters, BCR was considered the most appropriate metric to characterize the economic performance of the resilience measures. From data collection, it can be concluded that almost 70% of the case studies showed cost-efficient results (BCR ≥ 1) as seen in Figure 20:

- 33% of the case studies showed BCR lower than 1.
- 47% of the case studies showed BCR between 1 and 5.

- 9% of the case studies showed BCR between 5 and 10.
- 11% of the case studies showed BCR greater than 10.

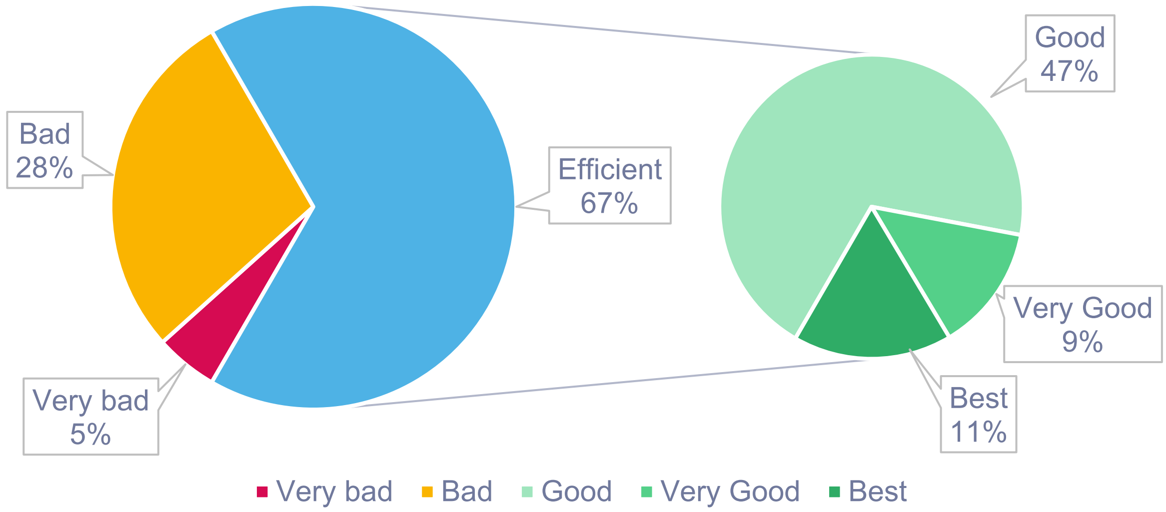


Figure 20. Percentage of case studies in each BCR range

In general terms, most of the groups presented more efficient than inefficient case studies, except for "rehabilitation, restoration and conservation interventions in buildings", where most of the analysed cases showed BCRs lower than 1.

By location, almost the same amount of case studies was collected for the most and least developed countries[12] (49% and 51% respectively). The information collected does not allow robust conclusions to be drawn, as both type of countries have both cost-efficient and inefficient case studies, with most of them being profitable:

- Most developed countries (HDI > 0,8) showed a 72% of cost-efficient measures.
- Least developed countries (HDI < 0,8) showed a 61% of cost-efficient measures.

As shown in Figure 21, the share of cost-efficient measures is higher in the most developed countries (53%) and the share of non-efficient measures is slightly higher in the least developed countries (60%).

[12] Criteria applied: Human Development Index (HDI). Most developed countries were selected as the ones with HDI score above 0,80 in accordance with Developed Countries List 2022 available in https://worldpopulationreview.com/country-rankings/developed-countries.

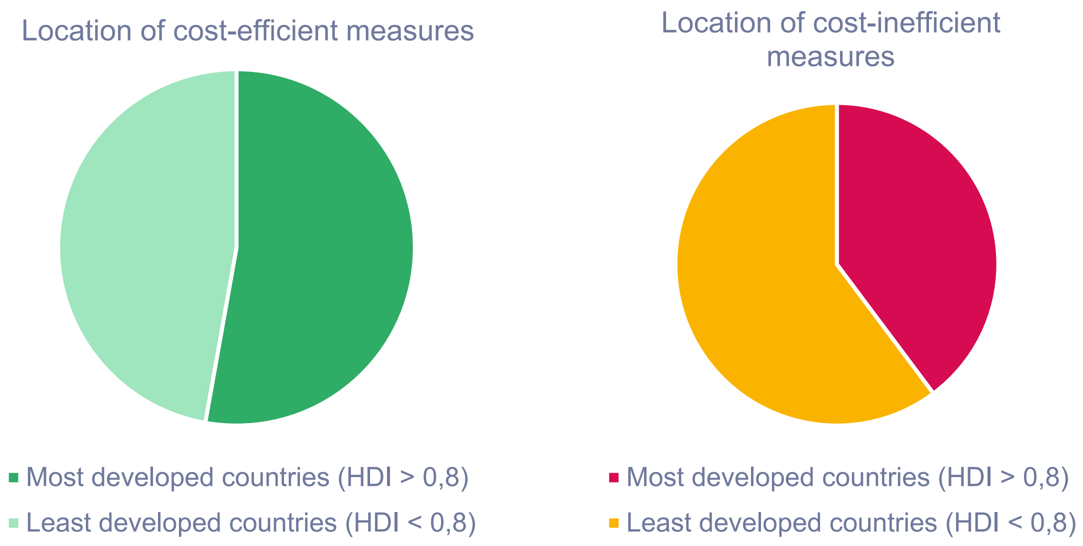


Figure 21. Relation between economic performance and location of the case study

The type of resilience measure applied was first grouped to look for tendencies. Differences in the amount of case studies collected for each group makes it difficult to draw robust conclusions. Most of the groups show more efficient than inefficient case studies, being measures grouped as "relocation or removal" and "buildings codes and regulations", which seem to show a poorer economic performance:

- Results shown for group "buildings codes and regulations" mainly refer to the measure "implementation of building code requirements for buildings at risk from flooding". 80% of the collected case studies where this measure was implemented resulted in BCR < 1, compared to 20% of cases showing BCR between 1 and 5.
- Results shown for group "relocation or removal" mainly refer to the measure "moving the built Heritage (partially or totally)". All de collected case studies where this measure was implemented resulted in BCR < 1.

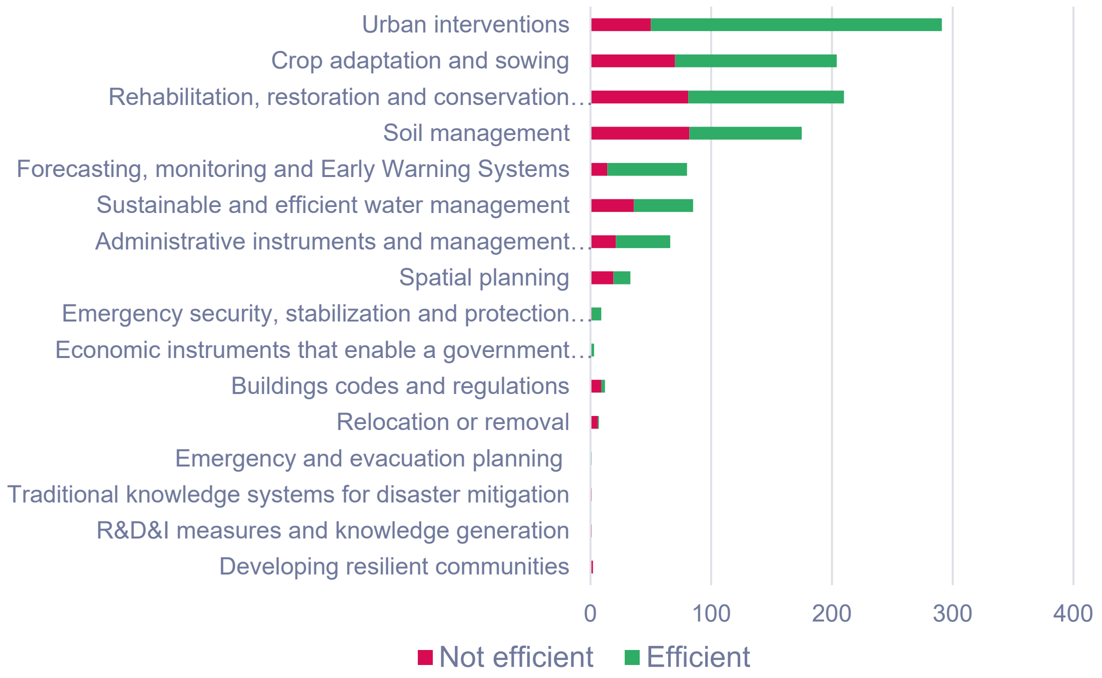


Figure 22. Number of case studies per group showing good (BCR > 1) and bad (BCR < 1) economic performance

5.1.1. Economic performance of resilience measures to cope with flooding

BCR collected from reviewed literature show a wide range of dispersion, finding measures whose implementation was not profitable (BCR < 1) for some case studies and very profitable (BCR > 10) for others. The differences in the amount of case studies collected for each measure makes it difficult to draw robust conclusions. Best average rates were observed for the following resilience measures:

- Awareness-raising campaign to the community on hazards and risks
- Building walled areas to maintain Heritage sites below sea level
- Establishment of small ponds in rainwater collection areas
- Identification of temporary alternatives to key physical infrastructure and basic services
- Economic instruments that enable institutions reducing vulnerability

Gazing over the cost-inefficient measures, the following present BCR lower than 1 in all the collected scenarios:

- Early warning systems for vulnerable groups
- Insurance allocation for emergencies
- Wrapping, relocating, and reporting
- Structural reinforcement to roofs
- Ditches to divert ground water and avoid erosion

Figure 23 summarise results collected for all the resilience measures analysed to cope with flooding. Green bars represent BCR range observed in literature for each measure.

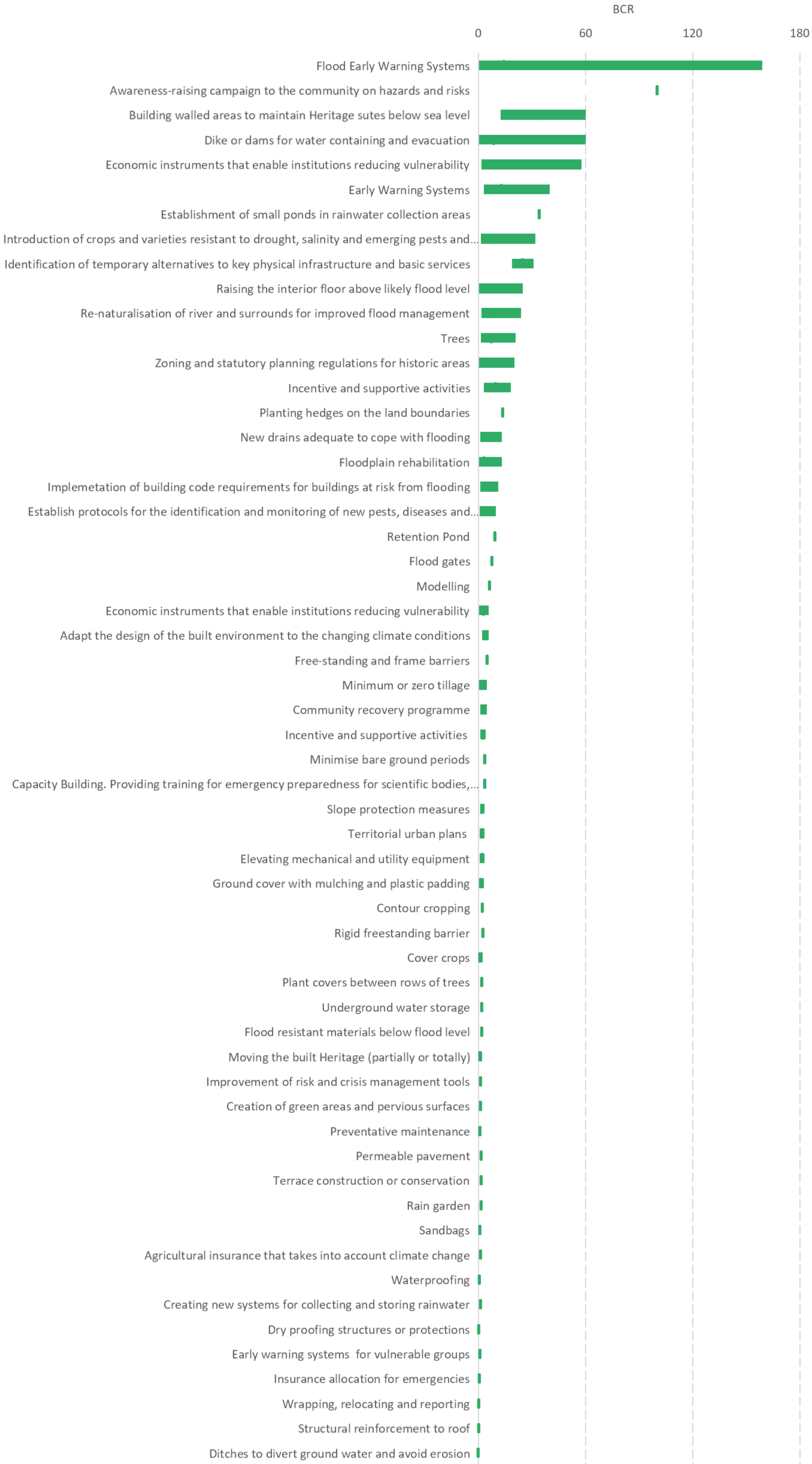


Figure 23. BCR ranges obtained for measures coping flooding

5.1.2. Economic performance of resilience measures to cope with extreme heat and heatwaves

The differences in the amount of case studies collected for each measure makes it difficult to draw robust conclusions. Best average rates were observed for the following resilience measures:

- Air conditioning
- Establishment of early warning systems for high temperatures
- Modelling
- Plant covers between rows of trees
- Crop rotation

On the contrary, “cover crops” showed the worst BCR followed by “awareness-raising campaigns” and “design and planning of irrigation based on water and energy efficiency criteria”. However, these two last measures are yet slightly efficient.

Figure 24 summarise results collected for all the resilience measures analysed to cope with extreme heat. Green bars represent BCR range observed in literature for each measure.

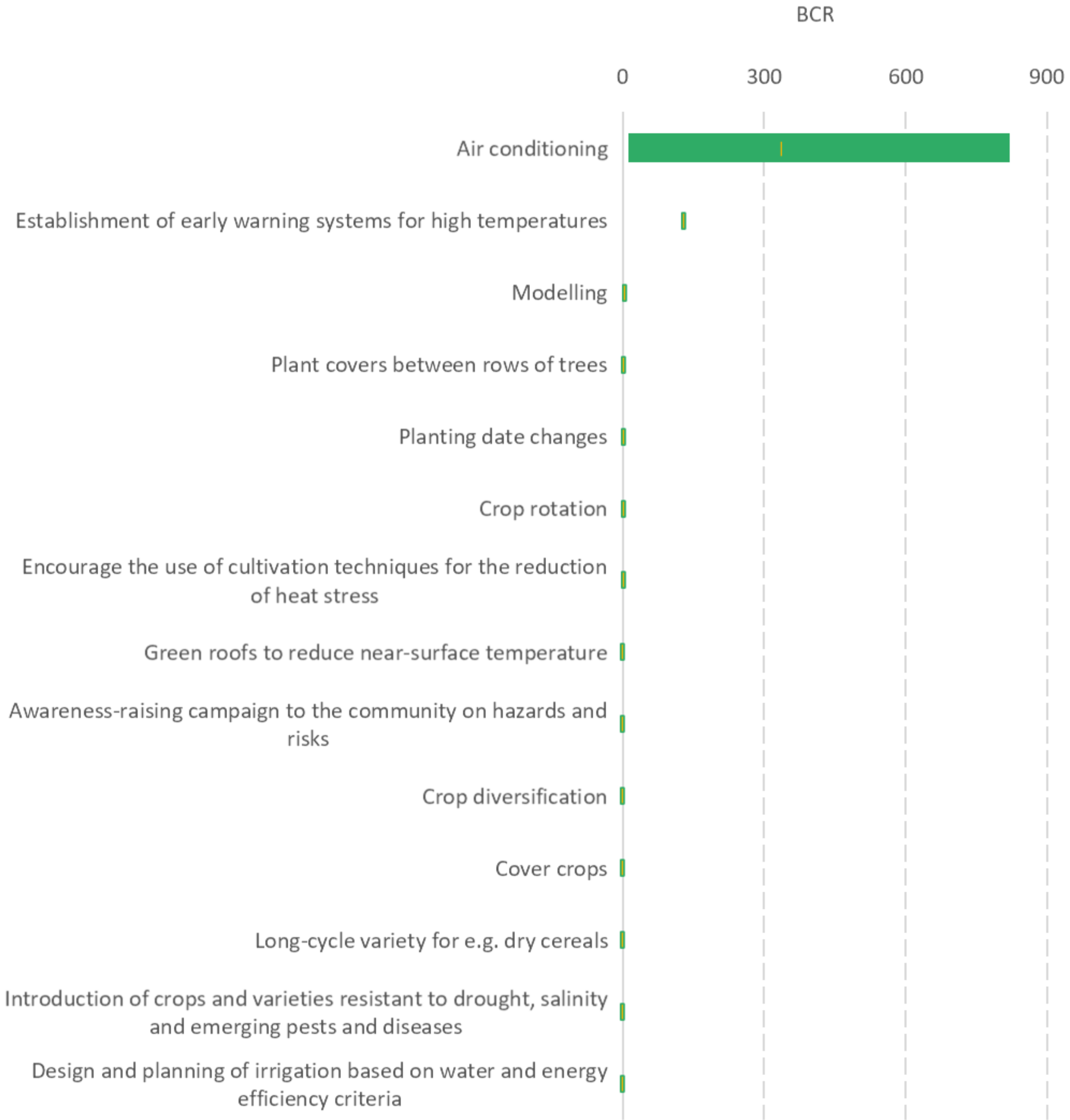


Figure 24. BCR ranges obtained for measures coping extreme heat and heatwaves

5.1.3. Economic performance of resilience measures to cope with drought and water scarcity

BCR collected from reviewed literature show a wide range of dispersion, finding case studies where the implementation of certain measures was not profitable (BCR < 1) and others with very high profitability (BCR > 10) for the same measures. The following are the ones showing greater dispersion.

- Planting date changes
- Introduction of crops and varieties resistant to drought, salinity and emerging pests and diseases
- Introduction of crops and varieties resistant to drought, salinity and emerging pests and diseases

- Efficient irrigation technology (e.g. drip)
- Creating new systems for collecting and storing rainwater
- Increase water retention in the soil through small drainage channels
- Design and planning of irrigation based on water and energy efficiency criteria
- Contour cropping

The differences in the amount of case studies collected for each measure makes it difficult to draw robust conclusions. Best average rates were observed for the following resilience measures:

- Automation and remote control of gravity irrigation
- Economic instruments that enable institutions reducing vulnerability
- Incentive and supportive activities
- Early Warning Systems
- Terrace construction or conservation

On the contrary, “minimum or zero tillage” and “planting date changes” showed the worst BCR results in the collected literature, followed by “Increase of freshwater availability” and “Public education for good response against hazards”

Figure 25 below summarise results collected for all the resilience measures analysed to cope with water scarcity. Green and red bars represent BCR range observed in literature for each measure (red bars highlight negative BCR values).

Figure 25. BCR ranges obtained for measures coping drought and water scarcity

5.1.4. Economic performance of resilience measures to cope with earthquakes

The differences in the amount of case studies collected for each measure makes it difficult to draw robust conclusions. Best average rates were observed for the following resilience measures:

- Anchoring of moveable objects to avoid damages
- Early Warning Systems
- Modelling
- Adapt the design of the built environment to the changing climate conditions
- Incentive and supportive activities

On the contrary, “resistance reinforcement of walls” and “traditional skills and techniques in building construction and periodic maintenance” showed the worst BCR results in the collected literature.

Figure 26 summarise results collected for all the resilience measures analysed to cope with earthquakes. Green bars represent BCR range observed in literature for each measure. Orange dots show average BCR. Blue line shows BCR down limit for cost-efficient measures (BCR = 1).

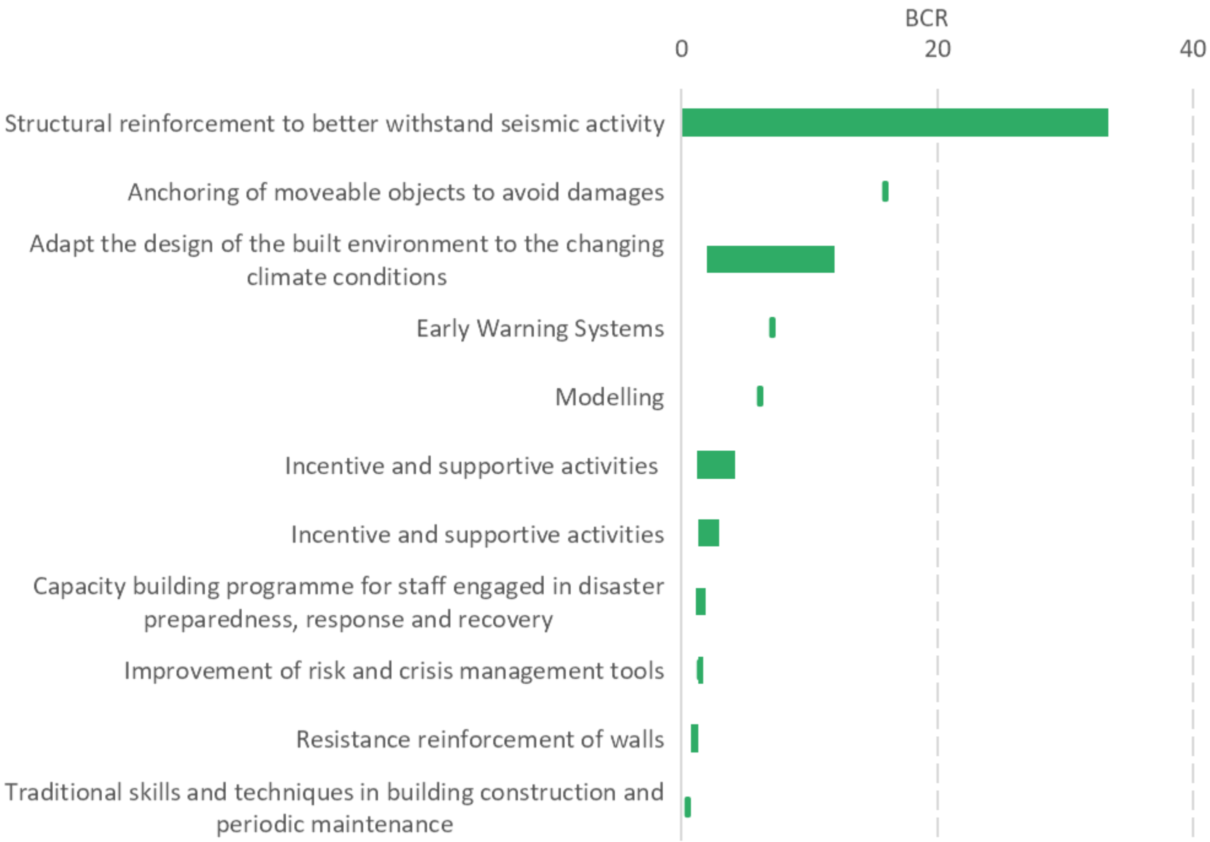


Figure 26. BCR ranges obtained for measures coping earthquakes

5.1.5. Economic performance of resilience measures to cope with biological hazard

The collected measures to cope with biological hazard seem to be profitable in most of the analysed case studies and scenarios. “Programmes and policies” and “plant covers between rows of trees” show very good average rates, however, a wide range of dispersion was observed with case studies with a not profitable (BCR < 1) and others with high profitability implementation.

Best average rates were observed for the following resilience measures:

- Programmes and policies
- Modelling
- Promoting biological control of pests and diseases
- Introduction of crops and varieties resistant to drought, salinity and emerging pests and diseases

Even though lower BCRs were observed in the implementation of “crop rotation” and “plant covers between rows of trees”, both could be cost-efficient (BCR>1) in accordance to the collected literature.

Figure 27 summarise results collected for all the resilience measures analysed to cope with biological hazard. Green bars represent BCR range observed in literature for each measure.

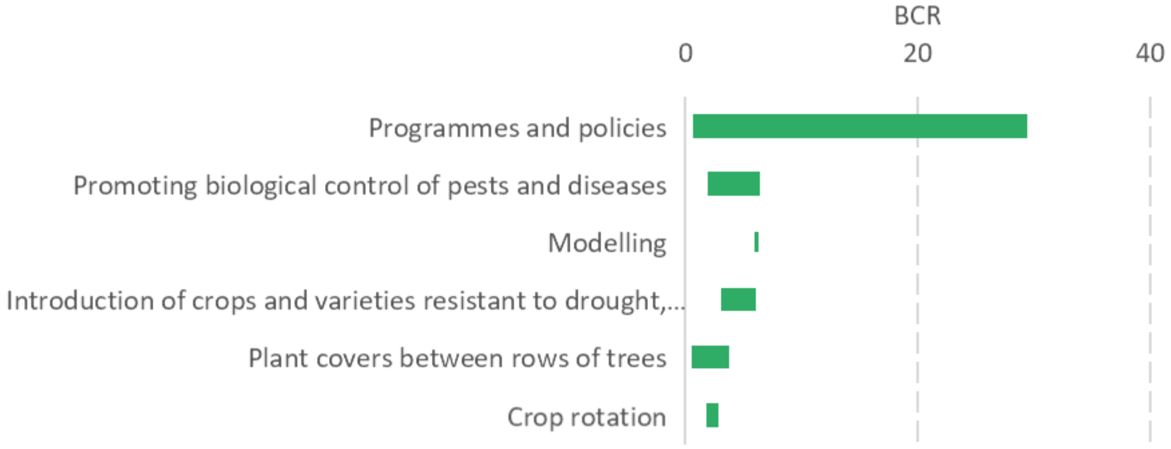


Figure 27. BCR ranges obtained for measures coping biological hazard

5.1.6. Economic performance of resilience measures to cope with soil erosion

Regarding soil erosion, the measures covered seem to be profitable in most of the analysed case studies and scenarios, showing all good average rates. However, a wide range of dispersion was observed in some cases, as for the same measure there are case studies where its implementation was not profitable (BCR < 1) and others with high profitability. The best average rates were observed for the following resilience measures:

- Re-naturalisation of river and surrounds for improved flood management
- Planting hedges on the land boundaries
- Implementing multifunctional margins
- Modelling

Figure 28 summarise results collected for all the resilience measures analysed to cope with soil erosion. Green bars represent BCR range observed in literature for each measure.

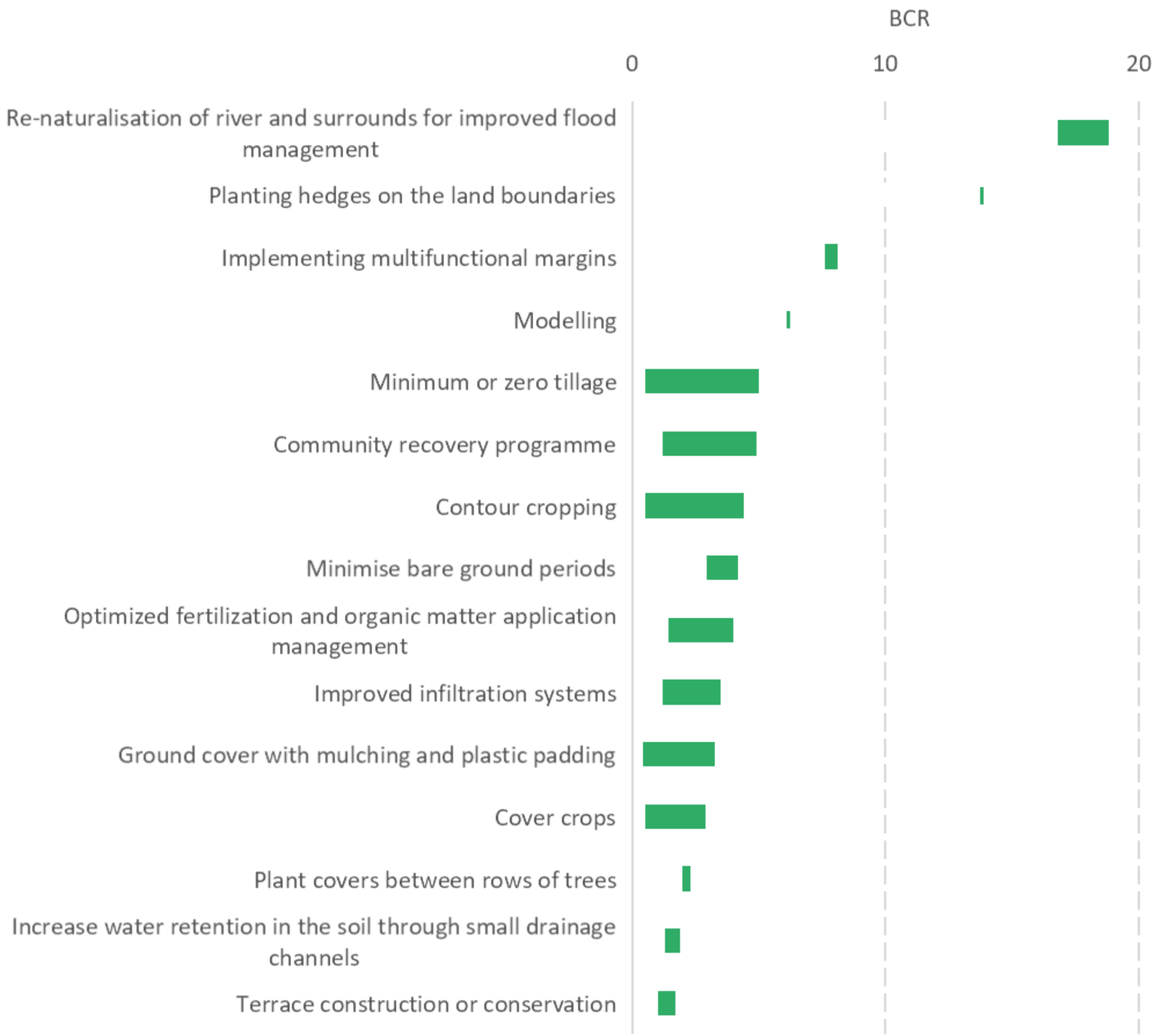


Figure 28. BCR ranges obtained for measures coping soil erosion

5.2. Benefit-cost ratio analysis: specific conclusions for measures

Based on the findings of Markanday [28], this explorative analysis aims to fill the gap discovered by this author with regards to the economy of climate change adaptation measures and decision-making in cities and urban environments. Such economic aspects have a higher level of complexity that is worthy to be evaluated in detail, as pointed out by the above-mentioned author.

The objective of this subchapter is to present the main conclusions of a wide-range analysis of the benefit-cost ratios (BCR) of different resilience measures and strategies aimed to reduce climate and other natural hazard risks.

There exists a wide variety of scenarios that have reported different BCRs for similar measures or investments as previous subchapters in section 5 have shown. In this sense, searching for economically efficient resilience measures should ideally go beyond a simple analysis of their benefits, costs or discount rates. **Deploying a comparative analysis of existing Cost Benefit (CB) analyses** in the context of this study will allow us to move forward with a

categorisation of the explored measures, **their BCRs and their particular context characteristics**. It is worth mentioning that one of the main barriers for achieving a harmonisation is the scatter BCR data that hinders a sound analysis considering the same parameter for all resilience measures. Built upon such limitation, this work sets the foundations for further harmonisation process though.

Having explored the wide range of CB rates for all the resilience measures analysed before, **a comparative assessment** of the data obtained has been developed to reach main conclusions about the elements that compose the calculation of the Cost-Benefit Ratios for different measures. As the analysis provided different dimensions of the gathered information, the approach chosen for the comparative assessment was **a scenario-based approach**. Hence, a range of BCRs is provided based on three explorative approaches assessing the economic efficiency of every "Type of resilience measure" (as resilience investment projects):

a) Range of BCRs by **countries and scale** (Element – *e.g*. building; District – *e.g*. Historic centre/town; Territory – *e.g*. Cultural Landscape; Territory_Natural Heritage) considering investment costs, benefits and discount rates
b) Range of BCRs by **nature of measure** based on different aspects (Institutional; Social; Structural)
c) Range of BCRs by the **amount of investment at different types of targets** (Moveable heritage/ Archaeological resources/ Building and structures/ Cultural Landscape)

The selection criteria used for the analysis of the references list was based on a common cost-benefit structure (Table 43). All references were evaluated according to CBA employed in the widest sense in terms of maximizing or comparing welfare, however, due to the lack of economic information in some of the references explored, instead of selecting those references which specifically fit all the selection criteria, the analysis of those measures without data were included to settle the basis for future research analysis.

Table 43. Elements of the cost-benefit analysis considered

Cost-benefit analysis elements	Unit
COSTS	
Investment Expenditure	(€ 2021)
Annual operating & maintenance costs	(€ 2021)
Costs of administrative implementation	(€ 2021)
Overall investment costs	(€ 2021)
Indirect costs	(€ 2021)
BENEFITS	
Overall benefit	(€ 2021)
Time Horizon	YEARS
PRESENT VALUE	
Time Horizon	YEARS
Value of the discount rate	%
Scenarios for the BCA	Text
BENEFIT COSTS RATIO	
Benefit-Cost Ratio (BCR)	UNIT

First, the wide range of economic data obtained was filtered to show the wide range of **time scales** and **discount rates** adopted in cost-benefit analyses on resilience measures. Figure 29 shows those examples with a time horizon inferior to 40 years.

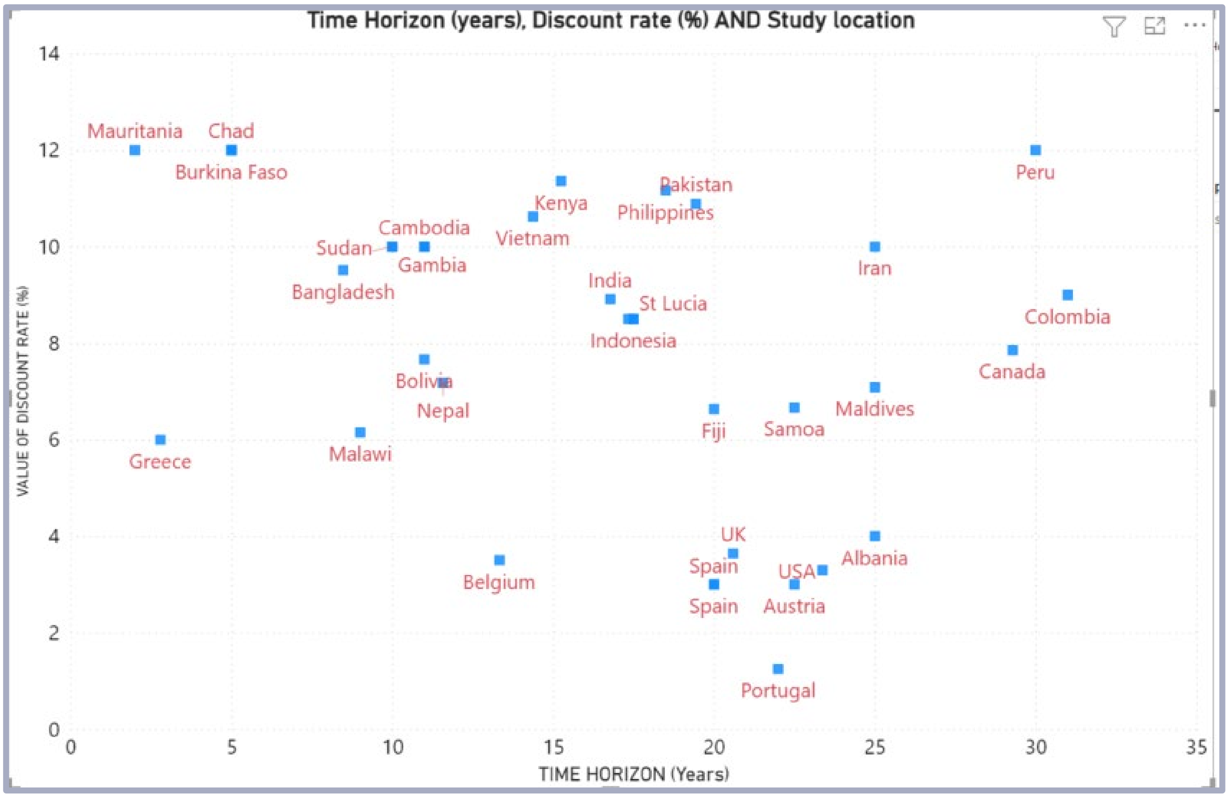


Figure 29. Value of discount rate per time horizon for case studies in different counties

Fiji and Scotland tied with the highest average time horizon (100 years) and Indonesia had the highest average value of the discount rate (12 %).

Figure 29 clearly shows that the bulk of appraisals favours short to medium time horizons*, i.e.*, between 1 and 40 years, with few extending past 60 years. These short time frames correspond to the group of measures presented in Figure 30.

Group of resilience measure	Promedio de Time Horizon (invc) (years)
Emergency and evacuation planning	30,00
Traditional knowledge systems for disaster mitigation	30,00
Urban interventions	30,00
Rehabilitation, restoration and conservation interventions in buildings	
Rehabilitation, restoration and conservation interventions in buildings	23,49
Forecasting, monitoring and Early Warning Systems	23,09
Relocation or removal	21,25
R&D&I measures and knowledge generation	20,00
Administrative instruments and management strategies (European, national or regional)	19,79
Emergency security, stabilization and protection techniques	19,17
Sustainable and efficient water management	11,33
Soil management	11,00
Crop adaptation and sowing	
Soil management	9,73

Figure 30. Group of measures with shorter time frames

Figure 31 focuses on the benefits obtained in each case and comparing the values of the discount rates used in the countries. The countries with higher discount rates are Nepal (12.5%), Colombia and Kenia (12%), Vietnam (11.4%) and Philippines (11.2%). While at the European level, rates over the value of 8% do not appear; most of the analysis of European countries has ranged from 1.4% to 8.5%.

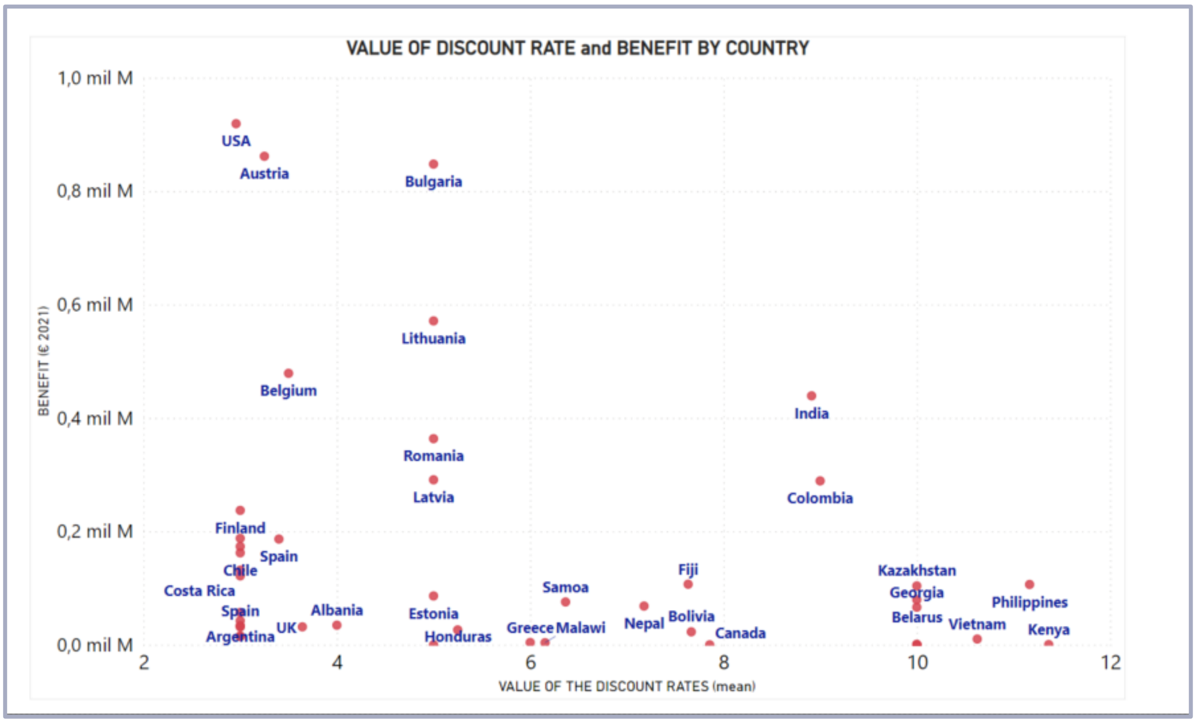


Figure 31. Benefit per values of discount rate and country

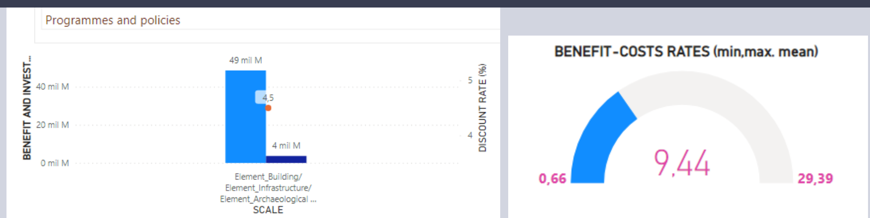
5.2.1. Benefit-cost ratio analysis: generic conclusions for measures

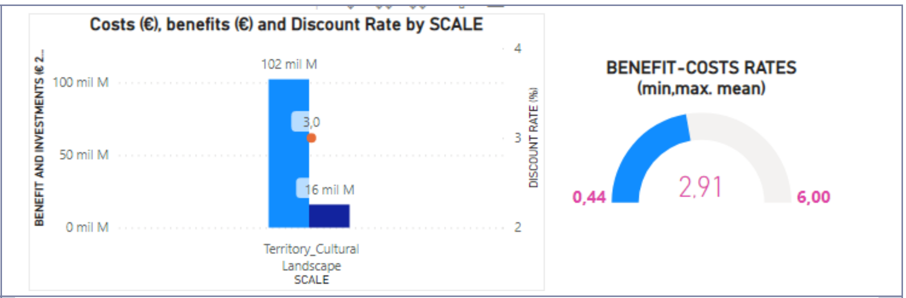
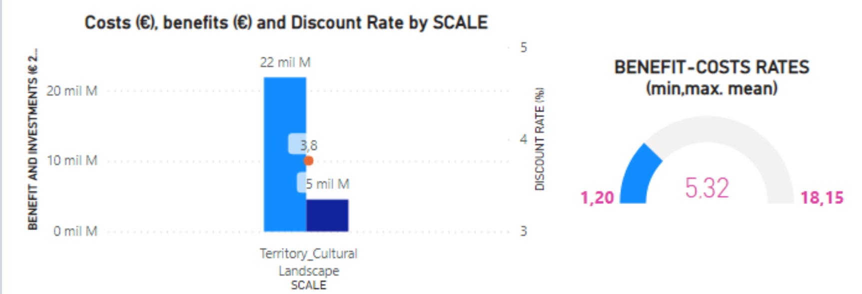
Data obtained for this resilience group has shown some measures without enough references concerning total benefits or investments, for instance. Figure 32 shows the global results of the first explorative approach which stems from observing the **range of BCRs by countries and scale** and shows the great disparity of BCRs depending on the country involved being Europe (as a whole) and the USA, those countries with higher values of benefits. Europe has obtained a BCR (13%) that is higher than most countries for which data was available in this regard.

Figure 32. Global analysis of all resilience measures

It is also noticeable that the benefits obtained from investments at ''Territory_Cultural Lanscape' with a relevant discount rate (7.1%), while the mean of the investments at scales resembles 4.5% as discount rate with a lower level of benefits and investments. A closer look at the specific measures reveals that the following measures stand for a higher volume of data for the analysis as seen in Table 44.

Table 44. Conclusions from the analysis for those groups with higher BCR data

Type of Measure – main conclusion	Analysis
'Programmes and Policies' resembles the higher BCRs	

Economic Instruments shows the highest level of investments	
Incentives and supportive activities measure resemble an unbalanced BCR mean built upon two superior BCR (14.8 & 18.2) regarding the scenario ‘Urban development and redevelopment. Ecosystem service benefits included’.	
Capacity building programmes measure shows a higher balance between total investments and benefits	

The second explorative approach shows **the range of BCRs by type of measure** based on three types: institutional, social, and structural. As the following figure shows, the vast majority of the measures analysed correspond to type ‘social’ within the subcategory ‘educational’ (Figure 33).

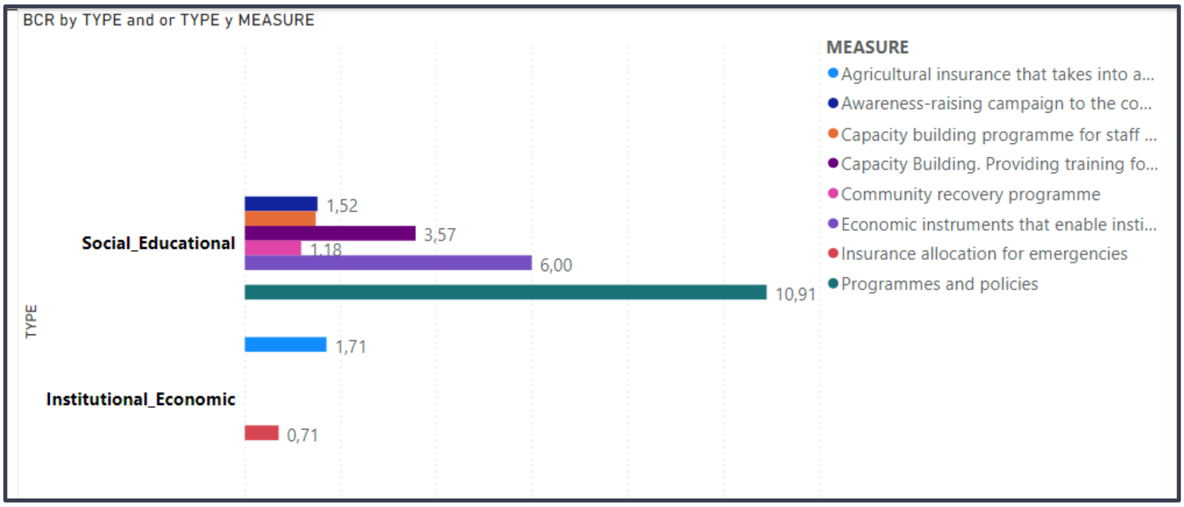


Figure 33. Range of BCRs by nature of the resilience measure

And finally, the analysis of **the range of BCRs considering the amount of investment at different types of targets** (Moveable heritage/ Archaeological resources/ Building and structures/ Cultural Landscape) has been proposed as the third explorative analysis.

The range of BCRs by the **amount of investment at different types of targets** (Moveable heritage/ Archaeological resources/ Building and structures/ Cultural Landscape). Over 48% of analysed measures correspond to the category Community Stakeholders followed by Cultural Landscape (27%). As far as the Investment value is concerned, the category ‘Building and structures’ target type represents the highest levels of investment, although the BCR is lower than the investments in Community Stakeholders target type (Table 45).

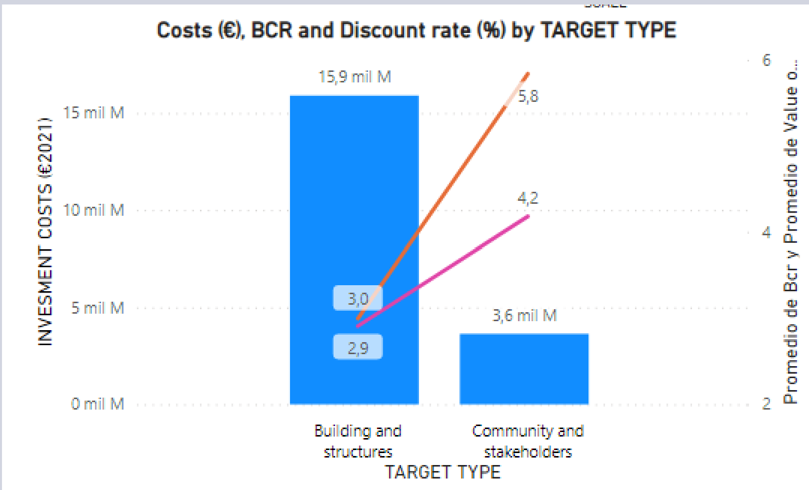
<table>
<tr><th>TARGET TYPE</th><th></th></tr>
<tr><td>Building and structures</td><td rowspan="2">
</td></tr>
<tr><td>Community Stakeholders</td></tr>
</table>

Table 45. Conclusions of the analysis by target type

6. Results and conclusions from socio-institutional performance of resilience measures

This deliverable presents the results of the workshop on assessing the acceptability of resilience measures for historic areas. This work is an initial step towards a better understanding of the limiting factors in the implementation of resilience measures in historic areas. Understanding the barriers and acceptability of resilience measures can contribute to a better consciousness of what gaps, needs, limitation heritage management face, which will allow challenges to be addressed and thus strategic planning to be better prepared.

6.1. Agriculture heritage

ARCH project aims to strengthen the resilience of historic areas to climate change-related and other hazards. While three Foundation cities focus on urban/building & structure heritage Valencia focuses on agricultural heritage, among other elements. In this case, the results of the consultation represent the acceptability and barriers in relation to Valencia which may depict the acceptability of a specific local context. Despite the limit transferability of the results to other contexts, some general conclusions can be drawn.

6.1.1. Perceived acceptability

Perceived acceptability of resilience measures was assessed at two levels:

- At subgroup of measures level for socio-institutional measures
- At measure level for structural or physical ones

The *perceived acceptability* was higher for socio-institutional measures compared to structural ones.

6.1.1.1. Socio-Institutional measures

Based on the results of the workshop, socio-Institutional measures presented higher acceptance for agricultural heritage than on urban/building & structure heritage.

These types of measures were moderately well accepted to widely accepted, being *Developing Resilient Communities*[13] the most accepted group of measures, being *Community ties* the most valued subgroup (scoring on average 5). *Research and knowledge generation* was also perceived as well accepted. Good agreement was seen among respondents on the perceive acceptability of the subgroups under these two groups of resilience measures. On the other hand, the subgroup of measures belonging to *Administrative instruments and management*

[13] Definition: Community-based adaptation and preparation instruments aiming at improving resilience against climate change-related and other hazards at both the level of the individual learner and at the level of socio-ecological systems including Cultural Heritage

strategies[14] group presented highest disagreement on acceptance among the participants. For further information see Annex 1.

6.1.1.2. Structural measures

Despite the evidence of climate change on agriculture and the need for adaptation [29], [30], structural measures often imply a physical intervention and/or a behavioural change, which burden their acceptability and thus implementation. Nevertheless, many measures were positively accepted (67%) by the three consulted stakeholders. Thirteen measures were moderately to well accepted (Figure 34). *Crop management strategies* and *Reduction of soil salinization* subgroups of measures included the highest number of measures with top-rated scores. It was also observed a good agreement among respondent for these subgroups of measures. More precisely, *Crop diversification (Crop management strategies)* and *Ridge planting (Reduction of soil salinization)* measures were the only ones that scored the highest value. On the other hand, *Efficient water conveyance* and *Reduction of soil erosion and compaction subgroups* accounted for the least preferrable measures, being *Terrace construction or conservation* the least valued measure as it is not applicable to Valencia's context. Covering of ancient open channels or their replacement are neither a valid option as it would result in the loss of their heritage.

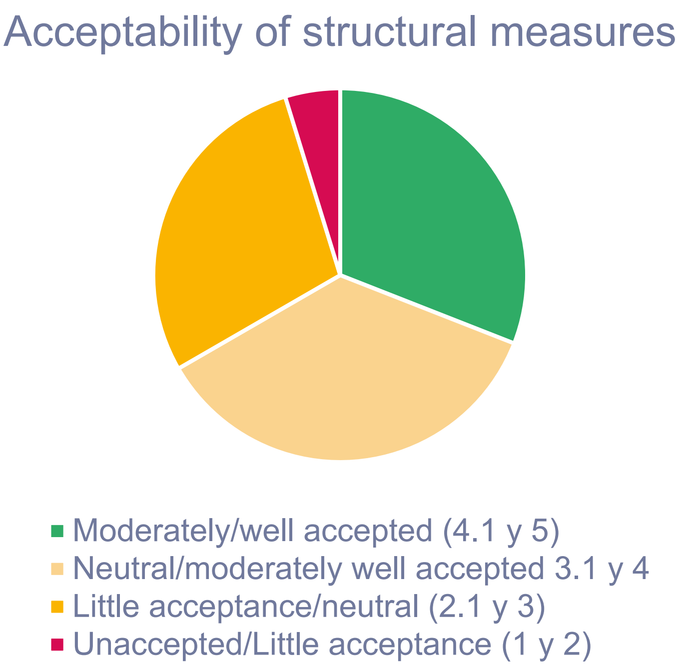


Figure 34. Perceived acceptability of structural measures dedicated to adapting agriculture

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[14] Definition: The institutional measures foster increasing resilience pre- or post-disaster by implementing economic, policy and governance measures promoted by public institutions and involving public and/or private sector. They enable being prepared to answer to the risks and damages that a hazard may cause to Cultural Heritage and therefore to the community

It must be highlighted that the participants (n=3) were local stakeholders that work close to the agriculture theme but are not farmers. Thus, this limited number of responses may not represent the general view of the end users of the agriculture section in Valencia, but a closer view of the practices from agrarian organizations.

6.1.2. Barriers

General factors that influence the adoption of climate-resilience practices in Valencia, based on the workshop, can be separated in two broad categories: (a) cultural-awareness and (b) technical-economic. Cultural barrier, understood as differences based on behaviour, communication and/or beliefs hinder the deployment of a resilience measure, was foreseen to be a significant obstacle as it implies that the way (methods, tools, knowledge) farmers have been producing their crops need to be updated. It is known that behaviour change is "complicated and complex as it requires a person to disrupt a current habit while simultaneously fostering a new, possible unfamiliar, set of actions"[15]. This often requires different stages and preparation as previously demonstrated [31]. On the other hand, it has to be highlighted that the process of adaptation to climate change in Valencia may imply a loss of intangible knowledge regarding traditional cultivation which may bring opposing interests. Further studies are needed, in this sense, to understand the value of intangible heritage and to quantify in which knowledge, practices, methods lies most of its value. This will allow to better understand how adaptation to climate change can be most beneficial with no or minimal loss on agriculture intangible practices and knowledge.

Awareness was the second most common barrier. Lack of awareness − not only to adaptation measures, but to climate change and impacts − among the agriculture community may hinder the deployment of resilience/adaptation measures. While efforts through new projects[16] may bridge the still existing gap, there still is a long way to go. Recently, in a survey among farmers and stockbreeders, almost 50% of them declared that they have not received any training in this matter.

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[15] https://accelerate.uofuhealth.utah.edu/resilience/why-is-behavior-change-so-hard

[16] http://www.liferesilience.eu/the-infoadapta-agri-ii-project-concludes-with-8-measures-against-climate-change/

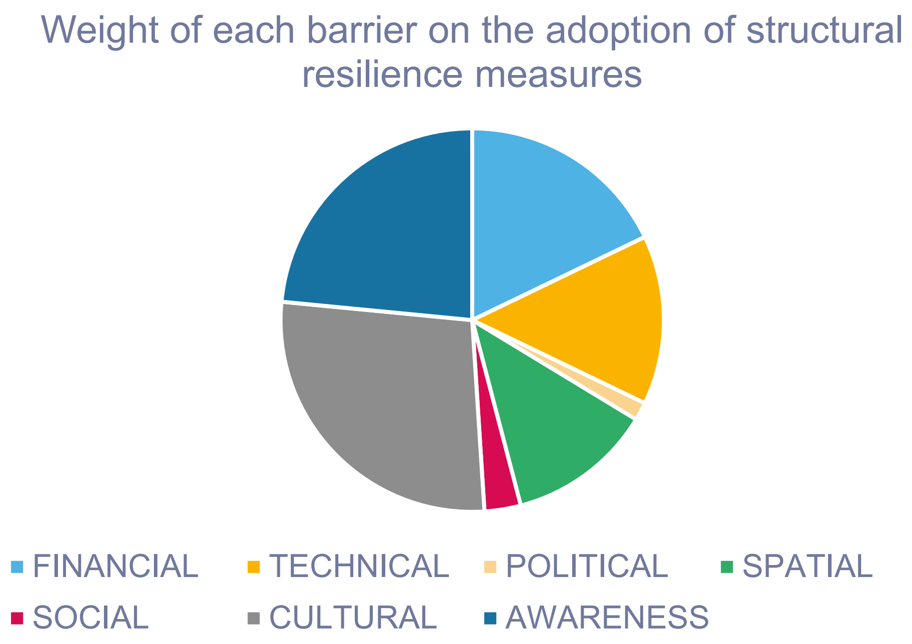

Figure 35. Weight of each barrier on the adoption of structural resilience measures for agriculture heritage

Financial barrier was the third most common barrier, based on the participants. However, in Spain, based on a recent survey 78% of the farmers consider that they have significant economic limitations to implement adaptation measures[17]. Again, this difference may be due to the lack of farmers in the consultation process.

6.2. Urban/building & structure heritage

6.2.1. Perceived acceptability

Due to the large number or resilience measure in the RMI *perceived acceptability* was assessed only at subgroup level for all type of measures. Structural measures were assessed, when pertinent, at site level and at urban level (beyond site level).

6.2.1.1. Social & Institutional measures

A broader range of perceive acceptance, compared to agriculture heritage, was observed for the socio-institutional measures for urban/building & structure heritage. A bit more than one third (36%) of the measures were moderately or well accepted (Figure 36). The top and bottom-rated subgroups of measures are listed below:

- Most accepted subgroups and good/acceptable agreement
  - Protocols and guidelines
  - Emergency stabilization
  - Historic areas regulations

[17] https://www.upa.es/upa/_depot/_uploadImagenes00/InfFinalInfoAdaptAgri-WEB.pdf

- Least accepted subgroup of measures
    - Relocation of infrastructure (planning)
    - Innovative institutional solutions[18]

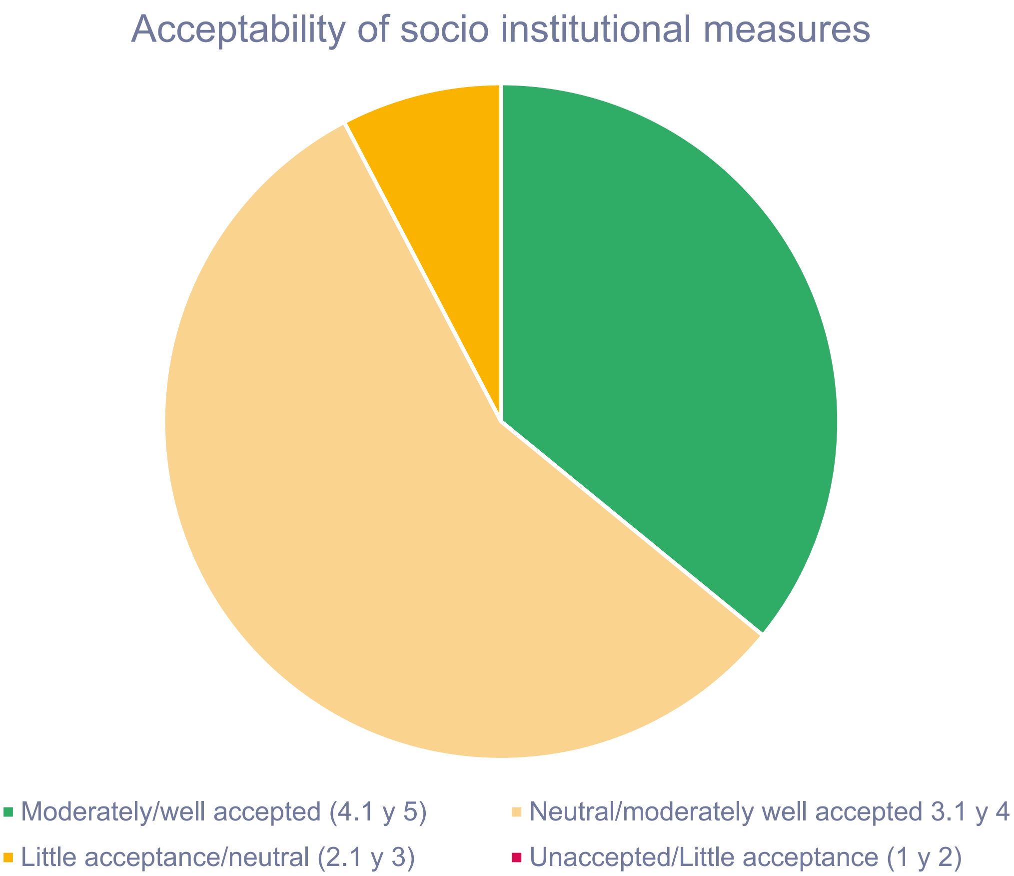

Figure 36. Socio-institutional perceived acceptance of resilience measures for buildings and structures heritage

Good agreement was observed among the most accepted subgroup of measures. *Relocation of infrastructure*[19], together with *Innovative legal frameworks* and *Salvage*[20] were the subgroups that showed highest disagreement. This may be due to context specificities or that the subgroup was understood differently among the participants.

It is interesting to note that *Innovative institutional solutions* were ranked as low as *Relocation of infrastructure* (planning) which obviously is a major disruption to the functioning of the historic area or system. Further investigation would be needed to understand the factors that led to this low scoring.

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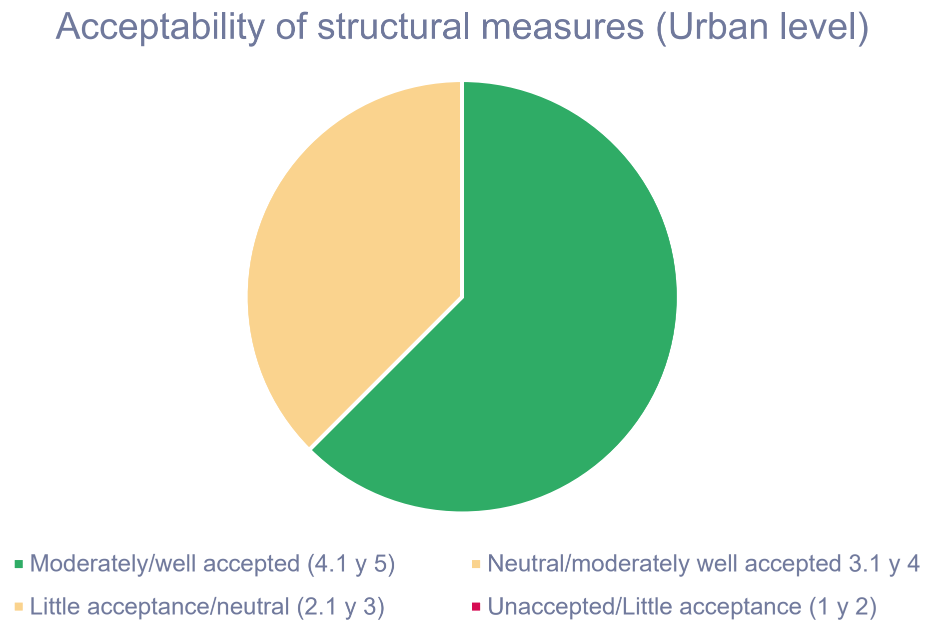
[18] Definition: Institutional solutions that enable a government being prepared to answer to the risks and damages that a hazard may cause

[19] Definition: Critical infrastructures need to be removed and relocated so that their use can be resumed

[20] Definition: Tools and methods to rescue Cultural Heritage elements in order to prevent further damages or losses

6.2.1.2. Structural measures

Identity and aesthetic value of architectural and heritage elements are generally considered precious elements that should be preserved. Thus, there are important challenges in the implementation of resilience structural measures in many historic areas while not losing the significance and identity of the site. This is also well represented by the difference in acceptance of specific subgroups of measures both at urban and at heritage site level (Figure 37). The acceptance of resilience measures (those that could be applied at both levels) scored higher at urban level (63% were moderately/well accepted in contrast to 50% for site level).



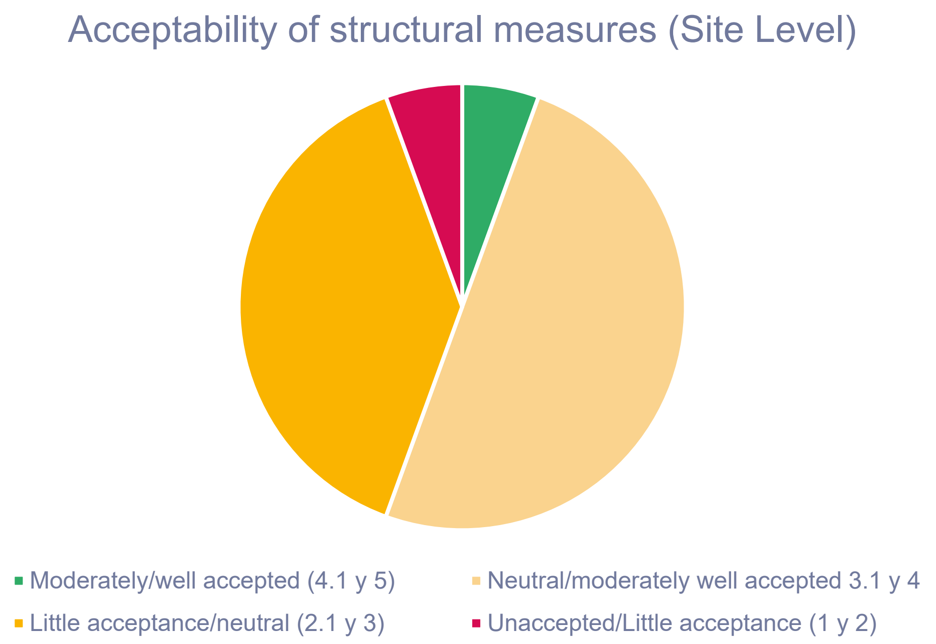


Figure 37. Acceptability of structural measures at urban and heritage site level

Below the most and least accepted subgroup of resilience measures are presented.

- Most accepted subgroups (Urban)
    - Water contention system (Highest agreement)
    - Green and foresting solutions
    - Urban cooling systems (Low agreement)
    - Infiltration techniques
    - Water storage solutions
- Most accepted subgroups (Site level)
    - Wet proofing
    - Building strengthening
- Least accepted subgroup of measures
    - Scarifying of heritage areas
    - Moving the built Heritage
    - Relocation

As initially stated, measures to relocate or remove historic areas are unacceptable because of the significance, uniqueness and identity of historic areas and would only be applied in the worst-case scenario.

6.2.2. Barriers

Urban interventions involve are associated with sophisticated sociological barriers and facilitators, especially when dealing with historic areas. These areas present a unique structure and set of regulations that tend to increase the number of barriers associated to structural or physical interventions. Barriers to disaster and climate change resilience may be defined as obstacles, constrains and/or burdens that delay or prevent the deployment of concrete actions and measures to reduce the vulnerability and risk of historic areas. Nevertheless, studies indicated that it is believed that *e.g.* adaptation of cultural heritage to climate change is possible [32].

Based on the ARCH workshop's outputs, for urban/building and structures heritage financial, technical and political barriers were the most important barriers for the implementation of structural resilience measures in historic areas, in this order (Figure 38). Limited finance mobilisation for climate change or resilience [32], complex governance processes with multi-level actors [33] and the significance and nature of the system (e.g. historic area) may be the main reasons for this result. A 2018 work [32] pointed out that one of the main barriers was the lack of knowledge of management methodologies to preserve cultural heritage from the implications of climate change. While most of the studies target the overall cultural heritage adaptation [32]–[34], the ARCH workshop focused more precisely on the resilience measures implementation barrier. It must be pointed out that 20% of the participant's departments were highly-moderately involved in the development and integration of resilience measures into plans and strategies while 40% were slightly involved. This may contribute to not perceive *Awareness* understood as *knowledge or understanding of the existence of a resilience measure or the details that characterize the measure*, which was as one of the main obstacles.

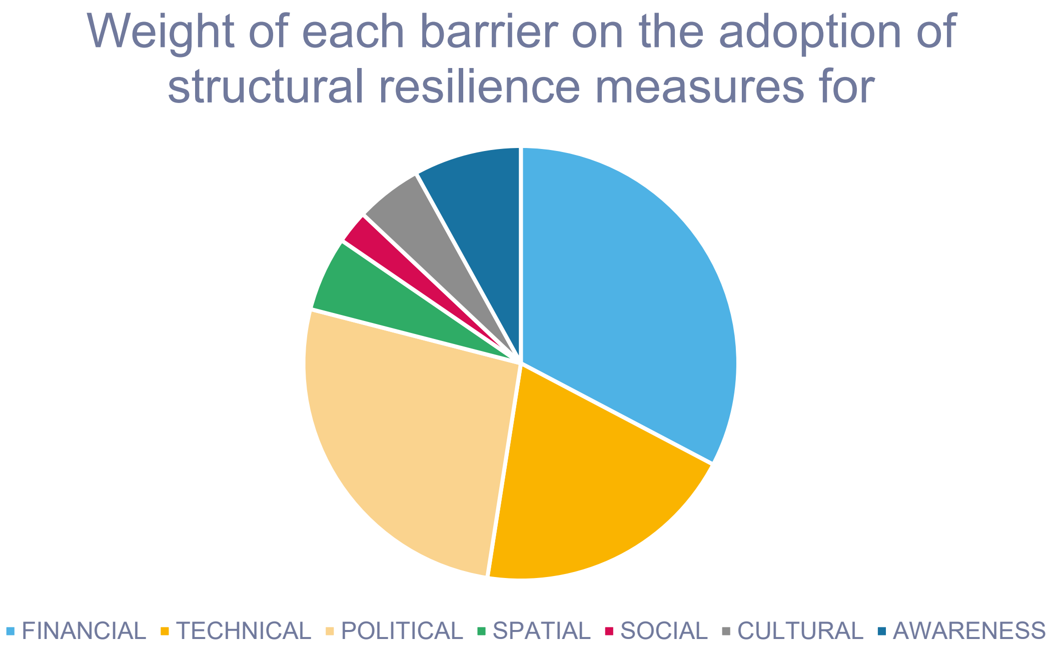


Figure 38. Weight of each barrier on the adoption of structural resilience measures for urban /building & structures heritage

Technical barriers accounted different aspects, but mainly to: (i) the difficulty in finding financial and human resources for an effective risk assessment which hinders the deployment of appropriate resilience measures, (ii) lack of practice in the deployment of resilience measures for historic areas, (iii) lack of trust or evidence in the performance of innovative technologies. During the post-exercise discussion a few aspects were highlighted that contribute to the political barrier: (i) lack of coherence of legislative instruments, which are often fragmented or way outdated and (ii) lack of political motivation, especially on the topic of sustainable reconstruction vs. land conservation. The lack of motivation may also be reflected in lower funding priorities for resilience of historic areas. The need for public-private cooperation and a financial mechanism to ensure integrated resilience building of historic areas was also highlighted.

Furthermore, good correlation was observed between the perceived acceptance of the structural resilience measures and a normalized barrier index for all the subgroups, except those belonging to *Relocation or removal* group of measures and *Infiltration technique* subgroup (Figure 39). As it was previously explained, *Relocation or removal* type of measures have by far the lowest acceptance as it implies a total or partial loss of the historic area which has an impact in its values, integrity, and authenticity. The infiltration techniques presented an unusual low barrier score, the cause of which was unclear.

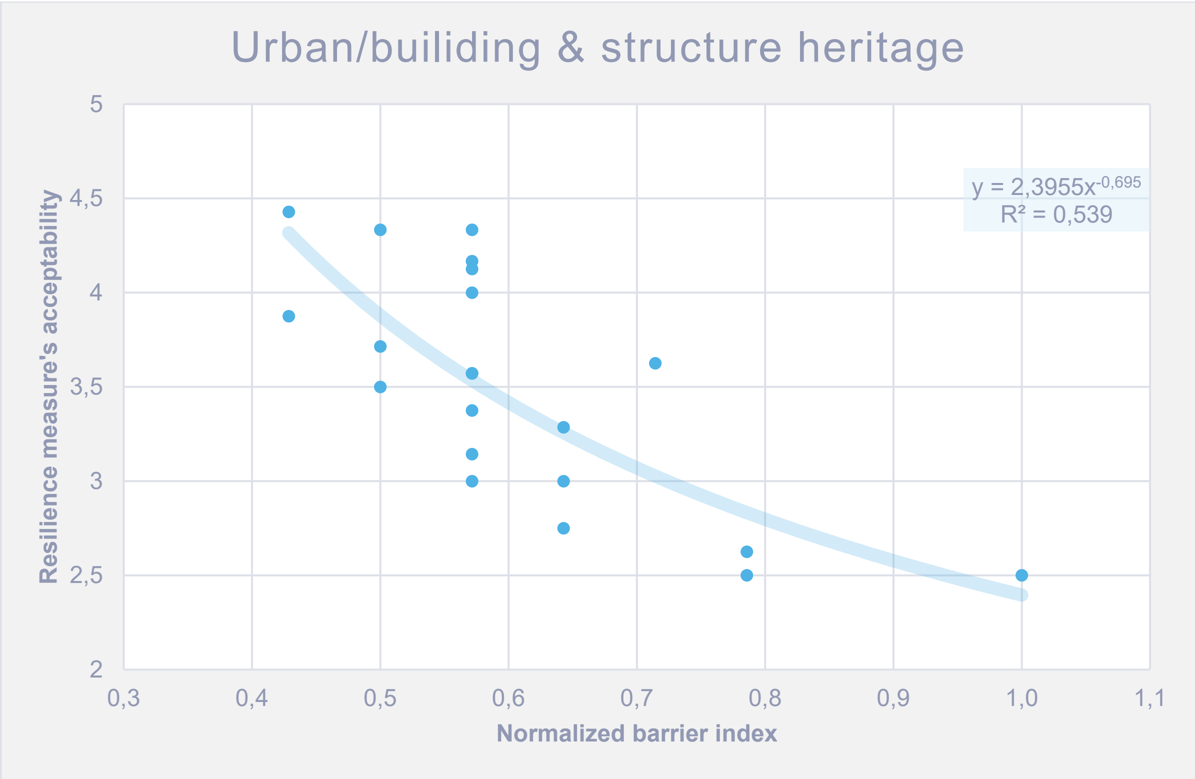


Figure 39. Correlation function between function between perceive acceptance and barrier index

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Annex 1

Table 46. Perceived acceptance of socio-institutional measures: Agricultural heritage

Subgroup of resilience measure	Score on perceived acceptability	Degree of convergence (agreement)
Communication & Awareness raising	4.7	0.58
Training communities	4.7	0.58
Community ties	5.0	0.00
Public and private economic instruments for agriculture	4.0	1.00
Innovative institutional solutions	4.3	1.15
Innovative legal framework	4.0	1.00
Innovative governance models	4.3	1.15
Capacity building for institutions	4.3	0.58
Programmes and policies	4.0	1.00
R+D+I in climate change assessment	4.3	0.58
R+D+I in adaptation evaluation and monitoring	4.7	0.58
R+D+I in adaptive measures	4.7	0.58

Table 47. Perceived acceptance of structural measures: Agricultural heritage

Subgroup of resilience measure	Score on perceived acceptability	Degree of convergence (agreement)
Crop rotation	5.0	0.0
Ridge planting	5.0	0.0
Encourage the use of cultivation techniques for the reduction of heat stress	4.7	0.6
Cover crops	4.7	0.6

Subgroup of resilience measure	Score on perceived acceptability	Degree of convergence (agreement)
Encourage the use of cultivation techniques for the reduction of heat stress	4.7	0.6
Redesigning pest and disease control systems	4.7	0.6
Precision farming for irrigation decision-making	4.7	0.6
Soil salinity assessment	4.7	0.6
Land levelling	4.7	0.6
Optimized fertilization and organic matter application management	4.3	0.6
Introduction of crops and varieties resistant to drought, salinity and emerging pests and diseases	4.3	0.6
Salinity leaching	4.3	0.6
Crop diversification	4.3	1.2
Residue retention	4.0	0.0
Maintain a cover of plant debris	4.0	0.0
Minimise bare ground periods	4.0	0.0
Precision farming for crop protection decision-making	4.0	1.0
Precision farming for fertilization decision-making	4.0	1.0
Automation and remote control of gravity irrigation	4.0	1.0

Subgroup of resilience measure	Score on perceived acceptability	Degree of convergence (agreement)
Planting hedges on the land boundaries	4.0	1.0
Implementing multifunctional margins	3.7	0.6
Planting date changes	3.7	1.2
Protective structures such as ditches for flooding or windbreaks	3.7	1.2
Improved infiltration systems	3.7	1.5
Design and planning of irrigation based on water and energy efficiency criteria	3.7	2.3
Plant covers between rows of trees	3.3	0.6
Increase water retention in the soil through small drainage channels	3.3	1.2
Recovery of existing rainwater collection and storage systems	3.3	2.1
Use of other alternative water sources	3.0	0.0
Perennial cropping systems	3.0	0.0
Long-cycle variety for e.g. dry cereals	3.0	0.0
Creating new systems for collecting and storing rainwater	3.0	1.7
Establishment of small ponds in rainwater collection areas	3.0	1.7
Efficient irrigation technology (e.g. drip)	3.0	2.0
Deep irrigation	2.7	0.6

Subgroup of resilience measure	Score on perceived acceptability	Degree of convergence (agreement)
Replacement of open channels with low pressure piping systems to reduce evaporation and filtration losses	2.7	2.1
Contour cropping	2.3	1.2
Ground cover with mulching and plastic padding	2.3	1.2
Soil erosion assessment and its management	2.3	1.2
Covering of open channels	2.3	1.5
Minimum or zero tillage	2.0	1.0
Terrace construction or conservation	1.3	0.6

Table 48. Perceived acceptance of socio-institutional measures: Urban/building and structures heritage

Subgroup of resilience measure	Score on perceived acceptability	Degree of convergence (agreement)
Protocols and guidelines	4.7	0.5
Emergency stabilization (buildings)	4.7	0.8
Historic areas regulations	4.6	0.8
Hazard mapping	4.4	0.7
Risk Mapping	4.4	0.7
Early Warning Systems	4.3	0.8
Urban planning regulations	4.3	0.8
Territorial planning	4.3	0.8
Indigenous management strategies and planning	4.3	0.8
Vulnerability assessment methods	4.3	0.9
Securing measures	4.2	0.8

Subgroup of resilience measure	Score on perceived acceptability	Degree of convergence (agreement)
Monitoring Systems	4.2	0.8
Built Cultural heritage codes	4.2	1.0
Damage assessment (office)	4.1	0.9
Modelling	4.0	0.6
Vulnerable groups exposure mapping	4.0	0.8
Buildings and structures construction codes and standards	4.0	09
Temporary protection systems	4.0	1.1
Communication and awareness raising	4.0	1.2
Salvage	4.0	1.3
Cultural Heritage exposure mapping	3.9	0.6
On-site reconnaissance	3.9	0.7
Vernacular resilient technical solutions	3.9	0.9
Programmes and policies	3.7	0.8
Back-up systems	3.5	1.0
Adaptation strategies	3.4	1.0
Capacity Building for institutions	3.3	0.8
Intelligent information units (ICT) to help emergency evacuation	3.3	0.8
Predictions to prepare the real-time response	3.3	1.0
Early warning for vulnerable groups	3.2	0.8
Mitigation and adaptation regulations (buildings)	3.2	1.0
Training communities	3.2	1.0
Community ties	3.2	1.0
Innovative governance models	3.2	1.2

Subgroup of resilience measure	Score on perceived acceptability	Degree of convergence (agreement)
Innovative legal frameworks	3.2	1.5
Losses estimation methods	3.1	1.1
Public and private economic instruments for urban	3.0	1.1
Relocation of infrastructures	2.7	1.7
Innovative institutional solutions	2.7	0.8

Table 49. Perceived acceptance of structural measures at site level: Urban/building and structures heritage

Subgroup of resilience measure	Score on perceived acceptability	Degree of convergence (agreement)
Wet proofing	4.1	1.0
Building strengthening	4.0	1.2
Water contention system	3.9	1.2
Green and foresting solutions	3.7	1.3
Dry proofing	3.6	1.3
Water storage solutions	3.6	1.3
Adaptation of uses	3.5	1.3
Infiltration techniques	3.4	1.1
Urbanistic interventions for Tourism Flows change	3.4	0.7
Urban cooling systems	3.1	1.6
Recovery plans for Building Back Better	3.0	1.2
Thermal management strategy	2.8	1.0
Sustainable reconstruction options	2.6	1.1
Smart energy solutions	2.5	0.9
Building cooling system strategy	2.5	1.1
Relocation	2.5	1.5

Subgroup of resilience measure	Score on perceived acceptability	Degree of convergence (agreement)
Sacrifying of heritage areas	2.1	1.6
Moving the built Heritage (partially or totally)	2.0	0.9

Table 50. Perceived acceptance of structural measures beyond site level e.g. neighbourhood or city level: Urban/building and structures heritage

Subgroup of resilience measure	Score on perceived acceptability	Degree of convergence (agreement)
Water contention system	4.4	0.5
Green and foresting solutions	4.3	0.8
Urban cooling systems	4.3	1.2
Infiltration techniques	4.2	0.8
Water storage solutions	4.2	1.0
Urbanistic interventions for Tourism Flows change	3.6	0.8
Thermal management strategy	3.3	1.2
Building walled areas (maintaining Heritage Sites below sea level)	3.0	1.2