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Universidad del País Vasco

Euskal Herriko Unibertsitatea

PhD Thesis

CLIMATE CHANGE RISK MANAGEMENT FOR THE SUSTAINABLE DEVELOPMENT OF THE HISTORIC CITY: FROM THE MATERIAL TO THE TERRITORY

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Bilbao, June 2017

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tecnalia Inspiring Business

POLITECNICO MILANO 1863

A Lorenzo,

per avermi insegnato ad amare, credere e lottare.

ABSTRACT

Cities are complex and interdependent systems, vulnerable to threats from natural hazards. Over recent years, sea-level rise, the increasing frequency of storms, and numerous other extreme precipitation events have all occurred, impacting on a large number of historic structures and increasing concern over risks due to weather patterns and global climate change.

Conservation of urban areas of historic value involves the management of change that, when properly addressed, is an opportunity to improve the quality of urban areas, ensuring the protection of social values as well as the authenticity and integrity of the physical material. Disaster risk reduction and adaptation to climate change should be seen as components of conservation, as they all share the objective of addressing the challenges of sustainable urban development.

The scope of this thesis is to analyse the impacts of flooding events caused by extreme precipitation and sea-level rise in urban areas with historic value, in order to prioritize interventions in the most sensitive areas.

A methodological approach for vulnerability and risk assessment has been developed, supported by an information strategy and a multi-scale urban model. The MIVES (Integrated Value Model for Sustainability Assessment) methodology was applied, in order to provide decision-making with objective and justified prioritization. The methodology delivers a balanced solution in terms of accurate results and data requirements, by using a categorization method for urban modelling. Information is organized and structured in hierarchical levels, permitting the comparison of building vulnerabilities and risks through the use of a unique index, thus facilitating the decision-making that is needed for the prioritization of efficient interventions.

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*"If a man will begin with certainties,
he shall end in doubts;
but if he will be content to begin with
doubts, he shall end in certainties."*

Francis Bacon

1

RATIONALE

Cities are complex and interdependent systems, vulnerable to threats from natural hazards. Over recent years, increasingly numerous and extreme precipitation events and subsequent flood events have occurred, impacting on a large number of historic structures. Furthermore, sea-level rise and the increasing frequency of storms, have posed new challenges to historic assets located in coastal areas, increasing concern over risks due to weather patterns and global climate change.

Disaster risk reduction and climate change adaptation should therefore be seen as components of conservation management, requiring a deep understanding of the vulnerability of historic buildings to flooding and associated extreme rainfall events and sea-level rise.

Historic cities, through adaptive processes, have always shown resilience, combining mixed uses on a human scale, density and vibrancy. They carry an identity forged over generations, encourage participation, communication and intimate relationships between public and private spaces. They are models from which the designers of new urban planning strategies may learn. While respecting their cultural values, specific methods for evidence-based decision-making have to be adapted and developed, in order to manage the evolution of historic cities and to guide them towards new comfort and climate-related parameters.

This situation calls for an efficient and holistic decision-making approach for sustainable urban planning, based on information management, that integrates disaster risk reduction, climate change adaptation and cultural heritage conservation.

1.1 BACKGROUND

The first World Climate Conference was held in 1979, following scientific warnings over increased levels of carbon dioxide emissions caused by human activities, which appeared to match heightened variations in global temperatures. In response to this situation and to provide a scientific view on climate change and its potential environmental and socio-economic impacts, in 1988, the World Meteorological Organization (WMO) together with the United Nations Environment Programme (UNEP) set up the Intergovernmental Panel on Climate Change (IPCC). A few years later, the Framework Convention on Climate Change (UNFCCC) was established, in which nations agreed to explore the causes and effects of global warming and how to cope with its subsequent impacts, resulting in the adoption of the Kyoto Protocol (1997). Since then, other provisions have been adopted, but climate change still remains a challenge.

Over past decades, the sensitivity of natural and human systems has become evident and the need to adapt to the effects of climate change has gained relevance. Surface temperature is projected to rise, heat waves will occur more often and last longer and extreme precipitation events will become more intense and frequent in many regions. Furthermore, the ocean will continue to warm and acidify and global sea levels will rise, thus leading to an increase of extreme climatic events in general (IPCC 2014b). According to the European Environment Agency (EEA), human systems and ecosystems in Europe are vulnerable to major climate change impacts. When major climate change impacts affect regions with a low adaptive capacity, the consequences are severe (EEA 2012).

Cities have become the focus of the fight against climate change, as urban land increases together with growing populations and migration to urban centres, which all contribute to higher vulnerability to heat waves, flooding, storms and droughts. Climate change has therefore been turned into an urban problem, as it presents unique challenges for urban areas and their growing populations. Beyond physical risks, caused by increased incidence of extreme weather events, cities will have to face challenges related to specific socio-economic and cultural conditions. Some cities are home to important cultural heritage, representing a fundamental aspect in regional identities that needs to be preserved for future generations. However, it is seriously threatened by the increased magnitude and frequency of natural disasters. Furthermore, cultural heritage, in its numerous shapes and forms, has great potential to contribute to the economic life of a city by stimulating tourism and enhancing the investment climate; it is a pillar of human culture and symbolizes the evolution of civilisation. Cities are characterized by a wide range of cultural heritage which, due to proper urban development, can mainly be found in what is usually defined as the historic city.

Although the negative impacts of climate change on urban areas are widely discussed, their implicit impacts on cultural heritage have not been studied as extensively (Bigio et al. 2014). In its communication *An EU strategy on adaption to climate change* (European Commission 2013), the Commission recognised the urgent need for adaption measures to deal with climate impacts and their mainstreaming in the policies of vulnerable sectors, reaffirming the commitment to promote urban adaption strategies. Cultural heritage is a sensitive element in the urban context that calls for the development of specific tools and methodologies in support of its integration as a fundamental feature within the climate change adaption strategy of the whole city. Furthermore, despite the increasing vulnerability of cultural heritage to hazards, disaster risk reduction is not a registered priority area for the management of World Heritage properties (UNESCO 2010). There is therefore a need to increase awareness of climate change impacts among heritage managers and professionals and to integrate adaptive strategies to safeguard cultural heritage and to promote conservation policies.

Urban development extends the urban areas at risk of flooding in cities due to climate change, which is the other global trend perceived to have a significant impact on flood risk. The projected patterns that can amplify the effect of flooding events are sea-level rise, causing increased flood damage in coastal areas and changes in rainfall patterns. Rising sea levels will lead to more frequent and higher river floods, intense flash floods, and changes in the frequency of drought events. Both groundwater extraction and land subsidence will be compounded by the impact of sea-level rise and the increasing frequency of storms, causing more frequent sea surges.

Floods affect more people worldwide than any other hazard, they contribute to 33% of average annual losses due to hazards and, unlike other hazards, they also cause major losses to highincome countries. Urban areas can be flooded by rivers, coastal floods, pluvial and ground-water floods. Urban flooding is usually due to a combination of causes, resulting from meteorological and hydrological extreme weather events, such as precipitations and water flows. River flooding alone contributes US$104 billion to global average annual loss (UNISDR 2015b).

There are recurring calls to be more efficient when managing the impacts of natural hazards by integrating both disaster risk reduction and climate change adaptation with development activities (Glantz et al. 2014; Kelman et al. 2015). Risk management is the process of identifying, assessing and analysing expected and possible damage, which is usually applied by decision makers to reduce losses. Risk is determined by the hazard, the vulnerability of a system and its exposure. In climate change, the concepts of adaptation and mitigation are interrelated. The first one refers to the ability of a system to adjust to climate change in order to reduce its vulnerability and enhance resilience, while the second one refers to any strategy or action taken to remove or reduce the GHGs released into the atmosphere.

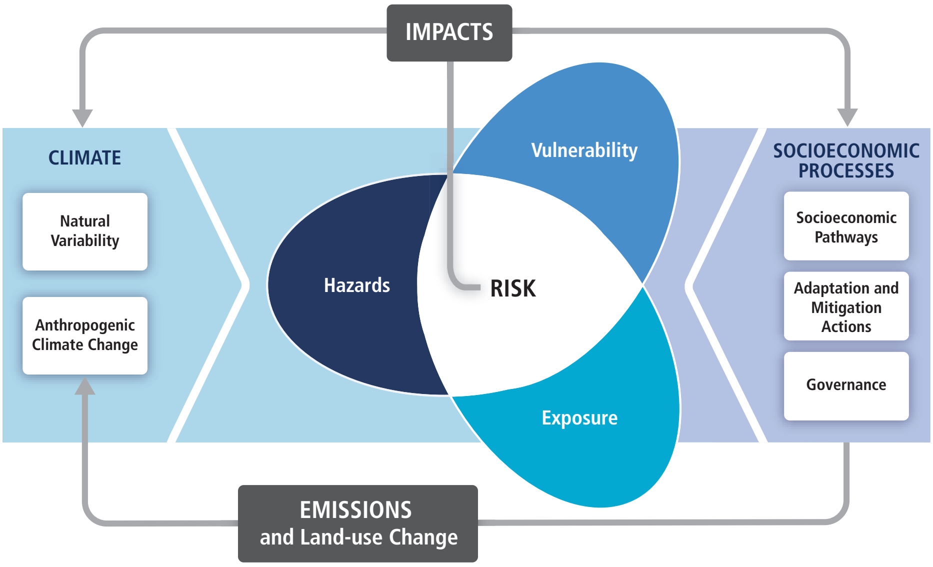


Figure 1: Illustration of the core concepts of the WGII AR5. Source: (IPCC 2014b)

The Sendai Framework (UNISDR 2015b) is the first major agreement of the Agenda 2030 and represents a successful model for addressing culture and heritage. Priority 1 discusses the importance of understanding disaster risk, in all of its dimensions of vulnerability, adaptive capacity and exposure through the systematic evaluation of disaster losses and cultural heritage impacts, among others, in the context of event-specific hazard-exposure and vulnerability information. Nevertheless, cultural heritage has not yet to be comprehensively incorporated in the Sustainable Development Goals (SDGs).

The main objective of planning is to increase the sustainability of cities by making them more inclusive, resilient, safe and sustainable; planning is a tool used to add value to historic urban areas and is able to transform them into catalysts for regeneration (ICOMOS 2016). Target 11.4 of the SDGs, acknowledges the critical role of culture and cultural heritage as emerging needs, in a shift of paradigm to a concept of development that views sustainability in more humanistic and ecological terms. It is necessary to integrate cultural heritage into sustainable urban development, in order to accomplish this objective, as historic cities are reference models for sustainable development. The Recommendation on the Historic Urban Landscape (UNESCO 2011) calls for an integrated approach to cultural heritage conservation for sustainable urban development, reaching beyond traditional efforts that limit conservation to the monuments and physical elements of historic cities.

Planning is a key element for decision-making. A planning process makes it possible to sort through the multiple layers of evaluation, to set priorities, to explain and to justify decisions and finally, to ensure that the results of decisions are sustainable. This process can be facilitated by the adoption of information management strategies designed to support the diagnosis and decision-making phases through a comprehensive and iterative flow of information. Looking forward, sustainable urban development, comprising disaster risk reduction and climate change adaptation, must be addressed through holistic approaches that integrate culture at both the policy and the operational level, in order to break away from a one-size-fits-all perspective.

1.2 SCOPE OF THE RESEARCH

Part of the research presented in this thesis has been undertaken within the ADVICE project (Infrastructure and buildings adaption to climate change), funded by the Basque Government and developed by Tecnalia.

The scope of this research falls into different domains related to sustainable urban planning, namely: disaster risk reduction, adaptation to climate change, cultural heritage preservation, information management, and decision-making.

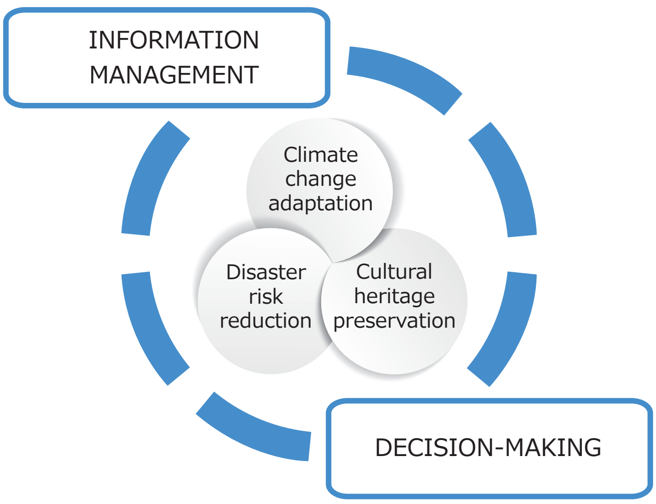


Figure 2: Research domains. Source: Author

The main objective of this research is to develop a methodological framework for risk assessment in historic cities of flooding events caused by extreme precipitation and sea-level rise, through a decision-making methodology and multiscale data model for the prioritization of adaptive and risk reduction interventions.

The methodology that is specifically developed relates to floods events and their associated damage potential to historic buildings. The vulnerability of built cultural heritage is appraised and quantified by the development of indicators, values functions and algorithms and risk is assessed by the inclusion of exposure parameters and indicators.

The following specific objectives have been addressed, in order to achieve the main objective of this thesis:

- ➪ Define the requirements for the **methodological approach** that is able to articulate comprehensive risk-evaluation for historic cities;
- ➪ Define the requirements of the **decision-making process** and **urban-modelling strategies** that will enable the acquisition of realistic information and the production of highly accurate results;
- ➪ Develop a **categorization method** for building stock representativeness supported by a data model;
- ➪ Develop a set of indicators for the **vulnerability and risk assessment** of historic buildings sustained by the use of objective and justified calculation models for the establishment of an intervention priority index;
- ➪ Validate the overall approach by its implementation in a real **case study**.

1.3 RESEARCH METHODOLOGY

The research developed in the framework of this thesis is based on some of the advances in the fields of knowledge under consideration and gathers them together to create a new comprehensive approach to vulnerability and risk assessment.

The process for the definition of methodological requirements is to disaggregate the essential procedures used in climate change adaptation and disaster risk mitigation, in order to understand how to adapt or use them in the context of heritage structures. First, the problem was defined and a literature review was conducted to understand how previous research has addressed and proposed solutions to the specific problem under study. In a second step, the requirements for a solution were identified and established and finally, the solution was designed, by mixing different alternatives and methods and by creating a new and *ad hoc* methodology for the decision-making process.

Research was based on the following hypothesis:

- ➪ The use and design of tailored multiscale information models can support vulnerability and risk assessments of historic cities and decision-making on adaptation strategies;
- ➪ The use of objective decision-making models can create evidence by determining comparable results and indexes, in order to prioritize areas or buildings where adaptive solutions are needed;
- ➪ A decision-making methodology for the risk assessment of historic buildings at urban level, based on different levels of information and proper modelling strategies, can be cost effective, reaching a balance between accessible information and accurate results.

1.4 SIGNIFICANCE AND MAIN CONTRIBUTIONS

The findings of this research will impact on improving risk-management procedures in historic cities, by delivering a risk-scoring methodology linked to climate change adaptation, disaster risk reduction and cultural heritage preservation. Greater concerns over the impact of climate change and related hazards on historic assets justify the need for more holistic strategies for sustainable urban planning. Furthermore, the potential of multiscale urban modelling in standardizing, analysing and synchronizing geographic and semantic information provides a holistic decision-making scenario for cultural heritage preservation, disaster management and adaptation to climate change. The definition of structured categories with regard to climate change vulnerability and the definition of context-specific indicators, thresholds, and algorithms for cultural heritage risk assessment, which are compatible with existing procedures, will provide an objective prioritization index for an adequate adaptive response.

The research is aligned with multiplying scientific and political commitments, in a context where climate change adaptation is a new emerging concern for the public administrations, as the current effects of climate change have been conclusively demonstrated. Opportunities are offered by finding new integrated relations in the fields of cultural heritage and disaster mitigation which have a longer scientific route. Organizations such as, among others, the European Commission, the United Nations, the World Bank, the IPCC, and UNESCO consider climate change impacts on urban areas as priorities that are discussed internationally, the results of which have led to the launch of several initiatives such as Climate Adapt[1] and Mayors Adapt[2], demonstrating the relevance of the thematic area at a local level.

[1] http://climate-adapt.eea.europa.eu/

[2] http://climate-adapt.eea.europa.eu/mayors-adapt

1.5 STRUCTURE OF THE DOCUMENT

The document is organized into 7 chapters, each one tackling a different key element of the research.

Chapter 1 – Rationale: describes the background of the research by giving an overview of the three thematic areas of knowledge - climate change adaptation, disaster risk reduction and cultural heritage - as well as their auxiliary spheres - information management and decision-making. It also presents the scope and methodology of the research, its main contributions and the structure of the document.

Chapter 2 – Conceptual framework: presents the state of the knowledge in relation to the different thematic areas and their interrelations, on which the methodological approach is defined and built. It presents the current concepts applied to climate change, disaster mitigation and cultural heritage as well as tools and methods used in urban planning, information management and decision-making and how they can be applied in this dissertation.

Chapter 3 – Methodological approach: explains the methodology developed for the risk assessment of historic cities by combining the shared similarities of the thematic areas of knowledge and the use of tools for the proper management of the information and the calculation of a vulnerability and risk index.

Chapter 4 – Implementation: addresses the implementation of the methodology for vulnerability and risk assessment in the case study of San Sebastian. The area considered, which goes beyond the boundaries of the historic city, comprises six districts located nearby the Urumea river and 2,262 buildings. A smaller area has been selected for the comparison of results between the categorization method used and real data.

Chapter 5 – Conclusions and future perspectives: summarizes the most significant conclusions of the research performed and the contribution of the methodology proposed to sustainable urban development. Furthermore, the chapter presents some future perspectives mainly oriented to decision-making for the selection of adaptive solutions in historic cities.

Chapter 6 – Afterthoughts: presents some reflections on focusing this dissertation on cultural heritage and its integration into wider strategies.

Chapter 7 – Bibliography: lists the bibliographical references resulting from the documental research within the scope of this thesis.

"When you make the finding yourself - even if you're the last person on Earth to see the light - you'll never forget it."

Carl Sagan

2

CONCEPTUAL FRAMEWORK

Climate change adaptation, disaster risk reduction and cultural heritage preservation share a common objective, which is urban sustainable development. Even if the different fields of knowledge under consideration require specific skills, priority should be given to improvements in people's quality of life. This can only be done by building a holistic approach for the sustainable development of the city, which considers all transformations and processes of change.

Decision-making, for the implementation of sustainable strategies, is a practice based on information management. Both methodologies which require a large amount of data and deliver highly accurate results and methodologies based on simple data that deliver generic results, are not feasible for the strategic level of decision-making. A proper balance between the data that are required and the accuracy of the results, based on flexible information strategies and objective assessment, should be sought. Data models can provide support in the management of complex information by organising and structuring the necessary data and creating an evidence-based framework for the decision-making process. Furthermore, the use of value analysis methodologies can provide objective conclusions for establishing strategic priorities, in order to overcome the barrier of involving different stakeholders, with diverse profiles and needs.

This chapter presents the current state of knowledge of the main methodologies and approaches used in the addressed thematic areas, in order to build the structure of the proposed methodological approach.

2.1 CLIMATE CHANGE, DISASTER RISK AND HISTORIC CITIES

"The Earth's climate system has demonstrably changed on both global and regional scales since the pre-industrial era, with some of these changes attributable to human activities" (IPCC 2001). Mitigation strategies (reducing emissions of greenhouse gases) are increasingly regarded as insufficient at limiting the amplitude of climate change and major efforts are needed to analyse and to prioritize adaptation solutions for extreme events, at all levels.

During the 20th Century, the average global temperature increased by 0.6ºC (IPCC 2001). But temperature increase is just one of the many indicators of on-going climate change that will impact directly on people and their environments. As a consequence of global warming, additional changes in climate geophysical features are expected, such as changes in precipitation patterns, changes in the frequency, intensity and seasonality of extreme events (droughts, heavy precipitation, floods, storms and cyclones) and sea-level rise. There is growing scientific confidence in the ability of climate models to project the future climate (EEA 2012). The main expected changes will be an increase by 1.4 to 5.8ºC by 2100 in global mean temperatures, an intensification of the hydrological cycle, with increased intensity of rainfall events and at the same time more frequent droughts in arid and semi-arid areas, an increase in global sea level of 0.09 to 0.88m by 2100, and an increase in the frequency of local storm surge (IPCC 2014a).

According to a questionnaire launched by the World Heritage Centre in 2005, of the 110 responses received from 83 States Parties, 72% acknowledged that climate change had an impact on their natural and cultural heritage (UNESCO et al. 2007). The main climate threats identified were hurricane and storms, sea-level rise, erosion (both wind and water driven) and flooding.

Most of the changes in the climatological indicators may have adverse impacts on historic cities, causing physical, social and cultural effects. Changes to cultural heritage caused by climatic change cannot be viewed separately from changes in the society, demographics, people's behaviour and urban planning. Assessment of the impacts of climate change on cultural heritage must account for the complex interactions within and between natural, cultural and societal aspects.

Disaster risk and climate change practices share common concepts, such as exposure, vulnerability and capacity to cope and to respond to an impact. The first United Nations World Conference on disaster risk reduction was held in 1994 to discuss preparation, response, and mitigation measures to face the growing incidence of natural disasters. Since then, two other conferences have been held: one in Kobe, Japan (2005), which adopted the Hyogo Framework for Action 2005 – 2015, and another in Sendai, Japan (2015), that adopted the Sendai Framework for Action 2015 - 2030. The latter placed emphasis on disaster risk management rather than disaster management, in all of its dimensions of vulnerability: capacity, exposure of persons and assets, hazard characteristics and the environment. The current need is to integrate climate change adaptation and disaster risk reduction by reviewing international frameworks and their implications on policy at national levels.

Urban areas and built heritage have been designed with the local climate in mind. Proper use of buildings and urban space, as well as social appropriation, is able to guarantee conservation of cultural heritage. Historic cities are living places which depend on their communities to be sustained and maintained. Despite the direct physical impacts on cultural heritage, the effects on the social structure may lead to further and accelerated degradation or loss. Adaptive solutions are therefore needed to allow use, occupation and social wellbeing to continue. Conservation, which is based on the management of change, should therefore be oriented and consider climate change, as one of the most significant global challenges today. The mainstreaming of cultural heritage protection in wider policy and planning for disaster risk reduction and climate change adaptation is needed.

2.1.1 Climate change impacts on cultural heritage

Risks on heritage sites are dependent on the nature, specific characteristics, the inherent vulnerability, and the geographical environment of the site.

In relation to cultural heritage, two main risk typologies may be distinguished: on the one hand, chronic typologies, which produce a cumulative degradation over a long period of time. These are usually related to environmental changes and are characterized as minor at an early stage, increasing rapidly after a certain period of time. On the other hand, some risks, known as catastrophic, occur accidentally, generating severe damage that may lead to the loss of cultural heritage. These may be of natural or anthropic origins and are related to natural phenomena and anti-social acts (Herráez 2012). As a consequence of climate change, both chronic and catastrophic events are increasing in frequency and intensity, leading to new and accelerated degradation mechanisms and increases in cultural heritage losses.

Damage to cultural heritage, as a result of natural and man-made disasters, are no longer extraordinary events and have become a continuous threat for which preparation is necessary, in order to avoid irreparable loss. For this reason, heritage managers are expected to develop new mechanisms to provide an appropriate response to these challenges.

Conservation work has traditionally addressed deterioration mechanisms related to materials and works of art, but has rarely been applied to analyse and to predict sudden damage in emergency situations. Nevertheless, the increasing numbers of extreme events is already affecting cultural heritage. At a European level, there has been a proactive approach to predicting the impact of climate change on cultural heritage through the projects CHEF (Drdácký 2010), CLIMATE FOR CULTURE (Kramer et al. 2013) and NOAH'S ARK (Sabbioni et al. 2010), but the work has however remained descriptive in nature (Drdácký, 2010; English Heritage, 2004) with consideration of losses other than physical damage to the building. Damage due to pollutants and environmental parameters on heritage materials in urban areas were however addressed to contribute to more accurate diagnosis and monitoring within the European project TeACH (Bernardi et al. 2012).

Heritage is usually not taken into account in global statistics concerning disaster risks, even though it is increasingly affected by diverse threats. With a few notable exceptions, efforts to protect heritage from disaster risk remain fragmented and efforts to learn from heritage for building resilience remain inconsistent (Jigyasu et al. 2013).

Figure 3 shows how climate change and related hazards may impact on cultural heritage:

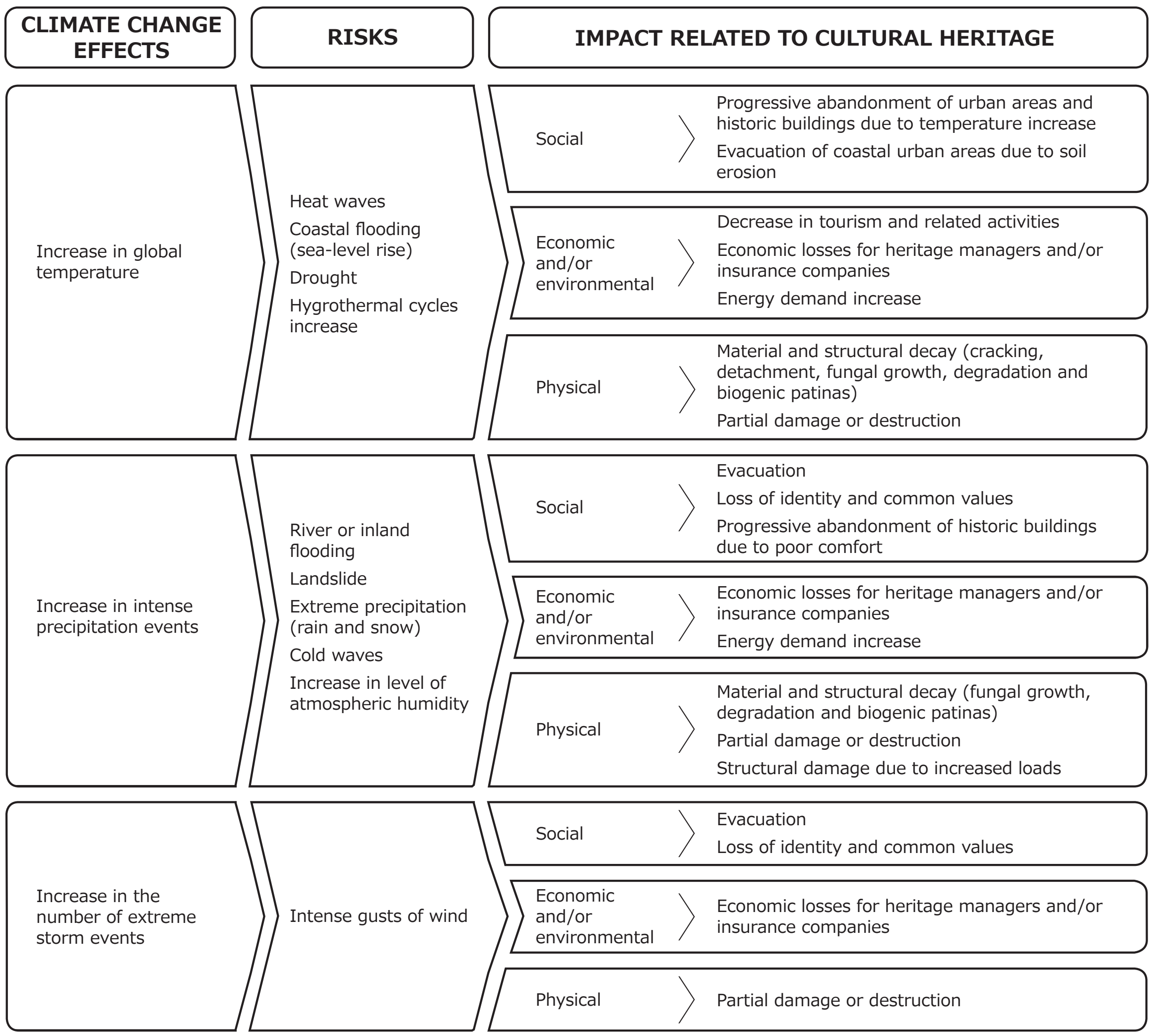


Figure 3: Impacts of climate change on cultural heritage. Source: Author

2.1.2 Flooding

The average annual losses from earthquakes, tsunamis, tropical cyclones and river flooding are now estimated at US$314 billion in the built environment alone (UNISDR 2015a). Floods are the most common and the costliest natural disaster around the world. Between 1998 and 2016, Europe suffered over 400 damaging floods, the direct cause of some 1900 fatalities, affecting over 7 million people and causing over €90 billion in direct economic losses (EM-DAT 2017).

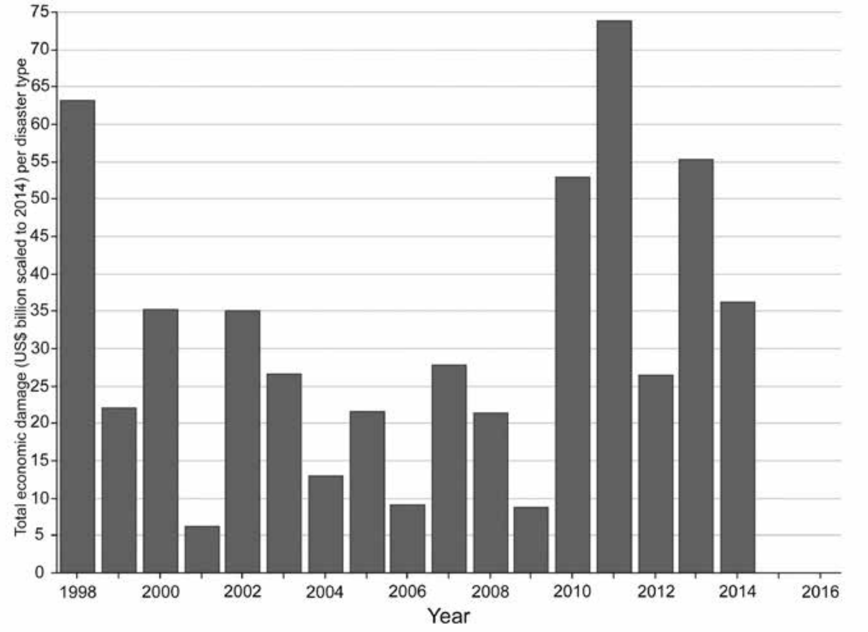


Figure 4: Total economic damage due to flood events. Source: (EM-DAT 2017)

Floods include river floods, flash floods, urban floods and sewer floods, and can be caused by intense and/ or long-lasting precipitation, snowmelt, dam break, and reduced conveyance due to ice jams and landslides. Floods are natural phenomena which cannot be prevented and depend on precipitation intensity, volume, timing, antecedent conditions of rivers and their drainage basins. However, human activity is contributing to an increase in the likelihood and the adverse impacts of extreme flood events. Firstly, the scale and the frequency of floods are likely to increase due to climate change. As reported by Munich Re (2017), the world's largest reinsurance company, the number of devastating floods that have triggered insurance payouts has more than doubled in Europe since 1980, following a pattern which fits with the outcomes of climate models.

Figure 5: Cars swept into a pile by torrential rain in Genoa, Italy. Source: Antonio Calanni

Through the 2007 Directive on the assessment and management of flood risks (EC 2007), the Commission established the first coordinated action at EU level to improve flood protection. It is aimed at reducing the risks and adverse consequences of floods and it also includes cultural heritage protection. The directive applies to all types of floods and was implemented in the Member States in three stages, beginning with a preliminary assessment of the river basin's flood risk, as well as associated coastal zones, which had to be carried out by 2011. This stage was followed by the development of flood hazard maps and flood risk maps by 2013. During the last stage, Member States were expected to have produced Flood Risk Management Plans (FRMP) by no later than 2015.

It has been recognised that effective management of floods is possible only by employing comprehensive risk-based models to reduce both the hazard and its consequences. This is in contrast to traditional methods that are only intended to contain the hazard itself (Birkmann et al. 2013).

Flood risk is generally defined as the function of hazard – the probability of a flood event; exposure – the population and the value of the assets exposed to flooding; and vulnerability – the capacity of a society to deal with the event (Kron 2005; IPCC 2012). While the understanding of hazard and exposure has greatly improved over the years, knowledge of vulnerability remains one of the biggest hurdles in flood risk assessment to date (Mechler & Bouwer 2015; Mechler et al. 2014; Visser et al. 2014).

(Merz et al. 2004) identified the need for refinement and standardization of data collection for flood damage estimation. A reliable building typology approach for supporting a pre-event assessment of the physical flood susceptibility at a large scale is required, if we are to move towards a systematic, transferable and standardised process. Moreover, there is a need for methods that assist in standardized data collection on the susceptibility of buildings, to provide an overview at district and neighbourhood levels (Blanco-Vogt & Schanze 2014).

Damage may range from the soiling of basements and lower floors and long-term increases in residual moisture to the collapse of structures due to flood water force (Taboroff 2000).

Hydro-meteorological hazards such as floods and storms have had dramatic impacts on historic structures, including those at the Ayutthaya World Heritage Site in Thailand (2011) and in Leh, India (2010). In 2011, the World Bank presented a paper, which included a comprehensive assessment of flood risk to World Heritage Cities (see Figure 6).

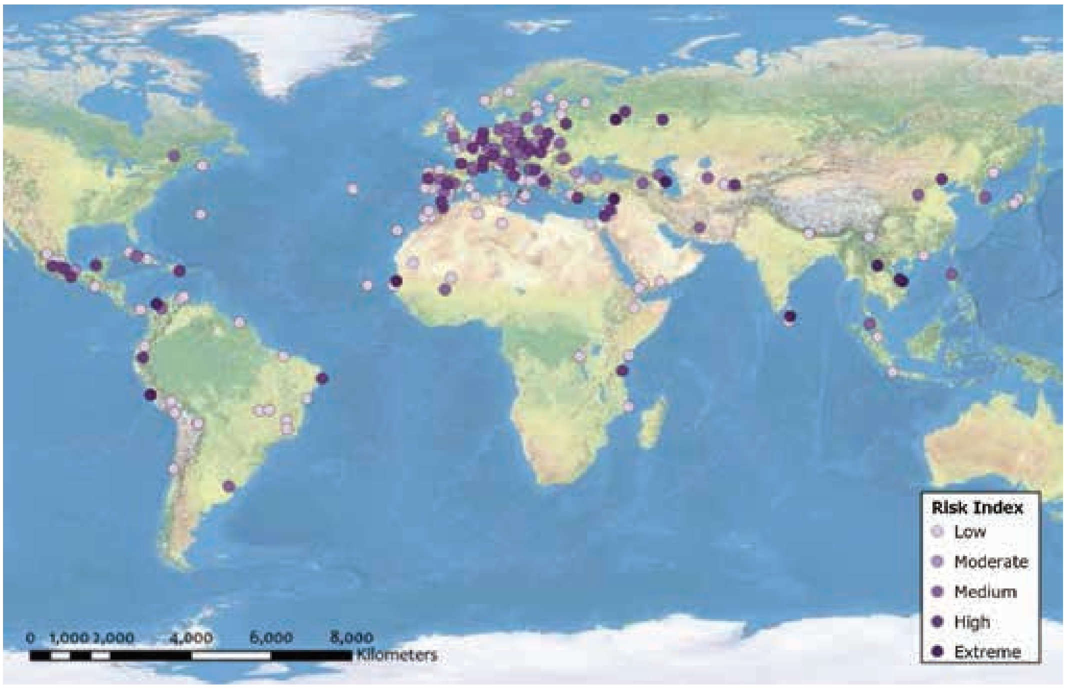


Figure 6: Flood risk to World Heritage Cities. Source: (Bigio et al. 2014)

Rather than planning separately, in order to deal with natural hazards and climate change risks, resilient, adaptive responses should be incorporated in urban planning instruments and in conservation plans and regulations (Bigio et al. 2014).

2.1.3 Conservation of historic cities as living and dynamic areas

The concept of cultural heritage has broadened considerably since the Venice Charter (ICOMOS 1964) and nowadays includes environmental and social factors, which stand away from the past conservation of objects and sites as ends in themselves. The Declaration of Amsterdam (ICOMOS 1975) introduced the concept of *integrated conservation*, stating that conservation cannot simply be limited to the built context, but must include protective measures, modification and implementation of uses and activities that take place within the built physical environment. The historic city consists of a continuous juxtaposition between "the monument," the representative building, and the "simpler constructions" that are buildings of simple materials and techniques that stand as testimony to the material culture of a region (Boriani et al. 2014).

Rapid and uncontrolled urbanization has resulted in social and spatial fragmentation, in the deterioration of the quality of the urban environment and an increasing risk of climate-related disaster (UNESCO 2011). Urban heritage, including its tangible and intangible components, constitutes a key resource in enhancing the liveability of urban areas, and fosters economic development and social cohesion in a changing global environment (UNESCO 2011). As stated in the Declaration of Hangzhou *"culture, in its manifold expressions, is both an enabler and a driver of the economic, social and environmental dimensions of sustainable development"* (UNESCO 2013). Preservation policies should therefore encompass a series of socio-economic and environmental variables and, in order to be effective, need instruments capable of regulating the pressure between a more or less rigid physical structure and a changing socio-economic and cultural asset.

Integrated urban development has become increasingly important in many Member States, principally as a consequence of the adoption of the Leipzig Charter on Sustainable European Cities (European Commission 2007b). The charter declares that *"all dimensions of sustainable development should be taken into account at the same time and with the same weight. These include economic prosperity, social balance and a healthy environment. A holistic approach is essential in order to reveal the potential of European cities in terms of cultural and architectural qualities, social integration and economic development"*. Given that cultural urban heritage is associated with physical systems and human communities, a priority for the effective management of the whole city is to develop a new generation of strategies that provide mechanisms for balancing conservation and sustainability, in the context of a changing environment.

This ideology, in the field of cultural heritage, is supported by the Valletta Principles (ICOMOS 2011) in which the aspects of change are recognized, if properly managed, as an opportunity to improve the quality of urban areas. The same document stressed the importance of protecting historic cities from the multiplying effects of climate change and natural disasters by taking advantage of strategies arising from climate change and applying them properly to conservation.

Cities encompass abundant and diverse manifestations of cultural heritage, shaped by generations and constitute a key testimony to humankind's endeavours and aspirations through space and time (UNESCO 2011).

Historic cities have demonstrated a resilient nature, proving their capacity to absorb transformations without losing their essential structure, while managing to survive centuries and disasters (Salat & Bourdic 2012). They are living labs for analysing the relationships between people, climate and urban environments. As a result of the astonishing growth of cities over past centuries, the efficient mechanisms of historic cities have sometimes failed.

The characteristics that make historic cities comfortable and pleasant, such as their architectural nature, the concentration of population and the availability of services and infrastructures, also make them more vulnerable to climate impacts. The density of people and assets within a relatively small geographic area means that there is a lot more at risk than in rural areas. Cities face major functional and social changes and should be understood as a living and dynamic reality. Municipal planners are expected to respond to the expected impacts and to the need to adapt the city to climate change. This situation means transforming the city into a resilient system, able to absorb external attacks, such as climate change, natural disasters and socio-economic change.

2.1.4 Methodologies and approaches

The Effect-Vulnerability-Adaption-Implementation (EVAI) model (Figure 7) has been used as the common framework in the adaption planning concept. The model represents a conventional top-down approach to climate change adaptation: vulnerability and the degree to which systems are susceptible to and able to cope with it, as well as the adverse effects that determine the damage done by climate change to cities. The outcome allows us to identify adaption measures for implementation. Once implemented, these measures will increase the adaptive capacity of cities and thus reduce their vulnerability.

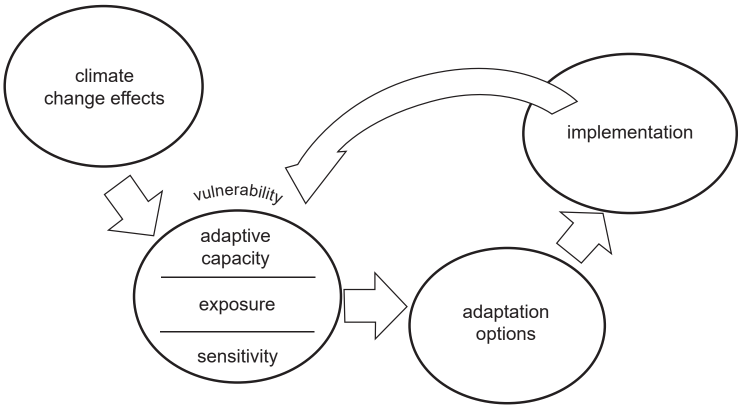


Figure 7: Effects-Vulnerability-Adaption-Implementation (EVAI) model.
Source: (Groot et al. 2015)

Demographic change, mass tourism and climate change are some of the conditions that pose new challenges for the conservation of cultural heritage. Many approaches related to the conservation and rehabilitation of cultural heritage in urban areas are still linked to spatially identified sites or groups of properties. Cultural heritage areas are seen as belonging to the past and disconnected from the present and from each other (Moylan et al. 2009). Nevertheless, urban heritage is a living and dynamic part of a broader area, an element of the overall urban setting.

Urban heritage, as the historic district or a monument or an object, forms complex and interdependent systems within the city. Modern conservation strategies should address a balance between urban growth and quality of life in a sustainable way and should match the interrelationships of physical forms, spatial organization, natural features and social, cultural and economic values. Emphasis needs to be put on the integration of conservation management, in order to support the protection of urban heritage, in a constantly changing environment, within wider goals of overall local sustainable development.

Given that cultural urban heritage is associated with physical systems and human communities, the need to address a new generation of strategies, providing mechanisms for balancing conservation and sustainability adapted to a changing environment, should be a priority for effective management of the whole city. This situation calls for a complex and multidisciplinary approach involving a cross-section of different stakeholders and decision makers, in order to identify key values in urban areas and to develop integrated urban governance dynamics.

As climate change adaptation has become more widely accepted, its scope has broadened, shifting from the management of the direct physical manifestation of climate change hazards, to risk-based approaches incorporating an assessment of vulnerability and capacity to adapt to these hazards. Uncertainty over the severity and timing of climate change impacts requires an iterative risk-management process, involving different profiles and levels of stakeholders in a complex decision-making scenario.

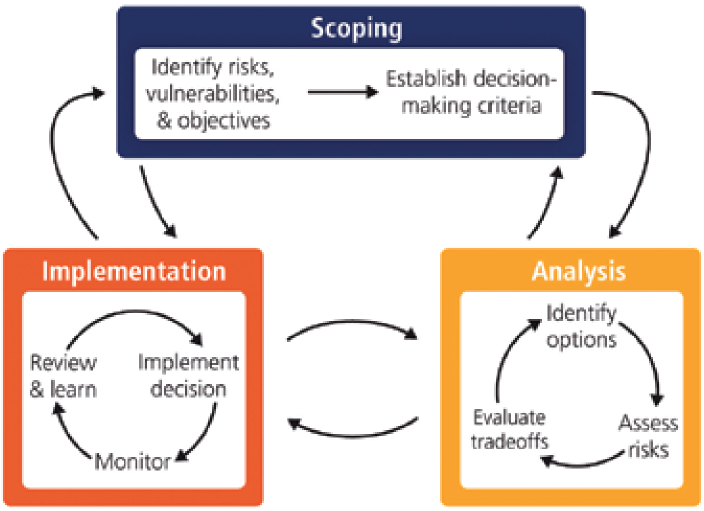


Figure 8: Climate-change adaptation as an iterative risk-management process. Source: (IPCC 2014b)

Impact and vulnerability mapping is one of the first steps in clarifying the challenges of climate change for urban assets. Assessments of climate change impacts vary widely, depending on the subject, time frame, geographic coverage and purpose of the assessment (UNFCCC 2011). Consequently, a wide range of methods and tools have been developed and applied, with the support of appropriate data and information (UNFCCC 2011).

Published analyses of the potential impacts of climate change on cultural heritage assessment tend to use one or a combination of the following techniques (Daly 2014):

- ➪ **Expert led**: Use of expert judgment to theorize on the potential impacts of projected climate change.
- ➪ **Stakeholder led**: In this approach, consultation with stakeholders is used to produce a hypothesis of potential impacts. Rooted in experience and knowledge of past events and the effectiveness of the response, it provides a more place-specific analysis than the previous "expert led" approach.
- ➪ **Mapping and/or Modelling**: Various combinations of computer software applications can be utilized to produce an analysis of the impacts of projected climate change.
- ➪ **Material Specific Studies**: utilizes material science and the study of deterioration mechanisms as the basis for understanding how projected climate change may impact on cultural heritage.

Vulnerability assessments are essential in responding to future climate risks and the assessment process itself can help to improve the management of the current ones. However, it should be noted, that vulnerability in general might be interpreted in several ways depending on the focus of the assessment (ENSURE 2013). For the common framework of vulnerability to climate change, risk is defined as the probability of an event multiplied by the expected consequences; a definition that is typically used for assessing the risks of structural damage to cultural heritage assets.

The general approach of probabilistic risk assessment of engineered systems captures this idea in which exposures and vulnerability are considered as risk indicators. Risk indicators may be understood as any observable or measurable characteristic of the systems or their constituents containing information on the risk. If the representation of the system has been performed appropriately, risk indicators will, in general, be available for the exposure of the system to risk, and the vulnerability and the robustness of the system (Faber et al. 2007). However, a probabilistic risk assessment might be too complex and lack relevant data for managing the adaptation of cultural heritage to climate change. Thus, there is a need for standardized approaches to assess vulnerability, and afterwards, to define adaption options.

2.2 URBAN MODELLING AND INFORMATION MANAGEMENT

Urban planning decisions involve an understanding of complex interactions between different aspects of the city, in its constructive, social, economic, environmental and cultural systems. Climate change and its concomitant challenges are driving reassessments of the ways cities and regions can contribute to sustainability, as they can be better prepared to mitigate environmental impacts and to adapt to climate change through more sustainable practice. Urban modelling is one of the support tools available for decision-making and provides an understanding of these complex interrelations and interactions, acting as a guide to urban policy and practice.

Urban models are digital environments that are used for analysing the consequences of changes in cities. Models are simplifications of reality – theoretical abstractions that represent systems, in such a way that essential features are identified and highlighted, by translating theory into a form that is testable and applicable (Batty 2009). As theoretical abstractions of urban attributes and realities, models of urban systems can be broadly categorized according to their focus and are selected according to the understanding that is required and the decisions to be taken.

Furthermore for the purpose of urban scale simulation, a good compromise between modelling accuracy, computational overheads and data availability should be achieved (Robinson et al. 2009). The process of selecting appropriate and specific indicators and data to model the performance of particular urban systems against sustainability criteria is of increasing significance (OECD 2011).

Addressing climate change and cities entails the analysis of both the changing climate and city system, which leads to several scientific challenges (Masson et al. 2014). The analysis of these interacting processes requires a strong interdisciplinary approach, comprising climate evolution, building systems and urban planning. As the components of the process operate on different spatial and temporal scales, models designed for different purposes (planning and climate models) should be linked. This requires a broad comprehension of information that can be supported and homogenised by one model, facilitating the understanding of the interactions, which cannot be apprehended by human expertise alone.

The strategy for urban modelling should therefore define the level of abstraction of the reality, by providing a manageable, accurate, comprehensible, predictive and low-cost model.

2.2.1 A matter of scale

In response to the European Floods Directive, there are multiple requests to simulate potential flood damages and risks. Even if vulnerability and risks maps are mandatory for Member States, the resolution of these maps is not specified. Three scales can be considered in flood loss estimation practice, as outlined by (Messner & Meyer 2006): the micro-scale, usually used in small investigation areas, evaluates flood loss on an object level, e.g. at single buildings, and provides detailed information on the type and use of buildings; the meso-scale estimates the loss on sectorial aggregations, e.g. land use categories and associated economic sectors, usually with a size of up to 1 km^2; the macro-scale is formed by large scale spatial units, e.g. municipalities, regions and countries.

Analyses of the vulnerability of buildings against floods on a large scale are scarce. Diverse approaches are available for assessing pre- and post-flood damage to buildings, as part of loss estimation calculations. However, large scale pre-event assessment methods for building stock are few and far between. FLEMO - Flood Loss Estimation MOdel (Kreibich et al. 2010) was developed for the commercial sector in Germany and is based on field data collected after an event. The approach is centred on multi-parameter models and considers water depth, size of the building, return period, contamination, inundation duration and precautionary measures as the most important contributory factors. HAZUS - HAZards United States (Scawthorn et al. 2006) is a GIS-based technology for estimating potential losses from earthquakes, floods, hurricanes and tsunamis. HOWAD - Flood Damage Simulation Model (Neubert et al. 2016), is a bottom-up approach which uses urban structure types recognized by GIS, and remote sensing and digital image processing, by characterizing usage, construction period and pattern (free-standing/blocks, single family/multi-unit). Both models assess physical and monetary damage prior to an event, through the application of an object-based approach with high spatial and contextual resolution. These methods cannot be easily replicated in large-scale assessments, due to the inexistence or restricted accessibility of cadastral data, lack of recognized classification approaches and extensive consumption of time and resources in the field work that is required for damage analysis.

A comprehensive vulnerability assessment at building level has been performed in the U.K.; partly based on the expected response of the building (engineering judgment), and partly on the perceived economic and historic value of the building (Stephenson & D’Ayala 2014). The parameters under consideration are: age, listed status, use, footprint, number of storeys, materials and structure and condition. For each parameter a range of attributes has been established and a vulnerability rating assigned, in order to determine which buildings are the most vulnerable.

A review of the most recent literature carried out by (Pasimeni et al. 2014), showed that the international debate regarding the interaction between climate change, land-use and energy is focused on the identification of suitable scale or scales for effective planning. Global environmental changes require multi-scale assessments for more effective political and decision-making processes. Furthermore, the problem of the adaptation of cities to climate change induces an additional scientific challenge: the time horizon. (Kates & Wilbanks 2003) noted that, although climate change is truly a global phenomenon, most of the specific adaptive actions can, and must, operate at different temporal and spatial scales.

The challenge of integrating quantitative modelling with qualitative data based on case-study approaches still stands. Quantitative modelling is often criticised due to its generalization, as it does not consider the specific features of the context, while the vagueness of the qualitative approach and the difficulties over its transferability are questioned. Starting from the premise of the uniqueness of every site, patterns need to be sufficiently abstracted to cover relevant properties of multiple specific areas. This abstraction should be general enough to be potentially found in more than one case, but not so abstract that it explains every case (Eisenack 2012).

Significant progress has recently been made towards the development of models in the field of energy efficiency, as the interest in analysing the energy performance of large existing building stocks has increased worldwide. Individual building models, on the one hand, and country or regional building stock models, on the other, have become established models for building designers and policy makers, respectively. More recently, hybrid methods have appeared following the merger of these two toolsets (Reinhart & Cerezo Davila 2016).

European Commission Regulation No. 244/2012 and its Guidelines provide incentives to develop new methods, stating that Member States are required to define “reference buildings” representing the typical and average building stock in each Member State, in order to obtain general results consistent with the characteristics of the building stock under analysis. The guidelines specify two different methods for the establishment of reference buildings: 1) selection of a real example, representing the most typical building in a specific category (e.g. type of use and reference occupancy pattern, floor area, compactness of the building expressed as envelope area/volume ratio, building envelope constructions with corresponding U-value, technical systems and energy carriers together with their share of energy use); and, 2) creation of a “virtual building” which, for each relevant parameter, includes the most commonly used materials and systems. The choice between these options should depend on expert enquiries and statistical data availability. It is possible to use different approaches for different building categories, to have (real or virtual) reference buildings able to represent the characteristics (geometry, envelope, systems, etc.) of each specific building category.

There is a growing recognition of the importance of scales to address environmental issues. In particular, built environment studies ideally require analysis that is both on a fine scale, limited to individual buildings and streets, and a large scale, to study city-wide processes (Smith & Crooks 2010). Numerous tools are available for modelling the building stock, especially in the field of energy efficiency. The feasibility of their application to building vulnerability assessment has to be addressed and the method adapted by defining the appropriate resolution levels that allow a better understanding of the interrelation between the different scales.

2.2.2 Methods

Models of urban systems have been developed at different times and for different purposes. The development of ICT tools has resulted in a shift away from the holistic mega models that characterized the field from the 1960s to the early 1990s, towards more specific models that investigate an identify cluster of relationships (OECD 2011).

An exhaustive review of modelling techniques can be found in the energy sector (Swan & Ugursal 2009). According to its authors, the techniques used to model residential energy consumption can broadly be grouped into two categories, “top-down” and “bottom-up”. Top-down models utilize the estimate of total residential sector energy consumption and other pertinent variables to attribute the energy consumption to characteristics of the entire housing sector. In contrast, bottom-up models calculate the energy consumption of individual or groups of houses and then extrapolate these results to represent the region or nation. Both techniques are presented in Figure 9:

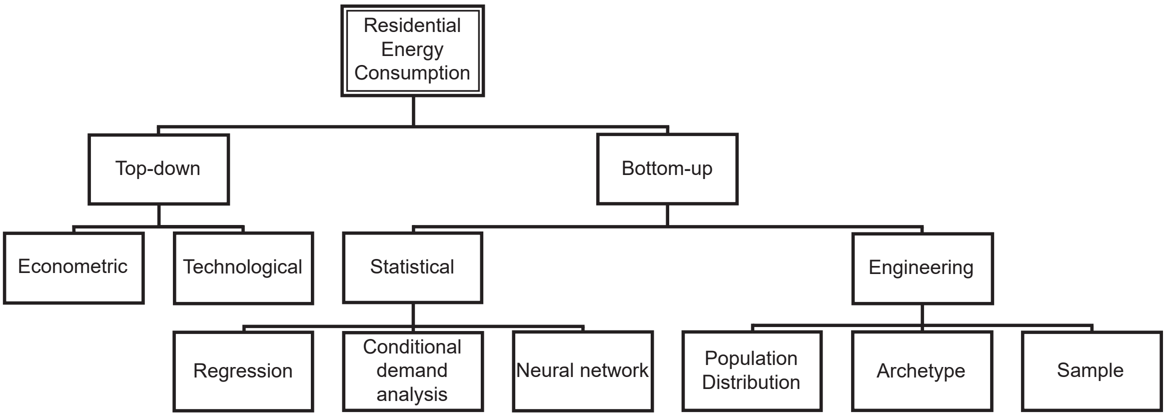


Figure 9: Top-down and bottom-up modelling techniques for estimating regional or national residential energy consumption. Source: (Swan & Ugursal 2009)

The bottom-up approach results in two subgroups: statistical methods rely on historical information and types of regression analysis which are used to attribute dwelling energy consumption to particular end-uses. Once the relationships between end-uses and energy consumption have been established, the model can be used to estimate the energy consumption of the dwellings that are representative of the residential stock. Engineering methods rely on information on dwelling characteristics and end-uses to calculate energy consumption based on power ratings, using characteristics and/or heat transfer and thermodynamic principles. Once developed, the bottom-up models may be used to estimate the energy consumption of houses that are representative of the residential stock and then these results can be extrapolated as representative of the regional or national residential sector. This extrapolation can be accomplished using a weight for each reference building or group of buildings on the basis of their representativeness by using different strategies: distribution of the population, archetypes and sample buildings.

The engineering method approach can be adapted and used as a basis for the estimation of building vulnerability analysis and adaptive strategies in urban environments. There is evidence of the use of this method in climate change and risk assessment research (Mavrogianni et al. 2012; Eisenack 2012) and the previously mentioned HOWAD model (Neubert et al. 2016). A major challenge associated with bottom-up engineering models is to find a level of detail with a reasonable input data requirement, while retaining sufficient spatial and temporal resolutions to allow the investigation of changes.

2.2.3 Building stock modelling

Building stock can be described in terms of sample buildings or archetypes (Swan & Ugursal 2009). Sample buildings represent actual buildings for which data are obtained through measurements. Archetypal buildings are instead statistical composites that provide an approximate description of the building stock. It is thus a “theoretical” building as opposed to a sample building where applied values are based on measurements of existing buildings that are unique (Mata 2011).

The methodology describing building stocks through archetype buildings consists of a segmentation, in which the number of archetype buildings required to represent the entire stock is decided; a characterization, in which each archetype is described by its physical and technical characteristics; a quantification, in which the number of buildings in the stock represented by each archetype building is determined.

The methodology describing building stock through sample buildings refers to the use of an actual sample of building data as the input information to the model. This methodology captures a wide variety of buildings within the stock and can be used to identify regions with high-priority. If the sample is representative enough of the regional or national stock, the overall stock can be estimated by applying appropriate weightings to the results. As the variety varies widely, this technique requires a large database of representative buildings.

The concept of “archetype” is applied in several fields of knowledge. An improved approach, already under the term “archetypes of vulnerabilities”, was developed for assessing the vulnerability of human-environment systems to environmental and socio-economic change within the 4th Global Environment Outlook (UNEP 2007). Archetype analysis is used to identify challenges and opportunities of cross-cutting environmental and social processes related to different components of human well-being.

The Canadian Urban Archetypes project (Webster 2007) investigates linkages between urban form, resident lifestyle patterns and associated energy consumption within selected Canadian neighbourhoods. An urban archetype is a profile of an individual neighbourhood, a synthesis of its physical infrastructure, energy consumption and reported resident behaviour.

The archetype buildings method is used as an input to the Energy, Carbon and Cost Assessment for Building Stocks (ECCABS) model, in which the net and final energy demands for the entire building stock under investigation are simulated. The ECCABS model is a bottom-up engineering model that has been developed to assess energy conservation measures (ECMs) and CO_2 mitigation strategies in building stock by using a set of individual representative buildings (either sample buildings or archetypes buildings), allowing their extrapolation to a region or country (Mata et al. 2013).

At a European level, the TABULA project (Ballarini et al. 2014) provided significant results by mapping data of existing residential buildings in 13 Member States, thereby creating a harmonized model for European building typologies and scenarios, it supports policy makers at the level of savings, by renovating each of the selected building typologies. Building types are defined according to their construction period and their size. The construction period varies for each country, as it should consider change in construction materials, architecture and legal requirements, while the size classes are common for all countries. The definition of building types was developed through three different methodological approaches (Ballarini et al. 2011):

- ➪ The “**Real Example Building**” (ReEx) approach identifies the building type through experience; the building type is selected by a panel of experts within an actual climatic context as the most representative of specific size and construction age classes. This approach is applied when statistical data are not available.
- ➪ The “**Real Average Building**” (ReAv) approach identifies the building type through the statistical analysis of a large building sample. The analysis is performed to find out a real building showing characteristics similar to the mean geometrical and construction features of the statistical sample.
- ➪ The “**Synthetical Average Building**” (SyAv) approach identifies the building type as an “archetype” based on the statistical analysis of a large building sample; the “archetype” is defined as “a statistical composite of the features found within a category of buildings in the stock” (IEA-ECBCS 2005). The archetype is not a real but a “virtual” building, characterized by a set of statistical properties pertaining to a building category.

When a large building stock is examined by means of a statistical approach, only the characteristics/ properties of a building sample are available. The large building stock, and as a consequence the building sample, is typically heterogeneous, so it is necessary to divide the buildings into categories (categorization process). Both the large building stock and the available building sample are consequently divided into categories: for each category, a reference building can be defined by means of a suitable procedure (Ballarini et al. 2011). To determine the representatives of groups of characteristic buildings, following which a typology of the whole building stock may be assembled (Naumann et al. 2009).

2.2.4 Data and metrics

There is a lack of standardized, accessible and reliable data sources and protocols for urban models responding to climate change and the sustainability agenda, as this field of research is still largely fragmented (OECD 2011). Disaster risk research has traditionally been more focused on hazards rather than the relatively more recent field of vulnerability. Current initiatives do not always clarify the primary and underlying causes of risk, the hazard severity or frequency, the vulnerability of the building stock, and lack of recovery capability.

Current international data harmonisation and standardization initiatives, such as the Integrated Research on Disaster Risk (IRDR) and the International Disaster Database EM-DAT (www.emdat.be) only very partially cover the needs of the risk assessment community. An example of an ambitious data collection project is that of the Global Earthquake Model (GEM), which develops computational tools together with a global database of earthquake events, losses and exposure data, with a spatial scale relevant both for local, national and global level analysis. The architecture of the tools and the database allows the inclusion of data and analytical models that are relevant to hazards other than earthquakes.

Reliable information on the existing building stock is often missing or incomplete and efforts should be made to improve access to existing data, which are usually unavailable or restricted. Some references can be found in the seismic risk assessment and energy efficiency fields. A few examples of national exposure databases of buildings and infrastructure exist, such as in Turkey, Australia, and New Zealand, but at the global level, only population data have been aggregated (e.g. LandScan). The project SYNER-G developed a methodological framework for the assessment of physical as well as socio-economic seismic vulnerability at urban and regional level based on a taxonomy for buildings, transports, and critical facilities. The modular SYNER-G taxonomy (Hancilar & Taucer 2013) makes use of the main categories which comprise the material, mechanisms resisting lateral force, floor and roof systems, seismic code level, etc.

Within the framework of several European projects, building inventories have been collected with a view to the assessment of energy performance. The EU Building Stock Observatory monitors the energy performance of buildings across Europe, and is available as an online tool (http://ec.europa.eu/energy/en/eu-buildings-database); the ENTRANZE project provides data to promote the introduction of nearly zero energy buildings in the existing building stock in Europe (www.entranze.eu). Useful risk-assessment data sets are collected, referring to the percentage of dwellings by period of construction and by type of building and the average floor area by type of building.

The INSPIRE Directive (European Commission 2007a) provides a building taxonomy organised in different schemes with increasing levels of detail. The simplest scheme includes information on the condition and date of construction, demolition and renovation, use, height and number of floors above ground, and number of dwellings and building units. It can be extended to comprise the building footprint or the tri-dimensional prism made up of the walls and roofs.

Another significant source of detailed information on the building stock, although not fully harmonised across countries, are the national housing censuses. The advantage of the census is that the information is gathered at the level of the building, but it only takes place every 10 years, usually as a result of considerable effort to aggregate information, therefore information is in many case not updated. These data are made available, in a harmonised classification, through the Eurostat Census Hub at regional level (NUTS 2), but are incomplete for smaller areas.

Data inventories are essential for collecting information on the characteristics and vulnerability of buildings and infrastructure, thus enabling a quantification of the exposure. With this information, exposed populations, assets and activities may be evaluated, in order to obtain an integrated view within a geographical area, which can be visualized and assessed through on-line maps.

2.2.5 Stakeholders and model users

The role of model users (usually non-experts) is emerging as a major issue influencing the effectiveness of models in practical applications, and their capacity to influence understanding and decision-making (OECD 2011). Policy making in complex urban environments, particularly those related to climate change and the conservation of historic cities, is characterized by scientific uncertainty and an increasing number of stakeholders with different values, needs and interest. While some models are designed with the purpose of improving understanding, others are developed to assist decision-making, which differ in their development and application processes.

Municipalities and urban managers are usually in charge of looking after the sustainability of cities and historic centres, by promoting different initiatives and supporting citizens in the process. The transition towards a more sustainable city requires the participation of different departments and agencies, involving several cross-thematic sectors. An integrated approach also comprises the participation of external stakeholders and the private sector, with the objective of implementing successful actions based on win-win strategies. The solutions have to come from the understanding of the needs that are important to each of the stakeholders in order for them to be sustainable and have to be designed to address the salient issues of each one (Khare et al. 2011). Data models can provide evidence to support and to facilitate stakeholder coordination and decision-making.

Model users can mainly be grouped under the following categories:

- ➪ **Technocrats**, employed within government or project related consultancies, who have political influence and interface with the community at large. This category includes grant managers, responsible for raising interest, together with the public administration (local and regional authorities), in specific thematic areas, releasing and supporting programs.
- ➪ **Policy and operations decision makers**, including advisors to government and private-sector planners and designers. This category comprises investors with the financial capacity to support specific projects and solution providers, interested in promoting their technologies.
- ➪ The **general public**, as communities and associations with interest in specific issues or places; building owners, who directly experience climate change challenges on their properties and building users, who identify the needs of the building and provide funding to owners.
- ➪ The **technical and scientific community**, and other urban specialists and planners.

Stakeholders are aware of the new challenges and consequences derived from environmental issues and wish to be better informed, but they do not always understand what information the models can provide and what the limits are of these tools, how they are influenced by data availability and the effort that goes into creating them. Expectations are usually related to a simple graphical presentation of complex information and interactions, often required as scenarios. On the other hand, model makers make assumptions about the applicability and use of models in political and cultural domains with which they may not be familiar and they will not usually consider the different levels of comprehension among the various users.

Effective models should therefore be appropriate for different decision-making process and different situations, by coupling diverse users in the same urban environment and by providing subjective judgments where it may be needed in collective decision-making.

2.2.6 Data representation and organization

Sustainability in urban development has become a critical issue due to the high levels of urbanization in almost all parts of the world (United Nations 2014). Urban planners use a variety of tools when developing strategies and plans to mitigate these problems. Traditionally, these have been prescriptive tools such as geographic information systems (GIS) (Webster 1994) or descriptive tools such as computer-aided design (CAD) software and 3D visualization packages (Levy 1995).

Urban system modelling can provide greater understanding and better decision-making in planning, design and management of cities and urban areas. As for the case of Building Information Modelling (BIM), used to provide project-based technical tools, urban models have the potential to become internationally recognized. One of the promising tools is CityGML, which is a commonly used information model that can represent various levels of detail of cities in 3D, from the city or regional scale to the individual building.

Several options for the generation of urban models are available. Some of them are based on pure geometry and lack of semantic information, although it is possible to include some parameters, such as population density or building age. These parameters are found in the generation of virtual 3D cities provided by Google Earth, based on user contributions and their automatic generation through LiDAR data, which can quickly provide urban models, but which lacks tools to identify urban elements, thereby hindering its use for realistic visualisation.

Lack of semantic data in urban models is a serious limitation to decision-making processes, but the generation of realistic 3D models, which combine geometric and semantic information in a cost-effective way, is still a challenge (Egusquiza 2015). Free or low-cost data are needed, in order to generate cost-effective city models. To that end and especially if the information remains incomplete, cadastre and remote imagery provide the most plentiful sources. Complementary data are provided through initiatives such as OpenStreetMap, but these data are generated by non-professional users and are only available for some areas, which can result in non-homogeneity and irregularity of parameters.

The limitations of current 3D models are associated with the lack of interoperability between data formats at syntax level and the absence of integration between the urban and the building scales, which have traditionally been treated as separate (Egusquiza 2015). Regional and urban environments have been dominated by the use of GIS tools which, over the past decades, have become commonplace worldwide and are increasingly accessible to the general public. At the level of the building, traditional tools based on Computer Aided Design (CAD) have evolved into the Building Information Model (BIM) paradigm, which provides both geometric as well as semantic information. Even if this approach provides detailed information for 3D buildings models, it is not a cost-effective tool and is too time consuming for its application to urban environments.

One of the main requirements for the development of data models is conformity to standards and commonly used formats to facilitate interoperability. In GIS, despite the existence of data formats such as .shp - widely used and considered as a *de facto* standard - each software tool has its own format which hinders interoperability (Towne 2009). With regard to 3D representations, GML and KML are the most widely used data formats, although both are intended to store geometric and not semantic information. A step forward was taken in the form of the evolution of CAD tools in application to the BIM concept, providing semantic information on building models, and ensuring interoperability through the implementation of open standards.

A multiscale data model format that falls between GIS and BIM is CityGML, an open data model and XML-based format for the storage and exchange of virtual 3D city models issued by the Open Geospatial Consortium (OGC) and the ISO TC211. It defines classes and relations for the most relevant topographic objects in cities and regional models with respect to their geometric, topological, and semantic properties and appearance. These thematic information types go beyond graphic exchange formats and allow users to employ virtual 3D city models for sophisticated analysis tasks in different application domains such as simulation, urban data mining, facilities management, decision support and thematic inquiries. Due to their ability to combine geometry and building databases, CityGML models have recently become the file format of choice for several European research projects (Reinhart & Cerezo Davila 2016).

The underlying model differentiates five consecutive levels of detail (LoD), where objects become more detailed with increasing LoD, both in geometry and thematic differentiation, as shown in Figure 10:

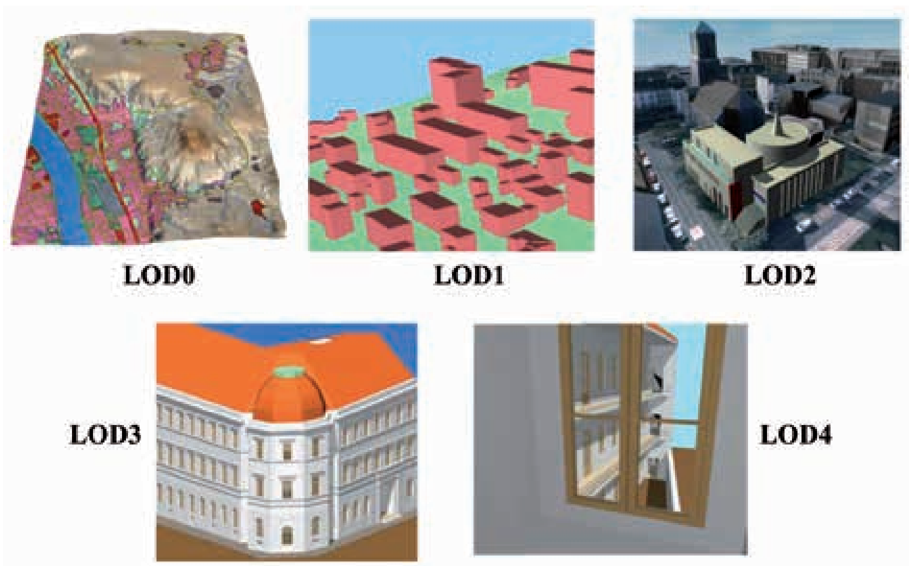


Figure 10: The five levels of detail (LoD) defined by CityGML. Source: (Kolbe 2009)

LoD0 is essentially a two-and-a-half dimensional Digital Terrain Model, over which an aerial image or a map may be draped. LoD1 is a blocks model, without any roof structures or textures. In contrast, a building in LoD2 has differentiated roof structures and textures. Vegetation objects may also be represented. LoD3 denotes architectural models with detailed wall and roof structures, balconies, bays and projections. High-resolution textures can be mapped onto these structures. In addition, detailed vegetation and transportation objects are components of a LoD3 model. LoD4 completes the LoD3 model by adding interior structures like rooms, interior doors, stairs, and furniture. The definition of the LoDs is provided by the work of different research groups (Köninger & Bartel 1998; Coors & Flick 1998; Kolbe 2009).

This kind of enriched model has potential in diverse fields, such as spatial analyses such as noise mapping (Herman & Reznik 2013), urban air flow analyses (Jurelionis & Bouris 2016) and provides substantial information for urban disaster management tasks (Kolbe 2016). The use of CityGML in risk management has been addressed using indoor LoD with respect to specific disaster types (Kemec et al. 2010) and, in LoD4, for fire events (Ren et al. 2012). Estimating the extent of floods has been a traditional topic in GIS, mostly with digital terrain models (Jain et al. 2005; Wang & Liu 2006). However, models on the propagation and impact of flooding following overflow of water from water bodies or due to heavy precipitation can be improved by using 3D city models (Schulte & Coors 2008). The purpose of recent studies (Schulte & Coors 2009; Mioc et al. 2011; Kemec et al. 2010) has focused on the visualization of flood extent and depth in an urban context, while aspects of buildings damages were not included. (Varduhn et al. 2015) and (Amirebrahimi et al. 2015) used 3D models to assess the flood risk and potential damage levels at a micro-scale, by integrating BIM and GIS, defining a high level of components for buildings.

Municipalities working on and supporting CityGML are, among others, Berlin, Hamburg, Cologne, Düsseldorf, Recklinghausen and Leverkusen.

Figure 11: Different Levels of Detail in a scene.
Source: http://www.directionsmag.com/entry/citygml-an-open-standard-for-3d-city-models/123103

Figure 12: Buildings in LoD2 with photorealistic textures in Berlin, Germany.
Source: Economic Atlas Berlin. http://www.businesslocationcenter.de/en/berlin-economic-atlas

Figure 13: Street setting in Frankfurt with 5 textured buildings in LOD 3. Source: OGC

Figure 14: LoD2 CityGML of Helsinki, Finland. Source: http://kartta.hel.fi/3d/

2.3 MIVES - INTEGRATED VALUE MODEL FOR SUSTAINABLE ASSESSMENT

Several multi-criteria approaches have been developed in the last decades and applied to the construction sector (Hokkanen & Salminen 1997; Al-Harbi 2001; Wang & Elhag 2006; Zavadskas et al. 2014). Among thd its applicability in diverse complex scenarios related to sustainability (San-José Lombera & Garrucho Aprea 2010; Aguado et al. 2012; Del Caño et al. 2012; Pons & Aguado 2012; Pons & De La Fuente 2013; Pardo-Bosch & Aguado 2015; Piñero et al. 2017). Its soundness has been demonstrated by its inclusion in the Spanish Structural Concrete Instruction (EHE-08) (Fomento 2008).

Jointly developed by the Polytechnic University of Catalonia (UPC), Tecnalia and the University of the Basque Country (UPV/EHU), it combines two analytical concepts: Multi-Criteria Decision-making Theory and Value Engineering (San-José Lombera & Garrucho Aprea 2010). MIVES is used to give homogeneity to different types of variables, either quantitative or qualitative and measured with different units, by transforming them in the same dimensionless unit. Moreover, it takes into account the relative importance of the circumstantial aspects under consideration and integrates environmental, social, economic, and technical indicators into a single index.

The versatility of this methodology has permitted its application to different fields such as security, health, design of industrial buildings and rehabilitation prioritization. The methodology developed in MIVES proposes a structure for analysis that can be easily adapted to any decision-making process.

2.3.1 MIVES Methodology

One of the most important characteristics of the MIVES methodology is that the whole evaluation model is established prior to the generation of the alternatives. In this way, decisions are taken from the beginning, having taken into account and defined all aspects and their assessment methods. This approach avoids subjectivity in the decision-making, as the alternative evaluation has no influence (Viñolas et al. 2009).

The phases of the methodology, chronologically listed, are as follows:

- ➪ **Problem definition and decision to be taken**: defines who makes the decision, fixes the limits of the system and establishes the boundary conditions;
- ➪ **Decision support tree definition**: establishes all the issues to be considered in an organized way, in the form of a requirements tree (hierarchy);
- ➪ **Setting the value functions**: generates mathematical functions that allow the transformation of quantitative and qualitative aspects of the last branch of the requirements tree into a set of variable with the same unit ("value"), between 0 and 1;
- ➪ **Weight assignment**: assigns the relative importance of one aspect compared to others on the same branch of the requirements tree;
- ➪ **Alternatives evaluation**: obtains the value index for each of the proposed alternatives;
- ➪ **Sensitivity analysis** (optional): the possible variation of the value index is analysed in cases where the weights or the value functions, defined in the first phase, change (Piñero 2013);
- ➪ **Results corroboration** (optional): verifies, in the long term, whether the model still matches what was initially evaluated and whether the calculations in each alternative are as expected.

Problem definition and delimitation

Clear identification of the problem, the person who will make the decision and establish the limits of the system is important, in order to structure the decision-making process and set its boundaries. Fundamental aspects to be considered are as follows:

What does the decision concern. The problem that the methodology has to solve should be clearly defined, as the decision to be taken has to select the most acceptable option, from among a set of alternatives.

Who makes the decision. In complex decision-making processes, several stakeholders, with different profile and needs, are involved. In many cases, no alternative exists, which represents the best option in all of the aspects under consideration. The selection of the best alternative is not immediate and depends on who will make the decision, responding to collective interests, which should be clearly identified.

Limits of the system. The decision-making is structured around three axes, (Figure 15), which can vary according to the type of study to be performed. Lines which separate the different shaded cubes represent the limits of the systems, in which these cubes are the ones that will be analysed in the decision-making. Separating and factorising the decision-making in each of the three axes helps to define, in a precise way, which decision is to be taken, reducing the risk of omitting some requirements or components, and thereby obtaining comparable and homogeneous alternatives.

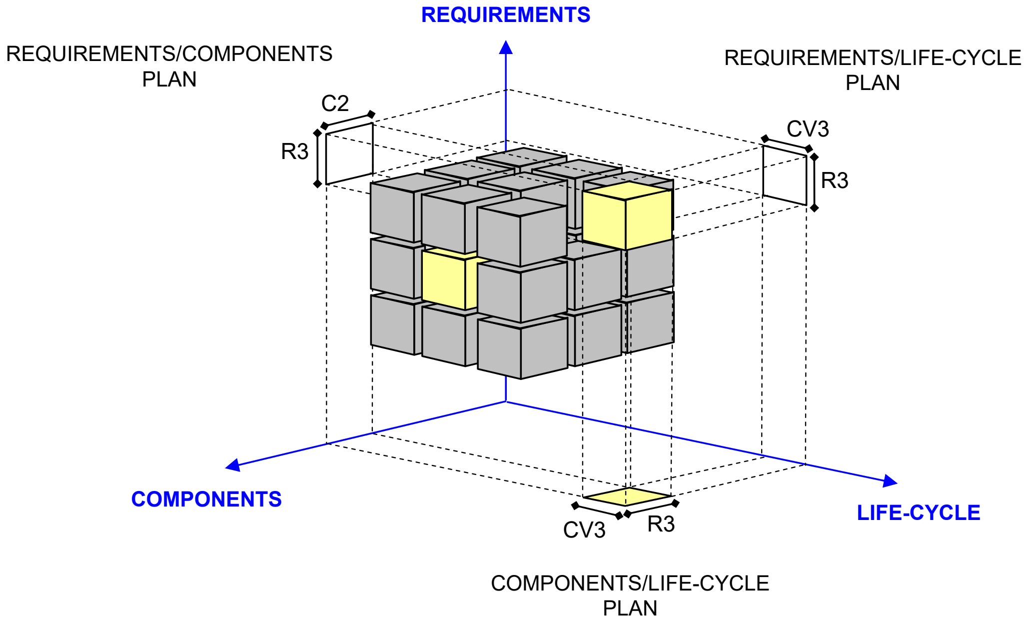


Figure 15: Decision-making axes. Source: (Villegas 2009)

Boundary conditions. Circumstances related to decision-making can differ in accordance with various factors whether temporal, geographic, and climatic among others. Boundary conditions should be the same, in order to establish a comparable evaluation of alternatives. Indeed, the quantification of each aspect, e.g. costs, time, return period etc. will be different according to the alternative under analysis. The approach to the initial problem should be the same, in order to compare which solution is the best, but each alternative yields a different solution to the problem. Some of these conditions may be determined, meaning that some alternatives cannot exceed certain limits. The list of determining conditions is called the check list, as it represents the minimum requirements the alternatives should meet before their evaluation. If the quantification of any conditioner is below or above the predetermined limits, then the alternative will not be evaluated.

Decision support tree definition

The branched structure of the decision-making tree represents all the aspects that were defined in the first phase of analysis. There are several levels from leaf to trunk and each branch (level) can be divided into different sublevels. At the first level, the requirements are established, which are the fundamental aspects that define the decision. At the intermediate levels, criteria and sub-criteria are expressed and at the last level the most concrete aspects are defined, which will be evaluated in depth: the indicators. A generic decision-making tree is shown in the following figure:

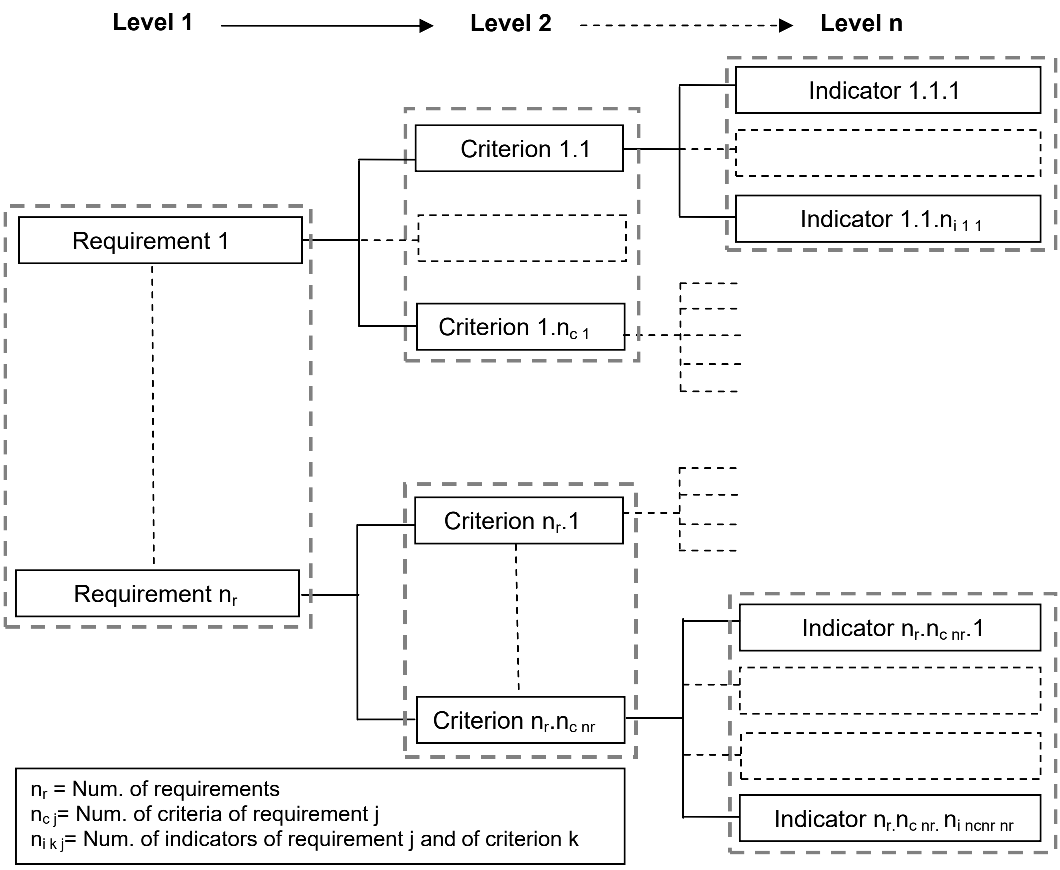


Figure 16: Generic decision tree. Source: (Viñolas et al. 2009)

Depending on the desired degree of precision, the system of branches can be extended. No more than 3 or 4 branches and no more than 20 indicators are recommended, as the assessment of non-relevant indicators may cloud the results of more important indicators (Alarcón 2006).

It is recommended that requirements and, in many cases, criteria, with their corresponding weights, should be selected by a panel of politicians, managers and experts, in order to build a proper strategy and to obtain a good decision-making tree. In any case, those with responsibility for defining the most important aspects to be considered and the guidelines and actions to be taken for effective improvements should be represented on the panel. Furthermore, the decision-making tree will not reflect specific aspects that may be beneficial to some stakeholders and disadvantageous to others. Technicians should define indicators, as these are related to more specific aspects, which are usually based on technical characteristics. They should also be in charge of defining weights and value functions for these indicators.

Requirements, criteria and indicators have to represent what we want to evaluate. The ideal situation will be to fill the whole decision sphere (white circle) with indicators (coloured circles). If this condition is to be met, the indicators should be located in the decision area of the different criteria and the requirements and should neither overlap those areas, nor occupy areas in which they do not belong (decision area of other criteria, requirements or outside of the decision-making) (Josa 2012).

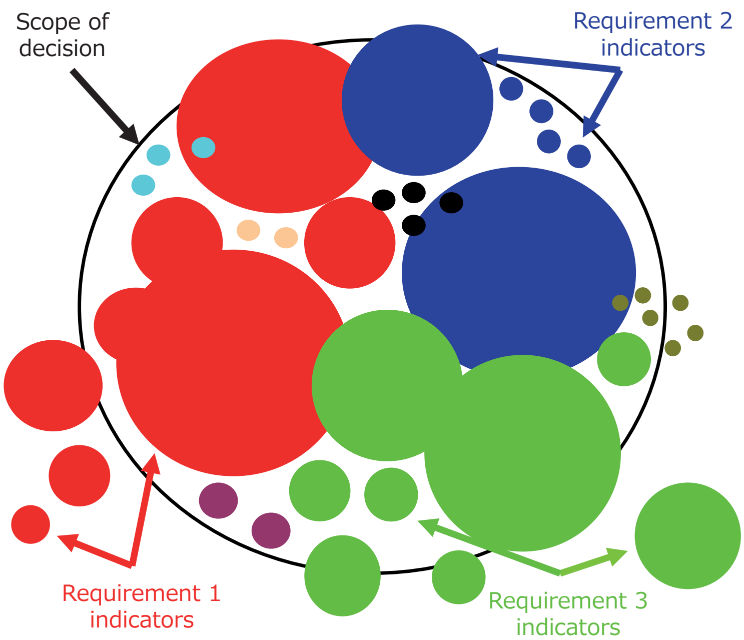


Figure 17: Graphical representation of the decision-making process. Source: (Josa 2012)

The main characteristics of the indicators should be as follows:

- ➪ **Representative**. The selected aspects should be representative of the decision-making. According to the above figure, the indicators that occupy the larger area of the decision sphere, especially of the requirement and criterion to which they belong, should be selected.
- ➪ **Differentiating**. The characteristics that differentiate the alternatives should be preferred. If indicators are evaluated with the same quantification for each alternative, the values will be the same and there will be fewer important results.
- ➪ **Complementary**. Indicators should be defined, in order to tackle, in a complementary way, all the information (Garrucho 2006) and they should measure variables that are independent of other indicators, thereby avoiding the overlapping of the circles.
- ➪ **Relative**. The objective is to give no advantage to units or elements that belong to larger groups in terms of absolute value.
- ➪ **Quantifiable**. The selection of different indicators that occupy the same sphere of the decision-making should be taken on the basis of ease of measurement.
- ➪ **Precise**. Indicators should have the minimum degree of uncertainty and should be clearly outlined (Garrucho 2006).
- ➪ **Traceable**. To guarantee the future comparison of data.

Value functions definition

The main objective of the value function is to compare the evaluation of indicators with different units of measurement (e.g. time, cost, temperature, etc.). A weighted sum of each indicator may be established by using this approach. The value function transforms the quantifications of a variable or attribute to a dimensionless variable somewhere between 0 and 1.

Different value functions are taken into consideration for the evaluation of the indicators. The value function varies from 0 to 1 on the vertical axis, which represents the minimum or the maximum level of satisfaction, respectively. The variable of the indicator is represented on the X-axis or abscisse. Usually four different shapes of the value function (concave, convex, linear, S-shaped) are determined, in order to connect the minimum and maximum levels of satisfaction. When the shape of the value function for an indicator is unclear, this may be defined by a working group.

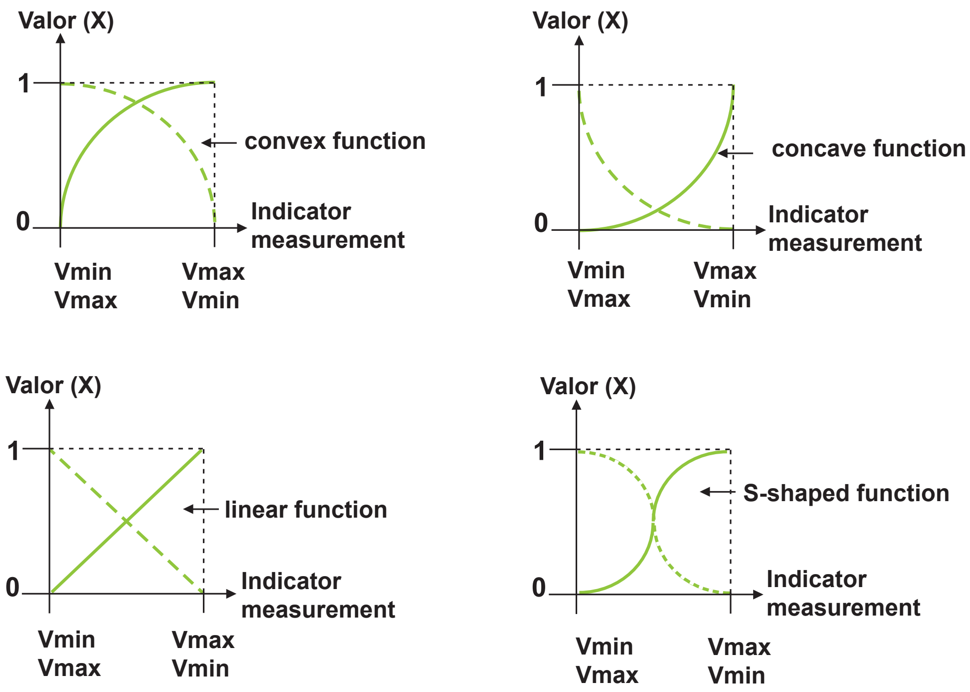


Figure 18: Different shapes of the value functions. Source: (Cuadrado 2009)

An increasing or decreasing value function may be used, depending on the nature of the indicator to be evaluated. An increasing function is used when an increase in the measurement variable results in an increase in the decision maker's satisfaction. In contrast, a decreasing value function shows that an increase in the measurement unit causes a decrease in the satisfaction of the decision-maker (Alarcon et al. 2011).

A convex function is appropriate when there is hardly any increase in satisfaction for small changes around the point that generates minimum satisfaction. This type of relationship is selected when it is more important to approach the point of maximum satisfaction than to move away from the point of minimum satisfaction. It is often used for economic or environmental indicators, because the aim is to ensure that the alternatives are located as close as possible to the point of maximum satisfaction.

A concave curve is used when, starting from a minimum condition, satisfaction rapidly increases at first in relation to the indicator. In this case, small changes around the point that generates minimum satisfaction are given high scores. This type of relationship is chosen when it is more important to move away from the point of minimum satisfaction than to approach the point of maximum satisfaction.

A linear function reflects a steady increase in the satisfaction produced by the alternatives. There is a proportional relationship throughout the range.

An S-shaped function is a combination of the concave and convex functions. A significant increase in satisfaction is detected at central values, while satisfaction changes little as the minimum and maximum points are approached. This type of relationship can be chosen when the majority of alternatives are concentrated in a middle range between the points of minimum and maximum satisfaction.

MIVES uses the following equation [Eq. 1] as a mathematical model, in order to define the different value functions of each indicator,

$$V_{ind} = B * \left[1 - e^{-K * \left(\frac{|X - S_{min}|}{C} \right)^{P}} \right]$$

[Eq. 1]

where:

V_{ind} is the value of the indicator under evaluation.

B is a factor that allows the function to remain within the range from 0 to 1. It is assumed that the highest level of satisfaction has a value of 1. This factor is determined by the following equation [Eq. 2]:

$$B = \frac{1}{\left[1 - e^{-K * \left(\frac{|S_{max} - S_{min}|}{C} \right)^{P}} \right]}$$

[Eq. 2]

S_{min} is the point of minimum satisfaction, with a value of 0.

S_{max} is the point of maximum satisfaction, with a value of 1.

X is the abscissa that generates a value equal to V_{ind}.

P approximately defines the shape of the curve: concave, convex, linear or S-shaped. If $P < 1$ the curve is concave; if $P > 1$ the curve is convex or S-shaped; if $P = 1$ it is linear.

C is a parameter that approximately defines the x-value of the point of inflexion for curves with $P > 1$.

K is a parameter that approximately defines the y-value at point C.

Weight assignment

In multi-criteria analysis, the decision-maker might consider that some aspects are more relevant than others. The measures of the relative importance of the different aspects are known as weights. The assignment of weight is performed under the same hierarchical level of the requirements tree, thus comparing homogeneous aspects. Indicator weights are calculated in relation to others of the same criterion. In the same way as for criteria, weights are calculated in relation to criteria corresponding to the same requirement.

Weights can be assigned through a direct score or through the Analytical Hierarchy Process (AHP). The first option is used when there are few elements in the comparison group or when the weight of each element is clear (e.g. all have the same importance).

The weight assignment can be performed by starting from weights α of the requirements, followed, for each requirement, by the calculation of the weights, β, of its criteria and, for each criterion, establishing the weights, γ, of the indicators (Brugha 2004). The process can also be done in reverse order, starting from the indicators and finishing with the requirements.

The AHP approach, developed by (Saaty 1980), is one of the more extensively used multicriteria decision-making (MCDM) methods. AHP can provide an analytical process that is able to combine and consolidate the evaluations of the alternatives and criteria by either an individual or group involved in the decision-making task (Crouch & Ritchie 2005). Elements at each level are compared in pairs with respect to their importance to an element in the next higher level. The analysis through a pair-wise comparison involves the development of a comparison matrix at each level of the hierarchy, the computing of the relative weights for each element of the hierarchy and the estimation of the consistency ratio.

Comparison matrix

The AHP starts by creating a pair-wise comparison matrix A, in order to compute the weights for the different criteria, The matrix A is an $n \times n$ real matrix, where n is the number of evaluation indicators, criteria or requirements considered. The values attached to each element of the matrix A are calculated according to the relative importance of the variable i with respect to the variable j, according to the opinion of the decision makers, expressed in a qualitative way, as shown in Table 1.

$$A = \begin{vmatrix} 1 & a_{12} & \dots & a_{1n} \\ a_{21} = \frac{1}{a_{12}} & 1 & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} = \frac{1}{a_{1n}} & a_{n2} = \frac{1}{a_{2n}} & \dots & 1 \end{vmatrix}$$

If the relative importance of variable *i* compared to variable *j* is $a_{ij}=x$, in order to maintain the coherence and the consistency of the matrix that has been prepared, the entry a_{ji} of the matrix, which represents the relative importance of the variable *j* with respect to the variable *i*, should be $a_{ji}=1/x$.

A scale of numbers that indicates how many times more important or more dominant one element is over another element is needed to draw comparisons:

Intensity of importance	**Definition**	**Explanation**	**Matrix element** a_{ij}	a_{ji}
1	Equal importance	Two activities contribute equally to the objective	1	1/9
2	Weak or slight		2	1/8
3	Moderate importance	Experience and judgement moderately favour one activity over another	3	1/7
4	Moderate plus		4	1/6
5	Strong importance	Experience and judgement strongly favour one activity over another	5	1/5
6	Strong plus		6	1/4
7	Very strong importance	An activity is strongly favoured and its dominance demonstrated in practice	7	1/3
8	Very, very strong		8	1/2
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation	9	1

Table 1: Scale of relative importance. Source: (Saaty 1980; Saaty 2008)

There will only be one matrix for the calculation of the requirement weights, and one for each group of criteria related to the same requirement, and a further matrix for each group of indicators related to the same criterion.

After all pair-wise comparison matrices are formed, the weights vector, $w=[w_1,w_2,...,w_n]$, is computed on the basis of Saaty's eigenvector procedure. The computation of the weights involves two steps. First, the pair-wise comparison matrix, $A=[a_{ij}]nxn$, is normalized and then the weights are computed.

The normalized pair-wise comparison matrix A_{norm} may be derived, by making the sum of the entries in each column equal to 1, i.e. each entry a_{ij} of the matrix A_{norm} is computed as in [Eq. 3]:

$$\bar{a}_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}}$$

[Eq. 3]

Finally, the criteria weight vector *w* (that is an *n*-dimensional column vector) is built by averaging the entries on each row of A_{norm}, i.e.

$$w_i = \frac{\sum_{j=1}^{n} \bar{a}_{ij}}{n}$$

[Eq. 4]

Consistency ratio

The consistency ratio is used to verify the coherence, or incoherence, of the values attributed by the decision makers to the matrix. Consistency is related to two characteristics, which are transitivity and proportionality (Alarcón 2006).

Transitivity indicates that relations between the order of the different elements are respected. If we compare a group of elements composed of *A*, *B* and *C* and it is considered that the importance of *A* is greater than *B* and the importance of *B* is greater than *C*, it means that *A* should be greater than *C*. Proportionality implies that proportions are maintained between the scales of importance. For instance, if *A* is 3 times greater than *B* and *B* is 2 times greater than *C*, *A* should be 6 times greater than *C*. If these two characteristics are met for all matrix elements, then the matrix will have a consistency of 100%.

When establishing priorities between two variables of a 2x2 matrix, there will never be inconsistency, while if the matrix is 3x3 it will hardly be inconsistency. If the matrix under consideration is larger, by establishing priorities between two elements at each time, the global overview may be lost and decision-makers may arrive at incoherent evaluations: the higher the number of variable, the higher the risk of incoherence. As possible solutions, (Saaty 1980; Saaty 2008) proposed to analyse the consistency of the matrix through the so-called consistency ratio (CR), calculated by the following equation [Eq. 5]:

$$CR = \frac{CI}{RI} \qquad \text{[Eq. 5]}$$

where, *CI* is the consistency index of the matrix and *RI* is the random index associated with a matrix of the same dimension.

The consistency index *(CI)* is calculated according to the following equation [Eq. 6]:

$$CI = \frac{\omega_{max} - n}{n - 1} \qquad \text{[Eq. 6]}$$

where ω_{max} is the highest eigenvalue and *n* the dimension of the matrix.

The random index *(RI)* is the average of all the consistency indexes of a comparison matrix generated in a random way. The values are reported in the table below and depend on the size of the matrix:

Matrix size (*n*)	1	2	3	4	5	6	7	8	9	10
Average RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Table 2: Average random number index for each size of the matrix

The *CR* should be no greater than 0.1, in the interests of consistency. If the CR is much in excess of 0.1 the judgments are untrustworthy, because they are uncomfortably close to randomness and the exercise is valueless and must be repeated.

Alternative evaluation

The evaluation of alternatives is performed at three levels: indicators, criteria and requirements, according to the following figure:

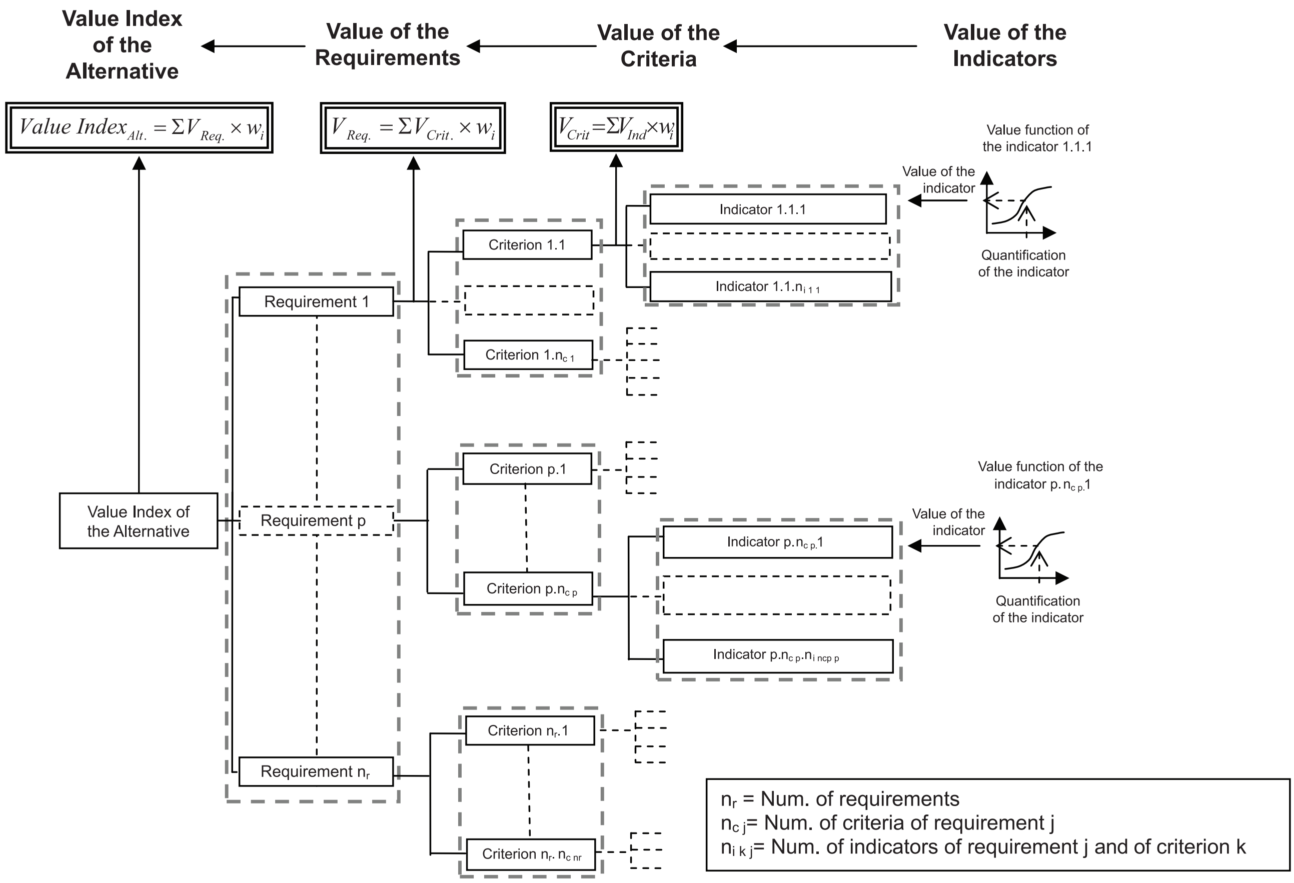


Figure 19: Evaluation of alternatives. Source: (Viñolas et al. 2009)

The indicator value is obtained by the value function and the quantification of the indicator for each alternative. The quantification of the alternative is given by the abscisse of the value function and the value of the indicator by its corresponding ordinate value.

The criterion value is given by the value of the indicators of the same criterion multiplied by their weights, as in the following equation [Eq. 7]:

$$V_{criterion} = \sum_{i=1}^{n} V_{indicator_i} \times W_i$$

[Eq. 7]

where *n* is the number of indicators belonging to the same criterion.

The requirements value is obtained in a similar way to the criterion value, which is the sum of the criterion values under the same requirement, multiplied by their weights:

$$V_{requirement} = \sum_{i=1}^{n} V_{criterion_i} \times W_i$$

[Eq. 8]

where *n* is the number of criteria hanging on the requirement under evaluation.

The value index of the alternatives is obtained by summing the value of the requirements multiplied by their weights, where *n* is the number of requirements:

$$ValueIndex_{alternative} = \sum_{i=1}^{n} V_{requirement_i} \times W_i$$

[Eq. 9]

Sensitivity analysis

As was explained in the definition of the decision-making process, the best alternative depends on whoever takes the decision, depending on the declared interests and needs. A sensitivity analysis is therefore interesting where preferences vary, in order to verify whether the final result of the alternatives shows any considerable changes. This step should not be considered in all types of decision-making, but is recommended when several points of view are gathered together.

The sensitivity analysis is used to understand the influence of the different parameters on the value index obtained for each alternative. Usually weight variations are examined at the requirement level, because the modification of weights at criterion or indicator level is usually not relevant (Viñolas 2011).

Variations within a range of 30% maximum are recommended for each requirement weight, as it has been demonstrated that differences of opinion usually stay within this range. The new value index is calculated according to the second equation [Eq. 11], rather than the first one:

$$V(A_i) = \sum_{j=1}^{n} w_j z_{ij}$$

[Eq. 10]

$$V'(A_i) = \sum_{j=1}^{n} w'_j z_{ij}$$

[Eq. 11]

where:

w_j is the weight of requirement j

z_{ij} is the value of requirement j for alternative i

w'_j is the new requirement weight

$$w'_j = w \left(1 - \frac{\Delta \text{ Weight of reference requirement}}{100 - \text{Weight of reference requirement}}\right)$$

Results corroboration

This last phase, as in the previous one, is not mandatory for the methodological process. Its objective is to verify all the aspects included in all phases of the methodology. Nevertheless, it is useful when the different elements need a periodic review or when indicators are calculated on the basis of estimates rather than pre-determined values.

As a final result, the decision-maker will obtain a ranking of solutions based on the numerical value of the evaluation. Once the results have been obtained, an objective and reliable decision can be made.

2.3.2 MIVES software application

The MIVES software application is a user-friendly application developed for the evaluation of alternatives in multicriteria decision-making, which incorporates the methodological aspects described in the previous sections. It includes 3 software modules: programmer, user and report interfaces: (https://www.etcg.upc.edu/prj/mives/herramienta-mives).

2.4 CONCLUSIONS

The complex process of decision-making is partially due to the contrasting interests of the actors that are involved, the uncertainty of particular aspects and the consideration of elements, which are in some cases difficult to compare and to evaluate. Furthermore, the inclusion of new emerging challenges in the sustainable development goals, further complicates urban planning. The incipient need to consider climate change and disaster mitigation as part of city management strategies will contribute to the generation of critical data, which should be seen within the context of city development. If the correct balance can be found between data acquisition and the accuracy of the results, the inclusion of relevant information in a unique urban model can provide a solution for an effective decision-making process. Furthermore, if this is combined with a multiple criteria decision analysis (MCDA) process, which helps the decision-maker by providing a systemic and organised way of thinking, the quality of the results will improve.

Considering the current methodologies and approaches developed in the different fields of knowledge, the main assumptions on which the present dissertation is founded are as follows:

- An integrated and holistic approach is needed for effective sustainable development, which considers the historic city as a core part of city planning and includes climate change and disaster mitigation as new challenges for city planning;
- A flexible information strategy, based on a balance between the required data and the accuracy of the results is needed for complex decision-making, in order to provide proper informational and organizational structures;
- Decision-making processes need to be based on multicriteria analysis and should include the multi-stakeholder perspective that will enable an integrated analysis of all aspects.

"Measure what can be measured, and make measurable what cannot be measured."

Galileo Galilei

3

METHODOLOGICAL APPROACH

Vulnerability is the first step towards informed decision-making. The effects of flooding on buildings, especially historic buildings, have to be determined in terms of the intrinsic and social conditions of the buildings themselves. Their characteristics and nature will mean that they are either more susceptible to the effects of climate change or more capable of coping with them. Nevertheless, the vulnerability of historic buildings should be assessed in the light of sustainable development objectives, integrated into urban planning. Efforts should therefore be balanced and a compromise should be reached between methods that consume resources and the accuracy of the results.

The complex ecosystems of historic cities generate a large amount of heterogeneous data, at different scales, in different formats, and for different uses (Egusquiza 2015). Many of these locally available data sources can be used to determine the vulnerability of the historic city by assessing it at the level of a building, through the creation of typologies representing the building stock. Historic cities are characterized by buildings that often share similarities and common constructive elements. These common features mean that the building stock may be easily categorized and the vulnerability assessment may be suitably approached through a sample or demonstration building. Furthermore, the use of a methodology which organises and structures the information, at various hierarchical levels, implies greater objectivity in decision-making. Through a value analysis method, vulnerabilities and risks may be compared on a unique index, thereby facilitating the prioritisation of interventions in a specific area or building of the historic city.

The organization of these data sets is essential for evidence-based decision-making on sustainable development and, in order to fully exploit this information, an interoperable and multi-scalar data model is required.

This chapter describes the methodology proposed for vulnerability and risk assessment in the historic city, based on the building categorization method and the use of indicators for decision-making based on value analysis. The methodological approach is a cost-effective procedure that not only saves time and resource costs in relation to data acquisition, but delivers accurate results.

3.1 SCOPE, REQUIREMENTS AND STRUCTURE OF THE METHODOLOGICAL APPROACH

Up until the present, there has been no agreed or unified definition of a historic city, district or centre. Nevertheless, one commonly accepted description of the historic city centre is that it forms part of a larger urban entity, in which the historical and architectural aspects of old buildings are considered valuable and in many cases deserving of protection. Nevertheless, the contemporary practice of conservation goes far beyond the concept of tangible heritage and now covers the intangible dimensions. This broader understanding implies that all knowledge capital that is derived from the experiential development of human practice, and from spatial, social and cultural constructions that are linked to it, may be encapsulated in the word “memory”

(ICOMOS 2016). In the context of this research, historic cities are subjected to dynamic forces, from economic, social and cultural spheres, and comprise the whole urban landscape, including buildings that may be left unprotected by legislation.

European cities are currently introducing adaption and disaster mitigation strategies, due to the increasing likelihood of urban disasters and as a result of an international political awareness that calls for new integrated approaches, by linking disaster risk reduction and adaptation to climate change. Both approaches share the same ultimate goal of reducing vulnerability to climate related hazards (UNISDR 2015b).

Heritage is not usually taken into account in these global approaches, even though it is the focus of certain actions (ICOMOS 2016; Hosagrahar et al. 2016). Historic districts should not be considered in isolation from the rest of the urban area. Conservation should be supported and integrated into an overall urban development plan that prevents the spatial or social segregation of the historic centre.

The first assumption of this methodological approach is that cultural heritage, including its values and vulnerability, must be integrated into wider frameworks of climate change adaptation plans and policies, as well as into disaster risk management plans, as a way of enhancing sustainability.

There is considerable confidence that climate change models provide credible quantitative estimates of future climate change, particularly at continental scales and above. Nevertheless, confidence in the changes projected by global models decreases at smaller scales (IPCC 2013). Two main downscaling methods are used for regional and local climate change: dynamic and statistical. In the first one, high-resolution climate models have to be run on a regional sub-domain, using observational data or lower-resolution climate model outputs as a boundary condition. Statistical downscaling is a two-step process consisting of the development of statistical relationships between local climate variables and large-scale predictors and the application of such relationships to the output of global climate model experiments to simulate local climate characteristics in the future. Faster models with lower resolution represent large scale average quantities and are used in cases of long multi-century simulations. Simulations with complex models are required to obtain finer details at a regional level. Furthermore, projections are commonly developed around three periods: 2016-2035, 2046-2065 and 2081-2100, representing the near future, the middle of the century, and the end of the century.

Climate change increasingly affects decisions at the municipal level, as local council policies promote resilience and enhance sustainability. If local government is at the core of urban adaption planning, it often lacks resources and data on related climate risks and vulnerabilities that are usually fragmented across departments. Urban climate data need to be geographically integrated, across time scales, to encourage local dialogue in adaption planning, and the range of regional benefits and the costs of climate policy need to be considered (Ruth 2010). The initial focus of many cities has been mitigation rather than adaptation, nevertheless, many operational strategies adopted for energy reduction can contribute to adaption deficits (e.g. green roofs which can reduce cooling demand, retain water during storm and reduce storm-water runoff).

Furthermore, urban governments with effective capacities for disaster risk reduction have institutional and financial capacities that are important for adaptation. This necessarily involves overlapping responsibilities and authority across other levels of government (Dietz 2003; Ostrom 2009; Blanco et al. 2011; Corfee-Morlot et al. 2011; McCarney et al. 2011; Kehew et al. 2013). Mainstreaming adaption strategies into urban planning, land-use management and legal and regulatory frameworks are the keys to successful adaption (Lowe & Foster 2009; Kehew et al. 2013). They can help planners to rethink traditional approaches to land use, infrastructure and building design based on past trends, and move to forward looking risk-based design for a range of future climate conditions (Kithiia 2010; Solecki 2012; Kennedy & Corfee-Morlot 2013). Exposure to weather-related risk in expanding urban areas increases when local governments fail to address their responsibilities by expanding or upgrading infrastructure and services and reducing risk through building standards and appropriate land-use management (UNISDR 2009; UNISDR 2011). Urban master plans and strategic plans with a time horizon of 10 or more years can incorporate climate risks and vulnerabilities, but assessments must be available to influence such plans. Adaption options include enforcement of building regulations and upgrading. The potential for housing is linked to the simultaneous promotion of mitigation, adaption and development goals.

The proposed methodological approach is based on a multi-disciplinary and multi-scalar dimension. The strategic (urban) scale is connected to the operational (building) scale, in order to support the integration of adaptive measures within disaster risk management, sustainable development and climatic scenarios. This approach also considers all stakeholders involved in the decision-making process and ensures access to relevant data for decision-making through proper information management.

Different groups of urban dwellers will face different levels of risk in relation to both the direct and indirect impacts of climate change (Hardoy & Pandiella 2009; Mitlin 2012). Vulnerability related to climate change expresses the degree to which a system is susceptible to, and unable to cope with, the adverse effects of climate change, including climatic variability and extreme events (IPCC 2014b). Vulnerability is a function of the character, magnitude and rate of climate change, as well as the variation to which a system is *exposed*, its *sensitivity* and its *adaptive capacity*.

It is obvious that systems are vulnerable to direct climate change impacts only to the extent that the hazard actually poses a risk. The impact can be contained by removing any exposure to the hazard (e.g., provide drains that prevent flooding). Resilience can be considered in relation to individuals/households, communities, and urban centres. In each of these scenarios, it includes the capacity to undertake anticipatory or recovery actions that avoid or reduce a climate change impact; for instance, by living in a safe location, having a safe house, or risk-reducing infrastructure. Adaptions by individuals, households, communities, private enterprises, and government service providers can all reduce risks.

This methodological approach defines a data model for historic city risk assessment that links the concept of vulnerability and risk management to the latest international approaches to climate change, by structuring information to facilitate adaptive decision-making. It considers the parameters of exposure to climate hazards vulnerability, by means of binomial sensitiveness and adaptive capacity and risk (exposure – hazard - vulnerability). The method is focused on the definition and evolution of exposure and vulnerability indicators, contextualized in the field of cultural heritage.

Figure 20 shows the concept of the risk assessment data model:

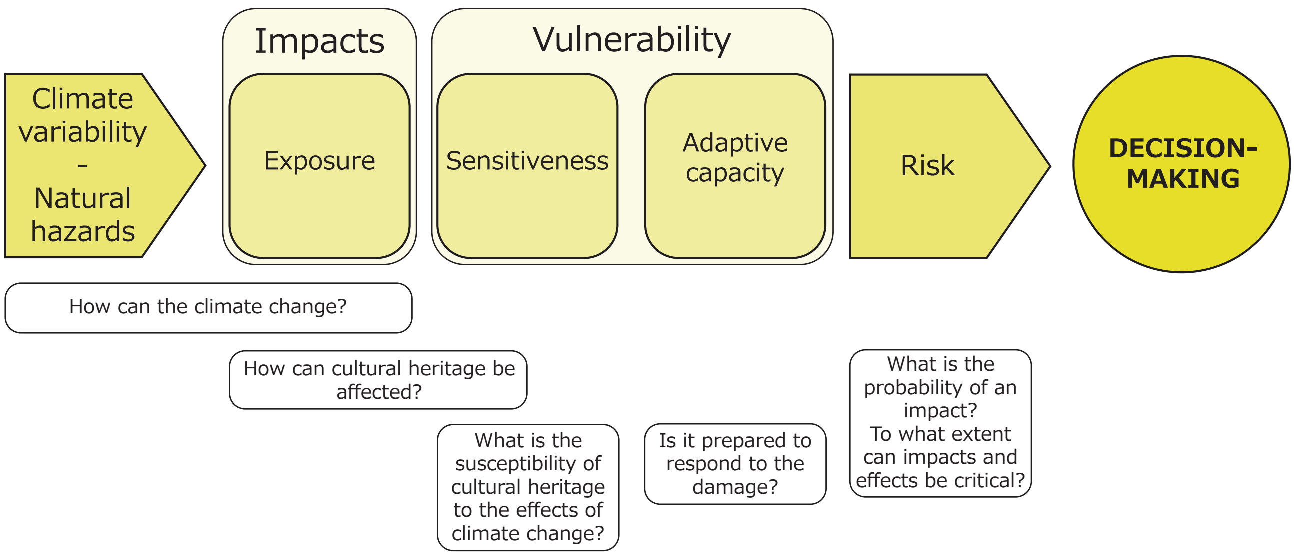


Figure 20: Risk assessment approach. Source: Author

The following requirements for the development of the risk assessment methodology are established, as a means to accomplish the above-mentioned objectives:

REQ ID	REQUIREMENTS
GEN_RQ_01	Permit the integration of risk management, urban sustainability and climate change concepts, taking into account the importance of cultural heritage values.
GEN_RQ_02	Allow for an iterative approach once adaptive measures are implemented.
GEN_RQ_03	Integrate the strategic (urban) level and the operational (building) level through a multiscale approach.
GEN_RQ_04	Structure the information flow, to facilitate the decision-making process.
GEN_RQ_05	Ensure public access to information and allow 3D visualisation, to facilitate the understanding of outputs.
GEN_RQ_06	Ensure interoperability with other tools and systems used in urban planning.
GEN_RQ_07	Implement a cost-effective method, based on public information, that integrates geometric and semantic data.
GEN_RQ_08	Permit the integration of data at a higher (building) level, if information is available, in order to provide feedback at the strategic (urban) level.

Table 3: General requirements of the methodological approach

The structure of the methodological approach is articulated in the categorization (modelling of the building stock towards flooding events) and risk assessment (vulnerability and exposure) to facilitate the decision-making in adaptive strategies, selection of solutions and emergency response, as shown by Figure 21:

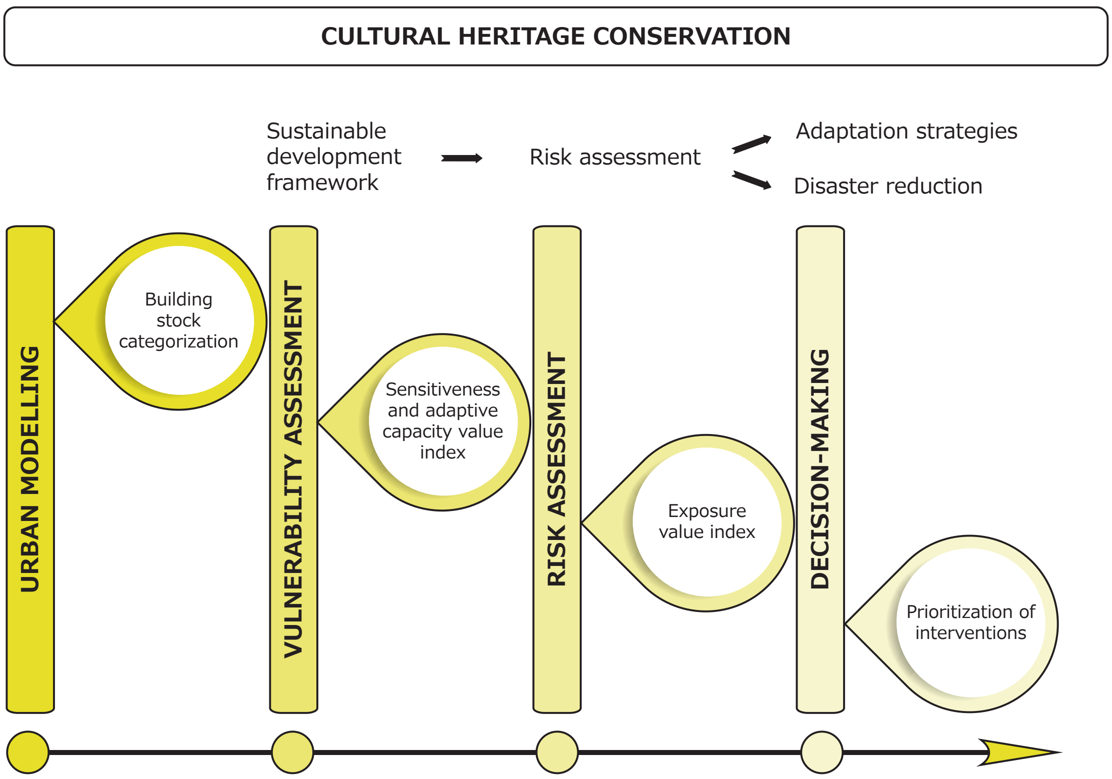


Figure 21: Structure of the methodological approach. Source: Author

3.2 VULNERABILITY ASSESSMENT

Vulnerability assessment is the first step towards evidence-based decision-making for the development of adaptive strategies. As described in the previous chapter, damage models are widely used as a tool for estimating losses due to flooding. The large range of applications has led to divergent methods, however, depth-damage functions remain the accepted means of assessing physical damage (Thieken et al. 2005). No account is taken in these functions of the characteristics of the building, other than their economic cost, even though probabilistic approaches to structural assessment are beginning to emerge, reflecting the approach used in seismic vulnerability assessment (D'Ayala et al. 2006). There is a need for methods to estimate the specific nature of vulnerability to flooding in historic buildings, as the use of flood depth as a single parameter is insufficient to capture the hazard that it represents for historic buildings. A more suitable approach is the one that has a holistic overview of the nature of historic buildings as an asset and determines the vulnerability according to a range of factors able to summarize the physical and social conditions of the building itself. The methodology that is proposed brings together data which characterize the intrinsic properties of the building as well as social and economic aspects that can contribute to decreasing vulnerability.

Furthermore, as adaptive solutions are of a different nature and can be applied either at an urban level or the level of the building, systems that characterize and classify the buildings on a large scale are needed, in order to select proper sustainable development strategies. Gaining an overview of the vulnerability of the whole historic district, by considering the building scale, will allow us to establish the magnitude of the interventions to prevent flooding damage in specific areas or buildings.

As one of the requirements of the methodological approach is to link and to integrate climate change, risk management, and urban development, vulnerability is considered as the interrelation between system sensitiveness and adaptive capacity. The integration of the information in a coherent urban data model will be of utility to other disciplines by providing open-access information.

Sensitiveness in the case of a building is considered as the propensity of it experiencing harm and is determined by its intrinsic properties, such as its constructive characteristics, conditions and use. The adaptive capacity can be understood as the building's resilience, comprising its cultural values, its adaptive characteristics and the socio-economic conditions of the inhabitants.

3.2.1 Building stock categorization

As previously mentioned, general knowledge on asset vulnerability can be obtained at a macro-scale with a sufficient level of confidence. The vulnerability of the buildings in historic cities have to be assessed one by one, implying a micro-scale approach. This method is related to different data sources, among which the field survey is the most common for data acquisition. Nevertheless, the characterisation of single elements consumes both time and resources that are not easily assumed by many local governments. So, there is a need to find a compromise between the macro-scale of regional and national territories and the micro-scale based on single elements, in order to characterize the buildings at a local level. This compromise can be found by modelling the historic city through a statistical distribution of buildings characteristics inside a determined area, starting from samples and applying their characteristics to the whole area.

A proper data model is needed, in order to support the entire methodological approach. Some of the capabilities of this data model can be exploited through a building stock categorization which will support the modelling process. The methodology will use sample buildings and the results will be extrapolated to the other buildings of the same category, thereby obtaining an overall vulnerability assessment for the whole historic district.

The objective is to create a limited number of unique samples which reflect almost the entire building stock of the historic city, considering the constraints of data availability. These groups should reflect the flooding vulnerabilities, the historic value and the constructive characteristics of the buildings. Furthermore, data should be automatically or semi-automatically obtained, in order to build a low-cost model. Geometric data are obtained directly from the model, while semantic data are obtained from public information systems, such as the cadastre.

Categories

According to the above-mentioned requirements, the following parameters have been selected for the building stock categorization:

- ➪ **Year of construction**: buildings built in the same period have similar construction techniques;
- ➪ **Use**: according to the main use of the building, the time frame in which it can stop operating can be determined, thus permitting the prioritisation of intervention in more sensitive buildings;
- ➪ **Existence of a basement**: the basement is one of the most exposed parts of the building to flooding, as it will retain all water that flows downwards into it. Its existence provides a metric of the vulnerability of the asset;
- ➪ **Level of protection**: a direct indicator of the historic value of the building and the measures that can be further applied in the selection of adaptive solutions. Together with the year of construction, it can provide a measure of the value of the building;
- ➪ **Number of dwellings**: the higher the number of dwellings, the higher the capacity of adapting the building to new climatic conditions, as intervention costs are shared among different owners;
- ➪ **Socio-economic status**: together with the number of dwellings, the categorization gives an overview of the economic capacity of undertaking adaptive interventions.

The selection of parameters to build categories represents one of the main sensitive steps. The right balance between representativeness, number of typologies and relevance of the information should be sought. The configuration of typologies is not unique and depends on the specific history and the location of the city under consideration. If we consider all the variables of all the parameters, it will result in a huge number of typologies. It is therefore necessary to select a proper threshold that will divide the parameter into diverse ranges, but it is also necessary to discard the less representative groups.

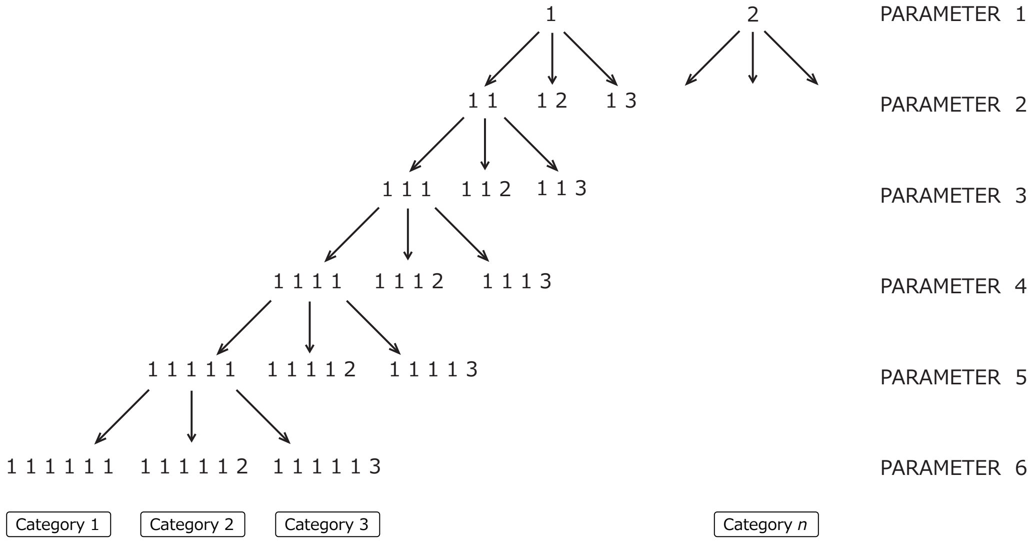


Figure 22: Generation of categories. Source: adapted from (Prieto et al. 2017)

The use of frequency histograms to identify the concentration of particular values of each parameter can facilitate the selection of possible ranges according to their representativeness. The ranges may be established, once the distribution of each parameter has been identified. It is recommended to start with parameters with a low number of variables and to proceed to divide up the categories with respect to other parameters. The categories will be established, by adjusting the ranges of each parameter.

Once all the categories have been identified, a selection of the most representative is done, by the establishment of a minimum threshold. The acceptable number of categories and percentages of building stock that they represent will differ according to size of the historic district and its homogeneity. The aim should be to achieve an optimum balance between both, considering that a minimum threshold of between 2% and 5% usually provides good results (Egusquiza 2015).

In summary, the following actions for the categorization process are foreseen:

- Statistical overview of the historic city;
- Discarding of buildings which, for some reason, are not included in the scope of the assessment;
- Select the parameters to be used for the generation of the categories and establish the ranges of each one; aiming for maximum representativeness with a minimum number of categories;

- ➪ Establishment of the threshold for the minimum representation: categories with lower representativeness will be discarded;
- ➪ Generation of the categories.

Sample buildings

Having established the categories of the buildings, a sample building representing each category has to be selected. Criteria for the selection of sample buildings can vary depending on the specific characteristic of the historic city under consideration. It is important to select a sample building in which information on the characteristic of the building is available. As the results obtained by the sample building will be extrapolated to the whole category, it should be selected according to its representativeness. Again, a statistical approach and frequency histograms can be a support tool for the selection of the appropriate sample building. By using this approach it is possible to discard the buildings which are outside the range of parameters representing the category as a whole.

Following the selection of the sample buildings, the data model will be completed with detailed information on these buildings. The geometric information is already included in the data model for each building, while the semantic information has to be completed at the level of the sample building. This information on the geometry and the 6 parameters used for the categorization of the building will be unique for each building, but additional information will be extrapolated from sample buildings.

The information at the level of the sample building may be accessed through municipal databases, field surveys and the use of Google Earth and Street View.

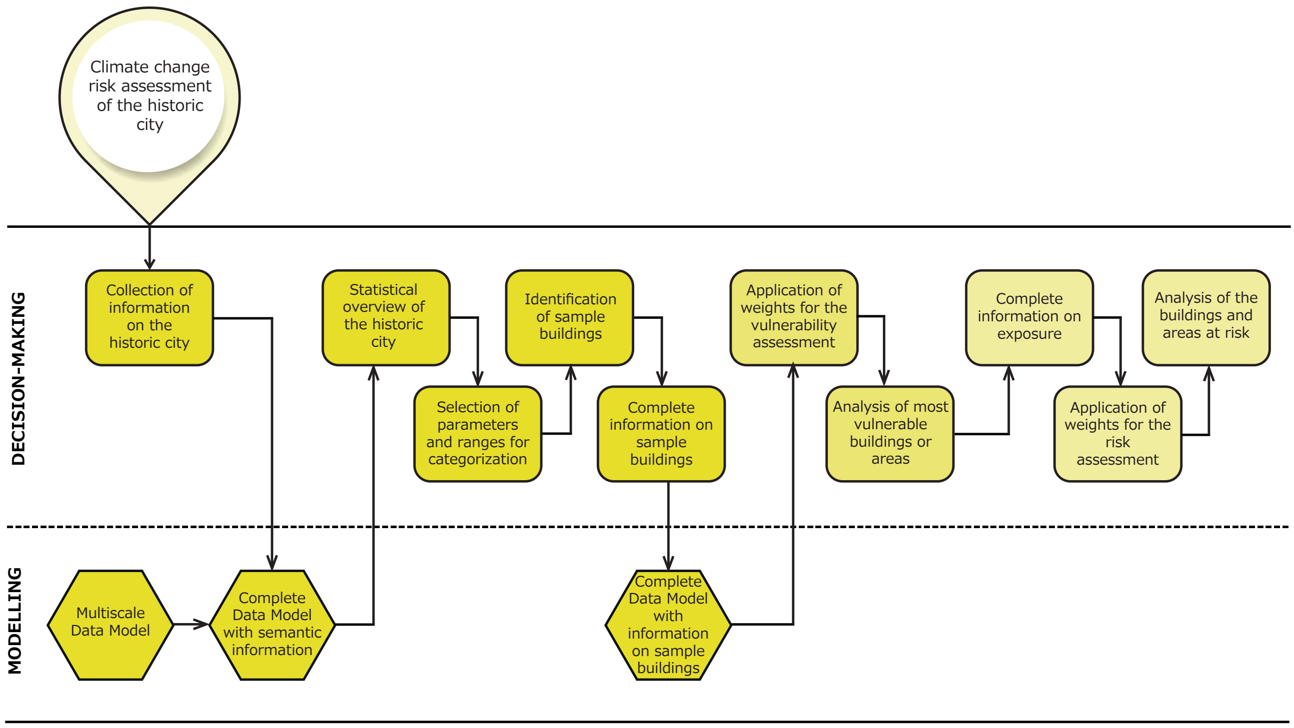


Figure 23: Work flow for risk assessment. Source: Author

Information on sample buildings

Current vulnerabilities are established for the sample buildings, in order to set the priorities for the areas and the buildings that require adaptive strategies or interventions. The indicators presented in this section are the result of the requirement tree established through the MIVES methodology, which will be explained in section 3.2.2. The selection of a set of indicators is performed taking into account the balance between high accuracy in the results and limited input for their application in the modelling of the historic city. The information related to the indicators will be filled for each sample building. The following indicators are considered in the vulnerability assessment of a building:

Requirement	Criterion	Indicator
Sensitiveness	Current situation	State of conservation Existence of water damage
	Constructive	Ground floor typology Existence of a basement
	Envelope	Openings ground floor Roof type Façade material
	Criticality	Use
	Structure	Structural material
Adaptive capacity	Interventions	Existence of adaptive systems Drainage system conditions
	Socio-economic	Previous interventions Num. of dwellings and socio-economic status
	Cultural	Cultural value

Table 4: Vulnerability assessment requirements, criteria and indicators for the sample building

3.2.2 The use of MIVES for calculating vulnerability

The proposed methodology for the vulnerability and risk assessment of coastal and river flooding and extreme precipitation in historic cities is formed by a hierarchic structure divided into three levels: requirements, criteria and indicators, as depicted in a requirements tree.

Criteria represent a way of clustering measurable aspects and are associated with sensitiveness, adaptive capacity and exposure requirements. Each criterion is divided into several evaluation indicators, which represent the last hierarchic level of the requirements tree.

Problem definition and decision to be taken

In urban areas that are vulnerable to climate change impacts, the buildings play an important role in the selection and the prioritization of the interventions that will be taken. The scope of applying the MIVES methodology is to identify, in an objective way, buildings which are more vulnerable and exposed to the effects of extreme precipitation and coastal and river flooding.

Requirements tree definition

The requirements tree is a hierarchic structure in which the characteristics of the vulnerability and risks assessment are defined, displayed and organized. In this section, vulnerability will be addressed, while risk will be presented in the following Section. Normally three hierarchic levels are defined (Aguado et al. 2006): requirements, criteria, and indicators. In the first levels, namely the requirements and criteria, general and qualitative aspects are defined, while the indicators, concrete and measurable aspects are considered at the last level.

The requirements tree defines the objectives that are raised and the decision-making process. In the framework of this research, the tree was designed according to the requirements commonly used in the environmental science for the identification of areas vulnerable to climate change impacts. This design relates to the purpose of this work: the development of a tool that is compatible and comparable with existing methodologies, so as to add value and to include the building perspective in existing knowledge.

Vulnerability is formed by the sensitiveness and the adaptive capacity of an element. The requirements tree is defined accordingly, considering sensitiveness and adaptive capacity as the two fundamental requirements, and the tree is adapted to the building perspective with the definition of criteria and indicators. In Section 3.3, the exposure requirement will be introduced for the calculation of the risk assessment.

The **sensitiveness** requirement has the objective of assessing the degree to which a building is affected by an event. Depending on the conditions, typology and characteristics of the structure that is considered, its response to climate impacts varies. With the objective of contributing to decision-making by selecting appropriate adaptive solutions to more vulnerable buildings, several elements are considered: current state of the building, constructive critical elements, envelope characteristics, main use, and structural material.

The current state of the building indicates its state of conservation, considering the technical state of the constructive system and existing water-related damage. The constructive elements and the envelope of the buildings represent the aspects that are considered the most critical in a flooding event. Criticality is related to building usage and consequently the period of time it may be unavailable for service to the population, while structural aspects are related to the behaviour of the structure that is damaged when exposed to water.

The requirement of **adaptive capacity** refers to the ability of a system to assume the potential effects of an event, overcoming its consequences. In this case, criteria refer to interventions, socio-economic conditions and the cultural value of the buildings.

Interventions refer to previous rehabilitation interventions and the quality and state of conservation of relevant equipment. Socio-economic conditions are related to the coping mechanisms of the inhabitants, in view of possible adaptive measures and the existence of adaptive systems in the building. The cultural value of the building reflects the historic, architectonic and cultural value of the building in accordance with the protection of cultural heritage.

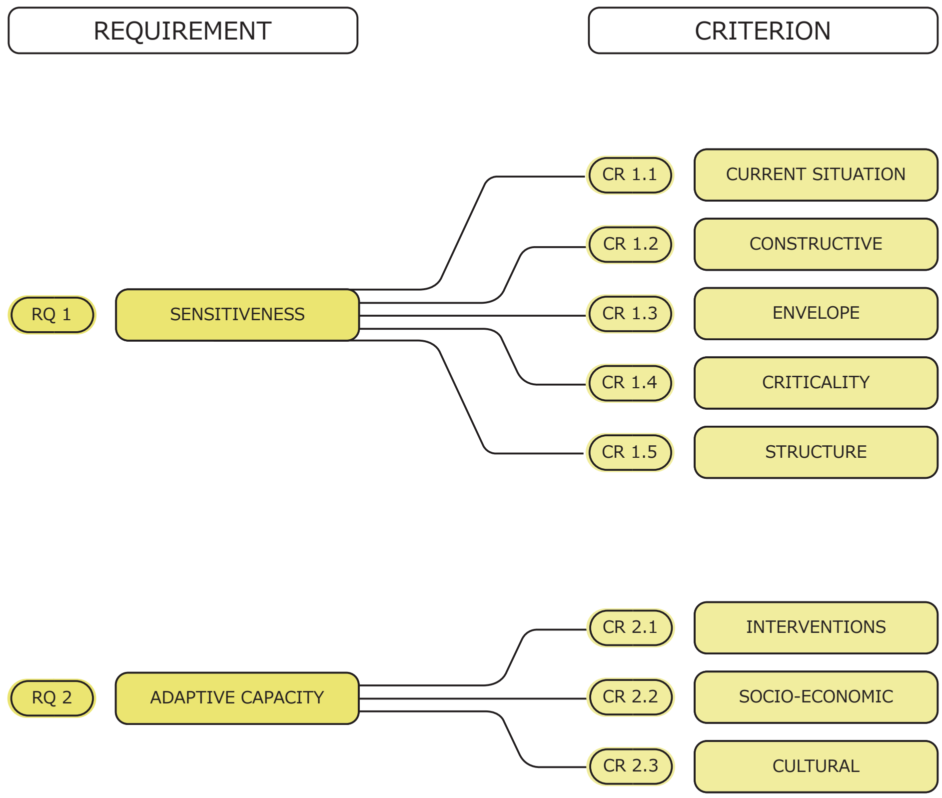


Figure 24: Requirements and criteria of the decision tree. Source: Author

The requirements tree developed for the vulnerability assessment is defined by two requirements (sensitiveness and adaptive capacity), which are divided into 8 criteria of evaluation and 14 quantification indicators, presented in the figure below. The objective of the lowest hierarchic level -the indicators- is to assess the vulnerability of the buildings.

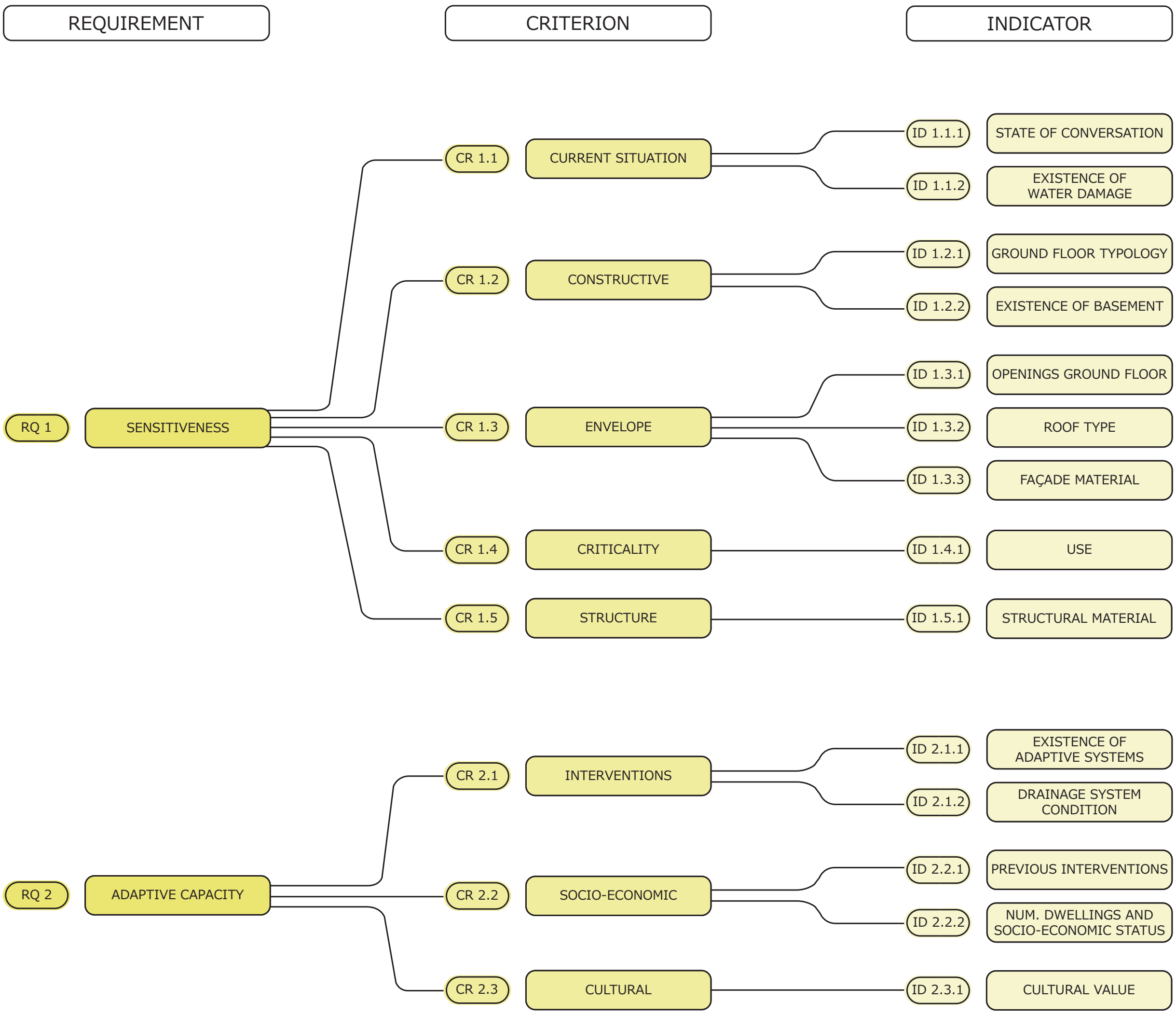


Figure 25: Requirements, criteria and indicators of the vulnerability decision tree. Source: Author

Establishment of value functions

Indicators of the sensitiveness requirement

State of conservation

This indicator assesses sensitiveness according to the current state of conservation of the building, the worst condition representing the greater sensitiveness. Alternatives have been established according to the following possibilities:

Good: Buildings with no damages. Their structures are in good condition and the rest of their elements (façade and roof) are also in a good or a fair state of conservation.

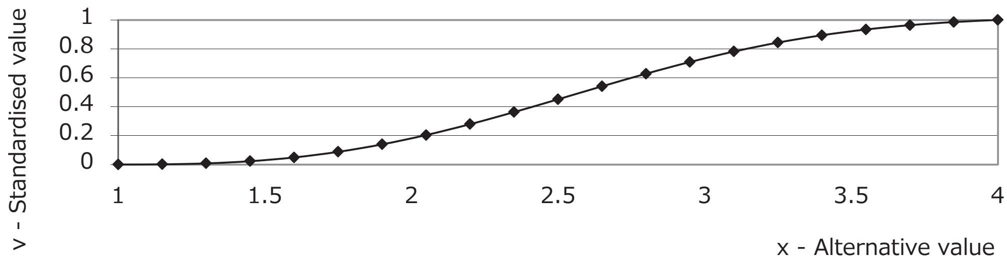
Fair: Buildings with occasional damage. Their structures are in a good or a fair state or require specific interventions on their secondary structures. Other elements, in a fair or a poor condition, may need interventions.

Poor: Buildings with widespread deterioration. Their structures (main and/or secondary) are in a poor condition and require structural interventions. Other elements are also in a poor condition and present areas in danger of material detachment.

Very bad: Highly deteriorated buildings. Their structures present serious damage, including partial collapse, with other deteriorated elements.

A matrix has been developed that considers both the main elements of the constructive systems and their degree of conservation, in order to calculate in the most objective way possible the overall state of conservation of a building.

A value function has been defined, to evaluate the different alternatives of the state of conservation. The maximum value (1) is attached to the buildings which are in very bad condition, while the minimum value (0) is attached to buildings in good condition.



Xmin	1
Xmax	4
P	2.7
K	1.1
C	1.9

Figure 26: Shape, tendency and maximum and minimum satisfaction values of the "state of conservation" indicator. Source: Author

The following table reports the values of the different alternatives:

STATE OF CONSERVATION	
GOOD	0.00
FAIR	0.18
POOR	0.73
VERY BAD	1.00

Table 5: Values of the alternatives of the "state of conservation" indicator

Besides, a matrix evaluating the importance of each element in relation to its state of conservation has also been developed. It is used to assign a value to each element by a pair-wise comparison, using the Analytic Hierarchy Process (AHP). A multidisciplinary panel of experts evaluated the technical alternatives of the methodology. The panel of experts, mainly composed of experts in the architectural and engineering fields and conservation managers, was asked to define which element is more important than another and to what extent, by filling the shaded cells. Once the matrix had been completed by all experts, the weight vector was calculated for each alternative.

	STRUCTURE	ROOF	FAÇADE
STRUCTURE	1	1/2	1/5
ROOF	2	1	1/3
FAÇADE	5	3	1

Table 6: Pair-wise comparison matrix evaluating the importance of the elements in relation to their state of conservation

The expert assessment of the average weight vector of each element is reported below:

IMPORTANCE OF THE STATE OF CONSERVATION OF BUILDING ELEMENTS	
STRUCTURE	0.62
ROOF	0.24
FAÇADE	0.14

Table 7: AHP weight factor of the importance of the elements in relation to their state of conservation

The final result was a value, which is the combination of the weight factor attached to the building element and the degree of conservation, as in the following table:

	FAÇADE	ROOF	STRUCTURE
GOOD	0.00	0.00	0.00
FAIR	0.03	0.04	0.11
POOR	0.10	0.18	0.45
VERY BAD	0.14	0.24	0.62

Table 8: AHP weight factor in relation to the element and the state of conservation

The overall value, which will be applied to the indicator, is the sum of the different elements according to their state of conservation.

As an indicative value for the overall state of conservation, some ranges have been established, according to the above-mentioned definitions:

OVERALL STATE OF CONSERVATION	
GOOD	0.00 - 0.10
FAIR	0.11 - 0.44
POOR	0.45 - 0.85
VERY BAD	0.86 - 1.00

Table 9: Ranges of the state of conservation in relation to the condition of each element

This information is not usually available from public sources, nor is it included in municipal databases. In some cases, technical inspection data sheets are available, but the information related to the results of the inspection is not usually public and is difficult to obtain. Data should be therefore gathered by *in situ* inspections.

Simplified method:

A simplified method can be used when analysing a large number of buildings within a short period of time. It assesses only the general state of conservation of the building and can be used when access to the building is difficult and inspections are limited to the exterior. The main criterion is to evaluate the façade, as it often shows damage related to the structure or roof. The values given to the different alternatives are the ones reported in the compound method:

STATE OF CONSERVATION	
GOOD	0.00
FAIR	0.18
POOR	0.73
VERY BAD	1.00

Table 10: Values of the alternatives of the “state of conservation” indicator (simplified method)

Existence of water damage

This indicator assesses the sensitiveness of the building according to type of damage (humidity, filtrations, erosion) and the type of element under consideration (façade, roof, structure above ground and foundations). A compound indicator was established and, using expert criteria, both parameters were evaluated.

As a first step, a matrix evaluating the gravity of water damage to the building elements was developed. It establishes priorities among the elements by making a series of judgments based on a pair-wise comparison. The experts were therefore asked to attach greater or lesser importance to one element with respect to another and to define their degree of importance. The following 4x4 matrix was filled in by each expert (shaded cells) and the weight vector for each one of them was calculated.

	FAÇADE	ROOF	STRUCTURE ABOVE GROUND	FOUNDATIONS
FAÇADE	1	1/3	1/4	1/7
ROOF	3	1	1/3	1/5
STRUCTURE ABOVE GROUND	5	3	1	1/2
FOUNDATIONS	7	5	2	1

Table 11: Pair-wise comparison matrix evaluating the importance of the elements in relation to water damage

The average weight vector for each element proposed by the experts is shown below:

IMPORTANCE OF WATER DAMAGE TO BUILDING ELEMENT	
FAÇADE	0.07
ROOF	0.14
STRUCTURE ABOVE GROUND	0.30
FOUNDATIONS	0.49

Table 12: AHP weight factor of the importance of the elements in relation to water damage

The same process was done for establishing the importance of the type of damage water may cause. The pair-wise comparison took the 3 most common types of damage into account:

	SUPERFICIAL HUMIDITY	FILTRATION	EROSION
SUPERFICIAL HUMIDITY	1	1/2	1/5
FILTRATION	2	1	1/3
EROSION	5	3	1

Table 13: Pair-wise comparison matrix evaluating the importance of the type of water damage

The expert average of the weight vector for each element was as follows:

IMPORTANCE OF TYPES OF WATER DAMAGE	
SUPERFICIAL HUMIDITY	0.09
FILTRATION	0.35
EROSION	0.56

Table 14: AHP weight factor of the importance of the type of water damage

An additional matrix was developed, in order to calculate the value of this compound indicator. This matrix facilitates comprehension and the calculation of the overall indicator value, by introducing the elements affected by water damage and indicating the type of damage. It is used by technicians when performing the inspections.

	FAÇADE	ROOF	STRUCTURE ABOVE GROUND	FOUNDATIONS	VALUE
SUPERFICIAL HUMIDITY	1	0	1	1	0.83
FILTRATION	0	0	1	1	
EROSION	0	0	1	1	

Table 15: Overall value of water damage in relation to the element affected

When a definite type of damage is detected, the element that is affected should be indicated by introducing a value corresponding to 1. The final value is calculated by the sum of the multiplication of the AHP weight factor of the element for the weight factor of the damage.

The maximum value (1) is given to the alternative which presents all types of damage on all elements, while the minimum value (0) is attached to buildings which present no damage to any of their elements.

This information is not usually available from public sources, nor is it included in municipal databases, and it should be gathered by *in situ* inspections.

Simplified method:

In the case of analysing a large number of buildings within a short period of time, a simplified method can be used. It assesses only the presence or otherwise of water damage to the building, without specifying either the type of damage or the element that is affected. It is therefore only formed of two alternatives, the values of which are reported in the following table, giving the maximum value (1) to buildings which present no damage caused by water:

EXISTENCE OF WATER DAMAGE	
NO EXISTING WATER DAMAGE ON THE BUILDING	0.00
PRESENCE OF WATER DAMAGE ON THE BUILDING	1.00

Table 16: Values of the alternatives of the "existence of water damage" indicator (simplified method)

Ground floor typology

The sensitiveness of the typology and the activity of the ground floor is assessed by this indicator. One of the most vulnerable parts of the building is the ground floor, as water damage will differ in the flooded area. If commercial activities and residential premises are on the ground floor, damage due to flooding events will be major in term of economic loss and social impacts, compared to ground floors used for recreational activities and vacant premises. Therefore, the type of activity has been chosen from among the possible different ways of evaluating vulnerability. Another important aspect is the typology of the ground floor, if it is a closed or portico structure, as the existence of a portico facilitates the circulation of water, minimizing any damage to the area.

The maximum value (1) is given to closed spaces allocating any type of residential or commercial activity, while the minimum value (0) is given to portico structures, as their intrinsic characteristics makes them less vulnerable to water damages. In this case, a linear function represents the values attributed to each alternative, assigning a medium impact, somewhere between the minimum and maximum value, to a closed structure without any kind of activity.

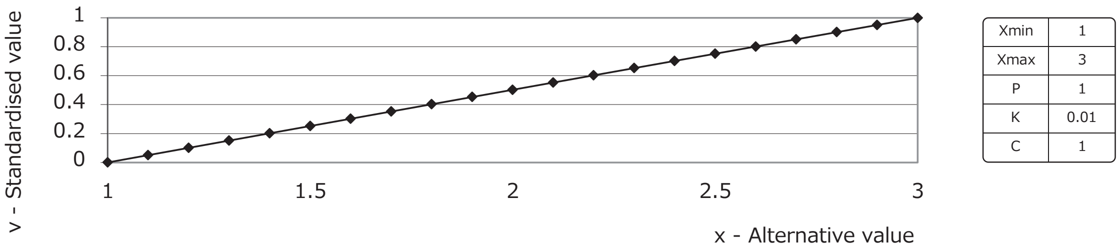


Figure 27: Shape, tendency and maximum and minimum satisfaction values of the "ground floor typology" indicator. Source: Author

The following table shows the value attached to each alternative:

GROUND FLOOR TYPOLOGY	
PORTICO STRUCTURE	0.00
CLOSED STRUCTURE WITH NO ACTIVITY	0.50
CLOSED STRUCTURE WITH ACTIVITY	1.00

Table 17: Values of the alternatives of the "ground floor typology" indicator

This type of indicator is qualitative, as it depends on the variable at a given moment, according to the perception and judgement of the person evaluating it. The information is not usually available by public sources, nor is it included in municipal databases. Nevertheless, this information can be gathered through online visualisation maps and *in situ* inspections.

Existence of basement

The existence of either a basement or a semi-basement is used to assess sensitiveness in the case of flooding events. The most exposed and the most sensitive building elements are floors beneath ground level that retain water in the structure. So, the maximum value (1) is given to buildings with floors beneath ground level and with a direct access to it, while the minimum value (0) is attached to buildings that have no basements or semi-basements.

EXISTENCE OF BASEMENT	
NEITHER A BASEMENT NOR A SEMI-BASEMENT	0.00
EXISTENCE OF A BASEMENT OR A SEMI-BASEMENT	1.00

Table 18: Values of the alternatives of the "existence of a basement" indicator

This indicator is part of the categorization method, as information on the existence of a basement is usually available at municipal level and, in the case of Spain, is recorded on the cadastre.

In the same way as the existence of a basement is considered an important factor, its accessibility should be also reflected, as a basement with a direct access from the street will be more sensitive to the entrance of water. If available through public sources, the inclusion of information on the type of access to the basement is recommended, according to the following value function:

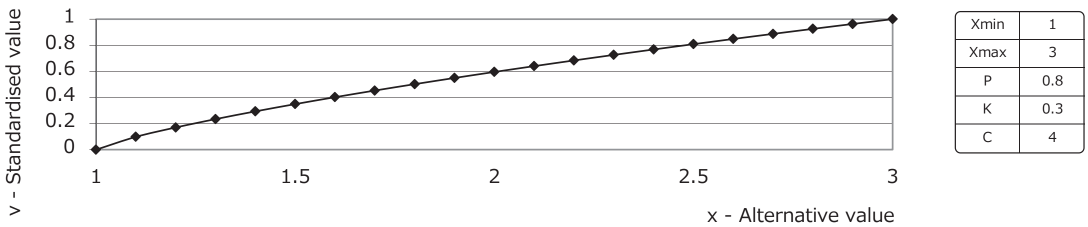


Figure 28: Shape, tendency and maximum and minimum satisfaction values of the "existence of basement" indicator. Source: Author

The existence of a basement is considered slightly more important than access to it, such that a building with an underground floor without direct access is weighted at 0.6. The following table summarizes the values attached to each alternative:

EXISTENCE OF BASEMENT AND ACCESS	
NEITHER A BASEMENT NOR A SEMI-BASEMENT	0.00
BASEMENT WITHOUT DIRECT ACCESS	0.60
BASEMENT WITH DIRECT ACCESS	1.00

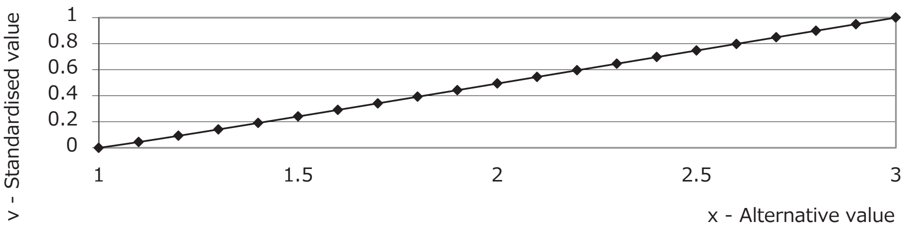
Table 19: Values of the alternatives of the "existence of basement and access" indicator

In the case of Spain, access to the basement should be verified *in situ* through inspections.

Openings on the ground floor

This indicator is used to assess the sensitiveness of the building according to the presence and typology of openings. In view of the possible risk of flooding or intense rainfall, the existence of openings in the building envelope increases the sensitiveness of the building, due to water entrance and filtrations as a consequence of poor sealing of joints and cracks. In the same way, the existence of openings and their dimensions are also important factors: a building with larger windows or doors is more likely to be affected by possible water entrance. Among the different possible ways of evaluating the influence of openings in the building, three alternatives have been chosen: buildings without openings (<25%), buildings with small openings (25-50%) and buildings with large openings (>50%).

The maximum value (1) is attached to buildings with large windows or glass fronted shop windows on the ground floor, while the minimum value (0) is attached to buildings where there are no windows on the ground floor and windows represent a reduced surface compared to the total surface. The following value function represents the alternatives and their values, assigning an intermediate value to buildings with small openings between the minimum and maximum values.



Xmin	1
Xmax	3
P	1.05
K	1.5
C	30

Figure 29: Shape, tendency and maximum and minimum satisfaction values of the "openings on the ground floor" indicator. Source: Author

The following table summarises the values given to each alternative:

OPENINGS GROUND FLOOR	
NO OPENINGS	0.00
SMALL OPENINGS	0.49
LARGE OPENINGS	1.00

Table 20: Values of the alternatives of the "openings ground floor" indicator

This information is not usually available from public sources nor is it included in municipal databases. Nevertheless, it can be gathered through online visualisation maps and by *in situ* inspections.

Roof type

The sensitiveness of the building is assessed by this indicator, considering the roof type: pitched or flat.

The roof is the constructive element which protects the buildings from external agents, especially intense rainfall, which is one of the impacts analysed in this research. Therefore the geometry of the roof influences the sensitivity of the building. In cases of intense rainfall, flat roofs are more prone to damage due to the retention of water, causing an increase of weight and possible filtrations.

The maximum value (1) is therefore given to flat roofs, as they are more sensitive to assume some impacts, while the minimum value (0) is attached to pitched roofs, which is the most favourable case.

ROOF TYPE	
PITCHED ROOF	0.00
FLAT ROOF	1.00

Table 21: Values of the alternatives of the "roof type" indicator

This type of indicator is called a normative one. It takes account of the existence or otherwise of a referent or antecedent with respect to a specific situation. In this group, dichotomous indicators, i.e. (yes or no), have also been included.

This information is not usually available from public sources, nor is it included in municipal databases. The roof type may only be evaluated through in situ inspections, which may be complicated by lack of visibility from the street. Data can be gathered through visualisation tools with a 3D perspective.

Façade material

This indicator assesses the finishing material of the façade in terms of the sensitiveness of the building toward the action of water in the short term. The constructive materials of the external façade are responsible to protect the building from external agents. Different finishing materials are more sensitive than others to a series of physical or chemical transformations, which can generate damage such as filtrations, deterioration, dirt, etc. Some materials are more vulnerable to water, due to their intrinsic properties, including water absorption, which can lead to deformation, corrosion, detachments or cracks. It should be noted, in case of façades integrating several types of materials, that the material that covers the larger percentage of the surface should be chosen.

The maximum value (1) is given to building where the majority of the façade material is more porous or more sensitive to degradation by the effects of water, while the minimum value (0) is given to buildings where the majority of the façade material is non-porous, as it behaves better against the action of water. The value function established for this indicator, considering the most common materials, is as follows:

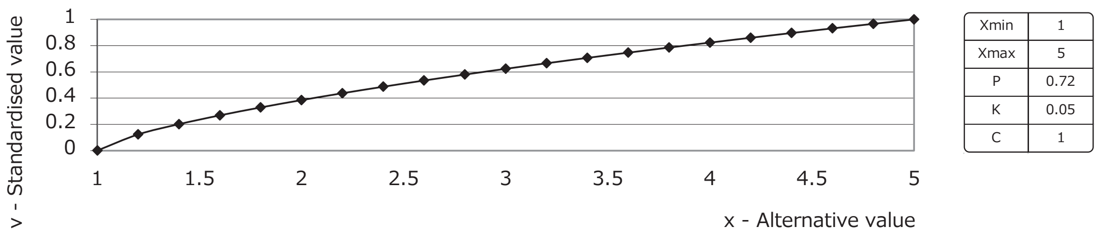


Figure 30: Shape, tendency and maximum and minimum satisfaction values of the "façade material" indicator. Source: Author

Results of the different alternatives are shown in the following table:

FAÇADE MATERIAL	
BRICK/NON POROUS STONE	0.00
MORTAR	0.38
STEEL	0.62
CONCRETE	0.82
POROUS STONE	1.00

Table 22: Values of the alternatives of the "façade material" indicator

This information is not usually available by public sources nor is it included in municipal databases. It can however be gathered through *in situ* inspections.

Use

This indicator is used to assess the sensitiveness of the service that the building provides. If the use of the building is a key service and its non-operation implies disruption to the population, it has to be considered as more sensitive. In this case, for the expert criteria evaluation, the period of time a building can stop operating has been considered, according to the following definitions:

Buildings that can remain out of service over lengthy periods of time: their activity is not essential in a disaster scenario and therefore implies no significant disruption to the inhabitants: i.e. cultural centres, public equipment without priority use, recreational facilities, parking, etc.

Buildings which can remain out of service over a medium length of time: their activity is of some relevance, especially for the economic recovery of the area and their operational conditions should be restored in the medium-term: i.e. small shops, offices, restaurants, etc.

Buildings which can only remain out of service for a short period of time: their activities are of relevance to society and their operational conditions should be restored in the short-term: a majority of residential buildings, considering single-family houses, flats blocks, residences, etc.

Buildings which cannot stop operating: their activity is essential, especially during the emergency phase. These include buildings such as hospitals, first-aid clinics, pharmacies and emergency services, such as police and fire stations.

The maximum value of the function (1) is given to this last category, as it represents buildings with critical activities and intensive use. The minimum value (0) is given to buildings which can stop providing service for a long period of time, as they represent non-essential activities in certain scenarios, without generating excessive disturbance to society.

For the value assignment, the operational time recovery, according to the activity of the building, has been evaluated taking into account the 4 possible alternatives. The following value function represents the curve evolution, considering the maximum, minimum and intermediate values of the different alternatives. The more critical the use of the building, the higher the value attached to it.

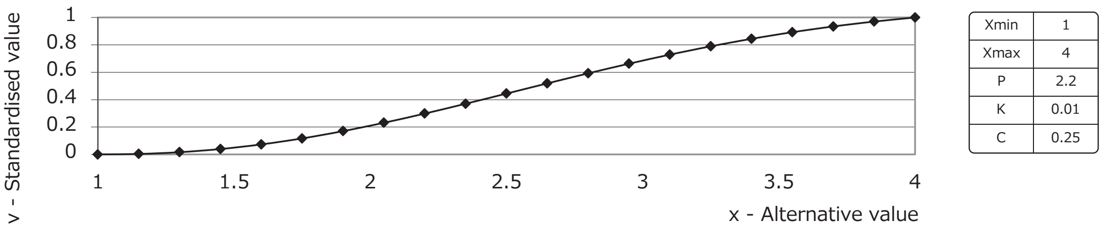


Figure 31: Shape, tendency and maximum and minimum satisfaction values of the "use" indicator. Source: Author

The following table shows the value attached to each alternative:

USE	
CULTURAL CENTRES; PUBLIC EQUIPMENT WITHOUT PRIORITY USE	0.00
COMMERCE	0.22
RESIDENCE	0.69
EMERGENCY AND SANITARY	1.00

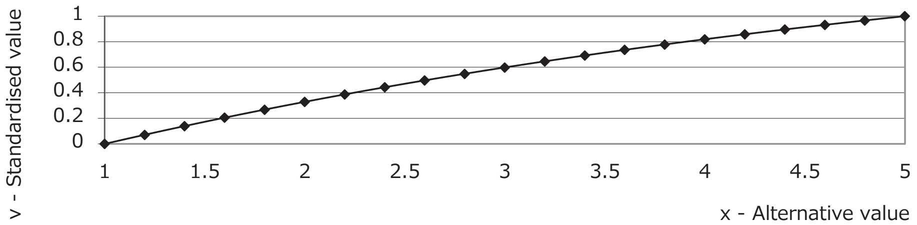
Table 23: Values of the alternatives of the "use" indicator

This indicator is included in the categorization method, as the use of the building is critical when establishing priorities of intervention. This type of indicator is usually available at municipal level and, in the case of Spain, data related to the use of a building, can be found in the cadastre records.

Structural material

This indicator is used to assess the sensitiveness of the constructive material of the building structure, considering the possible appearance of damages related to water absorption or filtration. The structure is that part of the building serving to support the rest of the elements that constitute it and that ensure physical stability over a long period of time. When a structure is exposed to a flooding event, the structural material will be damaged or affected in different ways, as some materials resist the action of water better than others.

The maximum value (1) is attached to buildings constructed from wooden structural materials, more sensitive than other materials, that are easily damaged by water; while the minimum value (0) is attached to buildings constructed out of stone, which behaves better in comparison with other materials. The value function has been calculated considering the main common materials.



Xmin	1
Xmax	5
P	1
K	20
C	100

Figure 32: Shape, tendency and maximum and minimum satisfaction values of the "structural material" indicator. Source: Author

Results of the different alternatives are shown in the following table:

STRUCTURAL MATERIAL	
STONE	0.00
BRICK	0.33
STEEL	0.60
CONCRETE	0.82
WOOD	1.00

Table 24: Values of the alternatives of the "structural material" indicator

The information related to this indicator is neither available from public sources nor is it usually stored on municipal databases. Data should be therefore gathered by *in situ* inspections.

Indicators of the adaptive capacity requirement

In the case of the adaptive capacity indicators, the values are attached in the opposite way to the sensitiveness requirement. So, the best situation will have the maximum value assigned to it (1). The sensitiveness assessment is used to record the degree to which a building is vulnerable according to its conditions (where 1 is the most sensitive value), while the adaptive capacity indicator reflects the degree to which a building can cope under certain conditions according to its characteristics (where 1 is the most adaptive value).

Existence of adaptive systems

In areas prone to flooding, some buildings that have suffered previous negative impacts, have upgraded their resilience through the introduction of adaptive solutions. In many cases these solutions consist of simple methods, such as temporary shield panels or sealants to prevent low level flooding from entering through an opening, such as door or window. Buildings that have implemented these kinds of systems are considered to present higher protection against flooding and intense rainfall.

The maximum value (1) of the function is therefore given to buildings with an improved adaption capacity, while the minimum value (0) is given to buildings that have not yet implemented any adaptive solutions.

EXISTENCE OF ADAPTIVE SYSTEMS	
ABSENCE OF ADAPTIVE SYSTEMS	0.00
EXISTENCE OF ADAPTIVE SYSTEMS	1.00

Table 25: Values of the alternatives of the "existence of adaptive systems" indicator

The information related to this indicator is not available on public sources neither is it usually included on municipal databases. Data should therefore be gathered by *in situ* inspections.

Drainage system condition

The drainage system has the function of evacuating rainwater and wastewater from the building. If the building has already experienced problems with the drainage system or it is maintained in poor conditions, it is more sensitive to heavy rainfall. The indicator is assessed against the state of conservation of the drainage system related to the evacuation of rainwater from the roof. The following alternatives were considered:

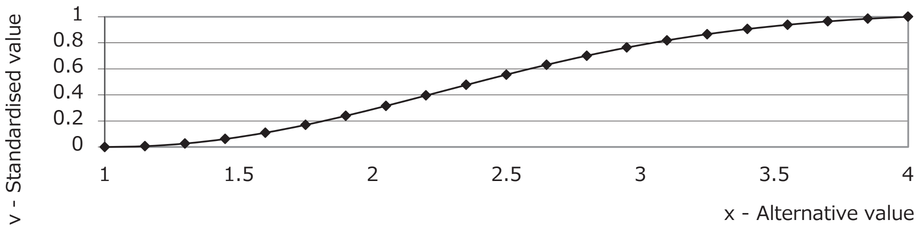
Good: The drainage system is in good condition and other related components of the building (anchors and surrounding façade) are also in good condition.

Fair: The drainage system is in good condition, but some isolated repairs are needed. Immediate repair is not requested, but this action should be considered to prevent further possible deterioration of the system.

Poor: The drainage system is in a poor condition, presents a risk of failure or collapse, and requires short-term repair actions.

Very bad: The drainage system is damaged at multiple points, cannot be used, and requires complete renovation.

The maximum value (1) is given to buildings with a drainage system in good conditions, which requires only simple preventive maintenance, while the minimum value (0) is attached to buildings with a drainage system in a very bad condition.



Xmin	1
Xmax	4
P	2.1
K	1.4
C	2

Figure 33: Shape, tendency and maximum and minimum satisfaction values of the "drainage system condition" indicator. Source: Author

The value of the different alternatives was as follow:

DRAINAGE SYSTEM CONDITION	
VERY BAD	0.00
POOR	0.29
FAIR	0.78
GOOD	1.00

Table 26: Values of the alternatives of the "drainage system condition" indicator

This type of indicator is qualitative, as it depends on the variable at a given moment, according to the perception and judgement of the person evaluating it. The information related to this indicator is not available on public sources neither it is usually included on municipal databases. Data should be therefore gathered by *in situ* inspections.

Previous interventions

Another indicator that has to be considered to assess adaptive capacity is the identification of interventions over the lifespan of the building. Usually, owners who have assumed repairs and rehabilitation work are more diligent with regard to maintenance.

Buildings that have undergone rehabilitation in the past are considered to have a greater adaptive capacity, so they are given the maximum value (1), while buildings without any interventions to date are given the minimum value (0).

PREVIOUS INTERVENTIONS	
NO INTERVENTIONS	0.00
PREVIOUS INTERVENTIONS	1.00

Table 27: Values of the alternatives of the "previous interventions" indicator

Municipal authorities usually record information on building interventions in the documentation attached to the building permits they issue. This information can be verified during the inspections of the building.

Number of dwellings and socio-economic status

It is usually considered that the higher the number of dwellings, the better the adaptation of the building, as the costs of interventions can be shared among owners. As this information can lead to misinterpretation, the socio-economic status of the owner has also been considered, yielding a compound indicator.

The value attached to the number of dwellings is calculated according to a linear function, the inexistence of dwellings having a minimum value (0), while if the number of dwellings in the same block is over 40 then the maximum value is (1), considering that this value can be adapted to the characteristics of the case study. According to the function, the value is calculated by multiplying the number of dwellings by 0.0244.

0 DWELLINGS	0.00
X DWELLINGS	x*0.0244
>40 DWELLINGS	1.00

The status is calculated on the basis of the occupational category of the inhabitants. The establishment of 3 status levels (high, medium, low) is adapted from the classification proposed by (Reques 2006). The sum of the percentage of each category multiplied by its value is considered, in order to represent the average of the census section under consideration:

HIGH STATUS	1.00
MEDIUM STATUS	0.50
LOW STATUS	0.00

The average status is therefore calculated according to the following equation

Average status= (% high status *1 + % medium status *0.5 + % low status*0)/100

As an indicative overall result, the following table presents the categories associated with the ranges obtained by the average status:

AVERAGE STATUS	
LOW	0.00 - 0.56
MEDIUM	0.57 - 0.60
HIGH	0.61 - 0.65
VERY HIGH	0.66 - 1.00

Table 28: Ranges of the status categories

The indicator is the result of combining both points, by attaching a weight of 70% to the socio-economic status and 30% to the number of dwellings:

$$\text{Average status} * 0.7 + (x*0.0244)*0.3$$

Where x is the number of dwellings

Data on the number of dwellings are available from municipal authorities. The occupational profile is accessible with the Eustat tool and the information is available at census sections, therefore the value has been attached to all buildings included in the same section.

<u>Cultural value</u>

This indicator refers to the protection degree that characterizes buildings in accordance with the laws established by the State of Municipality in charge of the conservation of cultural heritage.

Without protection: The buildings are not included in the list of protected buildings and therefore no restrictions are applied to any element of the building.

Grade IV: This level of protection corresponds to buildings and constructions of recognizable and protectable value in relation to their environment. The elements in which these values reside are always external elements that support their image. The treatment of similar buildings located in different environments can differ, where one environment needs greater protection than another or there is no possibility of protection, or an environment in which the permanence of the buildings prevents major urban planning objectives.

Grade III: This level of protection corresponds to buildings of recognized individual value. The protected elements refer only to the external envelope of the building. For these buildings, a protection regime has to be defined, limiting the possible interventions on the envelope for their effective conservation.

Grade II: Buildings and constructions with a recognized individual value are included at this level of protection. Protected elements refer to the exterior as well as to the interior envelope. A protection regime is defined for these buildings, limiting the possible interventions on the external and internal elements of the building, for effective conservation.

Grade I: This level of protection corresponds to buildings and constructions that have been declared of special interest, subject either to their own protection and intervention regimes or to generic and transitory protection and intervention regimes. In all cases, they are subject to compulsory consultations and corresponding authorizations of supra-municipal level. In other words, these buildings are affected by protection decisions, declarations and procedures promoted at a supra-municipal level, by the competent (Regional or State Administration) authorities in the matter. The specific regime of treatment and preservation of these buildings is included in the framework of the declaration, qualification or dossier.

The maximum value (1) is given to buildings with a cultural value designed as Grade I. These are buildings with a major degree of protection and, if they require further conservation, while interventions may be limited, higher budget allocations and social pressure are usually key issues in their preservation. The minimum value (0) is therefore given to non-protected buildings, usually considered less relevant than cultural heritage buildings, and requiring no special interventions.

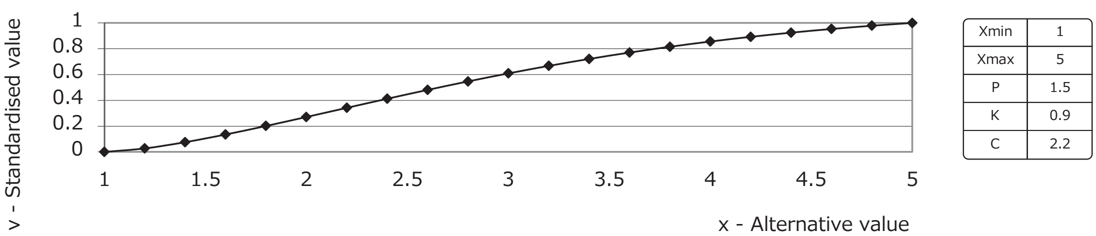


Figure 34: Shape, tendency and maximum and minimum satisfaction values of the "cultural value" indicator. Source: Author

The following table summarises the values given to each alternative by expert criteria:

CULTURAL VALUE	
NONE	0.00
GRADE IV	0.27
GRADE III	0.61
GRADE II	0.86
GRADE I	1.00

Table 29: Values of the alternatives of the "cultural value" indicator

This indicator is part of the categorization method, as the cultural value represents the historic significance of a building and interventions are related to the degree of its protection. Information on cultural heritage protection levels is available for each Municipality and is included in the General Plan.

The following table summarises the values for each alternative of the indicators.

INDICATOR CODE	INDICATOR MEANING	VALUE MEANING	VALUE
ID 1.1.1	STATE OF CONSERVATION	GOOD	0.00
		FAIR	0.18
		POOR	0.73
		VERY BAD	1.00
ID 1.1.2	EXISTENCE OF WATER DAMAGE	NO EXISTING WATER DAMAGE ON THE BUILDING	0.00
		PRESENCE OF WATER DAMAGE ON THE BUILDING	1.00
ID 1.2.1	GROUND FLOOR TYPOLOGY	PORTICO STRUCTURE	0.00
		CLOSED STRUCTURE WITH NO ACTIVITY	0.50
		CLOSED STRUCTURE WITH ACTIVITY	1.00
ID 1.2.2	EXISTENCE OF BASEMENT	NO BASEMENT NOR SEMI-BASEMENT	0.00
		EXISTENCE OF BASEMENT OR SEMI-BASEMENT	1.00
ID 1.3.1	OPENINGS GROUND FLOOR	NO OPENINGS	0.00
		SMALL OPENINGS	0.49
		LARGE OPENINGS	1.00
ID 1.3.2	ROOF TYPE	PITCHED	0.00
		FLAT	1.00
ID 1.3.3	FAÇADE MATERIAL	BRICK/NON POROUS STONE	0.00
		MORTAR	0.38
		STEEL	0.62
		CONCRETE	0.82
		POROUS STONE	1.00
ID 1.4.1	USE	CULTURAL CENTRES, PUBLIC EQUIPMENT WITHOUT PRIORITY USE	0.00
		COMMERCE	0.22
		RESIDENCE	0.69
		EMERGENCY AND SANITARY	1.00
ID 1.5.1	STRUCTURAL MATERIAL	STONE	0.00
		BRICK	0.33
		STEEL	0.60
		CONCRETE	0.82
		WOOD	1.00
ID 2.1.1	EXISTENCE OF ADAPTIVE SYSTEMS	EXISTENCE OF ADAPTIVE SYSTEMS	1.00
		ABSENCE OF ADAPTIVE SYSTEMS	0.00
ID 2.1.2	DRAINAGE SYSTEM CONDITION	GOOD	1.00
		FAIR	0.78
		POOR	0.29
		VERY BAD	0.00
ID 2.2.1	PREVIOUS INTERVENTIONS	PREVIOUS INTERVENTIONS	1.00
		NO INTERVENTIONS MADE	0.00
ID 2.2.2	NUM. OF DWELLINGS AND SOCIO-ECONOMIC STATUS	X DWELLINGS, Y AVERAGE STATUS	Y*0.7+(X*0.0244)*0.3
ID 2.3.1	CULTURAL VALUE	GRADE I	1.00
		GRADE II	0.86
		GRADE III	0.61
		GRADE IV	0.27
		NONE	0.00

Table 30: Values attached to each alternative of the sensitiveness and adaptive capacity indicators

Weights assignment

Weights have been assigned starting from the calculation of the *γ* weights of the indicators, followed by the *β* weights of the criteria, and lastly by the *α* weights of the requirements. Weight assignment is performed by comparing elements at the same level and in the same branch of the requirements tree. Thus, the indicator weights are calculated according to other indicators belonging to the same criterion. In the same manner, a criterion weight is calculated by other criteria belonging to the same requirement.

Analytic Hierarchy Process (AHP) was used for the weights assignment, by establishing the relative importance of each branch of the requirements tree. An adjustment was made of the final results, considering the opinion of each member of the expert panel.

Indicators (*y*) of the sensitiveness requirement

As explained in Section 2.3.1, the AHP pair-wise comparative judgments from the fundamental scale of absolute numbers (see Table 1) were entered into a reciprocal matrix. From the matrix an absolute scale of relative values was obtained on normalisation, by dividing each value by the sum of all values. The priorities are obtained by summing each row and dividing each by the total sum of all the rows. The highest eigenvalue was also calculated, in order to check the consistency of the judgements expressed by the expert panel. The consistency ratio should not exceed 0.1.

In the current situation criterion, two indicators are defined, the state of conservation and the presence of water damage to the building. The expert panel considered that the two indicators have the same importance, as both parameters affect the vulnerability of the structure against extreme precipitation or flooding events. The following matrix shows the pair-wise comparison. The consistency ratio, in a 2x2 matrix will always be 0, as there is no possible incoherence between the alternatives that are analysed.

	STATE OF CONSERVATION	EXISTENCE OF WATER DAMAGE	WEIGHTS AHP	CONSISTENCY
STATE OF CONSERVATION	1	1	0.50	0.00
EXISTENCE OF WATER DAMAGE	1	1	0.50	

Table 31: Pair-wise comparison of the indicators belonging to the "current situation" criterion

CURRENT SITUATION	STATE OF CONVERSATION	0.50
	EXISTENCE OF WATER DAMAGE	0.50

Two indicators are also defined in the constructive criterion: the type of ground floor and the existence of basements. The existence of basements in defining the vulnerability of a building, considered slightly more important than the type of ground floor, yielded the following weights:

	GROUND FLOOR TYPOLOGY	EXISTENCE OF BASEMENT	WEIGHTS AHP	CONSISTENCY
GROUND FLOOR TYPOLOGY	1	1/2	0.33	0.00
EXISTENCE OF BASEMENT	2	1	0.67	

Table 32: Pair-wise comparison of the indicators belonging to the "constructive" criterion

In this case, the results were rounded off and final values were as follows:

CONSTRUCTIVE	GROUND FLOOR TYPOLOGY	0.35
	EXISTENCE OF BASEMENT	0.65

The envelope criterion defines three indicators, which are the presence of openings on the ground floor, the type of roof, and the façade material. It is considered that the number of openings on the ground floor is slightly more important than the roof type and the façade material, while the roof type and façade material are of the same importance.

	NUMBER OF OPENINGS	ROOF TYPE	FAÇADE MATERIAL	WEIGHTS AHP
NUMBER OF OPENINGS	1	2	2	0.50
ROOF TYPE	1/2	1	1	0.25
FAÇADE MATERIAL	1/2	1	1	0.25

CONSISTENCY
0.00

Table 33: Pair-wise comparison of the indicators belonging to the "envelope" criterion

ENVELOPE	OPENINGS GROUND FLOOR	0.50
	ROOF TYPE	0.25
	FAÇADE MATERIAL	0.25

The criticality criterion has only one indicator with a weight of 1. This value will be 100%, when there are no indicators or criteria belonging to the same branch.

CRITICALITY	USE	1.00

The same happens for the structure criterion, where just one indicator was assigned.

STRUCTURE	STRUCTURAL MATERIAL	1.00

Criteria (β) of the sensitiveness requirement

A decision matrix was developed for comparing the criteria belonging to the same requirement (sensitiveness). The same process used for the indicators was followed. It is considered that the use of the building (criticality) is the most important parameter to assess vulnerability, as prioritization should be given to buildings with a critical use. The ranking followed the criteria used for the envelope and the constructive aspects, which are related to the intrinsic characteristics of the building, especially the existence of elements, which can influence the entrance of water into the building. The structure is considered to be less important than other criteria, as damage is usually related to long-term periods and influenced by the permanence of water in the building. The current situation, related to the state of the building, was considered the least important criterion.

	CURRENT SITUATION	CONSTRUCTIVE	ENVELOPE	CRITICALITY	STRUCTURAL MATERIAL	WEIGHTS AHP
CURRENT SITUATION	1	1/4	1/6	1/7	1/2	0.05
CONSTRUCTIVE	4	1	1/2	1/3	3	0.18
ENVELOPE	6	2	1	1	3	0.32
CRITICALITY	7	3	1	1	3	0.35
STRUCTURAL MATERIAL	2	1/3	1/3	1/3	1	0.10

CONSISTENCY
0.03

Table 34: Pair-wise comparison of the criteria belonging to the "sensitiveness" requirement

An adjustment was made to final values, which were rounded off as follows:

SENSITIVENESS	CURRENT SITUATION	0.05
	CONSTRUCTIVE	0.20
	ENVELOPE	0.30
	CRITICALITY	0.35
	STRUCTURE	0.10

Indicators (*y*) of the adaptive capacity requirement

Two indicators are defined for the intervention criterion: the existence of adaptive systems and the condition of the drainage system. The existence of an adaptive system is considered as equal to and even slightly more important than the drainage system, as a building that presents some adaptive measures means that it has previously been damaged in some way and is better prepared to negotiate new hazards.

	EXISTENCE OF ADAPTIVE SYSTEMS	DRAINAGE SYSTEM CONDITION	WEIGHTS AHP	CONSISTENCY
EXISTENCE OF ADAPTIVE SYSTEMS	1	1.50	0.60	0.00
DRAINAGE SYSTEM CONDITION	0.67	1	0.40	

Table 35: Pair-wise comparison of the indicators belonging to the "interventions" criterion

INTERVENTIONS	EXISTENCE OF ADAPTIVE SYSTEMS	0.60
	DRAINAGE SYSTEM CONDITIONS	0.40

The socio-economic criterion is associated with two indicators, previous interventions and number of dwellings and status. The number of dwellings and the socio-economic status of inhabitants are considered, which implies that a greater capacity to institute adaptive measures, in terms of economic possibilities, is slightly more important than any previous interventions on the building, indirectly related to the introduction of adaptive systems.

	PREVIOUS INTERVENTIONS	NUM. OF DWELLINGS AND ECONOMIC STATUS	WEIGHTS AHP	CONSISTENCY
PREVIOUS INTERVENTIONS	1	1/2	0.33	0.00
NUM. OF DWELLINGS AND ECONOMIC STATUS	2	1	0.67	

Table 36: Pair-wise comparison of the indicators belonging to the "socio-economic" criterion

An adjustment has been made, in order to round off final values.

SOCIO-ECONOMIC	PREVIOUS INTERVENTIONS	0.35
	NUM. DWELLINGS AND SOCIO-ECONOMIC STATUS	0.65

The cultural criterion has only one indicator with 100% of the weight:

CULTURAL	CULTURAL VALUE	1.00

Criteria (β) of the adaptive capacity requirement

As in the previous calculation, the three criteria are compared through pair-wise comparisons. The cultural value is the criterion with the highest score, as it represents the historic significance and influences the type of adaptive measures that can be applied. Socio-economic conditions are encountered in the following level, as they represent the economic capacity of inhabitants. The intervention criterion has the lowest score.

	INTERVENTIONS	SOCIO-ECONOMIC	CULTURAL	WEIGHTS AHP	CONSISTENCY
INTERVENTIONS	1	1	1/2	0.26	0.05
SOCIO-ECONOMIC	1	1	1	0.33	
CULTURAL	2	1	1	0.41	

Table 37: Pair-wise comparison of the criteria belonging to the "adaptive capacity" requirement

An adjustment to the final values was made:

ADAPTIVE CAPACITY	INTERVENTIONS	0.25
	SOCIO-ECONOMIC	0.35
	CULTURAL	0.40

Requirements weights (α)

The sensitiveness requirement and the adaptive capacity were considered to have the same importance for the final assessment of building vulnerability, in order to evaluate the weight of the requirements, as shown in the following matrix:

	SENSITIVENESS	ADAPTIVE CAPACITY	WEIGHTS AHP	CONSISTENCY
SENSITIVENESS	1	1	0.50	0.00
ADAPTIVE CAPACITY	1	1	0.50	

Table 38: Pair-wise comparison of the requirements

The following figure shows the overall weighting coefficients for the vulnerability requirement tree:

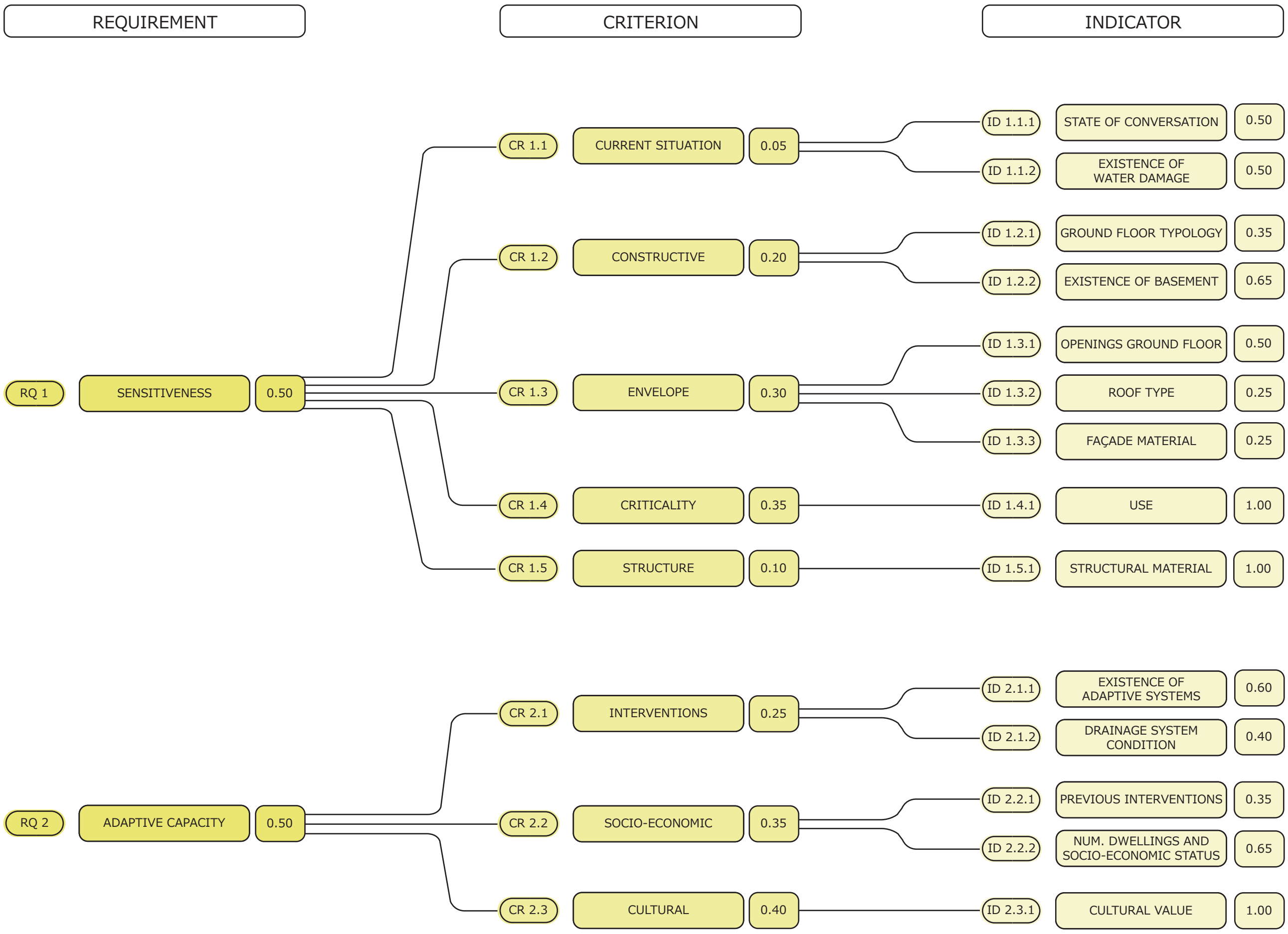


Figure 35: Overall weighting of the vulnerability requirements tree. Source: Author

3.2.3 Fine-tuning of the vulnerability assessment

In MIVES, the final vulnerability index is calculated by multiplying the weights of the indicators by their criteria and requirement. The final result is given by subtracting the index of adaptive capacity from the index of sensitiveness. This subtraction is done because the adaptive capacity is a positive factor, while sensitiveness is a negative aspect. The higher the number obtained in the calculation, the more vulnerable the building.

The two requirements were considered separate, in order to establish homogeneous criteria for defining vulnerabilities, considering both negative as well as positive aspects. Again, this fine-tuning methodology is borrowed from the field of climate change. It is used because very sensitive elements can have a high adaptive capacity and are less vulnerable than very sensitive elements with a low adaptive capacity.

The sensitiveness index and the adaptive capacity index, composed by criteria and indicators and their corresponding weights, are ranked and divided into different categories, according to the following parameters:

SENSITIVENESS INDEXES	ADAPTIVE CAPACITY INDEXES
S0 ≤ 0.10	AC0 ≤ 0.33
0.10 < S1 ≤ 0.40	0.33 < AC1 ≤ 0.75
0.40 < S2 ≤ 0.60	0.75 < AC2 ≤ 1.00
0.60 < S3 ≤ 0.90	
0.90 < S4 ≤ 1.00	

Table 39: Sensitiveness and adaptive capacity indexes

The ranking system is based on the approach proposed by Kleinfelder for the city of Cambridge-Massachusetts (City of Cambridge 2015), which modifies the mainly qualitative ICLEI ranking system, changing it into a quantitative data system.

The following table (Kleinfelder 2015) provides different levels of vulnerability according to the sensitiveness and adaptive capacity of the building, where V0 represents the less vulnerable and V5 the most vulnerable.

		SENSITIVITY: LOW → HIGH				
		S0	S1	S2	S3	S4
ADAPTIVE CAPACITY: LOW → HIGH	AC0	V2	V3	V4	V5	V5
	AC1	V1	V1	V2	V3	V4
	AC2	V0	V0	V0	V1	V2

Table 40: Levels of vulnerability. Source: (Kleinfelder 2015)

3.3 RISK ASSESSMENT

As previously described, risk is the result of the interaction between exposure and vulnerability, which is formed by the sensitiveness and the adaptive capacity of each element. As presented in the previous chapter, two requirements were considered for the calculation of vulnerability: sensitiveness and adaptive capacity. For the calculation of risk, a third requirement will be included: exposure.

The **exposure** requirement refers to the location of buildings or infrastructures that may be adversely affected by an event. In this case, the criterion considered refers to the location of the building and its surrounding urban system.

The final requirement tree, in all its levels (requirements, criteria and indicators), considering both vulnerability and exposure is presented in Figure 36. The final requirements tree developed is therefore defined by three requirements (sensitiveness, adaptive capacity and exposure), which are divided into 9 evaluation criteria and 18 quantification indicators.

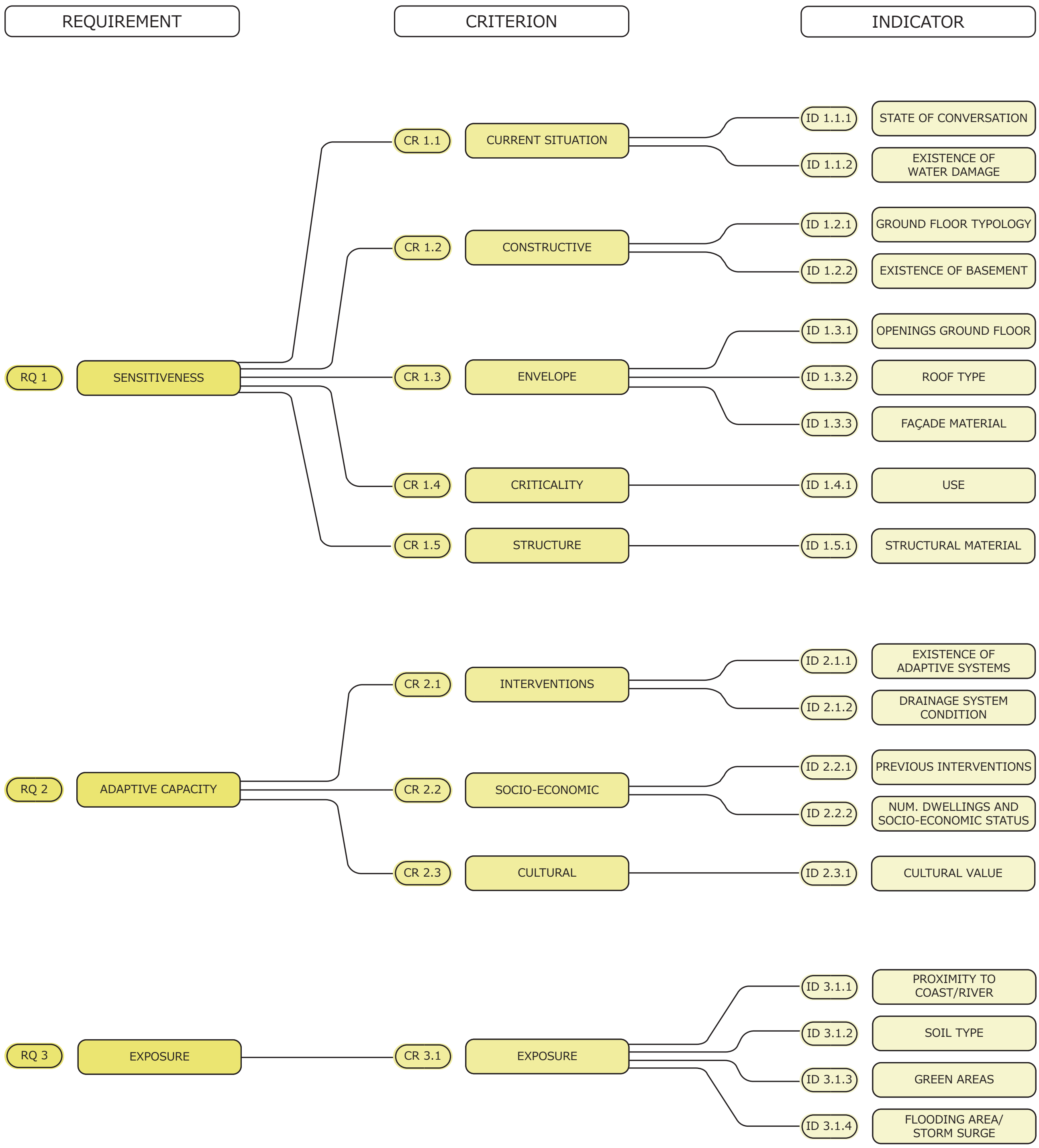


Figure 36: Requirements, criteria and indicators of the risk decision tree. Source: Author

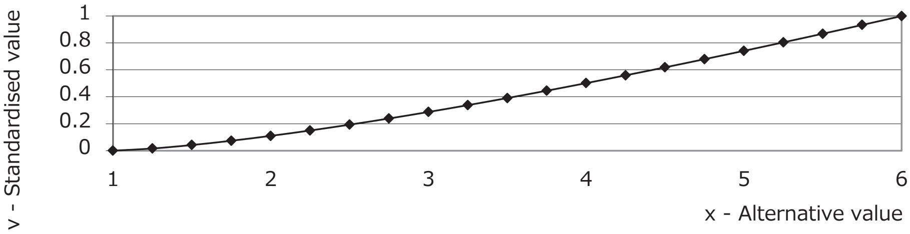
Establishment of value functions

Indicators of the exposure requirement

Proximity to coast or river

With this indicator, the exposure of a building to water penetration is assessed, by taking into consideration that constructions closer to the coastline or to a river are more exposed compared to those located in intermediate or interior areas.

The maximum value (1) is given to buildings located in a range of 25 meters from the coastline or river, as they are more exposed to any possible flooding, while the minimum value (0) is given to buildings which are far from the epicentre, according to the following value function:



Xmin	1
Xmax	6
P	1.4
K	0.1
C	5

Figure 37: Shape, tendency and maximum and minimum satisfaction values of the "proximity to coast or river" indicator. Source: Author

The following table shows the values for each alternative:

PROXIMITY TO COAST OR RIVER	
> 150 METERS	0.00
BETWEEN 101 AND 150 METERS	0.11
BETWEEN 76 AND 100 METERS	0.29
BETWEEN 51 AND 75 METERS	0.50
BETWEEN 25 AND 50 METERS	0.74
< 25 METERS	1.00

Table 41: Values of the alternatives of the "proximity to coast or river" indicator

The information was calculated by the creation of a buffer zone of the coastline or river, at 25, 50, 75, 100, 150 and 200 meters. The intersection between the buildings layer and the buffer areas, defines whether a building is included in a particular buffer area. The buildings were then classified by their proximity.

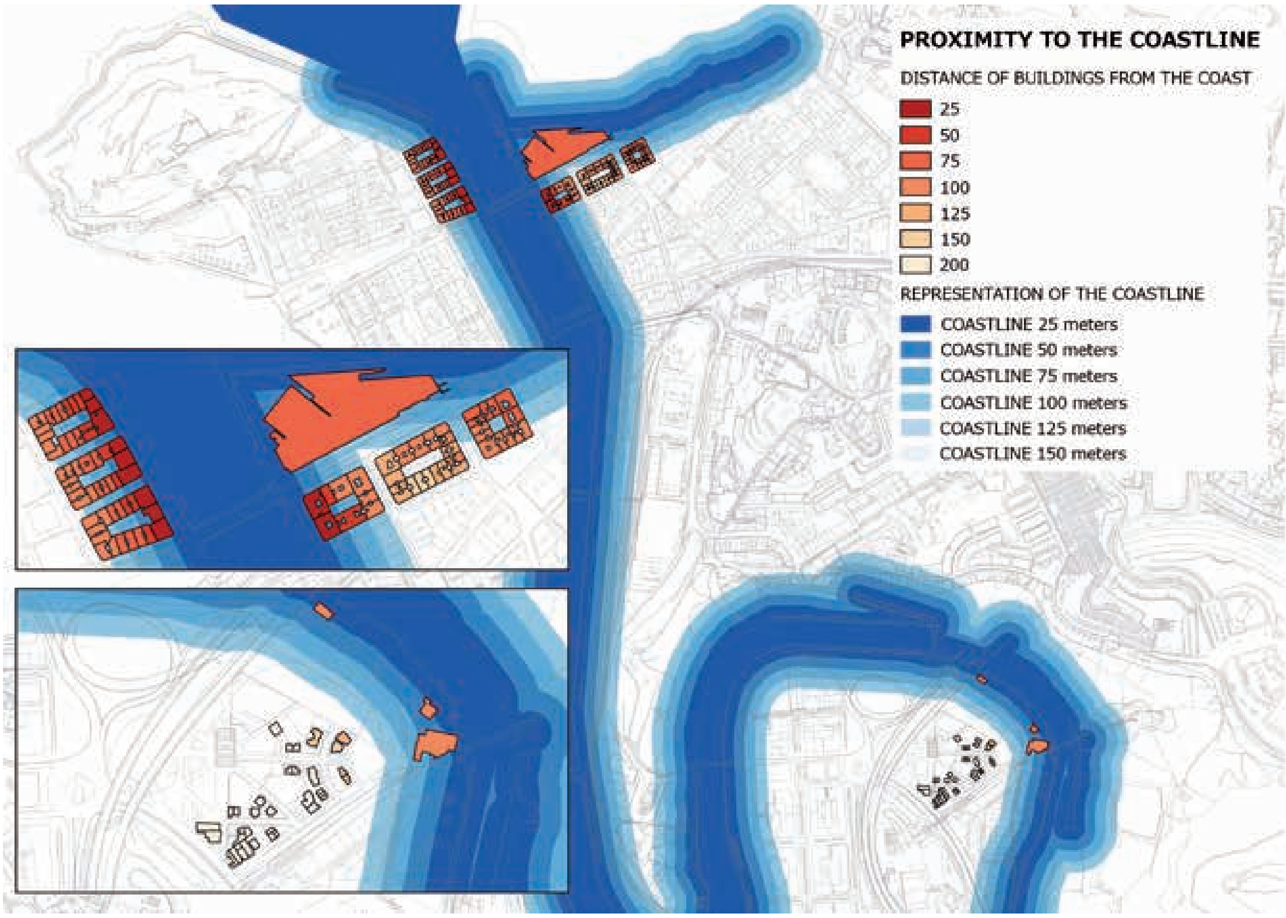
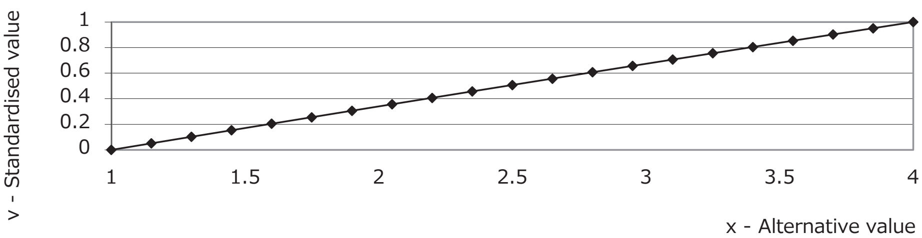


Figure 38: Buffer area of the coast-line and river of the case study area in San Sebastian. Source: Tecnalia

Soil type

The ground on which the building foundations are built is a decisive factor in risk assessment, as some types of soils present worse behaviour against the presence of water, such as backfilling and clays. Buildings located on these soils are more likely to undergo damage, especially to foundations, during intense rainfall periods and flooding events.

The maximum value (1) is given to most sensitive soils that can cause problems due to effect of rain. Buildings on these soils are more likely to be damaged by flooding scenarios and are therefore considered at risk. The minimum value (0) is given to soils which are altered less by the action of water, represented by the rock. Values are represented through the following value function:



Xmin	1
Xmax	4
P	1
K	0.1
C	5

Figure 39: Shape, tendency and maximum and minimum satisfaction values of the “soil type” indicator. Source: Author

The following table shows the values for the different alternatives, according to the most common types of soil:

SOIL TYPE	
ROCK	0.00
SAND	0.34
CLAY	0.68
BACKFILL, SILTS	1.00

Table 42: Values of the alternatives of the "soil type" indicator

The information of this indicator is usually available and provided by national geological institutions. In the case of Spain, the maps produced by the Geological and Mining Institute of Spain are widely distributed. The type of soil on which a building is located can be obtained by the intersection of the geological map and the building layer by the use of GIS.

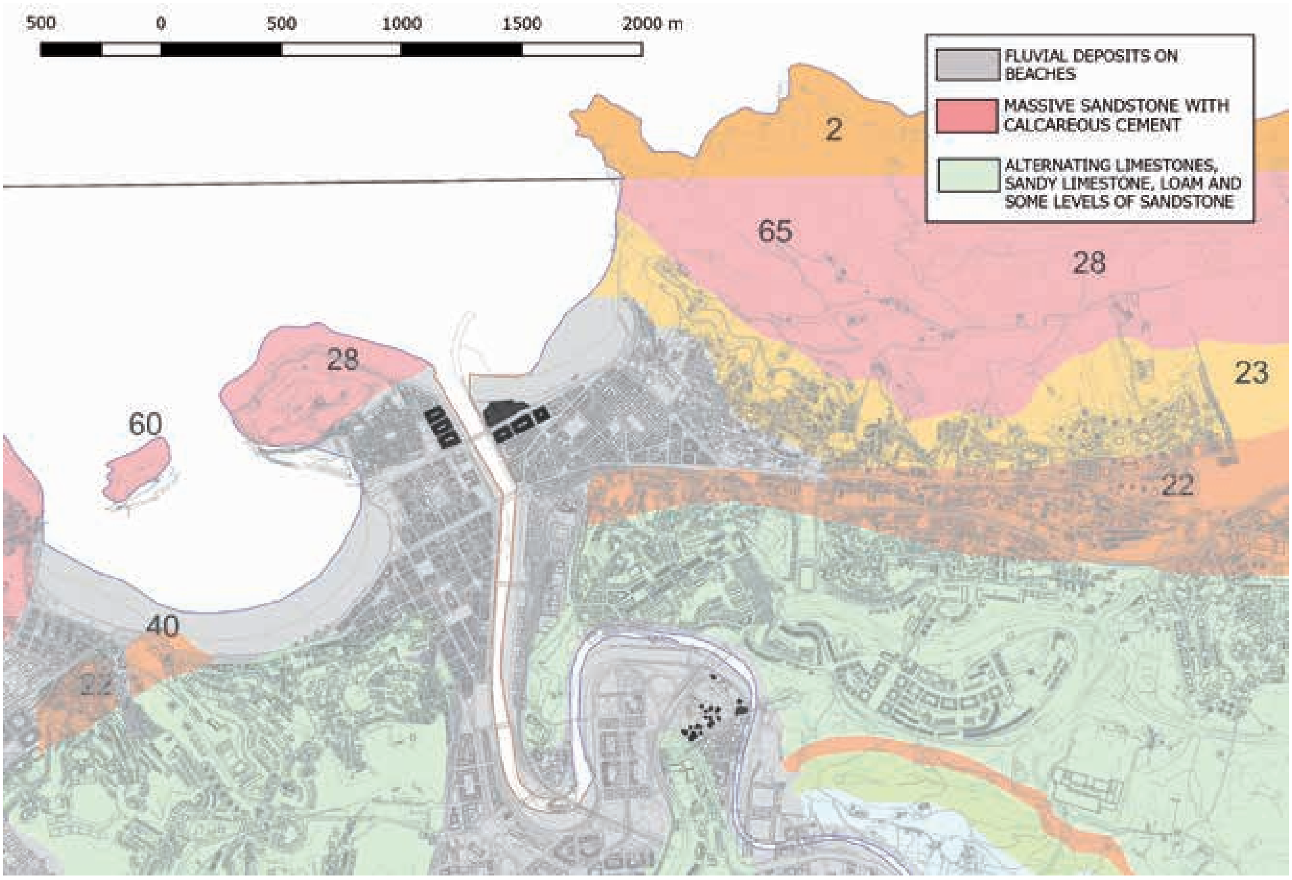


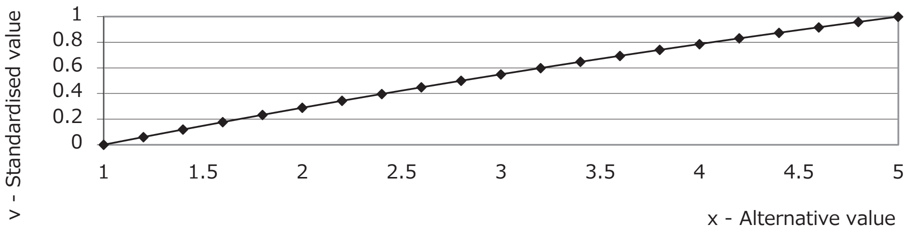
Figure 40: Soil type in the case study area of San Sebastian. Source: (Gobierno Vasco 1999)

Green areas

Intense rainfall facilitates flooding, especially in highly urbanised areas: asphalt prevents the absorption of water as it increases the ground waterproofing and the absence of green areas, which leaves the ground without any cover, facilitates runoff and contributes to the deposition of suspended material, exacerbating the effects of flooding. A building was therefore considered at risk when located in highly urbanized areas with few or no green spaces that could absorb excess rainwater.

For the evaluation of this indicator, a radius of 50 meters around the building was circumscribed and then the green area within the circle was then calculated.

The maximum value (1) was assigned to urbanized areas, where there are no green areas, while the minimum value (0) was assigned to buildings with a surrounding area occupied by a high percentage of green areas. The values for all the alternatives are presented below:



Xmin	1
Xmax	5
P	1
K	0.1
C	1

Figure 41: Shape, tendency and maximum and minimum satisfaction values of the "green areas" indicator. Source: Author

GREEN AREAS	
> 150,000 SQUARE METERS	0.00
100,001 - 150,000 SQUARE METERS	0.29
50,000 - 100,000 SQUARE METERS	0.55
< 50,000 SQUARE METERS	0.79
NONE	1.00

Table 43: Values of the alternatives of the "green areas" indicator

The information related to the mapping of green spaces is usually available from municipal authorities, information that is then cross-checked with the building layer. Data are obtained by the use of GIS, calculating buffer zones from the buildings, in order to calculate the total areas of green spaces within a ratio of 50 meters.

Flooding area

According to Directive 2007/60/CE on the assessment and management of flood risks, Member States are requested to assess whether all water courses and coastlines are at risk from flooding and to map the extent of flooding and the affected assets. These maps have been prepared according to topographic, hydrological, hydraulic and geomorphological studies that delimit precise flood zones over a period of 500 years.

If buildings are located in one of these flood areas, they are considered at risk. The alternatives created for this indicator are therefore only two, assigning a maximum value (1) to buildings included in the flooding area scenario and a minimum value (0) to buildings outside these areas.

FLOODING AREA	
BUILDING OUTSIDE THE FLOODING AREA	0.00
BUILDING LOCATED IN THE FLOODING AREA	1.00

Table 44: Values of the alternatives of the "flooding area" indicator

Information mapping flood zones under different scenarios (10, 100 and 500 years) is available for almost all Member States. These maps should be cross-checked with the building layer through GIS, to estimate whether the buildings are located inside or outside the flood zone.

Figure 42: Flooding in a 500 year scenario in the case study area of San Sebastian. Source: Tecnalia

Storm surge and sea-level rise

This indicator reflects the effect of heavy tides and sea-level rise on buildings. As municipalities express increasing concerned over climate change, cities are developing maps in anticipation of the effects of sea-level rise, representing the height of water at certain points.

The different heights are grouped in 5 categories, in order to assess the risk derived from heavy tides and sea-rise level: 0; <2 meters; between 2 and 4 meters; between 4 and 6 meters; > 6 meters. Their risks have been calculated according to the numbers of points, for each category, included in a 10-meter area surrounding each building. The overall risk (low, medium, high) is given by the sum of the different categories. The maximum value (1) is attached to buildings at high risk, with a range of values between 96 to 290, while the minimum value (0) is given to buildings at low risk, with a range of values between 0 and 24. The following table shows the values for the different alternatives:

STORM SURGE AND SEA-LEVEL RISE	
LOW RISK	0.00
MEDIUM RISK	0.50
HIGH RISK	1.00

Table 45: Values of the alternatives of the "buildings affected by storm surge and sea-level rise" indicator

Information on heavy tides and rising sea levels is increasingly widely available for cities in coastal areas. This information is cross-checked with the building layer, through GIS, for the calculation of the risk range, which is the result of the number of points and water height.

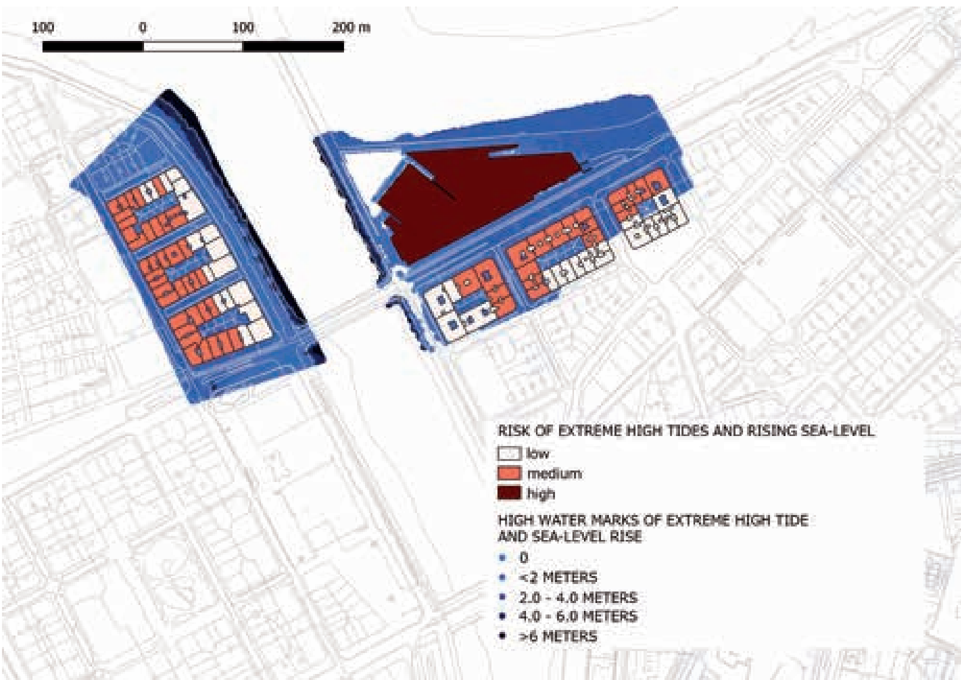


Figure 43:

Buildings at risk of storm surge in the case study area of San Sebastian.

Source: Tecnalia

The following table shows the summary of the values given to each alternative:

INDICATOR CODE	INDICATOR MEANING	VALUE MEANING	VALUE
ID 3.1.1	PROXIMITY TO COAST/RIVER	> 150 m	0.00
		101 - 150 m	0.11
		76 - 100 m	0.29
		51 - 75 m	0.50
		25 - 50 m	0.74
		< 25 m	1.00
ID 3.1.2	SOIL TYPE	ROCK	0.00
		SAND	0.34
		CLAY	0.68
		BACKFILL, SILTS	1.00
ID 3.1.3	GREEN AREAS PERCENTAGE	> 150,000 m^2	0.00
		100,001 - 150,000 m^2	0.29
		50,000 - 100,000 m^2	0.55
		< 50,000 m^2	0.79
		NONE	1.00
ID 3.1.4a	FLOODING AREA	BUILDINGS OUTSIDE THE FLOODING AREA	0.00
		BUILDINGS LOCATED IN THE FLOODING AREA	1.00
ID 3.1.4b	STORM SURGE AND SEA-LEVEL RISE	LOW	0.00
		MEDIUM	0.50
		HIGH	1.00

Table 46: Values attached to each alternative of the exposure indicators

Weights assignment

As for the vulnerability assessment, Analytic Hierarchy Process (AHP) was also used for the weights assignment of the exposure indicators, by establishing the relative importance of each element. The process described in this section is related to the inclusion of the third requirement of the decision tree, in order to obtain the building risk calculation.

Indicators (*γ*) of the exposure requirement

Once again, the fundamental scale of absolute numbers (Table 1) is entered in the reciprocal matrix through a pair-wise comparison, in order to obtain priorities for the elements considered and to check the consistency of the judgments.

In the exposure criteria, four indicators are established. It is considered that the location of the building in the flooding area is the most important parameter, while the presence of green areas and the type of soil indicators are both of equal importance, but slightly less important than the location in the flooding area. The proximity to the coastline or a river is less important, as the key indicator is land height.

	PROXIMITY	SOIL TYPE	GREEN AREAS	FLOODING AREA	WEIGHTS AHP
PROXIMITY	1	1/3	1/3	1/4	0.09
SOIL TYPE	3	1	1	1/2	0.24
GREEN AREAS	3	1	1	1/2	0.24
FLOODING AREA	4	2	2	1	0.43

CONSISTENCY
0.01

Table 47: Pair-wise comparison of the indicators belonging to the "exposure" criterion

In the case of analysing risk provoked by sea-level rise and storm surge, the flooding area indicator will be substituted by its corresponding indicator, which will have the same weight.

An adjustment to final values leaves them as follows:

EXPOSURE	PROXIMITY TO COAST/RIVER	0.10
	SOIL TYPE	0.25
	GREEN AREAS	0.25
	FLOODING AREA/ STORM SURGE	0.40

Criteria (β) of the exposure requirement

The exposure requirement has only one criteria assigned to, under the same name, which will therefore have a value of 1.

EXPOSURE	EXPOSURE	1.00

Requirements weights (α)

As a new requirement has been introduced for the risk assessment, a new index has to be calculated, considering the three requirements at the same time. As in the vulnerability assessment, sensitiveness and adaptive capacity are considered to be of the same importance. Vulnerability and exposure are therefore of the same importance.

	SENSITIVENESS	ADAPTIVE CAPACITY	EXPOSURE	WEIGHTS AHP
SENSITIVENESS	1	1	1/2	0.25
ADAPTIVE CAPACITY	1	1	1/2	0.25
EXPOSURE	2	2	1	0.50

CONSISTENCY
0.00

Table 48: Pair-wise comparison of the risk assessment requirements

The following figure shows the overall weighting coefficients for the risk assessment requirement tree:

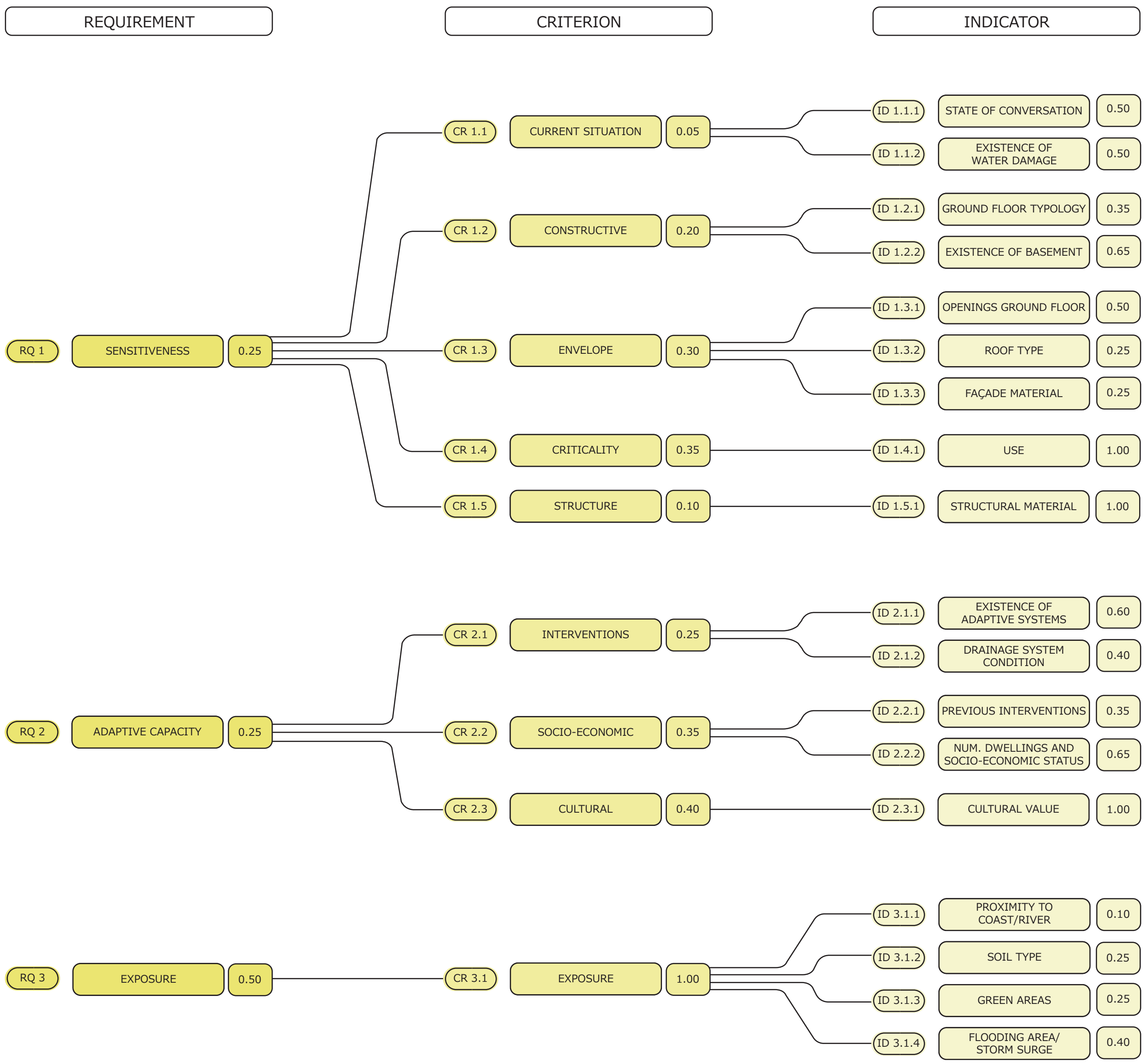


Figure 44: Overall weighting of the risk requirements tree

3.3.1 Assessment of alternatives

As described for the vulnerability assessment, the evaluation of alternatives is performed by multiplying the value of the indicator, given by the value function, in accordance with its weight, by the criteria weight, and finally the weight of the requirement. The risk index of each alternative is given by the sum of all the values of the sensitiveness and exposure requirements minus the value of the adaptive capacity requirement.

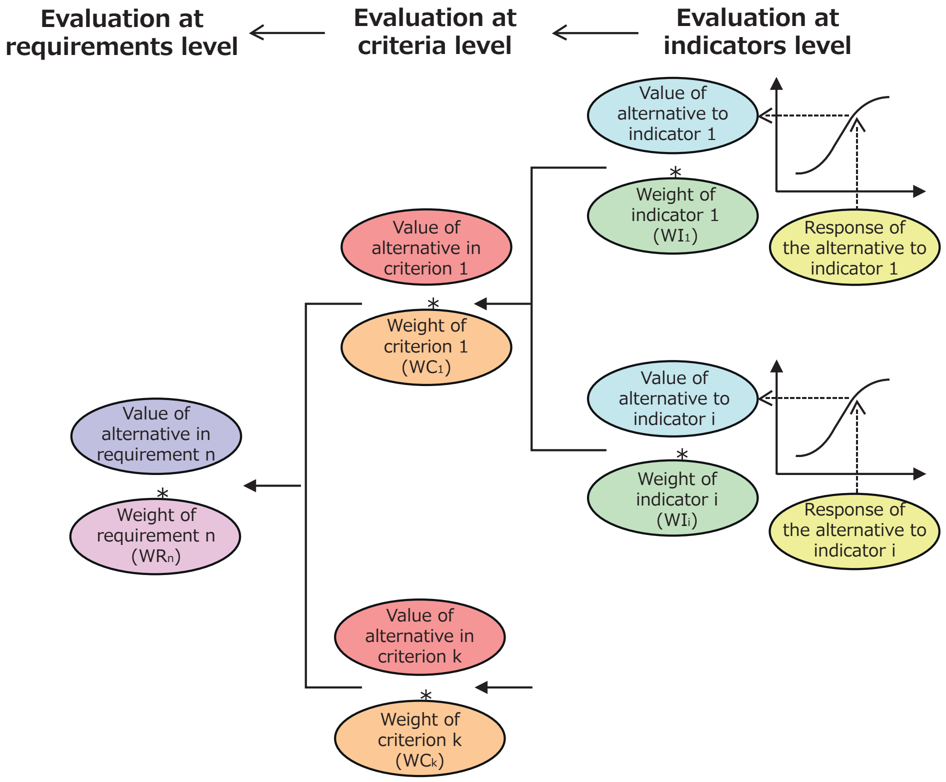


Figure 45: Alternative assessment. Source: (Viñolas et al. 2009)

As for the sensitiveness and adaptive capacity, exposure levels have been established, according to the following two ranges:

EXPOSURE INDEXES
$E0 \leq 0.40$
$0.40 < E1 \leq 1.00$

Table 49: Exposure indexes

The overall risk level is obtained by linking the vulnerability and the exposure, according to the following table:

		VULNERABILITY: LOW → HIGH					
		V0	V1	V2	V3	V4	V5
EXPOSURE: LOW ↓ HIGH	E0	R0	R1	R1	R2	R2	R3
	E1	R1	R2	R2	R3	R3	R4

Table 50: Levels of risk

3.3.2 Linking MIVES and the sample building methodology

As explained in section 3.2.1, the building stock categorization of the historic city is performed for the vulnerability assessment by assessing all buildings with 6 parameters, which are the year of construction, the use, the existence of a basement, the number of dwellings and socio-economic status and the cultural value. Once all the data have been introduced the categorization is performed and the sample buildings selected. The MIVES methodology will be applied to the sample building, and values attached to all of the indicators.

All the indicators included in the MIVES methodology will be completed for all buildings for the risk assessment.

By analysing the evaluation of the indicators expressed in percentages at both the criteria and the global level (Table 51, Table 52, Table 53), in accordance with MIVES, it is possible to advance some considerations on the parameters selected for the building categorization.

Apart from the year of construction parameter, which is used for the creation of homogeneous categories and is not included in the indicators of the MIVES methodology, all other parameters are selected as the most representative for the calculation of both vulnerability and risk assessment.

CRITERION	WEIGHT	INDICATOR	WEIGHT	OVERALL WEIGHT
CURRENT SITUATION	5%	STATE OF CONSERVATION	50%	3%
		WATER DAMAGE	50%	3%
CONSTRUCTIVE	20%	GROUND FLOOR TYPOLOGY	35%	7%
		EXISTENCE OF BASEMENT	65%	13%
ENVELOPE	30%	OPENINGS	50%	15%
		ROOF TYPE	25%	8%
		FAÇADE MATERIAL	25%	8%
CRITICALITY	35%	USE	100%	35%
STRUCTURE	10%	STRUCTURAL MATERIAL	100%	10%
INTERVENTIONS	25%	EXISTENCE OF ADAPTIVE SYSTEMS	60%	15%
		DRAINAGE SYSTEM CONDITIONS	40%	10%
SOCIO-ECONOMIC	35%	PREVIOUS INTERVENTIONS	35%	12%
		NUM. DWELLINGS AND STATUS	65%	23%
CULTURAL	40%	CULTURAL VALUE	100%	40%
EXPOSURE	100%	PROXIMITY TO COAST/RIVER	10%	10%
		SOIL TYPE	25%	25%
		GREEN AREAS	25%	25%
		FLOODING AREA/STORM SURGE	40%	40%

Table 51: Assessment of the indicators at criteria level expressed in percentage terms

Vulnerability assessment

Calculation of the percentages of the indicators at the criteria level reveals that the indicators selected for the categorization represent 48% of the sensitiveness requirement and 63% of the adaptive capacity requirement. In the sensitiveness requirement, the use of the building is the indicator which has a major impact at 35%. Even if, in the ranking, the second indicator with the highest percentage is represented by the number of openings (15%), these data are obtainable through field surveys and are otherwise difficult to obtain for the whole city. As one of the premises of the methodology was to build a cost-effective method, based on low-cost and available data, the next indicator of the ranking list was chosen, the existence of a basement, which represented 13%.

At a global level, the total percentage of the selected indicators for the vulnerability assessment calculation amounted to 55%.

REQUIREMENT	WEIGHT	CRITERION	WEIGHT	INDICATOR	WEIGHT	OVERALL WEIGHT
SENSITIVENESS	50%	CURRENT SITUATION	5%	STATE OF CONSERVATION	50%	1%
				WATER DAMAGE	50%	1%
		CONSTRUCTIVE	20%	GROUND FLOOR TYPOLOGY	35%	4%
				EXISTENCE OF BASEMENT	65%	7%
		ENVELOPE	30%	OPENINGS	50%	8%
				ROOF TYPE	25%	4%
				FAÇADE MATERIAL	25%	4%
		CRITICALITY	35%	USE	100%	18%
		STRUCTURE	10%	STRUCTURAL MATERIAL	100%	5%
ADAPTIVE CAPACITY	50%	INTERVENTIONS	25%	EXISTENCE OF ADAPTIVE SYSTEMS	60%	8%
				DRAINAGE SYSTEM CONDITIONS	40%	5%
		SOCIO-ECONOMIC	35%	PREVIOUS INTERVENTIONS	35%	6%
				NUM. DWELLINGS AND STATUS	65%	11%
		CULTURAL	40%	CULTURAL VALUE	100%	20%

Table 52: Assessment of the indicators at a global level expressed in percentage terms for the vulnerability assessment

Risk assessment

Apart from the parameters selected for the vulnerability assessment, the indicators defined for the exposure requirement will be also assessed for each building of the historic city. This assessment is necessary because, although vulnerability can be assessed according to a reduced number of categories with similar characteristics, exposure is related to location and is unique for each building.

Therefore, for the risk assessment, considering the percentage of indicators at a criteria level, representativeness will be 48% of the sensitiveness requirement, 63% of the adaptive capacity requirement and 100% of the exposure requirement. The overall total percentage, on a global level, will be 78%.

REQUIREMENT	WEIGHT	CRITERION	WEIGHT	INDICATOR	WEIGHT	OVERALL WEIGHT
SENSITIVENESS	25%	CURRENT SITUATION	5%	STATE OF CONSERVATION	50%	1%
				WATER DAMAGE	50%	1%
		CONSTRUCTIVE	20%	GROUND FLOOR TYPOLOGY	35%	2%
				EXISTENCE OF BASEMENT	65%	3%
		ENVELOPE	30%	OPENINGS	50%	4%
				ROOF TYPE	25%	2%
				FAÇADE MATERIAL	25%	2%
		CRITICALITY	35%	USE	100%	9%
		STRUCTURE	10%	STRUCTURAL MATERIAL	100%	3%
ADAPTIVE CAPACITY	25%	INTERVENTIONS	25%	EXISTENCE OF ADAPTIVE SYSTEMS	60%	4%
				DRAINAGE SYSTEM CONDITIONS	40%	3%
		SOCIO-ECONOMIC	35%	PREVIOUS INTERVENTIONS	35%	3%
				NUM. DWELLINGS AND STATUS	65%	6%
		CULTURAL	40%	CULTURAL VALUE	100%	10%
EXPOSURE	50%	EXPOSURE	100%	PROXIMITY TO COAST/RIVER	10%	5%
				SOIL TYPE	25%	13%
				GREEN AREAS	25%	13%
				FLOODING AREA/STORM SURGE	40%	20%

Table 53: Assessment of the indicators at global level expressed in percentage terms for the risk assessment

3.4 3D DATA MODEL FOR INFORMATION MANAGEMENT

Information management and multiscale data model are part of a methodological approach that supports the decision-making process.

As described in the categorization method, a data model, combing both geometric and semantic information is needed. The first step in modelling the historic city is to generate the geometry, in low detail, of the area under consideration, in a reasonably efficient manner (Prieto et al. 2012). Having established the geometry, the semantic information, based on the six identified parameters, is introduced. The result of this process is the establishment of building categories and the selection of sample buildings for the data extrapolation on the city scale. The data model will therefore be completed by collecting all of the indicators necessary for the vulnerability assessment at a sample building level. Vulnerability will be then calculated, for each sample building, representing one category, and extrapolated to all buildings belonging to the same category. The information yields, as a result, the vulnerability assessment of the entire historic city.

Data on the exposure are then included in the data model for each building and the risk assessment performed. The connection between vulnerability and exposure yields the risk to which a building is subjected. In this case, the risks are particularized for each building.

The reason for performing vulnerability and risk assessment in a separate way is that vulnerability considers the intrinsic characteristic of the building, while exposure is related to the probability of hazard. In a climate change scenario, where uncertainty is still a challenge, the possibility of changing the indicators related to the exposure is needed. Risk assessment can be performed considering various climate change scenarios (near future, mid-century and end of century), while the vulnerability of buildings is more static and will probably not change in a near future.

The data model yields sufficient information and is sufficiently representative of the historic city to guide reliable decision-making on adaptive strategies.

The CityGML data model was selected as the most appropriate tool for the vulnerability and risk assessment of the historic city, as it brings together the necessary requirements of the methodological approach, such as the coexistence of geometric and semantic information at different levels, its interoperability and its possibility of extension. Both geometric and semantic information can be introduced at different levels of detail, according to the decision-making issue. Semantic information can vary from the generic (e.g. year of construction and cadastre reference), to the thematic (static information on buildings), as well as information on indicators (to evaluate scenarios and to measure) and for dynamic records (e.g. sensors).

3.5 CONCLUSIONS

A modelling strategy of the historic city has been proposed, based on statistical distributions of building characteristics, in order to overcome the barriers inherent to the multi-scalarity of the disciplinary approach, based on both macro and micro scales. This strategy strikes the correct balance between required information and the accuracy of the results, through the identification of sample buildings, sufficiently representative for any particular group of buildings. The characteristics of the sample buildings are then applied to the whole category, which will have the same vulnerability index.

The vulnerability index has been calculated by the hierarchical structuring of the information, divided into three levels: namely, requirements, criteria and indicators, establishing a requirement tree. Indicators with different parameters and metrics can be compared by their transformation into dimensionless values, through the creation of value functions. Weights are then attached to each hierarchic level, in order to obtain a final vulnerability index, which yields a ranking of the vulnerability of the sample buildings.

Exposure indicators and their assessment have been calculated according to the same value analysis method, in order to obtain the risk index. As exposure applies to each building in a different way, it is calculated for each structure instead of using the sample building method.

In summary, the methodology presented in this chapter has provided the following central achievements and contributions:

- ➪ Historic city modelling, based on the categorization method and the selection of sample buildings representative of the historic building stock.
- ➪ Information structure and organization, based on the development of indicators and their structuring through a requirement tree.
- ➪ The establishment of a priority index and value analysis decision-making to counter vulnerability and risk.

"The city is redundant: it repeats itself so that something will stick in the mind. [...] Memory is redundant: it repeats signs so that the city can begin to exist."

Italo Calvino

4

IMPLEMENTATION

Decision-making is a process that comprises different steps, because the definition and analysis of the problem, the collection of data, the identification of the decision-making criteria, and the generation of alternative measures are all necessary, before a proper course of action may be selected. Making an informed decision to respond to climate change challenges requires a sound scientific basis. A modular, systemic and progressive method is needed to evaluate vulnerability scenarios, determined by an assessment of climate variability, if we are to face the complexities and the uncertainties of this field of analysis. The methodological approach presented in this thesis sets out an effective method to help decision-makers when selecting solutions for the most vulnerable areas of the city and establishing priorities for interventions. MIVES has been chosen as the vulnerability and risk-calculation tool, because the evaluation model is established prior to the generation of the alternatives. In this way, decisions are taken at the beginning of the process, when the aspects to be considered are defined and how these are assessed, avoiding subjectivity in the process.

Currently, the world's biggest urban climate and energy initiative is known as the "Covenant of Mayors", which brings together more than 500 municipalities. Born as a mitigation action to reduce CO_2 emissions, it has broadened its scope, and today includes adaptation to climate change, under the name of "Mayors Adapt". Through this action, local governments are committed to the European adaptive strategy to create a more resilient Europe to climate change. San Sebastian is one of the 10 Basque municipalities which have been recognized by ICLEI for the full accomplishment of the initiative "Compact of Mayors"[3] .

With regard to the impacts of climate change and the needs for possible adaptation, San Sebastian is mainly exposed to sea-level rise and the intensification of extreme events in waves, which caused important damages to the city and consequent economic losses over recent years. According to the new planned scenarios (2013), sea-level rise is likely to be more severe than expected (2007), moving from ranges of 18-59 cm to 26-82 cm. A risk assessment was carried out (Liria et al. 2011) along the coast of Gipuzkoa, considering a moderate scenario, which already pointed to the risk of flooding in urban areas, erosion, intrusion of salt-water in estuaries and groundwater and sea-level rise. Once these scenarios have been reviewed, the risks are expected to be even greater.

The area considered for the implementation and validation of the methodological approach goes beyond the boundaries of the historic city. This extended area is because the methodology can be applied to all kinds of buildings, not only to cultural heritage and because priority was given to the climatic impact that affects the overall building stock. The flood prone area of San Sebastian, considering both sea-level rise and intense precipitation, is extended to several districts, which have a historical character, but might also include modern constructions. One of the assumptions of this thesis is that the historic city should be considered part of the overall urban plot and not an isolated space, because the application of the methodology to an extended area permits comparable and coherent results.

[3] https://www.compactofmayors.org/

4.1 THE CASE STUDY OF DONOSTIA-SAN SEBASTIAN

4.1.1 Description of the area

San Sebastian, located on the northern coast of Spain near the French boarder, is a medium-sized city of approximately 186,000 inhabitants. The city traces its history back to 1180, when it was founded by Sancho the Strong. Its geographic features make it a natural harbour and the perfect place for a port and later a military stronghold. The city faced several wars and was almost completely destroyed in 1813. Citizens took refuge in Zubieta and decided to rebuild the city. Its reconstruction started with the "Old Part", built in a neoclassical and austere architectural style. In 1863, the defensive walls were demolished and the city began to expand around an orthogonal shape planned in a neoclassical Parisian style, characterized by elegant buildings. Towards the end of the 19th century, the Spanish monarchy chose San Sebastian as a summer residence and the city became a popular destination for the Spanish nobility. The Belle Epoque of the city came to its end under the dictatorship of Primo de Rivera. After the Spanish Civil War, waged intensely in the Basque Country, the city was stricken with poverty, famine, and severe social repression; industry nevertheless developed and paved the way for further urban expansion. As of the 1990s, major renovation of the city centre was planned to enhance and to revamp the neoclassical and modernist aspects of San Sebastian's architecture.

The area selected for the implementation of the risk assessment methodology is located next to the boundaries of the Urumea river and is formed of 6 districts, each with its different characteristics that are described below.

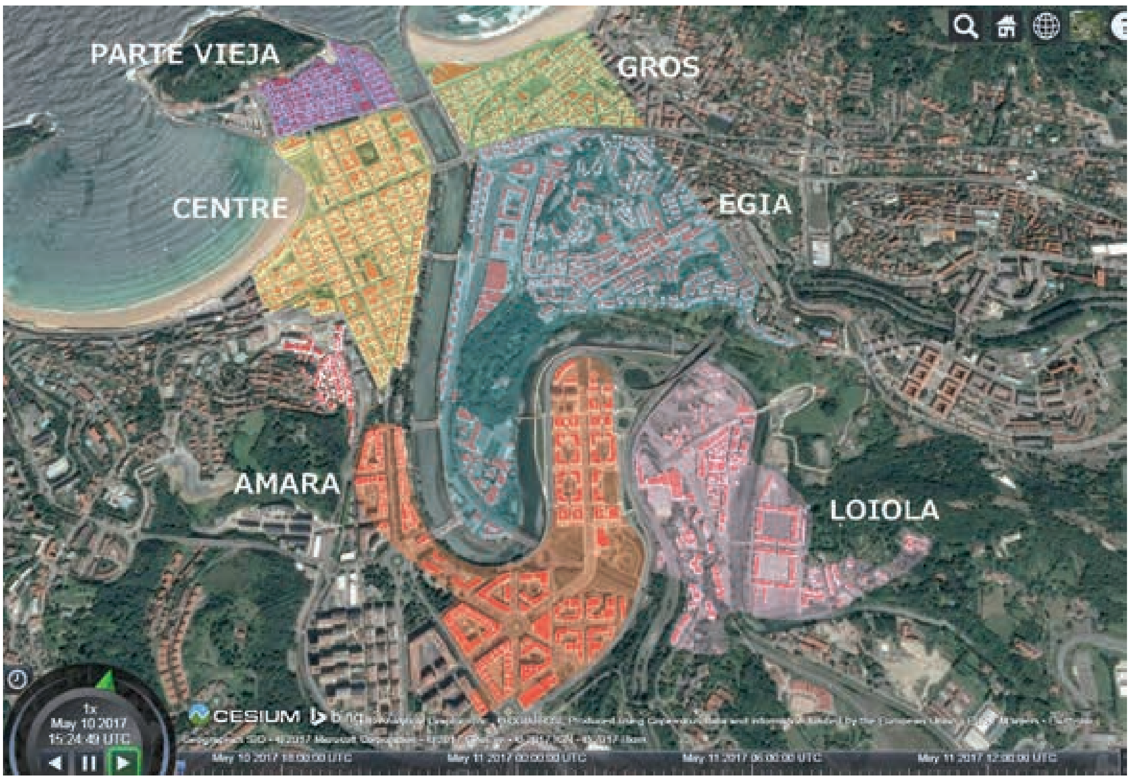


Figure 46: 3D model of the implementation area. Source: Tecnalia

Gros district: located in the eastern part of the city and separated from the city centre by two bridges. The urban nature of the neighbourhood has changed over time, since interventions on the sandy areas that occupied the right bank of the river began at the end of the 19th century. The district gradually metamorphosed from an industrial district to a commercial area, which is now considered the trade area second in importance after the centre. The district with a population of 19,442 has undergone different renovations, to public spaces, buildings, the promenade and the construction of the Auditorium and Congress and exhibition Palace.

Figure 47: View of Gros district. Source: Author

Egia district: one of the oldest districts of San Sebastian that was built up in the middle of the 19th century, with the advent of the railway in the city. It has its own personality, presenting particular social conditions and a characteristic population. This district with a population of 14,956 is also bounded by the river bank that separates it from the city centre.

Figure 48: View of Egia district. Source: Author

Loiola district: For centuries Loiola had been a district of farmhouses and detached houses. In 1926, the military headquarters, which occupy the main area of the district, were inaugurated, which began the regeneration of Loiola that later became a working class neighbourhood. Recently complex urban renovation interventions have been carried out and the development of the river bank has started. The population of Loiola district numbers some 4,962 inhabitants.

Figure 49: View of one of the old houses of Loiola district. Source: Tecnalia

Old part "Parte vieja" (Alde Zaharra): is the oldest and most well known district of the city. Up until 1863, when surrounded by the walls, it encompassed the whole city. Once the walls had been demolished, the construction of new houses started beyond the Boulevard. It now has a population of 6,083 inhabitants and although almost completely destroyed in the Spanish War of Independence in 1813, some of the oldest constructions still remain.

Figure 50: View of "Parte vieja" district. Source: Author

Centre: its boundaries mark out the "central city" and constitute, from both a social and an economic point of view, the place of commercial and business exchange. Its construction began after the demolition of the city walls, following the project of the architect Antonio Cortázar. It constitutes the geographic and perceptive core of the city and is characterized by a rich and homogeneous architectural heritage, as a result of a coherently planned construction process completed within a short period of time. The population at present stands at 10,077 inhabitants.

Figure 51: View of Centre district. Source: Author

Amara: the construction of this modern district, the most extensive in the city, began in the 1960s. It is a mainly a functional and residential district, located near the city centre. The district that now has a population of 31,039 inhabitants has grown in proportion with the expansion of the city, with different areas corresponding to different periods of construction.

Figure 52: View of Amara district. Source: Author

4.1.2 Modelling the area of San Sebastian

A 3D city model is defined as a georeferenced digital representation of objects, structures and features that correspond to a real city (Ross et al. 2009) CityGML[4] is a standard open data model defined by the Open Geospatial Consortium (OGC) for the storage and exchange of a 3D city model, which was used within the ADVICE project, for the case study of San Sebastian. The generation process of 3D city models, based on CityGML, is divided into two main stages:

1. Generation of 3D model geometry
2. Introduction of semantic properties of the model

Generation of the geometry

The following information is required for the generation of the geometry of the 3D city model:

➪ Cadastral information in .shp format: containing the geometry of the footprints of buildings in the area of interest.

➪ LiDAR - Light Detection and Ranging - data: a system that generates a point cloud of the ground by means of an airborne laser scanner. It represents the Digital Surface Model (Figure 53) of the area of interest.

➪ DTM - Digital Terrain Model - data: a false 3D representation of topography from a terrestrial zone (Figure 53) that is stored as a matrix of points with heights.

From these data sources, a 3D City Model with different levels of detail is generated in a semi-automatic process. Pre-processing of the data is required to eliminate erroneous data, duplicated data and other information outside the area of interest. Then, by using the LIDAR and DTM data, the actual height of the buildings and their altitudes is obtained. In this way it is possible to generate buildings in 3D with their actual height, correctly defining both position and altitude. A detailed process for the generation of the 3D city model is described by (Prieto et al. 2012). As a result of the geometric generation process, the 3D city model includes buildings of the area of interest with different levels of detail (LoD0: building footprints in 2D, LoD1: buildings represented by 3D boxes and LoD2: including façades and roofs). The geometric generation process is presented as a graph in the following figure (Figure 53).

[4] CityGML: OGC City Geography Markup Language (CityGML) Encoding Standard 12-019 - http://www.opengeospatial.org/standards/citygml

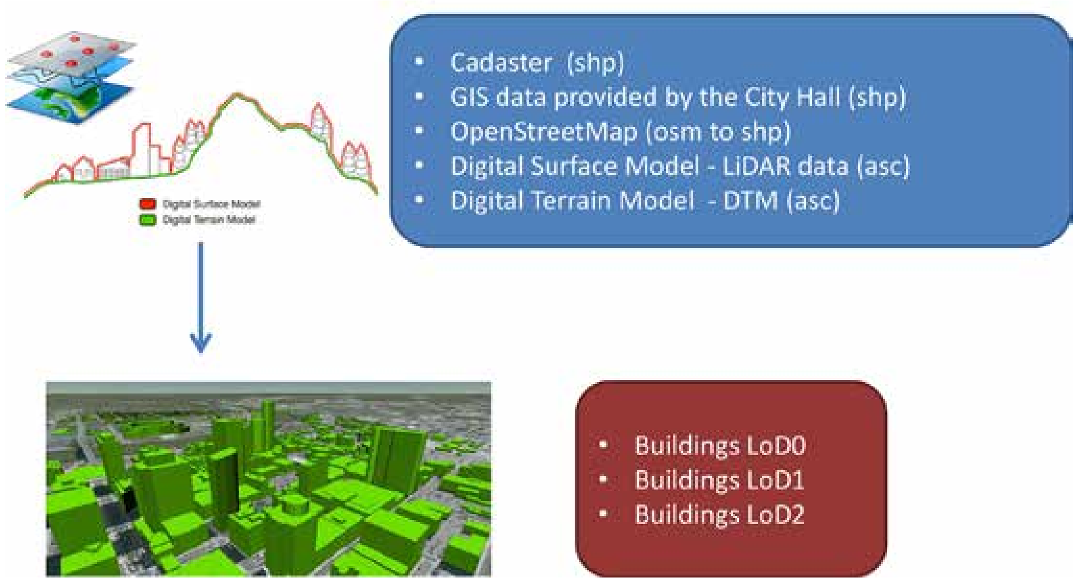


Figure 53: Geometric generation of 3D urban model. Source: Tecnalia

Introduction of semantic properties

Once the geometry of the 3D urban model is generated, the semantic properties that have been identified need to be added to the model. The completion of the semantic properties firstly requires the adaptation/extension of the CityGML data model with specific attributes related to the application domain. The required information has to be referenced to the corresponding element, in order to complete these semantic properties. Information is then automatically entered into the 3D urban model through a process of semanticization. In this process information from a file in .shp or .xls format is collected and fed into the CityGML file with the results of the geometric generation of the model.

As described in the methodological approach, one of the general requirements is a method that consumes few resources, requiring commonly available and easily accessible information. Semantic data referring to the lot unit, a parcel of land, with defined boundaries, owned by the same owner(s), are included in the model. Usually a lot is sized for a single building, but it can refer to more than one doorway. The selection of the lot unit instead of the building unit is due to the availability of information on public databases based on information of the lots. The Spanish cadastre was taken as the main data source for this first stage of the implementation. The basic data included in the model are the following:

Reference number of the lot: the cadastral registration of the lot, defined by a unique code identifier from the Spanish cadastre.

Year of construction: the year of construction of the building included in the lot, as indicated by the Spanish cadastre. In the case of including more than one building in the same lot, the oldest date was considered.

Use: The main function of the building is indicated according to the Spanish cadastre. In case of including more than one building in the same lot, the most frequent use was considered.

Existence of a basement: indicates whether the building in the lot has a basement, according to the Spanish cadastre. In case of including more than one building in the same lot, the worst condition (existence of a basement) was considered.

Cultural value: the level of protection of the buildings and their associated lots were manually included using data from the general urban plan of San Sebastian (plan general de ordenación urbana).

Number of dwellings: the number of dwellings in the data provided by the Spanish cadastre was considered. In case of including more than one building in the same lot, the sum of the dwellings was considered.

Socio-economic status: data on the socio-economic status of the buildings were calculated in accordance with the occupational profile, based on the adaptation of the methodology proposed by (Reques 2006). The information on the occupational profile is available through Lurdata[5] , a Eustat tool, under the category "Population over 16 years old in employment by profession". The status is divided into three ranges, considering high categories such as managing directors and professional technicians; medium category employees, administrative staff, qualified workers, traders, and army personnel; and lower categories such as farmers, fishermen, and unqualified workers. As data are available on census units, the % of each range is calculated on this unit and it is then applied to all the buildings included in the corresponding unit. The % of each range is weighted, in order to evaluate the final status.

Statistical overview of the area

It is necessary to prepare a statistical overview of the parameters for the area under consideration, in order to build a proper characterization. As each historic city has its own characteristics, this process helps to identify ranges, in order to obtain the right balance between the number of categories and the percentage of the building stock under analysis. The following figures show the distribution of the parameters for the area of San Sebastian that is under study.

[5] http://www.eustat.eus/estad/gis_c.html#axzz4ggCs6Ur7

Figure 54: Geographical distribution of the lots by their level of protection. Source: Tecnalia

LEVEL OF PROTECTION	NUM. OF LOTS	COLOUR
None	1,245	
Grade IV	773	
Grade III	179	
Grade II	49	
Grade I	16	

Table 54: Distribution of the lots by their level of protection

Figure 55: Geographical distribution of the lots by the existence of a basement. Source: Tecnalia

BASEMENT	NUM. OF LOTS	COLOUR
Existence of a basement	1,788	
Absence of basement	474	

Table 55: Distribution of the lots by the existence of a basement.

Figure 56: Geographical distribution of the lots by the socio-economic status. Source: Tecnalia

SOCIO-ECONOMIC STATUS	NUM. OF LOTS	COLOUR
Low	459	
Medium	605	
High	705	
Very high	493	

Table 56: Distribution of the lots by the socio-economic status.

Figure 57: Geographical distribution of the lots according to the main use. Source: Tecnalia

USE	NUM. OF LOTS	COLOUR
Cultural centres, public equipment	120	
Commerce	141	
Dwellings	1,974	
Emergency, health	27	

Table 57: Distribution of the lots according to the main use.

Figure 58: Geographical distribution of the lots by the number of dwellings. Source: Tecnalia

NUM. OF DWELLINGS	NUM. OF LOTS	COLOUR
None	169	
< 10	676	
10 - 40	1,295	
> 40	122	

Table 58: Distribution of the lots by the number of dwellings.

Figure 59: Geographical distribution of the lots by the year of construction. Source: Tecnalia

YEAR OF CONSTRUCTION	NUM. OF LOTS	COLOUR
< 1900	143	
1900 - 1950	1,323	
> 1950	777	

Table 59: Distribution of the lots by the year of construction.

Generation of categories

Following the distribution and statistical overview of the area of San Sebastian in this study, it was considered that use, level of protection, existence of a basement and status had to be considered, with regard to all their variables, as primary parameters. For the year of construction, 1950 was considered as the date on which to divide the categories. This date was chosen, on the one hand, because it is a relevant division between historic and new buildings and, on the other hand, because it represents the era when constructive elements started to be homogeneous in terms of material (common use of concrete). The number of dwellings was discarded as the parameter in this area is too homogeneous to be representative. The threshold of minimum representation was established at 2%. The following table shows the generation of the categories for the case study:

USE			LEVEL OF PROTECTION			EXISTENCE OF BASEMENT			SOCIO-ECONOMIC STATUS			YEAR OF CONSTRUCTION			
TYPE	NUM. OF LOTS	% ON TOTAL	TYPE	NUM. OF LOTS	% ON TOTAL	TYPE	NUM. OF LOTS	% ON TOTAL	TYPE	NUM. OF LOTS	% ON TOTAL	TYPE	NUM. OF LOTS	% ON TOTAL	
Cultural centres	120	5.3%	None	90	4.0%	with basement	54	2.4%	Low	29	**1.3%**				
									Medium	16	**0.7%**				
									High	7	**0.3%**				
									Very high	2	**0.1%**				
						without basement	36	**1.6%**							
			Grade IV	13	**0.6%**										
			Grade III	4	**0.2%**										
			Grade II	5	**0.2%**										
			Grade I	8	**0.4%**										
Commerce	141	6.2%	None	76	3.4%	with basement	49	2.2%	Low	5	**0.2%**				
									Medium	11	**0.5%**				
									High	10	**0.4%**				
									Very high	23	**1.0%**				
						without basement	27	**1.2%**							
			Grade IV	34	**1.5%**										
			Grade III	20	**0.9%**										
			Grade II	8	**0.4%**										
			Grade I	3	**0.1%**										
Residential	1974	87.3%	None	1057	46.7%	with basement	752	33.2%	Low	188	8.3%	<1950	56	2.5%	CATEGORY 1
												>1950	132	5.8%	CATEGORY 2
									Medium	246	10.9%	<1950	123	5.4%	CATEGORY 3
												>1950	123	5.4%	CATEGORY 4
									High	205	9.1%	<1950	66	2.9%	CATEGORY 5
												>1950	139	6.1%	CATEGORY 6
									Very high	113	5.0%	<1950	20	**0.9%**	
												>1950	93	4.1%	CATEGORY 7
						without basement	305	13.5%	Low	186	8.2%	<1950	68	3.0%	CATEGORY 8
												>1950	118	5.2%	CATEGORY 9
									Medium	81	3.6%	<1950	67	3.0%	CATEGORY 10
												>1950	14	**0.6%**	
									High	31	**1.4%**				
									Very high	7	**0.3%**				
			Grade IV	726	32.1%	with basement	671	29.7%	Low	0	**0.0%**				
									Medium	124	5.5%	<1950	120	5.3%	CATEGORY 11
												>1950	4	**0.2%**	
									High	312	13.8%	<1950	302	13.4%	CATEGORY 12
												>1950	10	**0.4%**	
									Very high	235	10.4%	<1950	215	9.5%	CATEGORY 13
												>1950	20	**0.9%**	
						without basement	55	2.4%	Low	0	**0.0%**				
									Medium	37	**1.6%**				
									High	17	**0.8%**				
									Very high	1	**0.0%**				
			Grade III	151	6.7%	with basement	135	6.0%	Low	1	**0.0%**				
									Medium	25	**1.1%**				
									High	55	2.4%	>1950	50	2.2%	CATEGORY 14
												>1950	5	**0.2%**	
									Very high	54	2.4%	>1950	49	2.2%	CATEGORY 15
												>1950	5	**0.2%**	
						without basement	16	**0.7%**							
			Grade II	35	**1.5%**										
			Grade I	5	**0.2%**										
Emergency	27	1.2%	None	22	**1.0%**										
			Grade IV	2	**0.1%**										
			Grade III	3	**0.1%**										
			Grade II	0	**0.0%**										
			Grade I	0	**0.0%**										
														TOTAL: **76.1%**	

Table 60: Generation of categories for the case study of San Sebastian

With these 15 categories a degree of representativeness of 76% has been achieved. The following table summarizes the selected categories:

USE	LEVEL OF PROTECTION	EXISTENCE OF BASEMENT	SOCIO-ECONOMIC STATUS	YEAR OF CONSTRUCTION	CATEGORY	REPRESENTA-TIVENESS	NUM. OF LOTS
Residential	None	With basement	Low	<1950	CATEGORY 1	2.5%	56
				>1950	CATEGORY 2	5.8%	132
			Medium	<1950	CATEGORY 3	5.4%	123
				>1950	CATEGORY 4	5.4%	123
			High	<1950	CATEGORY 5	2.9%	66
				>1950	CATEGORY 6	6.1%	139
			Very high	>1950	CATEGORY 7	4.1%	93
		Without basement	Low	<1950	CATEGORY 8	3.0%	68
				>1950	CATEGORY 9	5.2%	118
			Medium	<1950	CATEGORY 10	3.0%	67
	Grade IV	With basement	Medium	<1950	CATEGORY 11	5.3%	120
			High	<1950	CATEGORY 12	13.4%	302
			Very high	<1950	CATEGORY 13	9.5%	215
	Grade III	With basement	High	>1950	CATEGORY 14	2.2%	50
			Very high	>1950	CATEGORY 15	2.2%	49
					TOTAL:	**76.1%**	**1721**

Table 61: Selected categories for the case study of San Sebastian

The following figure shows the geographical distribution of the categories:

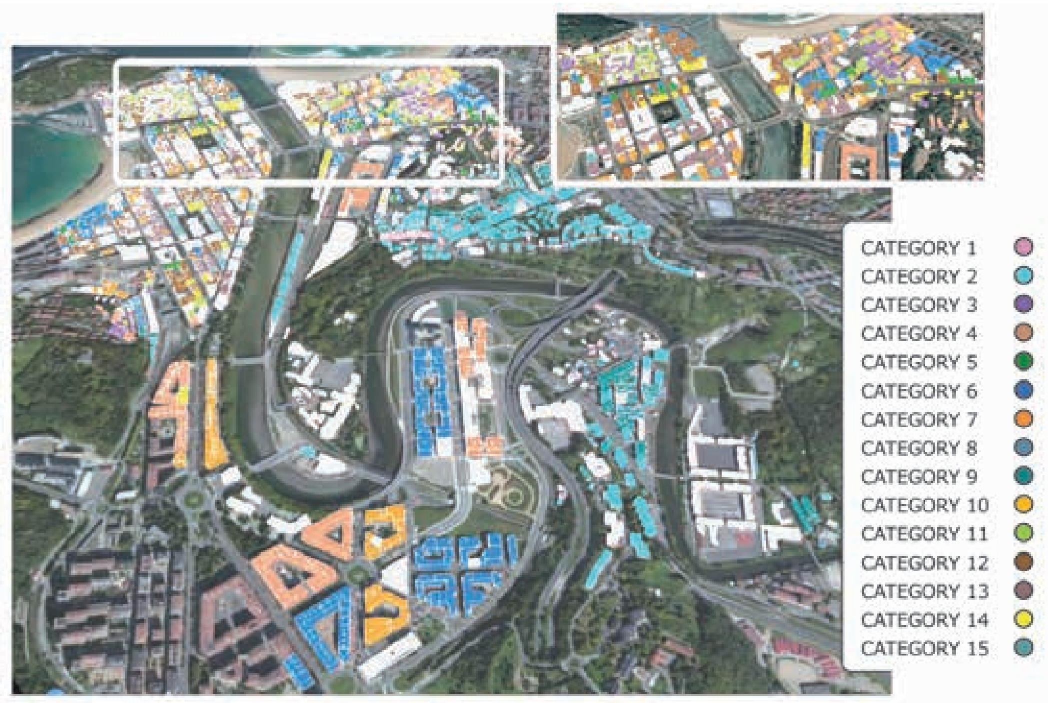


Figure 60: Geographical distribution of the categories. Source: Tecnalia

Selection of sample buildings

As the area considered goes beyond the boundaries of the historic city, sample buildings were, wherever possible, selected in the oldest part of the city. As explained in the methodological approach, sample buildings are real buildings that are representative enough of a group of elements with the same characteristics. Sample buildings have mainly been selected according to the representativeness of the parameters compared to the whole category and the availability of relevant information. For the vulnerability calculation, semantic information on the sample buildings was completed and extrapolated to the category.

Category 1

Category characteristics

Parameter	Value	
Year of construction	Less than 1950	
Representativeness	2.5%	
Cultural value	None	0.00
Existence of a basement	Yes	1.00
Socio-economic status	Low	0.54
Use	Residential	0.69

Sample building semantic information

Parameter	Value	
Reference	8396354	
Address	Calle Matxiñene 11, 13	
District	Loiola	
Year of construction	1933	
State of conservation	Good	0.00
Existence of water damage	No	0.00
Ground floor typology	Closed structure with activity	1.00
Openings ground floor	Small openings	0.49
Roof type	Pitched roof	0.00
Façade material	Mortar	0.38
Structural material	Wood	1.00
Existence of adaptive systems	No	0.00
Drainage system conditions	Good	1.00
Previous interventions	No	0.00

Category 2

Category characteristics

Parameter	Value	
Year of construction	Greater than 1950	
Representativeness	5.8%	
Cultural value	None	0.00
Existence of a basement	Yes	1.00
Socio-economic status	Low	0.54
Use	Residential	0.69

Sample building semantic information

Parameter	Value	
Reference	8396357	
Address	Calle Egia 19	
District	Egia	
Year of construction	1963	
State of conservation	Good	0.00
Existence of water damage	Yes	1.00
Ground floor typology	Closed structure with activity	1.00
Openings ground floor	Large openings	1.00
Roof type	Pitched roof	0.00
Façade material	Brick/non porous stone	0.00
Structural material	Concrete	0.82
Existence of adaptive systems	No	0.00
Drainage system conditions	Fair	0.78
Previous interventions	Yes	1.00

Category 3

Category characteristics

Parameter	Value	
Year of construction	Less than 1950	
Representativeness	5.4%	
Cultural value	None	0.00
Existence of a basement	Yes	1.00
Socio-economic status	Medium	0.57
Use	Residential	0.69

Sample building semantic information

Parameter	Value	
Reference	8297106	
Address	Calle Esterlines 2	
District	Parte vieja	
Year of construction	1900	
State of conservation	Fair	0.18
Existence of water damage	Yes	1.00
Ground floor typology	Closed structure with activity	1.00
Openings ground floor	Large openings	1.00
Roof type	Pitched roof	0.00
Façade material	Mortar	0.38
Structural material	Wood	1.00
Existence of adaptive systems	No	0.00
Drainage system conditions	Good	1.00
Previous interventions	Yes	1.00

Category 4

Category characteristics

Parameter	Value	
Year of construction	Greater than 1950	
Representativeness	5.4%	
Cultural value	None	0.00
Existence of a basement	Yes	1.00
Socio-economic status	Medium	0.57
Use	Residential	0.69

Sample building semantic information

Parameter	Value	
Reference	8397100	
Address	Calle Segundo Izpizua 6	
District	Gros	
Year of construction	1979	
State of conservation	Bad	0.73
Existence of water damage	Yes	1.00
Ground floor typology	Closed structure with activity	1.00
Openings ground floor	Large openings	1.00
Roof type	Pitched roof	0.00
Façade material	Mortar	0.38
Structural material	Concrete	0.82
Existence of adaptive systems	No	0.00
Drainage system conditions	Fair	0.78
Previous interventions	No	0.00

Category 5

Category characteristics

Parameter	Value	
Year of construction	Less than 1950	
Representativeness	2.9%	
Cultural value	None	0.00
Existence of a basement	Yes	1.00
Socio-economic status	High	0.62
Use	Residential	0.69

Sample building semantic information

Parameter	Value	
Reference	8297107	
Address	Calle Iñigo 5	
District	Parte vieja	
Year of construction	1900	
State of conservation	Bad	0.73
Existence of water damage	Yes	1.00
Ground floor typology	Closed structure with activity	1.00
Openings ground floor	Large openings	1.00
Roof type	Pitched roof	0.00
Façade material	Porous stone	1.00
Structural material	Wood	1.00
Existence of adaptive systems	No	0.00
Drainage system conditions	Fair	0.78
Previous interventions	Yes	1.00

Category 6

Category characteristics

Parameter	Value	
Year of construction	Greater than 1950	
Representativeness	6.1%	
Cultural value	None	0.00
Existence of a basement	Yes	1.00
Socio-economic status	High	0.62
Use	Residential	0.69

Sample building semantic information

Parameter	Value
Reference	8297117
Address	Calle General Etxague 15
District	Parte vieja
Year of construction	1970

State of conservation	Good	0.00
Existence of water damage	No	0.00
Ground floor typology	Closed structure with activity	1.00
Openings ground floor	Large openings	1.00
Roof type	Pitched roof	0.00
Façade material	Brick/non porous stone	0.00
Structural material	Concrete	0.82
Existence of adaptive systems	No	0.00
Drainage system conditions	Good	1.00
Previous interventions	No	0.00

Category 7

Category characteristics

Parameter	Value	
Year of construction	Greater than 1950	
Representativeness	4.1%	
Cultural value	None	0.00
Existence of a basement	Yes	1.00
Socio-economic status	Very high	0.64
Use	Residential	0.69

Sample building semantic information

Parameter	Value	
Reference	8296741	
Address	Calle Urbieta 1	
District	Centre	
Year of construction	1962	
State of conservation	Fair	0.73
Existence of water damage	Yes	1.00
Ground floor typology	Closed structure with activity	1.00
Openings ground floor	Large openings	1.00
Roof type	Pitched roof	0.00
Façade material	Brick/non porous stone	0.00
Structural material	Concrete	0.82
Existence of adaptive systems	No	0.00
Drainage system conditions	Fair	0.78
Previous interventions	No	0.00

Category 8

Category characteristics

Parameter	Value	
Year of construction	Less than 1950	
Representativeness	3.0%	
Cultural value	None	0.00
Existence of a basement	No	0.00
Socio-economic status	Low	0.54
Use	Residential	0.69

Sample building semantic information

Parameter	Value	
Reference	8396375	
Address	Calle Urbia 11	
District	Loiola	
Year of construction	1930	
State of conservation	Good	0.00
Existence of water damage	Yes	1.00
Ground floor typology	Closed structure with no activity	0.50
Openings ground floor	Small openings	0.49
Roof type	Pitched roof	0.00
Façade material	Mortar	0.38
Structural material	Wood	1.00
Existence of adaptive systems	Yes	1.00
Drainage system conditions	Fair	0.78
Previous interventions	No	0.00

Category 9

Category characteristics

Parameter	Value	
Year of construction	Greater than 1950	
Representativeness	5.2%	
Cultural value	None	0.00
Existence of a basement	No	0.00
Socio-economic status	Low	0.54
Use	Residential	0.69

Sample building semantic information

Parameter	Value	
Reference	8396351	
Address	Calle Urbia 5, 6	
District	Loiola	
Year of construction	1985	
State of conservation	Good	0.00
Existence of water damage	No	0.00
Ground floor typology	Closed structure with activity	1.00
Openings ground floor	Small openings	0.49
Roof type	Pitched roof	0.00
Façade material	Mortar	0.38
Structural material	Concrete	0.82
Existence of adaptive systems	No	0.00
Drainage system conditions	Good	1.00
Previous interventions	No	0.00

Category 10

Category characteristics

Parameter	Value	
Year of construction	Less than 1950	
Representativeness	3.0%	
Cultural value	None	0.00
Existence of a basement	No	0.00
Socio-economic status	Medium	0.57
Use	Residential	0.69

Sample building semantic information

Parameter	Value	
Reference	8397051	
Address	Calle San Francisco 46	
District	Gros	
Year of construction	1936	
State of conservation	Good	0.00
Existence of water damage	No	0.00
Ground floor typology	Closed structure with activity	1.00
Openings ground floor	Large openings	1.00
Roof type	Flat roof	1.00
Façade material	Mortar	0.38
Structural material	Concrete	0.82
Existence of adaptive systems	No	0.00
Drainage system conditions	Good	1.00
Previous interventions	Yes	1.00

Category 11

Category characteristics

Parameter	Value	
Year of construction	Less than 1950	
Representativeness	5.3%	
Cultural value	Grade IV	0.27
Existence of a basement	Yes	1.00
Socio-economic status	Medium	0.57
Use	Residential	0.69

Sample building semantic information

Parameter	Value	
Reference	8297113	
Address	Calle Pescadería 5	
District	Parte vieja	
Year of construction	1900	
State of conservation	Fair	0.18
Existence of water damage	Yes	1.00
Ground floor typology	Closed structure with activity	1.00
Openings ground floor	Small openings	0.49
Roof type	Pitched roof	0.00
Façade material	Mortar	0.38
Structural material	Wood	1.00
Existence of adaptive systems	No	0.00
Drainage system conditions	Good	1.00
Previous interventions	Yes	1.00

Category 12

Category characteristics

Parameter	Value	
Year of construction	Less than 1950	
Representativeness	13.4%	
Cultural value	Grade IV	0.27
Existence of a basement	Yes	1.00
Socio-economic status	High	0.62
Use	Residential	0.69

Sample building semantic information

Parameter	Value	
Reference	8297590	
Address	Calle Peña y Goñi 2	
District	Gros	
Year of construction	1912	
State of conservation	Good	0.00
Existence of water damage	No	0.00
Ground floor typology	Closed structure with activity	1.00
Openings ground floor	Large openings	1.00
Roof type	Flat roof	1.00
Façade material	Porous stone	1.00
Structural material	Concrete	0.82
Existence of adaptive systems	Yes	1.00
Drainage system conditions	Fair	0.78
Previous interventions	Yes	1.00

Category 13

Category characteristics

Parameter	Value	
Year of construction	Less than 1950	
Representativeness	9.5%	
Cultural value	Grade IV	0.27
Existence of a basement	Yes	1.00
Socio-economic status	Very high	0.64
Use	Residential	0.69

Sample building semantic information

Parameter	Value	
Reference	8296379	
Address	Calle Fuentearribia 21	
District	Centre	
Year of construction	1905	
State of conservation	Good	0.00
Existence of water damage	Yes	1.00
Ground floor typology	Closed structure with activity	1.00
Openings ground floor	Large openings	1.00
Roof type	Pitched roof	0.00
Façade material	Porous stone	1.00
Structural material	Wood	1.00
Existence of adaptive systems	No	0.00
Drainage system conditions	Good	1.00
Previous interventions	Yes	1.00

Category 14

Category characteristics

Parameter	Value	
Year of construction	Less than 1950	
Representativeness	2.2%	
Cultural value	Grade III	0.61
Existence of a basement	Yes	1.00
Socio-economic status	High	0.62
Use	Residential	0.69

Sample building semantic information

Parameter	Value	
Reference	8297194	
Address	Calle Reina Regente 3	
District	Parte Vieja	
Year of construction	1900	
State of conservation	Good	0.00
Existence of water damage	Yes	1.00
Ground floor typology	Closed structure with activity	1.00
Openings ground floor	Large openings	1.00
Roof type	Pitched roof	0.00
Façade material	Porous stone	1.00
Structural material	Wood	1.00
Existence of adaptive systems	No	0.00
Drainage system conditions	Good	1.00
Previous interventions	Yes	1.00

Category 15

Category characteristics

Parameter	Value	
Year of construction	Less than 1950	
Representativeness	2.2%	
Cultural value	Grade III	0.61
Existence of a basement	Yes	1.00
Socio-economic status	Very high	0.64
Use	Residential	0.69

Sample building semantic information

Parameter	Value	
Reference	8296496	
Address	Calle Alfonso VIII 7	
District	Centre	
Year of construction	1903	
State of conservation	Good	0.00
Existence of water damage	Yes	1.00
Ground floor typology	Closed structure with activity	1.00
Openings ground floor	Large openings	1.00
Roof type	Pitched roof	0.00
Façade material	Porous stone	1.00
Structural material	Wood	1.00
Existence of adaptive systems	No	0.00
Drainage system conditions	Fair	0.78
Previous interventions	No	0.00

4.1.3 Calculation of sensitiveness, adaptive capacity and vulnerability

As described in the methodological approach, vulnerability is composed of a sensitiveness index and an adaptive capacity index. These requirements are calculated by multiplying the value of the parameter (given by the value function) by the indicator weight and by the weight of the criteria to which they belong, according to the decision tree established through the MIVES methodology.

			SENSITIVENESS									
			CURRENT SITUATION		CONSTRUCTIVE		ENVELOPE			CRITICALITY	STRUCTURE	
CRITERIA WEIGHTS			0.05		0.20		0.30			0.35	0.10	
CATEGORY	REFERENCE	YEAR OF CONSTRUCTION	STATE OF CONSERVATION	EXISTENCE OF WATER DAMAGE	GROUND FLOOR TYPOLOGY	EXISTENCE OF BASEMENT	OPENINGS GROUND FLOOR	ROOF TYPE	FAÇADE MATERIAL	USE	STRUCTURAL MATERIAL	**SENSITIVENESS INDEX**
INDICATORS WEIGHTS			0.50	0.50	0.35	0.65	0.50	0.25	0.25	1.00	1.00	
CATEGORY 1	8396354	1933	0.00	0.00	1.00	1.00	0.49	0.00	0.38	0.69	1.00	0.64
CATEGORY 2	8396357	1963	0.00	1.00	1.00	1.00	1.00	0.00	0.00	0.69	0.82	0.70
CATEGORY 3	8297106	1900	0.18	1.00	1.00	1.00	1.00	0.00	0.38	0.69	1.00	0.75
CATEGORY 4	8397100	1979	0.73	1.00	1.00	1.00	1.00	0.00	0.38	0.69	0.82	0.75
CATEGORY 5	8297107	1900	0.73	1.00	1.00	1.00	1.00	0.00	0.00	0.69	1.00	0.73
CATEGORY 6	8297117	1970	0.00	0.00	1.00	1.00	1.00	0.00	0.00	0.69	0.82	0.67
CATEGORY 7	8296741	1962	0.73	1.00	1.00	1.00	1.00	0.00	0.00	0.69	0.82	0.72
CATEGORY 8	8396375	1930	0.00	1.00	0.50	0.00	0.49	0.00	0.38	0.69	1.00	0.50
CATEGORY 9	8396351	1985	0.00	0.00	1.00	0.00	0.49	0.00	0.38	0.69	0.82	0.50
CATEGORY 10	8397051	1936	0.00	0.00	1.00	0.00	1.00	1.00	0.38	0.69	0.82	0.65
CATEGORY 11	8297113	1900	0.18	1.00	1.00	1.00	0.49	0.00	0.38	0.69	1.00	0.67
CATEGORY 12	8297590	1912	0.00	0.00	1.00	1.00	1.00	1.00	1.00	0.69	0.82	0.82
CATEGORY 13	8296379	1905	0.00	1.00	1.00	1.00	1.00	0.00	1.00	0.69	1.00	0.79
CATEGORY 14	8297194	1900	0.00	1.00	1.00	1.00	1.00	0.00	1.00	0.69	1.00	0.79
CATEGORY 15	8296496	1903	0.00	1.00	1.00	1.00	1.00	0.00	1.00	0.69	1.00	0.79

Table 62: Sensitiveness indicator values and sensitiveness index calculation for each sample building

			ADAPTIVE CAPACITY					
			INTERVENTIONS		SOCIO-ECONOMIC		CULTURAL	
CRITERIA WEIGHTS			0.25		0.35		0.40	
CATEGORY	REFERENCE	YEAR OF CONSTRUCTION	EXISTENCE OF ADAPTIVE SYSTEMS	DRAINAGE SYSTEM CONDITIONS	PREVIOUS INTERVENTIONS	SOCIO-ECONOMIC STATUS	CULTURAL VALUE	**ADAPTIVE CAPACITY INDEX**
INDICATORS WEIGHTS			0.60	0.40	0.35	0.65	1.00	
CATEGORY 1	8396354	1933	0.00	1.00	0.00	0.54	0.00	0.22
CATEGORY 2	8396357	1963	0.00	0.78	1.00	0.54	0.00	0.32
CATEGORY 3	8297106	1900	0.00	1.00	1.00	0.57	0.00	0.35
CATEGORY 4	8397100	1979	0.00	0.78	0.00	0.57	0.00	0.21
CATEGORY 5	8297107	1900	0.00	0.29	1.00	0.62	0.00	0.29
CATEGORY 6	8297117	1970	0.00	1.00	0.00	0.62	0.00	0.24
CATEGORY 7	8296741	1962	0.00	0.78	0.00	0.64	0.00	0.22
CATEGORY 8	8396375	1930	1.00	0.78	0.00	0.54	0.00	0.35
CATEGORY 9	8396351	1985	0.00	1.00	0.00	0.54	0.00	0.22
CATEGORY 10	8397051	1936	0.00	1.00	1.00	0.57	0.00	0.35
CATEGORY 11	8297113	1900	0.00	1.00	1.00	0.57	0.27	0.46
CATEGORY 12	8297590	1912	1.00	0.78	1.00	0.62	0.27	0.60
CATEGORY 13	8296379	1905	0.00	1.00	1.00	0.64	0.27	0.48
CATEGORY 14	8297194	1900	0.00	1.00	1.00	0.62	0.61	0.61
CATEGORY 15	8296496	1903	0.00	0.78	0.00	0.64	0.61	0.47

Table 63: Adaptive capacity indicator values and adaptive capacity index calculation for each sample building

The sensitiveness and the adaptive capacity categories are determined and the vulnerability level is established in accordance with the pre-established ranges and the sensitiveness and the adaptive capacity indexes.

CATEGORY	REFERENCE	SENSITIVENESS INDEX		ADAPTIVE CAPACITY INDEX		VULNERABILITY
CATEGORY 1	8396354	0.64	S3	0.22	A0	V5
CATEGORY 2	8396357	0.70	S3	0.32	A1	V3
CATEGORY 3	8297106	0.75	S3	0.35	A1	V3
CATEGORY 4	8397100	0.75	S3	0.21	A0	V5
CATEGORY 5	8297107	0.73	S3	0.29	A0	V5
CATEGORY 6	8297117	0.67	S3	0.24	A0	V5
CATEGORY 7	8296741	0.72	S3	0.22	A0	V5
CATEGORY 8	8396375	0.50	S2	0.35	A1	V2
CATEGORY 9	8396351	0.50	S2	0.22	A0	V4
CATEGORY 10	8397051	0.65	S3	0.35	A1	V3
CATEGORY 11	8297113	0.67	S3	0.46	A1	V3
CATEGORY 12	8297590	0.82	S3	0.60	A1	V3
CATEGORY 13	8296379	0.79	S3	0.48	A1	V3
CATEGORY 14	8297194	0.79	S3	0.61	A1	V3
CATEGORY 15	8296496	0.79	S3	0.47	A1	V3

Table 64: Vulnerability value for each sample building

Once the vulnerability has been established for each sample building, it is possible to extrapolate the results to the whole area, giving the same value to all the buildings belonging to the same category. The 1,721 buildings, which have been categorized, will therefore have an associated vulnerability level. Figure 61 and Figure 62 show the graphical representation of the vulnerability level of the area:

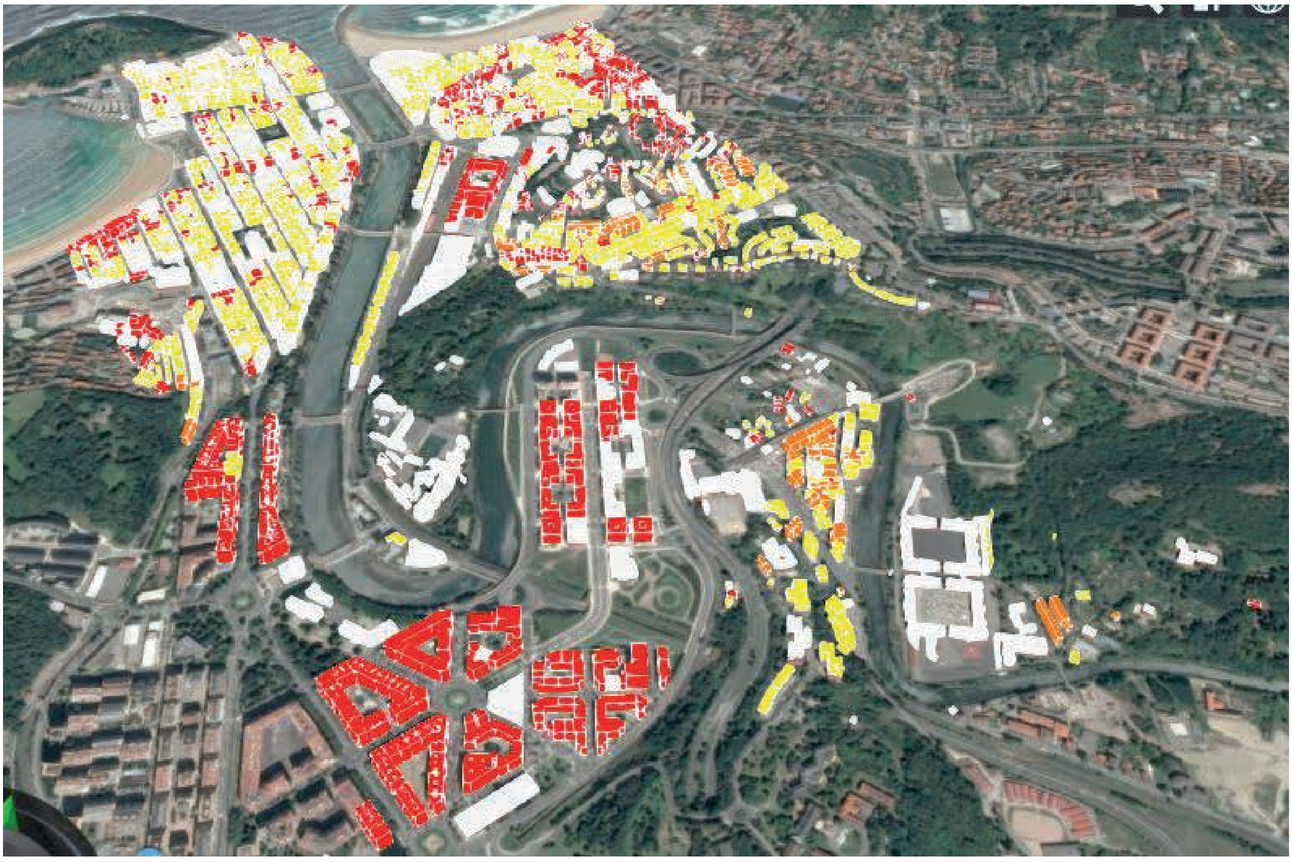


Figure 61: Graphical representation of the lots' vulnerability of the case study area. Source: Tecnalia

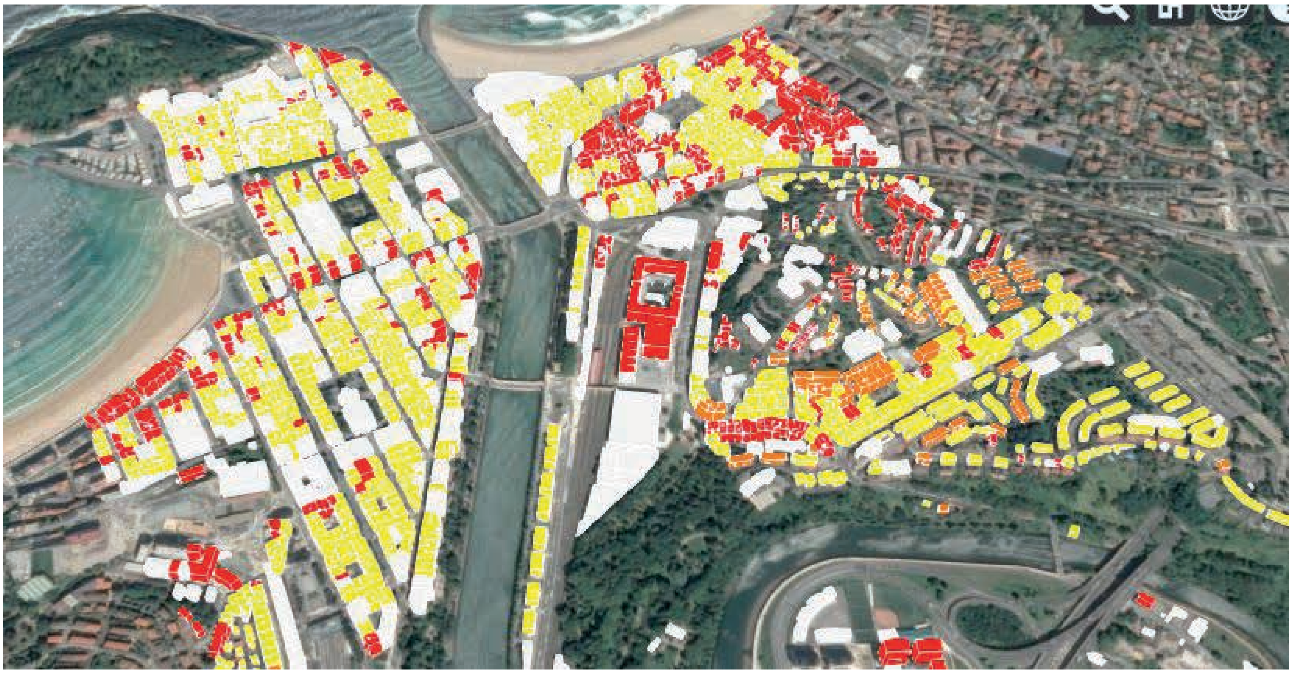


Figure 62: Graphical representation of the lots' vulnerability of the Gros, Egia, Parte Vieja and Centre districts. Source: Tecnalia

4.1.4 Validation of the vulnerability assessment methodology

A smaller area, comprising several blocks of the districts of Gros, Pate Vieja and Loiola was analysed in depth, in order to verify the methodological approach. 113 buildings were inspected, in order to complete the semantic information and compare it with the results given by the methodology. Figure 63 and Figure 64 show the 3D model of the area in LoD2.

Figure 63: 3D Model of the blocks for analysis in Gros and Parte Vieja. Source: Tecnalia

Figure 64: 3D Model of the blocks for analysis in Loiola. Source: Tecnalia.

Visual inspections, carried out from the exterior of the buildings, were performed by a group of architects and engineers from Tecnalia, with the objective of collecting the necessary information to complete the set of indicators. A technical datasheet was prepared in advance and criteria agreed among the participants, so that the work could be done systematically. In the interests of methodological coherence, the first level of data (year of construction, use, existence of a basement, cultural value and socio-economic status) was kept as defined in the cadastre, even if small differences can be found in municipal databases. Nevertheless, the use of a basement was confirmed by field surveys. Furthermore, as it was not possible to visualise the type of roof from the street, Google Earth was used as a source of information.

Of the 113 buildings inspected, 100 belong to the categories established for the larger area. The following table shows the buildings inspected according to their category of belonging.

CATEGORY	REFERENCE	LOT ID	STREET	NUM.	YEAR OF CONSTRUCTION	EXISTENCE OF BASEMENT	USE	NUM. OF DWELLINGS	SOCIO-ECONOMIC STATUS	CULTURAL VALUE
CATEGORY 1	8396057	8957	SIERRA DE ARALAR	3	1944	Yes	Residential	6	Low	None
CATEGORY 1	8396157	9003	MATXIÑENE	12, 14	1933	Yes	Residential	4	Low	None
CATEGORY 1	8396354	9021	MATXIÑENE	11, 13	1933	Yes	Residential	4	Low	None
CATEGORY 1	8396355	9134	MATXIÑENE	3, 5	1933	Yes	Residential	4	Low	None
CATEGORY 1	8396369	9010	URBIA	25	1918	Yes	Residential	2	Low	None
CATEGORY 1	8396370	9025	URBIA	24	1918	Yes	Residential	2	Low	None
CATEGORY 1	8396371	9040	URBIA	23	1940	Yes	Residential	3	Low	None
CATEGORY 1	8396419	9031	MATXIÑENE	10	1933	Yes	Residential	4	Low	None
CATEGORY 5	8297172	2441	GENERAL ETXAGUE	11	1900	Yes	Residential	12	High	None
CATEGORY 6	8297021	3461	GENERAL ETXAGUE	1	1965	Yes	Residential	17	High	None
CATEGORY 6	8297117	2493	GENERAL ETXAGUE	15	1970	Yes	Residential	25	High	None
CATEGORY 6	8297205	3429	GENERAL ETXAGUE	14	1976	Yes	Residential	35	High	None

CATEGORY 8	8396352	9140	MATXIÑENE	6	1927	No	Residential	2	Low	None
CATEGORY 8	8396353	9141	MATXIÑENE	8	1920	No	Residential	5	Low	None
CATEGORY 8	8396367	9006	URBIA	17, 18, 19	1933	No	Residential	5	Low	None
CATEGORY 8	8396372	9033	URBIA	20, 21, 22	1933	No	Residential	4	Low	None
CATEGORY 8	8396373	9022	URBIA	10	1933	No	Residential	3	Low	None
CATEGORY 8	8396374	9041	URBIA	9	1933	No	Residential	3	Low	None
CATEGORY 8	8396375	9023	URBIA	11	1930	No	Residential	3	Low	None
CATEGORY 8	8396376	9036	URBIA	13, 14	1933	No	Residential	2	Low	None
CATEGORY 9	8396351	9016	URBIA	5, 6	1985	No	Residential	3	Low	None
CATEGORY 12	8297001	2486	GENERAL JAUREGI	14	1895	Yes	Residential	10	High	Grade IV
CATEGORY 12	8297002	2480	GENERAL JAUREGI	16	1890	Yes	Residential	8	High	Grade IV
CATEGORY 12	8297003	2471	GENERAL JAUREGI	12	1900	Yes	Residential	12	High	Grade IV
CATEGORY 12	8297004	2470	GENERAL JAUREGI	10	1895	Yes	Residential	12	High	Grade IV
CATEGORY 12	8297005	2456	EUSKAL HERRIA	7	1900	Yes	Residential	11	High	Grade IV
CATEGORY 12	8297006	2446	GENERAL JAUREGI	8	1900	Yes	Residential	13	High	Grade IV
CATEGORY 12	8297007	2447	GENERAL JAUREGI	6	1900	Yes	Residential	13	High	Grade IV
CATEGORY 12	8297008	2472	GENERAL JAUREGI	4	1900	Yes	Residential	6	High	Grade IV
CATEGORY 12	8297009	2474	GENERAL JAUREGI	18	1895	Yes	Residential	6	High	Grade IV
CATEGORY 12	8297010	2466	EUSKAL HERRIA	5	1900	Yes	Residential	14	High	Grade IV
CATEGORY 12	8297011	2457	SALAMANCA, PS DE	7	1900	Yes	Residential	16	High	Grade IV
CATEGORY 12	8297013	2455	EUSKAL HERRIA	9	1900	Yes	Residential	26	High	Grade IV
CATEGORY 12	8297014	2451	EUSKAL HERRIA	1	1900	Yes	Residential	12	High	Grade IV
CATEGORY 12	8297015	2452	ALDAMAR	22	1900	Yes	Residential	11	High	Grade IV
CATEGORY 12	8297017	2476	ALDAMAR	26	1900	Yes	Residential	12	High	Grade IV
CATEGORY 12	8297018	2473	ALDAMAR	28	1900	Yes	Residential	12	High	Grade IV
CATEGORY 12	8297020	2475	SALAMANCA, PS DE	8	1900	Yes	Residential	7	High	Grade IV
CATEGORY 12	8297024	2449	SALAMANCA, PS DE	5	1900	Yes	Residential	19	High	Grade IV
CATEGORY 12	8297032	2468	EUSKAL HERRIA	14	1890	Yes	Residential	13	High	Grade IV
CATEGORY 12	8297034	2485	EUSKAL HERRIA	8	1900	Yes	Residential	11	High	Grade IV
CATEGORY 12	8297035	2467	EUSKAL HERRIA	3	1900	Yes	Residential	10	High	Grade IV
CATEGORY 12	8297044	3456	ALDAMAR	12	1900	Yes	Residential	11	High	Grade IV
CATEGORY 12	8297045	3457	ALDAMAR	14	1900	Yes	Residential	14	High	Grade IV
CATEGORY 12	8297046	2442	ALDAMAR	16	1900	Yes	Residential	11	High	Grade IV
CATEGORY 12	8297047	2450	EUSKAL HERRIA	12	1900	Yes	Residential	18	High	Grade IV
CATEGORY 12	8297082	2454	EUSKAL HERRIA	4	1890	Yes	Residential	6	High	Grade IV
CATEGORY 12	8297159	2440	GENERAL ETXAGUE	7, 9	1900	Yes	Residential	20	High	Grade IV
CATEGORY 12	8297173	3391	GENERAL ETXAGUE	4	1908	Yes	Residential	14	High	Grade IV
CATEGORY 12	8297174	3468	GENERAL ETXAGUE	5	1900	Yes	Residential	12	High	Grade IV
CATEGORY 12	8297175	3472	GENERAL ETXAGUE	3	1900	Yes	Residential	12	High	Grade IV
CATEGORY 12	8297176	2479	EUSKAL HERRIA	10	1900	Yes	Residential	7	High	Grade IV
CATEGORY 12	8297177	2443	EUSKAL HERRIA	6	1900	Yes	Residential	10	High	Grade IV
CATEGORY 12	8297178	2453	EUSKAL HERRIA	2	1900	Yes	Residential	7	High	Grade IV
CATEGORY 12	8297186	3397	GENERAL ETXAGUE	8	1900	Yes	Residential	13	High	Grade IV
CATEGORY 12	8297199	3425	GENERAL ETXAGUE	10	1890	Yes	Residential	10	High	Grade IV
CATEGORY 12	8297201	3396	GENERAL ETXAGUE	6	1900	Yes	Residential	12	High	Grade IV
CATEGORY 12	8297212	3424	GENERAL ETXAGUE	12	1900	Yes	Residential	11	High	Grade IV
CATEGORY 12	8297575	3571	USANDIZAGA	7	1910	Yes	Residential	12	High	Grade IV
CATEGORY 12	8297579	2515	ZURRIOLA, AV DE	6	1910	Yes	Residential	14	High	Grade IV
CATEGORY 12	8297584	3528	PEÑA Y GOÑI	5	1926	Yes	Residential	12	High	Grade IV
CATEGORY 12	8297585	2524	PEÑA Y GOÑI	3	1920	Yes	Residential	26	High	Grade IV
CATEGORY 12	8297586	3491	PEÑA Y GOÑI	4	1920	Yes	Residential	20	High	Grade IV
CATEGORY 12	8297587	3573	USANDIZAGA	5	1900	Yes	Residential	17	High	Grade IV
CATEGORY 12	8297588	2522	ZURRIOLA, AV DE	12	1925	Yes	Residential	12	High	Grade IV
CATEGORY 12	8297590	2539	PEÑA Y GOÑI	2	1912	Yes	Residential	14	High	Grade IV
CATEGORY 12	8297603	3538	ZURRIOLA, AV DE	4	1910	Yes	Residential	17	High	Grade IV
CATEGORY 12	8397200	2536	RAMON Y CAJAL	6	1925	Yes	Residential	13	High	Grade IV
CATEGORY 12	8397242	2526	USANDIZAGA	17	1925	Yes	Residential	13	High	Grade IV
CATEGORY 12	8397337	2534	ZURRIOLA, AV DE	16	1945	Yes	Residential	7	High	Grade IV
CATEGORY 12	8397338	2521	MIGUEL IMAZ	4	1944	Yes	Residential	14	High	Grade IV
CATEGORY 12	8397339	2519	MIGUEL IMAZ	6	1944	Yes	Residential	15	High	Grade IV
CATEGORY 12	8397340	2520	MIGUEL IMAZ	8	1925	Yes	Residential	12	High	Grade IV
CATEGORY 12	8397341	2529	USANDIZAGA	19	1925	Yes	Residential	12	High	Grade IV
CATEGORY 12	8397366	2509	MIGUEL IMAZ	5	1919	Yes	Residential	13	High	Grade IV
CATEGORY 12	8397367	2498	MIGUEL IMAZ	3	1932	Yes	Residential	12	High	Grade IV
CATEGORY 12	8397380	2504	USANDIZAGA	27	1925	Yes	Residential	12	High	Grade IV
CATEGORY 12	8397383	2505	USANDIZAGA	25	1923	Yes	Residential	12	High	Grade IV
CATEGORY 12	8397384	2510	USANDIZAGA	23	1923	Yes	Residential	12	High	Grade IV
CATEGORY 12	8397389	2503	ZURRIOLA, AV DE	20	1906	Yes	Residential	7	High	Grade IV
CATEGORY 12	8397390	2507	ZURRIOLA, AV DE	22	1931	Yes	Residential	7	High	Grade IV
CATEGORY 12	8397716	2537	USANDIZAGA	13	1920	Yes	Residential	12	High	Grade IV
CATEGORY 12	8397717	2516	ZURRIOLA, AV DE	14	1925	Yes	Residential	12	High	Grade IV

CATEGORY 12	8397718	2527	ZURRIOLA, AV DE	16	1949	Yes	Residential	9	High	Grade IV
CATEGORY 12	8397719	3486	USANDIZAGA	11	1925	Yes	Residential	12	High	Grade IV
CATEGORY 12	8397720	2525	USANDIZAGA	15	1924	Yes	Residential	12	High	Grade IV
CATEGORY 12	8397728	3487	USANDIZAGA	9	1900	Yes	Residential	13	High	Grade IV
CATEGORY 14	8297166	3394	ALDAMAR	4	1900	Yes	Residential	10	High	Grade III
CATEGORY 14	8297168	3390	ALDAMAR	6	1886	Yes	Residential	13	High	Grade III
CATEGORY 14	8297169	3439	GENERAL ETXAGUE	2	1900	Yes	Residential	12	High	Grade III
CATEGORY 14	8297171	3449	ALDAMAR	2	1900	Yes	Residential	9	High	Grade III
CATEGORY 14	8297193	3448	REINA REGENTE	2	1900	Yes	Residential	8	High	Grade III
CATEGORY 14	8297194	3454	REINA REGENTE	3	1900	Yes	Residential	8	High	Grade III
CATEGORY 14	8297195	3453	REINA REGENTE	4	1900	Yes	Residential	9	High	Grade III
CATEGORY 14	8297197	3409	REINA REGENTE	5	1900	Yes	Residential	11	High	Grade III
CATEGORY 14	8297202	3408	REINA REGENTE	6	1886	Yes	Residential	10	High	Grade III
CATEGORY 14	8297204	3444	SALAMANCA, PS DE	2	1900	Yes	Residential	20	High	Grade III
CATEGORY 14	8397365	2508	USANDIZAGA	21	1924	Yes	Residential	26	High	Grade III
CATEGORY 14	8397369	2502	ZURRIOLA, AV DE	18	1936	Yes	Residential	15	High	Grade III
CATEGORY 14	8397377	2499	MIGUEL IMAZ	1	1940	Yes	Residential	12	High	Grade III

Table 65: Categories and characteristics of the buildings inspected located in the smaller area of study

By including all the parameters of the inspected buildings (see Annex I) in the calculation of the sensitiveness and the adaptive capacity indexes for the vulnerability assessment, it is possible to compare the results given by the categorization method and the real data. A comparison that is shown in the following table:

CATEGORY	REFERENCE	SENSITIVENESS		ADAPTIVE CAPACITY		VULNERABILITY	
		REAL DATA	CATEGORIES	REAL DATA	CATEGORIES	REAL DATA	CATEGORIES
CATEGORY 12	8297159	S3	S3	A1	A1	V3	V3
CATEGORY 12	8297001	S3	S3	A1	A1	V3	V3
CATEGORY 12	8297002	S3	S3	A1	A1	V3	V3
CATEGORY 12	8297003	S3	S3	A1	A1	V3	V3
CATEGORY 12	8297004	S3	S3	A1	A1	V3	V3
CATEGORY 12	8297005	S3	S3	A1	A1	V3	V3
CATEGORY 12	8297006	S3	S3	A1	A1	V3	V3
CATEGORY 12	8297007	S3	S3	A1	A1	V3	V3
CATEGORY 12	8297008	S3	S3	A1	A1	V3	V3
CATEGORY 12	8297009	S3	S3	A1	A1	V3	V3
CATEGORY 12	8297010	S3	S3	A1	A1	V3	V3
CATEGORY 12	8297011	S3	S3	A1	A1	V3	V3
CATEGORY 12	8297013	S3	S3	A1	A1	V3	V3
CATEGORY 12	8297014	S3	S3	A1	A1	V3	V3
CATEGORY 12	8297015	S3	S3	A1	A1	V3	V3
CATEGORY 12	8297017	S3	S3	A1	A1	V3	V3
CATEGORY 12	8297018	S3	S3	A1	A1	V3	V3
CATEGORY 12	8297020	S3	S3	A1	A1	V3	V3
CATEGORY 6	8297021	S3	S3	A1	A0	V3	V5
CATEGORY 12	8297024	S3	S3	A1	A1	V3	V3
CATEGORY 12	8297032	S3	S3	A1	A1	V3	V3

CATEGORY	REFERENCE	SENSITIVENESS		ADAPTIVE CAPACITY		VULNERABILITY	
		REAL DATA	CATEGORIES	REAL DATA	CATEGORIES	REAL DATA	CATEGORIES
CATEGORY 12	8297034	S3	S3	A1	A1	V3	V3
CATEGORY 12	8297035	S3	S3	A1	A1	V3	V3
CATEGORY 12	8297044	S3	S3	A0	A1	V5	V3
CATEGORY 12	8297045	S3	S3	A1	A1	V3	V3
CATEGORY 12	8297046	S3	S3	A1	A1	V3	V3
CATEGORY 12	8297047	S3	S3	A1	A1	V3	V3
CATEGORY 12	8297082	S3	S3	A1	A1	V3	V3
CATEGORY 6	8297117	S3	S3	A0	A0	V5	V5
CATEGORY 14	8297166	S3	S3	A1	A1	V3	V3
CATEGORY 14	8297168	S3	S3	A1	A1	V3	V3
CATEGORY 14	8297169	S3	S3	A1	A1	V3	V3
CATEGORY 14	8297171	S3	S3	A1	A1	V3	V3
CATEGORY 5	8297172	S3	S3	A0	A0	V5	V5
CATEGORY 12	8297173	S3	S3	A1	A1	V3	V3
CATEGORY 12	8297174	S3	S3	A1	A1	V3	V3
CATEGORY 12	8297175	S3	S3	A1	A1	V3	V3
CATEGORY 12	8297176	S3	S3	A1	A1	V3	V3
CATEGORY 12	8297177	S3	S3	A1	A1	V3	V3
CATEGORY 12	8297178	S3	S3	A1	A1	V3	V3
CATEGORY 12	8297186	S3	S3	A1	A1	V3	V3
CATEGORY 14	8297193	S3	S3	A1	A1	V3	V3
CATEGORY 14	8297194	S3	S3	A1	A1	V3	V3
CATEGORY 14	8297195	S3	S3	A1	A1	V3	V3
CATEGORY 14	8297197	S3	S3	A1	A1	V3	V3
CATEGORY 12	8297199	S3	S3	A1	A1	V3	V3
CATEGORY 12	8297201	S3	S3	A1	A1	V3	V3
CATEGORY 14	8297202	S3	S3	A1	A1	V3	V3
CATEGORY 14	8297204	S2	S3	A1	A1	V2	V3
CATEGORY 6	8297205	S3	S3	A0	A0	V5	V5
CATEGORY 12	8297212	S3	S3	A1	A1	V3	V3
CATEGORY 12	8297575	S3	S3	A1	A1	V3	V3
CATEGORY 12	8297579	S3	S3	A1	A1	V3	V3
CATEGORY 12	8297584	S3	S3	A1	A1	V3	V3
CATEGORY 12	8297585	S3	S3	A1	A1	V3	V3
CATEGORY 12	8297586	S3	S3	A1	A1	V3	V3
CATEGORY 12	8297587	S3	S3	A1	A1	V3	V3
CATEGORY 12	8297588	S3	S3	A1	A1	V3	V3
CATEGORY 12	8297590	S3	S3	A1	A1	V3	V3
CATEGORY 12	8297603	S3	S3	A1	A1	V3	V3
CATEGORY 1	8396057	S2	S3	A0	A0	V4	V5
CATEGORY 1	8396157	S3	S3	A1	A0	V3	V5
CATEGORY 9	8396351	S2	S2	A0	A0	V4	V4
CATEGORY 8	8396352	S2	S2	A1	A1	V2	V2
CATEGORY 8	8396353	S2	S2	A1	A1	V2	V2
CATEGORY 1	8396354	S3	S3	A0	A0	V5	V5
CATEGORY 1	8396355	S3	S3	A0	A0	V5	V5

CATEGORY	REFERENCE	SENSITIVENESS		ADAPTIVE CAPACITY		VULNERABILITY	
		REAL DATA	CATEGORIES	REAL DATA	CATEGORIES	REAL DATA	CATEGORIES
CATEGORY 8	8396367	S2	S2	A1	A1	V2	V2
CATEGORY 1	8396369	S2	S3	A1	A0	V2	V5
CATEGORY 1	8396370	S2	S3	A1	A0	V2	V5
CATEGORY 1	8396371	S3	S3	A0	A0	V5	V5
CATEGORY 3	8396372	S2	S2	A0	A1	V4	V2
CATEGORY 3	8396373	S2	S2	A1	A1	V2	V2
CATEGORY 3	8396374	S2	S2	A0	A1	V4	V2
CATEGORY 3	8396375	S2	S2	A1	A1	V2	V2
CATEGORY 3	8396376	S2	S2	A1	A1	V2	V2
CATEGORY 1	8396419	S3	S3	A0	A0	V5	V5
CATEGORY 12	8397200	S3	S3	A1	A1	V3	V3
CATEGORY 12	8397242	S3	S3	A1	A1	V3	V3
CATEGORY 12	8397337	S3	S3	A1	A1	V3	V3
CATEGORY 12	8397338	S3	S3	A1	A1	V3	V3
CATEGORY 12	8397339	S3	S3	A1	A1	V3	V3
CATEGORY 12	8397340	S3	S3	A1	A1	V3	V3
CATEGORY 12	8397341	S3	S3	A1	A1	V3	V3
CATEGORY 14	8397365	S3	S3	A1	A1	V3	V3
CATEGORY 12	8397366	S3	S3	A1	A1	V3	V3
CATEGORY 12	8397367	S3	S3	A1	A1	V3	V3
CATEGORY 14	8397369	S3	S3	A1	A1	V3	V3
CATEGORY 14	8397377	S3	S3	A1	A1	V3	V3
CATEGORY 12	8397380	S3	S3	A1	A1	V3	V3
CATEGORY 12	8397383	S3	S3	A1	A1	V3	V3
CATEGORY 12	8397384	S3	S3	A1	A1	V3	V3
CATEGORY 12	8397389	S3	S3	A1	A1	V3	V3
CATEGORY 12	8397390	S3	S3	A1	A1	V3	V3
CATEGORY 12	8397716	S3	S3	A1	A1	V3	V3
CATEGORY 12	8397717	S3	S3	A1	A1	V3	V3
CATEGORY 12	8397718	S3	S3	A1	A1	V3	V3
CATEGORY 12	8397719	S3	S3	A1	A1	V3	V3
CATEGORY 12	8397720	S3	S3	A1	A1	V3	V3
CATEGORY 12	8397728	S3	S3	A1	A1	V3	V3

Table 66: Comparison of the sensitiveness, adaptive capacity and vulnerability levels given by real data and the categorization method

Of the 100 buildings that were analysed, 9 of them present a vulnerability level which differs by using real data and the categorization method. Nevertheless, 6 of those buildings belong to categories 1 and 3, mainly located in Loiola district. These typologies of buildings are single-family houses, which present different characteristics and are less homogeneous than other areas. Loiola was one of the districts in which most regeneration interventions took place, so the extrapolation is less applicable to other areas that present common historic characteristics.

4.1.5 Risk assessment

As explained in the methodological approach, risk has been calculated considering the location of each lot. This is done by calculating the exposure of all lots as single units, as the location is of primary importance when establishing the risk to which a building is exposed. Information necessary for completing the indicators of the exposure criteria have been elaborated in GIS, starting from available maps of the area. According to the location of the lot, the proximity to the coast or river, the soil type, the existence of green areas and the location in a flooding area or area subjected to storm surge, have been calculated and the corresponding indicator values assigned to the 2,262 buildings under consideration.

The exposure requirement is calculated by multiplying the value of the parameter (given by the value function) by the indicator weight and by the weight of the criteria to which they belong, according to the decision tree established through the MIVES methodology. An exposure level, according to the previously established ranges, is therefore given to each building. The following table shows and example for the sample buildings:

			EXPOSURE								
			EXPOSURE								
CRITERIA WEIGHTS			**1.00**								
CATEGORY	REFERENCE	YEAR OF CONSTRUCTION	PROXIMITY TO COAST/RIVER	SOIL TYPE	GREEN AREA	PRECIPITATION	STORM SURGE AND SEA-LEVEL RISE	**EXPOSURE INDEX (PRECIPITATION)**		**EXPOSURE INDEX (STORM SURGE AND SEA-LEVEL RISE)**	
INDICATORS WEIGHTS			**0.10**	**0.25**	**0.25**	**0.40**	**0.40**				
CATEGORY 1	8396354	1933	0.00	1.00	0.55	1.00	0.00	0.79	E1	0.39	E0
CATEGORY 2	8396357	1963	0.00	0.40	0.79	0.00	0.00	0.30	E0	0.30	E0
CATEGORY 3	8297106	1900	0.00	0.40	0.79	0.00	0.00	0.30	E0	0.30	E0
CATEGORY 4	8397100	1979	0.29	0.40	0.79	0.00	0.00	0.33	E0	0.33	E0
CATEGORY 5	8297107	1900	0.00	0.40	1.00	0.00	0.00	0.35	E0	0.35	E0
CATEGORY 6	8297117	1970	1.00	1.00	1.00	0.00	0.00	0.60	E1	0.60	E1
CATEGORY 7	8296741	1962	0.00	0.40	0.79	0.00	0.00	0.30	E0	0.30	E0
CATEGORY 8	8396375	1930	0.00	1.00	0.29	1.00	0.00	0.72	E1	0.32	E0
CATEGORY 9	8396351	1985	0.00	1.00	0.79	1.00	0.00	0.85	E1	0.45	E1
CATEGORY 10	8397051	1936	0.00	0.40	0.79	0.00	0.00	0.30	E0	0.30	E0
CATEGORY 11	8297113	1900	0.00	0.40	1.00	0.00	0.00	0.35	E0	0.35	E0
CATEGORY 12	8297590	1912	0.29	1.00	0.79	0.00	0.50	0.48	E1	0.68	E1
CATEGORY 13	8296379	1905	0.00	0.40	0.79	0.00	0.00	0.30	E0	0.30	E0
CATEGORY 14	8297194	1900	0.74	1.00	0.79	0.00	0.50	0.52	E1	0.72	E1
CATEGORY 15	8296496	1903	0.00	0.40	0.79	0.00	0.00	0.30	E0	0.30	E0

Table 67: Exposure indicator values and exposure index calculation for sample buildings

The risk index is therefore established by the ratio of the vulnerability index given by the sample building method and the real data on exposure. The risk level is given by considering, on the one hand, risk derived by flooding events caused by the increase of extreme precipitation events and, on the other hand, by flooding events caused by the increase in storm surge and sea-level rise. The following figures show the distribution of the risk level from extreme precipitation for each lot:

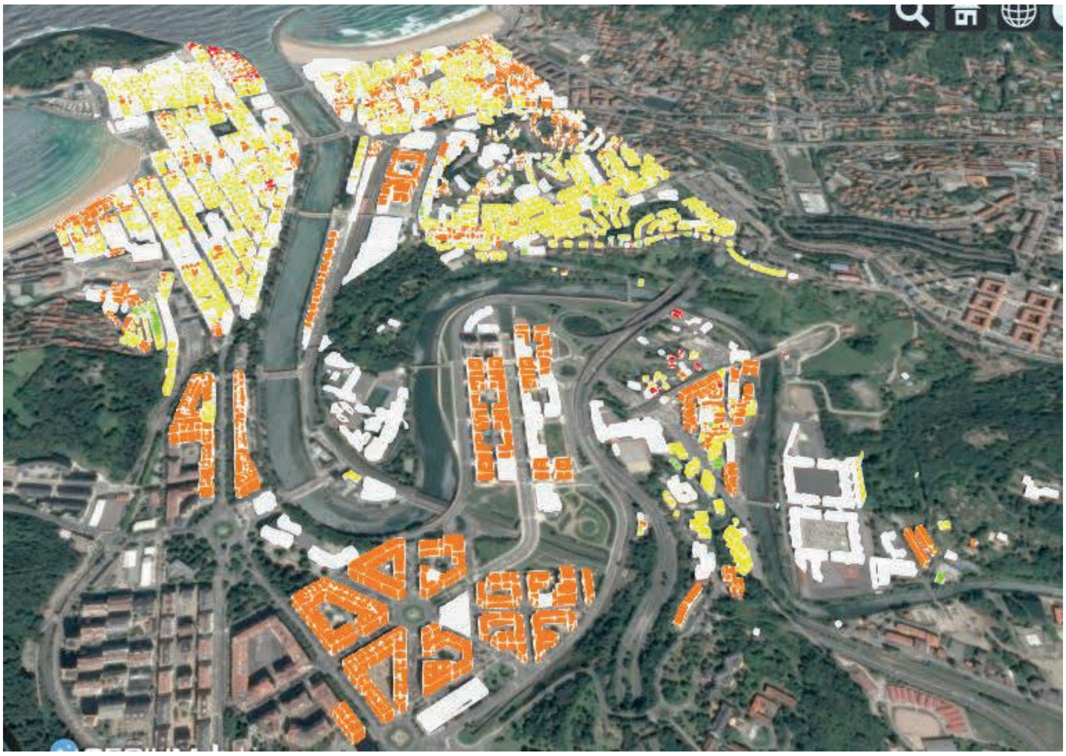


Figure 65: Risk levels derived from extreme precipitation. Source: Tecnalia

Figure 66: Area at highest risk from extreme precipitation. Source: Tecnalia

The following table shows the vulnerability and risk indexes for the smaller area considered. Again, as risk depends on the vulnerability of the lot under consideration, 9 lots out of 100 present a risk assessment that differs from the one established with real data.

CATEGORY	REFERENCE	VULNERABILITY		RISK (PRECIPITATION)	
		REAL DATA	CATEGORIES	REAL DATA	CATEGORIES
CATEGORY 12	8297159	V3	V3	R2	R2
CATEGORY 12	8297001	V3	V3	R3	R3
CATEGORY 12	8297002	V3	V3	R3	R3
CATEGORY 12	8297003	V3	V3	R3	R3
CATEGORY 12	8297004	V3	V3	R2	R2
CATEGORY 12	8297005	V3	V3	R2	R2
CATEGORY 12	8297006	V3	V3	R2	R2
CATEGORY 12	8297007	V3	V3	R2	R2
CATEGORY 12	8297008	V3	V3	R2	R2
CATEGORY 12	8297009	V3	V3	R3	R3
CATEGORY 12	8297010	V3	V3	R2	R2
CATEGORY 12	8297011	V3	V3	R3	R3
CATEGORY 12	8297013	V3	V3	R3	R3
CATEGORY 12	8297014	V3	V3	R2	R2
CATEGORY 12	8297015	V3	V3	R2	R2
CATEGORY 12	8297017	V3	V3	R2	R2
CATEGORY 12	8297018	V3	V3	R2	R2
CATEGORY 12	8297020	V3	V3	R3	R3
CATEGORY 6	8297021	V3	V5	R2	R3
CATEGORY 12	8297024	V3	V3	R3	R3
CATEGORY 12	8297032	V3	V3	R3	R3
CATEGORY 12	8297034	V3	V3	R2	R2
CATEGORY 12	8297035	V3	V3	R2	R2
CATEGORY 12	8297044	V5	V3	R3	R2
CATEGORY 12	8297045	V3	V3	R2	R2
CATEGORY 12	8297046	V3	V3	R2	R2
CATEGORY 12	8297047	V3	V3	R3	R3
CATEGORY 12	8297082	V3	V3	R2	R2
CATEGORY 6	8297117	V5	V5	R4	R4
CATEGORY 14	8297166	V3	V3	R2	R2
CATEGORY 14	8297168	V3	V3	R2	R2
CATEGORY 14	8297169	V3	V3	R2	R2
CATEGORY 14	8297171	V3	V3	R2	R2
CATEGORY 5	8297172	V5	V5	R4	R4
CATEGORY 12	8297173	V3	V3	R2	R2
CATEGORY 12	8297174	V3	V3	R2	R2
CATEGORY 12	8297175	V3	V3	R2	R2
CATEGORY 12	8297176	V3	V3	R2	R2

CATEGORY 12	8297177	V3	V3	R2	R2
CATEGORY 12	8297178	V3	V3	R2	R2
CATEGORY 12	8297186	V3	V3	R2	R2
CATEGORY 14	8297193	V3	V3	R2	R2
CATEGORY 14	8297194	V3	V3	R3	R3
CATEGORY 14	8297195	V3	V3	R2	R2
CATEGORY 14	8297197	V3	V3	R2	R2
CATEGORY 12	8297199	V3	V3	R3	R3
CATEGORY 12	8297201	V3	V3	R2	R2
CATEGORY 14	8297202	V3	V3	R2	R2
CATEGORY 14	8297204	V2	V3	R1	R2
CATEGORY 6	8297205	V5	V5	R4	R4
CATEGORY 12	8297212	V3	V3	R3	R3
CATEGORY 12	8297575	V3	V3	R2	R2
CATEGORY 12	8297579	V3	V3	R2	R2
CATEGORY 12	8297584	V3	V3	R2	R2
CATEGORY 12	8297585	V3	V3	R2	R2
CATEGORY 12	8297586	V3	V3	R2	R2
CATEGORY 12	8297587	V3	V3	R2	R2
CATEGORY 12	8297588	V3	V3	R2	R2
CATEGORY 12	8297590	V3	V3	R3	R3
CATEGORY 12	8297603	V3	V3	R2	R2
CATEGORY 1	8396057	V4	V5	R3	R4
CATEGORY 1	8396157	V3	V5	R3	R4
CATEGORY 9	8396351	V4	V4	R3	R3
CATEGORY 8	8396352	V2	V2	R2	R2
CATEGORY 8	8396353	V2	V2	R2	R2
CATEGORY 1	8396354	V5	V5	R4	R4
CATEGORY 1	8396355	V5	V5	R4	R4
CATEGORY 8	8396367	V2	V2	R2	R2
CATEGORY 1	8396369	V2	V5	R2	R4
CATEGORY 1	8396370	V2	V5	R2	R4
CATEGORY 1	8396371	V5	V5	R4	R4
CATEGORY 3	8396372	V4	V2	R3	R2
CATEGORY 3	8396373	V2	V2	R2	R2
CATEGORY 3	8396374	V4	V2	R3	R2
CATEGORY 3	8396375	V2	V2	R2	R2
CATEGORY 3	8396376	V2	V2	R2	R2
CATEGORY 1	8396419	V5	V5	R4	R4
CATEGORY 12	8397200	V3	V3	R2	R2
CATEGORY 12	8397242	V3	V3	R2	R2
CATEGORY 12	8397337	V3	V3	R2	R2
CATEGORY 12	8397338	V3	V3	R2	R2
CATEGORY 12	8397339	V3	V3	R2	R2
CATEGORY 12	8397340	V3	V3	R2	R2
CATEGORY 12	8397341	V3	V3	R2	R2

CATEGORY 14	8397365	V3	V3	R2	R2
CATEGORY 12	8397366	V3	V3	R2	R2
CATEGORY 12	8397367	V3	V3	R2	R2
CATEGORY 14	8397369	V3	V3	R2	R2
CATEGORY 14	8397377	V3	V3	R2	R2
CATEGORY 12	8397380	V3	V3	R2	R2
CATEGORY 12	8397383	V3	V3	R2	R2
CATEGORY 12	8397384	V3	V3	R2	R2
CATEGORY 12	8397389	V3	V3	R2	R2
CATEGORY 12	8397390	V3	V3	R2	R2
CATEGORY 12	8397716	V3	V3	R2	R2
CATEGORY 12	8397717	V3	V3	R2	R2
CATEGORY 12	8397718	V3	V3	R2	R2
CATEGORY 12	8397719	V3	V3	R2	R2
CATEGORY 12	8397720	V3	V3	R2	R2
CATEGORY 12	8397728	V3	V3	R2	R2

Table 68: Risk assessment for precipitation events of the detailed case study

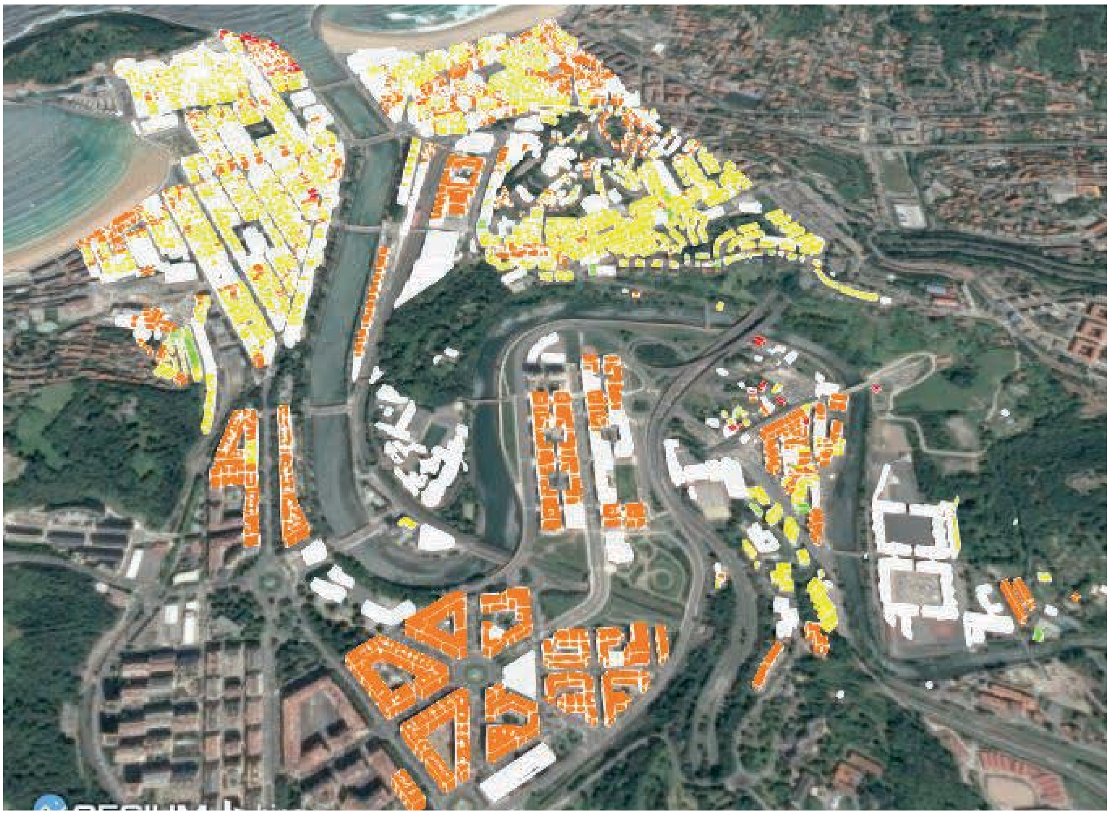


Figure 67: Risk levels derived from storm surge and sea-level rise. Source: Tecnalia

Figure 68: Area at highest risk from storm surge and sea-level rise. Source: Tecnalia

CATEGORY	REFERENCE	VULNERABILITY		RISK (STORM SURGE AND SEA-LEVEL RISE)	
		REAL DATA	CATEGORIES	REAL DATA	CATEGORIES
CATEGORY 12	8297159	V3	V3	R2	R2
CATEGORY 12	8297001	V3	V3	R3	R3
CATEGORY 12	8297002	V3	V3	R3	R3
CATEGORY 12	8297003	V3	V3	R3	R3
CATEGORY 12	8297004	V3	V3	R2	R2
CATEGORY 12	8297005	V3	V3	R2	R2
CATEGORY 12	8297006	V3	V3	R2	R2
CATEGORY 12	8297007	V3	V3	R2	R2
CATEGORY 12	8297008	V3	V3	R2	R2
CATEGORY 12	8297009	V3	V3	R3	R3
CATEGORY 12	8297010	V3	V3	R2	R2
CATEGORY 12	8297011	V3	V3	R3	R3
CATEGORY 12	8297013	V3	V3	R3	R3
CATEGORY 12	8297014	V3	V3	R2	R2
CATEGORY 12	8297015	V3	V3	R2	R2
CATEGORY 12	8297017	V3	V3	R2	R2
CATEGORY 12	8297018	V3	V3	R2	R2
CATEGORY 12	8297020	V3	V3	R3	R3
CATEGORY 6	8297021	V3	V5	R2	R3
CATEGORY 12	8297024	V3	V3	R3	R3
CATEGORY 12	8297032	V3	V3	R3	R3
CATEGORY 12	8297034	V3	V3	R2	R2
CATEGORY 12	8297035	V3	V3	R2	R2
CATEGORY 12	8297044	V5	V3	R3	R2
CATEGORY 12	8297045	V3	V3	R2	R2

CATEGORY 12	8297046	V3	V3	R2	R2
CATEGORY 12	8297047	V3	V3	R3	R3
CATEGORY 12	8297082	V3	V3	R2	R2
CATEGORY 6	8297117	V5	V5	R4	R4
CATEGORY 14	8297166	V3	V3	R2	R2
CATEGORY 14	8297168	V3	V3	R2	R2
CATEGORY 14	8297169	V3	V3	R2	R2
CATEGORY 14	8297171	V3	V3	R2	R2
CATEGORY 5	8297172	V5	V5	R4	R4
CATEGORY 12	8297173	V3	V3	R2	R2
CATEGORY 12	8297174	V3	V3	R2	R2
CATEGORY 12	8297175	V3	V3	R2	R2
CATEGORY 12	8297176	V3	V3	R2	R2
CATEGORY 12	8297177	V3	V3	R2	R2
CATEGORY 12	8297178	V3	V3	R2	R2
CATEGORY 12	8297186	V3	V3	R2	R2
CATEGORY 14	8297193	V3	V3	R2	R2
CATEGORY 14	8297194	V3	V3	R3	R3
CATEGORY 14	8297195	V3	V3	R2	R2
CATEGORY 14	8297197	V3	V3	R2	R2
CATEGORY 12	8297199	V3	V3	R3	R3
CATEGORY 12	8297201	V3	V3	R2	R2
CATEGORY 14	8297202	V3	V3	R2	R2
CATEGORY 14	8297204	V2	V3	R1	R2
CATEGORY 6	8297205	V5	V5	R4	R4
CATEGORY 12	8297212	V3	V3	R3	R3
CATEGORY 12	8297575	V3	V3	R2	R2
CATEGORY 12	8297579	V3	V3	R2	R2
CATEGORY 12	8297584	V3	V3	R2	R2
CATEGORY 12	8297585	V3	V3	R2	R2
CATEGORY 12	8297586	V3	V3	R2	R2
CATEGORY 12	8297587	V3	V3	R2	R2
CATEGORY 12	8297588	V3	V3	R2	R2
CATEGORY 12	8297590	V3	V3	R3	R3
CATEGORY 12	8297603	V3	V3	R2	R2
CATEGORY 1	8396057	V4	V5	R3	R4
CATEGORY 1	8396157	V3	V5	R3	R4
CATEGORY 9	8396351	V4	V4	R3	R3
CATEGORY 8	8396352	V2	V2	R2	R2
CATEGORY 8	8396353	V2	V2	R2	R2
CATEGORY 1	8396354	V5	V5	R3	R3
CATEGORY 1	8396355	V5	V5	R4	R4
CATEGORY 8	8396367	V2	V2	R2	R2
CATEGORY 1	8396369	V2	V5	R2	R4
CATEGORY 1	8396370	V2	V5	R2	R4
CATEGORY 1	8396371	V5	V5	R4	R4

CATEGORY 3	8396372	V4	V2	R3	R2
CATEGORY 3	8396373	V2	V2	R2	R2
CATEGORY 3	8396374	V4	V2	R3	R2
CATEGORY 3	8396375	V2	V2	R1	R1
CATEGORY 3	8396376	V2	V2	R2	R2
CATEGORY 1	8396419	V5	V5	R4	R4
CATEGORY 12	8397200	V3	V3	R2	R2
CATEGORY 12	8397242	V3	V3	R2	R2
CATEGORY 12	8397337	V3	V3	R2	R2
CATEGORY 12	8397338	V3	V3	R2	R2
CATEGORY 12	8397339	V3	V3	R2	R2
CATEGORY 12	8397340	V3	V3	R2	R2
CATEGORY 12	8397341	V3	V3	R2	R2
CATEGORY 14	8397365	V3	V3	R2	R2
CATEGORY 12	8397366	V3	V3	R2	R2
CATEGORY 12	8397367	V3	V3	R2	R2
CATEGORY 14	8397369	V3	V3	R2	R2
CATEGORY 14	8397377	V3	V3	R2	R2
CATEGORY 12	8397380	V3	V3	R2	R2
CATEGORY 12	8397383	V3	V3	R2	R2
CATEGORY 12	8397384	V3	V3	R2	R2
CATEGORY 12	8397389	V3	V3	R2	R2
CATEGORY 12	8397390	V3	V3	R2	R2
CATEGORY 12	8397716	V3	V3	R2	R2
CATEGORY 12	8397717	V3	V3	R2	R2
CATEGORY 12	8397718	V3	V3	R2	R2
CATEGORY 12	8397719	V3	V3	R2	R2
CATEGORY 12	8397720	V3	V3	R2	R2
CATEGORY 12	8397728	V3	V3	R2	R2

Table 69: Risk assessment for storm surge and sea-level rise of the detailed case study

4.2 CONCLUSIONS

An understanding of the vulnerability of the buildings to the impacts under consideration permits a more realistic approximation to the real situation of the area, a detailed prioritization and a better management of available resources. By including the building approach, it is possible to obtain an adequate strategy adapted to the real situation of the most vulnerable and critical areas, in which interventions should start. However, harmony between resource commitments and the accuracy of results should be sought.

For the validation of the methodology, six districts of San Sebastian, comprising 1,721 buildings have been modelled. The categorization method, based on publicly available data, yielded 15 categories, representing 76% of the building stock under consideration. Through the sample building modelling strategy and MIVES, it was possible to calculate the sensitiveness, adaptive capacity and vulnerability index, which was extrapolated to the buildings belonging to the same category. A survey campaign was carried out and 100 buildings inspected, as a means of checking the accuracy of results obtained by using a limited amount of information. The results given by using real data and the categorization method were therefore compared and the margin of error resulted in a 9%. The largest difference was appreciated in the Loiola district blocks, where mainly single-family houses which presented diverse characteristics were analysed. The methodology has therefore presented its highest potential in districts which have been characterized by smooth development over time, such as the historic ones, providing a feasible and affordable solution for vulnerability and risk assessment in urban areas.

"In scientific research, neither the degree of one's intelligence nor the ability to perform one's task with thoroughness and precisionare essential factors in personal success and fulfilment. More important are total dedication and a tendency to underestimate difficulties."

Rita Levi-Montalcini

5

CONCLUSIONS AND FUTURE PERSPECTIVES

With regard to climate change, historic cities have to face the same challenges as modern urban areas. They are both exposed to negative environmental impacts, so they both share the objective of promoting sustainable development in a changing environment, pursuing safety and liveability for their inhabitants. Nevertheless, as non-renewable resources, representing the cultural and identity-making background of individuals, historic cities are deserving of special attention. Climate change and disaster mitigation should therefore be linked and integrated into wider city development plans as well as into conservation practice. The incipient production of large amounts of data and their use by local governments creates a positive environment for evidence-based decision-making, if a proper information management strategy is ensured.

This chapter summarizes the main conclusions arising from the development of this thesis; in particular, the problems that are identified, the methodological approach for vulnerability and risk assessment, and its implementation in the case study of San Sebastian. In addition, future research perspectives are proposed for the improvement of the knowledge that has been generated.

5.1 CONCLUSIONS ON THE PROBLEM THAT IS IDENTIFIED

Climate change and related natural hazards are impacting on cities and built-heritage assets located in coastal areas, with special regard to extreme precipitation and subsequent flood events, sea-level rise, and storms. This scenario is posing new challenges in the urban-planning process, because of uncertainty in future climatic patterns and the real impact of adaptive measures, which is still high. The scope of climate change adaptation has broadened considerably, shifting from the management of direct physical damage to risk-based approaches incorporating vulnerability and adaptive capacity assessments. Sustainable development, which has the overall objective of improving the quality of life of all city inhabitants, must incorporate the whole process of change, which requires a holistic approach, including climate change and disaster risk reduction.

Even if cultural heritage has been taken into account in certain actions, related to the conservation field, it is not considered as an element in global approaches of climate change. It is recognised that climate change is increasing the frequency of disasters, which are adversely impacting on social values and increasing damage and loss of cultural heritage. As a limited resource and a contributor to collective identity, cultural heritage should, with all of its specificities, be integrated into wider frameworks of climate change adaptation and disaster risk reduction, as a sensitive element of the urban environment.

The decision-making process, which accompanies the implementation of the strategies, requires efficiency and efficacy in the delivery of results but, at the same time, it involves long-term consultations between stakeholders with different competences and interests. Addressing climate change and cities entails the analysis of both the changing climate and city system, systems which operate on different spatial and temporal scales. Furthermore, the management of data in the holistic decision-making process is often challenging and demanding on resources.

Vulnerability mapping is the first step towards an informed decision-making as, by understanding the impact of negative effects on the built environment, solutions can be properly selected and prioritized.

Methodologies for encountering a proper balance between results accuracy and the required data are needed. The balance can be achieved through the use of a flexible information strategy, data models, and multiple criteria decision analysis, which can provide a systemic and organized way of thinking, as a support tool for complex decision-making scenarios.

5.2 CONCLUSIONS ON THE METHODOLOGICAL APPROACH

Climate change, as a new challenge for sustainable urban development, is related to the design and planning of strategies that will guide the transformation of historic cities and their adaptation to modern requirements and changing environments. The concepts of vulnerability and risk are of major importance, in order to support the selection of adaptive strategies.

The methodology proposed in this thesis is based on a comprehensive set of indicators aimed at prioritizing interventions in flood risk areas, according to building vulnerabilities.

Climate change is an urban problem and strategies are established considering the city scale, while adaptive measures and their implementation can be on the scale of either the city or the building. A multi-scalar approach is therefore needed, in order to cover both the strategic and operational scale, thereby supporting the integration of adaptive measures within disaster risk management, sustainable development and climatic scenarios. A proper information management strategy is needed, to ensure the interconnection between scales and the promotion of data access and exchange among stakeholders. This strategy should be tailored to support data in diverse fields of application, such as adaptation to climate change, disaster risk reduction and heritage conservation. It should be flexible enough to permit updates and adjustment, ensuring a strategy coherent with changes over time. A data model for the historic city is proposed, linked to the concepts of vulnerability and risk management in response to climate change approaches, for structuring information and the facilitation of decision-making.

The CityGML standard has been selected for building the data model, to structure the information from different fields, formats and scales. The model permits geometric and semantic information to be structured in the same infrastructure in a coherent and interoperable way, providing the necessary information for decision-making. Information is provided both at city and building level, thus permitting micro and meso-scale assessments.

The proposed modelling strategy is based on the *sample building* method, aiming to generate a limited number of sample buildings, which are sufficiently representative of the building stock. This method offers the optimal balance between ease of data acquisition and results. Categories are generated according to 6 parameters: year of construction, use, existence of a basement, level of protection, number of dwellings and socio-economic status. These parameters have been selected, as they are accessible and easy to obtain and they are significant for the clustering process.

The vulnerability assessment methodology proposed, which is applied to sample buildings, has been based on the MIVES method. The impacts of flooding on buildings depend on the physical characteristics of the buildings and the social conditions of their inhabitants. A hierarchic structure based on a requirements tree has been established, in order to provide decision-making with an objective intervention priority index, in which the characteristics of the vulnerability assessment are defined, displayed and organized. At the first levels, the requirements and criteria, general, and qualitative aspects are defined, while the indicators consider concrete and measurable aspects. The 14 indicators defined for the vulnerability assessment have been transformed, through value functions, in a dimensionless value of between 0 and 1, thereby permitting comparisons between qualitative and quantitative elements of a different nature. Weights have been assigned, using the Analytic Hierarchy Process (AHP), in order to calculate the vulnerability index, by establishing the relative importance of each branch of the requirements tree. The process has resulted in a vulnerability ranking of the sample buildings. A method for the fine-tuning of the methodology, on the one hand, considering the sensitiveness index and, on the other hand, the adaptive capacity index, has been established, providing vulnerability levels defined by these parameters.

For the risk assessment, another 4 indicators have been considered. Exposure indicators and their assessment have been calculated according to the same value analysis method, in order to obtain the risk index. As exposure applies to each building in a different way, it has been calculated for each structure instead of using the sample building method.

5.3 CONCLUSIONS ON THE IMPLEMENTATION OF THE METHODOLOGICAL APPROACH

The methodology has been implemented in the city of San Sebastian, specifically in the area located nearby the boundaries of the Urumea River, comprising six districts with different characteristics and 2,262 buildings of both a modern and a historic character. The data model, including the necessary geometric and semantic information has been built and the sample building method applied, generating 15 categories and representing 76% of the building stock. The information considered in this process can be easily obtained from public sources and can be added to the data model almost automatically, providing an affordable and fast vulnerability assessment at urban level, improving the balance between the required information and the accuracy of the results.

Both the sensitiveness and the adaptive capacity have been calculated, using the MIVES methodology, for each of the selected sample building. Once assigned, the vulnerability level has been extrapolated to the buildings belonging to the same category.

A smaller area, comprising 113 buildings in three districts, has been subjected to in-depth analysis, in order to verify the accuracy of results obtained by the methodological approach. The semantic information for these buildings has been completed by using real data instead of using the sample building method. Of the 113 buildings that were inspected, 100 belonged to the categories established for the larger area. Among these buildings, 9 presented a different vulnerability level from the one established in the methodology, 6 of which were single-family houses located in the same area, at present less homogeneous than the other districts under consideration.

The proposed methodology has its highest potential in districts which have demonstrated a homogeneous and continuous development over time, such as historic districts, where typologies are well defined according to the characteristics of the era in which the buildings were constructed.

By applying the proposed methodology, it is possible to obtain an assessment of both vulnerability and risk which, through simple key parameters, can deliver a diagnosis as a first step for decision-making. The data model can be easily updated and additional information stored, in order to provide more accurate results when data are available, as the strategy allows for an incremental use of information: the higher the level of information the greater the accuracy of results.

5.4 FUTURE PERSPECTIVES

The research presented in this thesis is related to the first phase of decision-making: the diagnosis process. The model can be extended to the implementation phase, by including scenario simulations for the selected adaptive measures. Much still remains to be done for measuring the impact and the possibilities given by adaptive solutions, such as nature based, new and traditional solutions, in order to build a proper repository, which enables us to quantify the benefits of the implementation. The inclusion of a simulation tool in the data model will enrich the decision-making process.

Furthermore, developing and detailing the monitoring and maintenance management of the strategies and the solutions that are selected will ensure the long-term efficiency of the adaptation plan of the city. Algorithms can be implemented directly in the multi-scale data model to allow for an automatic or semi-automatic monitoring process. The inclusion of real-time data or big data analysis will ensure a higher-level of model completeness.

Considering the specificities of cultural heritage and their proven resilience, the study and the understanding of traditional solutions typical of the vernacular architecture can provide knowledge for conservation techniques and inspire technologies for new constructions, in order to build more resilient cities. In materials science, new conservation techniques, adapted to changing climates, can reduce the vulnerability of cultural heritage by preventing damage, due to humidity or patterns of temperature change. Furthermore, flooding events are often associated with the introduction of pollutants and soluble salts in structures which, in the case of heritage buildings, can cause severe and irreparable damage. A deeper understanding of the relation between climate change and historic materials should be sought.

The proposed methodological approach, based on information management and a multi-scale data model, can be extended for use in the emergency phase of disaster risk reduction. Including information provided by sensors and real time data with social, economic, and other characteristics such as possible architectural barriers, can provide useful information to emergency managers or organizations in the pre and post-disaster phases. Other kinds of analysis, such as economic loss, impacts on natural landscapes, and social studies can complement the vulnerability assessment.

The MIVES methodology could be used to explore other systematic approaches. Firstly, value functions other than exponential ones (hyperbolic, etc.) and, secondly, by analysing uncertainty establishing non-deterministic rules by applying probabilistic models (stochastic simulation and fuzzy logic).

"In no other activity perhaps is the work so difficult and the reasoning so easy as in that which refers to restoration."

Camillo Boito

6

AFTERTHOUGHTS

The focus on cultural heritage

Over recent years, large-scale disasters have occurred more frequently across the world, causing enormous losses to life and property, and damage to cultural heritage. Climate change impacts on cultural heritage are demonstrated by flooding events in the Balkans in May 2014, which caused damage to many historic towns and villages; by flooding in Uttarakhand in India, in June 2013, severely damaging many temples and other historic structures along its rivers; at the Ayutthaya World Heritage site in Thailand, in 2011; in Pakistan, in August 2010, causing damage to many traditional settlements and archaeological sites; in Leh, in India, in August 2010, that suffered from flash floods due to unprecedented heavy rains which caused the destruction of vernacular adobe heritage; Rome (Italy) and Beverley (UK) which suffered floods in December and June 2007, respectively.

In the light of these events, managing disaster risk in cultural heritage assets is of primary importance, within the overall planning framework. Comprehensive disaster risk management plans need to be drawn up, based on the specific characteristics of cultural heritage and the nature of the hazards within a regional context (Jigyasu & Arora 2013). Furthermore, plans should take into account diverse heritage typologies such as traditional settlements, landscapes and intangible aspects, setting the focus on the living dimension of heritage that seeks continuity and evolution rather than mere preservation.

Traditionally, cities were located near rivers and seas, strategically established for transportation and connectivity purposes such as trade centres. This natural geographic advantage is now threatening low-lying delta cities which, due to the effects of climate change, are experiencing severe flooding and stronger gales and storms due to sea-level rise and heavy rainfall.

Even if historic cities were strategically located in favourable environments, recent scenarios have shown that the risks associated with climate change are incremental and will increase gradually (IPCC 2014a; Curcic et al. 2012). Also, if natural disasters occur outside the boundaries of heritage sites, they will still have a direct impact, which can be seen over a short or long period of time, such as a change in humidity and temperatures and a decrease in tourism. According to a study on hydro-geological instability in Italy (Trigila et al. 2015), there are 12,000 heritage sites at risk in the worst scenario (probability of return every 20-50 years), which rise to 30,000 in a medium-risk scenario (probability of return every 100-200 years), most of them concentrated in the cities of Rome, Naples, Genoa, Milan and other cities, reaching a significant peak in Venice.

A study performed by (Marzeion & Levermann 2014), in which estimates of sea-level rise were considered at different levels of future warming, analysed which cultural heritage sites would be affected by changes in the coastline. Considering the 720 sites listed in the cultural and mixed categories in the UNESCO World Heritage List (as for October 2012), if the global mean temperature is sustained for the next 2000 years, 40 sites will be affected by sea-level rise, while the number of sites will increase to 136 at a warming rate of ΔT=3K. Research has also concluded that within the considered temperature range, a maximum of 109 sites will be more than 5m below sea level.

Areas where major rivers flow into the sea are particularly susceptible to sea-level rise, especially low-lying areas and their landforms which are constantly changing due to water flows and the transportation of sediment from river banks and the surrounding land. Additionally, infrastructures such as seawalls and other structures, built to preserve important historic cities and to maintain the stability of river deltas, are preventing natural processes that would possibly help adaptation. All actions should be oriented towards the adaptation of cities for the future by increasing their resilience (De Santoli 2015; Meerow et al. 2016). Only by increasing the resilience of cities will the impact of current and future climatic conditions and natural hazards be reduced. Additionally, the recovery capacity after extreme events will be enhanced (Leichenko 2011; Brown et al. 2012; Wamsler et al. 2013).

Adaptation plans should take into account the principles of risk management and the values of cultural heritage and, at the same time, address greater urban development challenges. The historic and aesthetic value of heritage located in urban areas is of primary importance in the planning process. It forms part of the factors influencing and even defining the limitations when choosing solutions and strategies. The capability of urban systems to prepare for and to respond to risks requires both soft measures, such as urban planning, land use, early warning systems, awareness campaigns etc. and hard measures, comprising physical interventions to buildings, infrastructure and urban spaces etc. Both types of measures should consider preservation, by proposing solutions that will not harm heritage.

The methodology developed within this dissertation is focused on historic cities, considering urban historic assets as small but significant parts of complex urban systems to be protected. Historic cities have changed over time and attempts to define precise boundaries between old and new results in a limited and partial vision. Indicators for vulnerability and risk assessment have been developed, considering the potential application of the methodology to all structures, but also including cultural value as a primary indicator. This is because on the one hand, the historic city is part of a wider area and is subjected to transformation and the consequent inclusion of new buildings and, on the other hand, the preservation of historic values is of major importance, as heritage provides a unique testimony of the past and guidance in the design of future low-carbon, resilient, and liveable cities.

Encouraging traditional adaptation

Heritage is often a source of inspiration among urban planners when defining protective strategies. Traditional systems embedded in cultural heritage have, as a consequence of trial and error, evolved over time. These systems can play a significant role in disaster prevention, as they have stood the test of time and survived several natural hazards. Some coastal communities have become better equipped at dealing with natural hazards through diverse measures, such as constructing on stilts and erecting wind-resistant structures. When traditional skills and practice are kept alive and dynamic, they can contribute to the rebuilding of resilient and sustainable communities, by reusing materials from collapsed structures, reducing dependency on external support and providing livelihood sources crucial for sustainable recovery (Jigyasu 2014). From this perspective, the experience of Pakistan is of outstanding value. Due to the unprecedented natural disasters of the past few years, mainly earthquakes and floods, communities have been trained to use improved vernacular techniques, resulting in the reconstruction of over 40,000 housings, a large number of which have survived the floods of 2011, 2012 and 2013. Adapted from vernacular architectural forms and using locally available and sustainable materials, the resulting structures can withstand flooding and seismic events (Lari 2014). Heritage and traditional knowledge can therefore contribute to wider sustainable development goals, if properly maintained and transmitted to the next generation. The exchange of good practice should be sought as communities which had in the past faced specific hazards can contribute to the adaptation of communities that are at present facing new challenges.

The value of cultural heritage

Disasters pose challenges to the physical attributes of cultural heritage, as their architectural and aesthetic values are influenced by new climatic conditions (Brimblecombe 2014a; Brimblecombe 2014b; Nik et al. 2015; D'Ayala & Aktas 2016). Furthermore, risks affect the viability of traditional usage and their management systems, continuation of visitors and local communities and movable heritage, often located inside heritage buildings.

Even if the physical damage to cultural heritage can be estimated, the value of such damage is challenging to assess, as cultural heritage is unique non-renewable and provides intangible benefits, which are not associated with quantitative measurements (UNFCCC 2013).

The impacts of climate change on cultural heritage are included in the concept on non-economic loss and damage, as they are hard to quantify and connected to the material and non-material spheres (Serdeczny et al. 2016). Although the scientific community has not reached an agreement on the definition and conceptualization of non-economic loss and damage, cultural heritage appears in almost all sources (Morrissey & Oliver-Smith 2013; Fankhauser et al. 2014; Serdeczny et al. 2016). The economic value of cultural heritage is difficult to assess in monetary terms, as many studies analyse it in qualitative terms, with no reliable figures. Nevertheless, cultural heritage is associated with traditional knowledge and place distinctiveness, so that loss of this heritage will inevitably leave communities disconnected from their identity, leaving irreplaceable losses in their wake.

Even if economic losses to cultural heritage are hard to estimate, the indirect impact on job and incomes derived from activities based on heritage resources should be considered, together with the negative social impacts, as disasters can compromise cultural identity, cohesion, and knowledge of the past (ICOMOS Netherlands 2013; King et al. 2006).

In a study conducted by (Nypan 2014), the number of people directly employed in the cultural heritage sector in Europe stands at 306,000 or more. The potential of cultural heritage on employment is not related to direct jobs, but to stimulating job creation in other sectors, which account for 7.8 million person-year (Nypan 2014). According to research carried out by The EU-funded project Cultural Heritage Counts for Europe (CHCfE Consortium 2015), the cultural heritage sector is estimated to produce up to 26.7 indirect jobs for each direct job.

It is well worth developing a proper strategy for cultural heritage, as the impacts, even if they are difficult to estimate in economic terms, can be of major importance. The methodological approach included in this dissertation evaluates the vulnerability of structures but provides no quantification of possible damage according to different risk scenarios. The focus is placed on a preventive approach, by identifying the most vulnerable buildings for the prioritization of interventions, which have the objective of avoiding or limiting further damage. Nevertheless, knowing the vulnerability level of each building and if the economic value of cultural heritage were quantifiable, it would be possible to estimate the economic loss derived from natural hazards.

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BIBLIOGRAPHY

Aguado, A. et al., 2012. Sustainability assessment of concrete structures within the Spanish structural concrete code. *Journal of Construction Engineering and Management*, 138(2), pp.268–276.

Aguado, A., Manga, R. & Ormazábal, G., 2006. Los aspectos conceptuales del proyecto MIVES. In LABEIN, UPV-EHU, & UPC, eds. *La medida de la sostenibilidad en edificación industrial . Modelo integrado de Valor en Edificios Sostenibles (MIVES)*, pp. 113–134.

Alarcon, B. et al., 2011. A value function for assessing sustainability: Application to industrial buildings. *Sustainability*, 3(1), pp.35–50.

Alarcón, D.B., 2006. Marco informático amigable de evaluación. In TECNALIA, UPV/EHU, & UPC, eds. *La medida de la sostenibilidad en edificación industrial*. Bilbao, pp. 135–158.

Al-Harbi, K.M.A.S., 2001. Application of the AHP in project management. *International Journal of Project Management*, 19(1), pp.19–27.

Amirebrahimi, S. et al., 2015. A framework for a microscale flood damage assessment and visualization for a building using BIM–GIS integration. *International Journal of Digital Earth*, 8947(April 2015), pp.1–24. Available at: http://dx.doi.org/10.1080/17538947.2015.1034201

Ballarini, I. et al., 2011. Improving energy modeling of large building stock through the development of archetype buildings. *Building Simulation*, pp.2874–2881.

Ballarini, I., Corgnati, S.P. & Corrado, V., 2014. Use of reference buildings to assess the energy saving potentials of the residential building stock: The experience of TABULA project. *Energy Policy*, 68, pp.273–284.

Batty, M., 2009. Urban Modeling. In *International Encyclopedia of Human Geography*, pp. 51–58. Available at: http://www.casa.ucl.ac.uk/rits/BATTY-Urban-Modelling-2009.pdf

Bernardi, A. et al., 2012. A Methodology to Monitor the Pollution Impact on Historic Buildings Surfaces: The TeACH Project. In pp. 765–775. Available at: http://link.springer.com/10.1007/978-3-642-34234-9_81

Bigio, A.G., Ochoa, M.C. & Amirtahmasebi, R., 2014. *Climate-resilient, Climate-friendly World Heritage Cities.* World Bank, ed., Washington, DC. Available at: https://openknowledge.worldbank.org/handle/10986/19288

Birkmann, J. et al., 2013. Framing vulnerability, risk and societal responses: the MOVE framework. *Natural Hazards*, 67(2), pp.193–211. Available at: http://link.springer.com/10.1007/s11069-013-0558-5

Blanco, H. et al., 2011. The role of urban land in climate change. In C. Rosenzweig et al., eds. . Cambridge University Press, pp. 217–248.

Blanco-Vogt, A. & Schanze, J., 2014. Assessment of the physical flood susceptibility of buildings on a large scale - Conceptual and methodological frameworks. *Natural Hazards and Earth System Sciences*, 14(8), pp.2105–2117.

Boriani, M., Giambruno, M. & Pistidda, S., 2014. Guidelines for the Walled City of Multan: Knowledge, Conservation, and Relationship Ancient/New for a Sustainable Rehabilitation. In A. Del Bo & D. F. Bignami, eds. Springer International Publishing, pp. 211–223. Available at: http://link.springer.com/10.1007/978-3-319-02117-1_17

Brimblecombe, P., 2014a. Damage to Materials and Buildings in a Changing Urban Climate. In B. Freedman, ed. *Global Environmental Change*. Dordrecht, pp. 455–460. Available at: http://dx.doi.org/10.1007/978-94-007-5784-4_20

Brimblecombe, P., 2014b. Refining climate change threats to heritage. *Journal of the Institute of Conservation*, 37(2), pp.85–93. Available at: https://www.tandfonline.com/doi/full/10.1080/19455224.2014.916226

Brown, A., Dayal, A. & Rumbaitis Del Rio, C., 2012. From practice to theory: emerging lessons from Asia for building urban climate change resilience. *Environment and Urbanization*, 24(2), pp.531–556. Available at: http://journals.sagepub.com/doi/10.1177/0956247812456490

Brugha, C.M., 2004. Structure of multi-criteria decision-making. *Journal of the Operational Research Society*, 55(11), pp.1156–1168. Available at: http://link.springer.com/10.1057/palgrave.jors.2601777

Del Caño, A., Gómez, D. & De La Cruz, M.P., 2012. Uncertainty analysis in the sustainable design of concrete structures: A probabilistic method. *Construction and Building Materials*, 37, pp.865–873.

CHCfE Consortium, 2015. *Cultural heritage counts for Europe* C. Giraud-Labalte et al., eds., International Cultural Centre, Krakow.

City of Cambridge, 2015. C*ambridge Climate Change Vulnerability Assessment*.

Coors, V. & Flick, S., 1998. Integrating levels of detail in a Web-based 3D-GIS. In *Proceedings of the sixth ACM international symposium on Advances in geographic information systems - GIS '98*. New York, New York, USA: ACM Press, pp. 40–45. Available at: http://portal.acm.org/citation.cfm?doid=288692.288701

Corfee-Morlot, J. et al., 2011. Multilevel risk governance and urban adaptation policy. *Climatic Change*, 104(1), pp.169–197. Available at: http://link.springer.com/10.1007/s10584-010-9980-9

Crouch, G.I. & Ritchie, J.R.B., 2005. Application of the analytic hierarchy process to tourism choice and decision making: a review and illustration applied to destination competitiveness. *Tourism Analysis*, 10(1), pp.17–25. Available at: http://www.ingentaconnect.com/content/cog/ta/2005/00000010/00000001/art00003

Cuadrado, J., 2009. *Establecimiento de una metodología general para la medida de la sostenibilidad en el ciclo de vida de los edificios Industriales*. UPV/EHU.

Curcic, L. et al., 2012. Interaction between tourism and climate change. *Journal of Environmental Protection and Ecology*, 13(2), pp.620–627.

D'Ayala, D. & Aktas, Y.D., 2016. Moisture dynamics in the masonry fabric of historic buildings subjected to wind-driven rain and flooding. *Building and Environment*, 104, pp.208–220. Available at: http://www.sciencedirect.com/science/article/pii/S0360132316301676 [Accessed May 1, 2017].

D'Ayala, D.F., Copping, A.G. & Wang, H., 2006. A conceptual model for Multihazard assessment of the vulnerability of historic buildings. In P. B. Lourenco et al., eds. *Structural Analysis of Historical Constructions: Possibilities of Numerical and Experimental Techniques. Proceedings of the Fifth International Conference*.Vol. 1. New Delhi: Macmillian, pp. 121–140. Available at: http://opus.bath.ac.uk/569/

Daly, C., 2014. *A Cultural Heritage Management Methodology for Assessing the Vulnerabilities of Archaeological Sites to Predicted Climate Change Focuing on Ireland's Two World Heritage Sites*. Dublin Institute of Technology.

Dietz, T., 2003. The Struggle to Govern the Commons. *Science*, 302(5652), pp.1907–1912. Available at: http://www.sciencemag.org/cgi/doi/10.1126/science.1091015

Drdácký, M.F., 2010. Flood Damage to Historic Buildings and Structures. *Journal of Performance of Constructed Facilities*, 24(5), pp.439–445. Available at: 10.1061/(ASCE)CF.1943-5509.0000065¥nhttps://ezp.lib.unimelb.edu.au/login?url=https://search.ebscohost.com/login.aspx?direct=true&db=bcr&AN=53711635&site=eds-live&scope=site

EC, 2007. Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks. *Official Journal of the European Union*, L288/27, pp.27–34. Available at: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32007L0060

EEA, 2012. *Climate change, impacts and vulnerability in Europe 2012: an indicator-based report*. Available at: http://www.citeulike.org/group/15400/article/12590420

Egusquiza, A., 2015. *Multiscale information management for historic districts' energy retrofitting. A framework. A methodology. A model*. Universidad Politécnica de Cataluña.

Eisenack, K., 2012. Archetypes of Adaptation to Climate Change. In M. Glaser et al., eds. *Human/Nature Interactions in the Anthropocene: Potentials of Social-Ecological Systems Analysis*. Routledge, pp. 107–122.

EM-DAT, 2017. EM-DAT: The OFDA/CRED International Disaster Database. Université Catholique de Louvain – Brussels – Belgium. Available at: www.emdat.be

English Heritage, 2004. *Flooding and historic buildings*. Available at: https://content.historicengland.org.uk/images-books/publications/flooding-and-historic-buildings-2ednrev/heag017-flooding-and-historic-buildings.pdf

ENSURE, C., 2013. *Final Report - ENSURE* (Enhancing resilience of communities and territories facing natural and na-tech hazards). Available at: http://cordis.europa.eu/publication/rcn/14275_en.html

European Commission, 2007a. Directive 2007/2/EC of the European Parliament and of the council of 14 March 2007 establishing an Infrastructure for Spatial Information in the European Community (INSPIRE). *Official Journal of the European Union*, 50(January 2006), pp.1–14. Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2007:108:0001:0014:EN:PDF

European Commission, 2007b. LEIPZIG CHARTER on Sustainable European Cities. *Europe*, (May), pp.1–7. Available at: http://www.eu2007.de/en/News/download_docs/Mai/0524-AN/075DokumentLeipzigCharta.pdf

European Commission, 2013. *The EU strategy on adaptation to climate change*.

Faber, M.H. et al., 2007. Principles of risk assessment of engineered systems. *Applications of Statistics and Probability in Civil Engineering – Icasp 10*, (July), pp.1–8.

Fankhauser, S., Dietz, S. & Gradwell, P., 2014. *Non-economic losses in the context of the UNFCCC work programme on loss and damage*.

Fomento, M., 2008. *Instrucción de Hormigón Estructural (EHE-08)*.

Garrucho, I., 2006. *Desarrollo de una metodología para el proceso de diseño sostenible de edificaciones industriales bajo requerimientos medioambientales*. UPV/EHU.

Glantz, M.H. et al., 2014. *Working with a changing climate, not against it— Hydro-meteorological disaster risk reduction: A survey of lessons learned for resilient adaptation to a changing climate*, Boulder.

Gobierno Vasco, 1999. Cartografía de litología y permeabilidad de la Comunidad Autónoma del País Vasco a escala 1:25.000.

Groot, A.M.E. et al., 2015. Integration in urban climate adaptation: Lessons from Rotterdam on integration between scientific disciplines and integration between scientific and stakeholder knowledge. *Building and Environment*, 83, pp.177–188.

Hancilar, U. & Taucer, F., 2013. *Guidelines for typology definition of European physical assets for earthquake risk assessment*.

Hardoy, J. & Pandiella, G., 2009. Urban poverty and vulnerability to climate change in Latin America. *Environment and Urbanization*, 21(1), pp.203–224.

Herman, L. & Reznik, T., 2013. Web 3D Visualization of Noise Mapping for Extended INSPIRE Buildings Model. In *IFIP Advances in Information and Communication Technology*, pp. 414–424.

Herráez, J.A., 2012. Estrategias de conservación preventiva ante catástrofes. *Patrimonio cultural de España*, 6, pp.61–67.

Hokkanen, J. & Salminen, P., 1997. Choosing a solid waste management system using multicriteria decision analysis. *European Journal of Operational Research*, 98(1), pp.19–36. Available at: <Go to ISI>://A1997WV16000002¥nC:¥Documents and Settings¥Ozge Kaplan¥My Documents¥Research¥Papers¥Hokkanen and Salminen.pdf

Hosagrahar, J. et al., 2016. Cultural Heritage, the UN Sustainable Development Goals, and the New Urban Agenda. In *Third United Nations Conference on Housing and Sustainable Urban Development (HABITAT III)*.

ICOMOS, 2016. *Cultural Heritage, the UN Sustainable Development Goals, and the New Urban Agenda*.

ICOMOS, 1975. The Declaration of Amsterdam -1975. *Congress on the European Architectural Heritage*, (October), pp.1–8.

ICOMOS, 2011. The Valletta Principles for the Safeguarding and Manage ment of Historic Cities, Towns and Urban Areas.

ICOMOS, 1964. *The Venice Charter 1964*.

ICOMOS Netherlands, 2013. *Protecting deltas: heritage helps!*. Available at: https://www.youtube.com/watch?v=eIz3pKXs9ck

IEA-ECBCS, 2005. *Technical Synthesis Report Annex 31.* Energy-Related Environmental Impact of Buildings R. Hobday, ed., FaberMaunsell Ltd on behalf of the International Energy Agency Energy Conservation in Buildings and Community Systems Programme.

IPCC, 2014a. *Climate Change 2014: Synthesis Report.* Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change,

IPCC, 2001. *IPCC Third Assessment Report.* Assessment, 5, pp.1–29. Available at: http://www.ipcc.ch/ipccreports/assessments-reports.htm

IPCC, 2012. *Managing the risks of extreme events and disasters to advance climate change adaptation.* Special Report of the Intergovernmental Panel on Climate Change, Available at: https://www.ipcc.ch/pdf/special-reports/srex/SREX_Full_Report.pdf¥npapers2://publication/uuid/41AD43FB-2529-4ACD-AD33-4C2D0AB4A0F3¥nhttp://ipcc-wg2.gov/SREX/

IPCC, 2014b. Summary for policymakers. In M. D. M. Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, S. M. T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, & and L. L. W. P.R. Mastrandrea, eds. *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects.* Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, pp. 1–32.

IPCC, 2013. *Working Group I Contribution to the IPCC Fifth Assessment Report, Climate Change 2013: The Physical Science Basis*. Available at: http://ipccwg1.jp/AR4/meeting/pdf/SyR0407-siryo2.pdf¥nhttp://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:IPCC,+2014:+Climate+Change+2014:+Impacts,+Adaptation,+and+Vulnerability.+Part+A:+Global+and+Sectoral+Aspects.+Contribution+of+Working+Group

Jain, S.K. et al., 2005. Delineation of flood-prone areas using remote sensing techniques. *Water Resources Management*, 19(4), pp.333–347.

Jigyasu, R., 2014. Fostering resilience: towards reducing disaster risks to world heritage. *World heritage review*, pp.4–13.

Jigyasu, R. et al., 2013. *Heritage and Resilience: Issues and Opportunities for Reducing Disaster Risks*.

Jigyasu, R. & Arora, V., 2013. D*isaster risk management of cultural heritage in urban areas: a training guide*, Kyoto, Japan: Research Center for Disaster Mitigation of Urban Cultural Heritage, Ritsumeikan University (RitsDMUCH).

Josa, A., 2012. *Introducción a MIVES y el análisis multicriterio*.

Jurelionis, A. & Bouris, D., 2016. Impact of Urban Morphology on Infiltration-Induced Building Energy Consumption. *Energies*, 9(3), p.177. Available at: http://www.mdpi.com/1996-1073/9/3/177

Kates, R.W. & Wilbanks, T.J., 2003. Making the Global Local Responding to Climate Change Concerns from the Ground. *Environment: Science and Policy for Sustainable Development*, 45(3), pp.37–41. Available at: http://www.tandfonline.com/doi/pdf/10.1080/00139150309604534

Kehew, R., Kolisa, M. & Rollo, C., 2013. Formulating and implementing climate change laws and policies in the Philippines, Mexico (Chiapas), and South Africa: a local government perspective. *Local Environment*, 18(6), pp.723–737.

Kelman, I., Gaillard, J.C. & Mercer, J., 2015. Climate change's role in disaster risk reduction's future: Beyond vulnerability and resilience. *International Journal of Disaster Risk Science*, 6(1), pp.21–27.

Kemec, S. et al., 2010. Selecting 3D Urban Visualisation Models for Disaster Management : Fethiye Tsunami Inundation. *3rd International Conference on Cartography and GIS*.

Kennedy, C. & Corfee-Morlot, J., 2013. Past performance and future needs for low carbon climate resilient infrastructure- An investment perspective. *Energy Policy*, 59, pp.773–783.

Khare, A., Beckman, T. & Crouse, N., 2011. Cities addressing climate change: Introducing a tripartite model for sustainable partnership. *Sustainable Cities and Society*, 1(4), pp.227–235. Available at: http://www.sciencedirect.com/science/article/pii/S221067071100045X [Accessed April 19, 2017].

King, J., Wijesuriya, G. & Copithorne, J., 2006. Integrating traditional knowledge systems and concern for cultural and natural heritage into risk management strategies. In S. and C. O. (UNESCO); W. H. C. (WHC) International Centre for the Study of the Preservation and Restoration of Cultural Property (ICCROM); United Nations Educational, ed. *International Disaster Reduction Conference (IDRC)*. Davos, Switzerland, p. 155.

Kithiia, J., 2010. Old notion–new relevance: setting the stage for the use of social capital resource in adapting East African coastal cities to climate change. *International Journal of Urban Sustainable Development*, 1(1-2), pp.17–32.

Kleinfelder, 2015. *Ranking Reports Critical Infrastructure & Community Resources*.

Kolbe, T.H., 2016. *Making 3D City Models Dynamic*. Available at: http://www.gdmc.nl/3DCadastres/workshop2016/programme/Pres2016_30.pdf

Kolbe, T.H., 2009. Representing and Exchanging 3D City Models with CityGML. *3D Geo-Information Sciences*, pp.15–31. Available at: http://dx.doi.org/10.1007/978-3-540-87395-2_2¥nhttp://misc.gis.tu-berlin.de/igg/htdocs/docs/CityGML_Paper_Kolbe_2008.pdf

Köninger, A. & Bartel, S., 1998. 3D-GIS for Urban Purposes. *Geoinformatica*, 2(1), pp.79–103. Available at: http://link.springer.com/10.1023/A:1009797106866

Kramer, R., van Schijndel, J. & Schellen, H., 2013. Inverse modeling of simplified hygrothermal building models to predict and characterize indoor climates. *Building and Environment*, 68, pp.87–99.

Kreibich, H. et al., 2010. Development of FLEMOcs – a new model for the estimation of flood losses in the commercial sector. *Hydrological Sciences Journal*, 55(8), pp.1302–1314.

Kron, W., 2005. Flood Risk = Hazard x Values x Vulnerability. *Water International*, 30(1), pp.58–68. Available at: http://dx.doi.org/10.1080/02508060508691837

Lari, Y., 2014. Post-disaster heritage initiative in Pakistan. *World heritage review*, pp.28–35.

Leichenko, R., 2011. Climate change and urban resilience. *Current Opinion in Environmental Sustainability*, 3(3), pp.164–168. Available at: http://linkinghub.elsevier.com/retrieve/pii/S1877343510001533

Levy, R.M., 1995. Visualization of urban alternatives. *Environment and Planning B: Planning and Design*, 22(3), pp.343–358. Available at: http://epb.sagepub.com/lookup/doi/10.1068/b220343

Liria, P. et al., 2011. Extreme Wave Flood-Risk Mapping Within the Basque Coast. *Proceedings of ICS2011*, (64), pp.225–229.

Lowe, A. & Foster, J., 2009. *Ask the climate question: adapting to climate change impacts in urban regions*. Available at: http://www.cakex.org/sites/default/files/documents/Urban_Climate_Adaptation-FINAL_CCAP 6-9-09.pdf

Marzeion, B. & Levermann, A., 2014. Loss of cultural world heritage and currently inhabited places to sea-level rise. *Environmental Research Letters*, 9(3), p.034001. Available at: http://stacks.iop.org/1748-9326/9/i=3/a=034001?key=crossref.b354dee9225889ff61938a83ebed6099

Masson, V. et al., 2014. Adapting cities to climate change: A systemic modelling approach. *Urban Climate*, 10(P2), pp.407–429. Available at: http://linkinghub.elsevier.com/retrieve/pii/S2212095514000212

Mata, É., 2011. *Energy efficiency and carbon dioxide mitigation in building stocks. Development of methodology using the Swedish residential stock*. Chalmers University of Technology.

Mata, É., Kalagasidis, A.S. & Johnsson, F., 2013. A modelling strategy for energy, carbon, and cost assessments of building stocks. *Energy and Buildings*, 56, pp.100–108. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0378778812004926

Mavrogianni, A. et al., 2012. Building characteristics as determinants of propensity to high indoor summer temperatures in London dwellings. *Building and Environment*, 55, pp.117–130. Available at: http://www.sciencedirect.com/science/article/pii/S0360132311004197 [Accessed April 19, 2017].

McCarney, P. et al., 2011. Cities and Climate Change - The challenges for governance. In C. Rosenzweig et al., eds. *Cities and climate change. Climate Change and Cities: First Assessment Report of the Urban Climate Change Research Network*. Cambridge University Press, pp. 249–269.

Mechler, R. et al., 2014. Managing unnatural disaster risk from climate extremes. *Nature Climate Change*, 4(4), pp.235–237. Available at: http://www.nature.com/nclimate/journal/v4/n4/full/nclimate2137.html

Mechler, R. & Bouwer, L.M., 2015. Understanding trends and projections of disaster losses and climate change: is vulnerability the missing link? *Climatic Change*, 133(1), pp.23–35. Available at: http://link.springer.com/10.1007/s10584-014-1141-0

Meerow, S., Newell, J.P. & Stults, M., 2016. Defining urban resilience: A review. *Landscape and Urban Planning*, 147, pp.38–49. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0169204615002418

Merz, B. et al., 2004. Estimation uncertainty of direct monetary flood damage to buildings. *Natural Hazards and Earth System Science*, 4(1), pp.153–163. Available at: http://www.nat-hazards-earth-syst-sci.net/4/153/2004/

Messner, F. & Meyer, V., 2006. FLOOD DAMAGE, VULNERABILITY AND RISK PERCEPTION – CHALLENGES FOR FLOOD DAMAGE RESEARCH. In F*lood Risk Management: Hazards, Vulnerability and Mitigation Measures*. Dordrecht: Springer Netherlands, pp. 149–167. Available at: http://link.springer.com/10.1007/978-1-4020-4598-1_13

Mioc, D. et al., 2011. Flood Progression Modelling and Impact Analysis. In *Efficient Decision Support Systems - Practice and Challenges in Multidisciplinary Domains*. InTech. Available at: http://www.intechopen.com/books/efficient-decision-support-systems-practice-and-challenges-in-multidisciplinary-domains/flood-progression-modelling-and-impact-analysis

Mitlin, D., 2012. *Urban Poverty in the Global South*, Routledge. Available at: http://www.scopus.com/inward/record.url?eid=2-s2.0-84909435834&partnerID=40&md5=1237b0f7cd45a51f798d0fdc122182d2

Morrissey, J. & Oliver-Smith, A., 2013. *Perspectives on Non-Economic Loss and Damage*.

Moylan, E., Brown, S. & Kelly, C., 2009. Toward a Cultural Landscape Atlas: Representing all the Landscape as Cultural. *International Journal of Heritage Studies*, 15(5), pp.447–466. Available at: http://dx.doi.org/10.1080/13527250903072781

Naumann, T., Nikolowski, J. & Golz, S., 2009. Synthetic depth–damage functions – A detailed tool for analysing flood resilience of building type. In E. Pasche et al., eds. *Road Map Towards a Flood Resilient Urban Environment*. Institut für Wasserbau der TU Hamburg.

Neubert, M. et al., 2016. The Geographic Information System-based flood damage simulation model HOWAD. *Journal of Flood Risk Management*, 9(1), pp.36–49. Available at: http://doi.wiley.com/10.1111/jfr3.12109 [Accessed April 19, 2017].

Nik, V.M. et al., 2015. Future moisture loads for building facades in Sweden: Climate change and wind-driven rain. *Building and Environment*, 93(P2), pp.362–375.

Nypan, T., 2014. Cultural Heritage Monuments and Historic buildings as value generators in a post-industrial economy (excerpts). In *Economics and Built Heritage – Seminar proceedings*. pp. 43–50. Available at: http://www.norden-ilibrary.org/environment/economics-and-built-heritage-seminar-proceedings/cultural-heritage-monuments-and-historic-buildings-as-value-generators-in-a-post-industrial-economy-excerpts_9789289334761-7-en

OECD, 2011. *Effective Modelling of Urban Systems to Address the Challenges of Climate Change and Sustainability*.

Ostrom, E., 2009. A polycentric approach for coping with climate change - Background paper to the 2010 World Development Report. *World Bank Policy Research Working Paper Series*, (October 2009). Available at: http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1494833&

Pardo-Bosch, F. & Aguado, A., 2015. Investment priorities for the management of hydraulic structures. *Structure and Infrastructure Engineering*, 11(10), pp.1338–1351.

Pasimeni, M.R. et al., 2014. Scales, strategies and actions for effective energy planning: A review. *Energy Policy*, 65, pp.165–174.

Piñero, I., 2013. *Metodología para priorizar y planificar de manera sostenible, la rehabilitación de estructuras degradadas: caso extremo del centro histórico de La Habana*. UPV/EHU.

Piñero, I. et al., 2017. Multi-criteria decision making for grading the rehabilitation of heritage sites. Application in the historic center of La Habana. *Journal of Cultural Heritage* (In press).

Pons, O. & Aguado, A., 2012. Integrated value model for sustainable assessment applied to technologies used to build schools in Catalonia, Spain. *Building and Environment*, 53, pp.49–58.

Pons, O. & De La Fuente, A., 2013. Integrated sustainability assessment method applied to structural concrete columns. *Construction and Building Materials*, 49, pp.882–893.

Prieto, I., Izkara, J.L. & Egusquiza, A., 2017. Building stock categorization for energy retrofitting of historic districts based on a 3D city model. *DYNA Ingenieria e Industria* (In press).

Prieto, I., Usobiaga, E. & Izkara, J.L., 2012. Generación semiautomática de ciudades en 3D en CityGML a partir de fuentes de datos libres. X Congreso TOPCART 2012 - *I Congreso Iberoamericano de Geomática y C.C. de la Tierra*.

Reinhart, C.F. & Cerezo Davila, C., 2016. Urban building energy modeling - A review of a nascent field. *Building and Environment*, 97, pp.196–202.

Ren, S. et al., 2012. 3D Building Modeling and Indoor Fire Event Representation in CityGML. In *Progress in Structure*, pp. 2631–2636.

Reques, P., 2006. *Geodemografía : fundamentos conceptuales y metodológicos*. Servicio de Publicaciones de la Universidad de Cantabria.

Robinson, D. et al., 2009. CITYSIM: Comprehensive Micro-Simulation Of Resource Flows For Sustainable Urban Planning. In *International IBPSA Conference*, pp. 1083–1090.

Ross, L. et al., 2009. Enhancing 3D City Models with Heterogeneous Spatial Information: Towards 3D Land Information Systems. In *Advances in GIScience*, pp. 113–133. Available at: http://dx.doi.org/10.1007/978-3-642-00318-9_6

Ruth, M., 2010. Economic and Social Benefits of Climate Information: Assessing the Cost of Inaction.

Procedia Environmental Sciences, 1, pp.387–394. Available at: http://linkinghub.elsevier.com/retrieve/pii/S1878029610000277

Saaty, T.L., 2008. Decision making with the analytic hierarchy process. *International Journal of Services Sciences*, 1(1), p.83.

Saaty, T.L., 1980. The Analytic Hierarchy Process. *Education*, pp.1–11. Available at: http://www.mendeley.com/research/the-analytic-hierarchy-process/

Sabbioni, C., Brimblecombe, P. & Cassar, M., 2010. *The Atlas of Climate Change Impact on European Cultural Heritage. Scientific Analysis and Management Strategies.* The Anthem, London: Anthem Press.

Salat, S. & Bourdic, L., 2012. Urban Complexity, Efficiency and Resilience. *Energy Efficiency - Abridge to Low Carbon Economy*, 53(9), pp.1689–1699.

San-José Lombera, J.T. & Garrucho Aprea, I., 2010. A system approach to the environmental analysis of industrial buildings. *Building and Environment*, 45(3), pp.673–683. Available at: http://www.scopus.com/inward/record.url?eid=2-s2.0-70449100769&partnerID=40&md5=2ff9051383671b408811d4d6e564ea51

De Santoli, L., 2015. Guidelines on energy efficiency of cultural heritage. *Energy and Buildings*, 86, pp.534–540.

Scawthorn, C. et al., 2006. HAZUS-MH Flood Loss Estimation Methodology. I: Overview and Flood Hazard Characterization. *Natural Hazards Review*, 7(2), pp.60–71. Available at: http://ascelibrary.org/doi/10.1061/%28ASCE%291527-6988%282006%297%3A2%2860%29

Schulte, C. & Coors, V., 2008. Development of a CityGML ADE for dynamic 3D flood information. In *Joint ISCRAM-CHINA and GI4DM Conference on Information Systems for Crisis Management*. Harbin, China.

Schulte, C. & Coors, V., 2009. *Development of a CityGML ADE for Dynamic 3D Flood Information*. University of Applied Sciences Stuttgart.

Serdeczny, O., Waters, E. & Chan, S., 2016. *Non-economic loss and damage in the context of climate change*.

Smith, D. & Crooks, A., 2010. *From buildings to cities: techniques for the multi-scale analysis of urban form and function*.

Solecki, W., 2012. Urban environmental challenges and climate change action in New York City. *Environment and Urbanization*, 24(2), pp.557–573. Available at: http://journals.sagepub.com/doi/10.1177/0956247812456472

Stephenson, V. & D'Ayala, D., 2014. A new approach to flood vulnerability assessment for historic buildings in England. *Natural Hazards and Earth System Science*, 14(5), pp.1035–1048. Available at: http://www.nat-hazards-earth-syst-sci.net/14/1035/2014/

Swan, L.G. & Ugursal, V.I., 2009. Modeling of end-use energy consumption in the residential sector: A review of modeling techniques. *Renewable and Sustainable Energy Reviews*, 13(8), pp.1819–1835. Available at: http://linkinghub.elsevier.com/retrieve/pii/S1364032108001949

Taboroff, J., 2000. Cultural Heritage and Natural Disasters: for Risk Management Incentives and Mitigation. In *Disaster Risk Management Series* No. 2 Managing Disaster Risk in Emerging Economies. pp. 71–79.

Thieken, A.H. et al., 2005. Flood damage and influencing factors: New insights from the August 2002 flood in Germany. *Water Resources Research*, 41(12), pp.1–16. Available at: http://doi.wiley.com/10.1029/2005WR004177

Towne, N., 2009. GIS and BIM Interoperability. In *ESRI Federal User Conference*. Washington, D.C.

Trigila, A. et al., 2015. *Dissesto idrogeologico in Italia: pericolosità e indicatori di rischio. Rapporto 2015*.

UNEP, 2007. *Global Environment Outlook 4. Early Warning and Assessment Technical Report*, 4(October), p.540.

UNESCO et al., 2007. *Climate Change and World Heritage*.

UNESCO, 2010. *Managing Disaster Risks for World Heritage*.

UNESCO, 2011. *Recommendation on the Historic Urban Landscape*.

UNESCO, 2013. The Hangzhou Declaration: Placing Culture at the Heart of Sustainable Development Policies. *Culture: Key to Sustainable Development*, (May), pp.1–6. Available at: http://www.unesco.org/new/fileadmin/MULTIMEDIA/HQ/CLT/images/FinalHangzhouDeclaration20130517.pdf

UNFCCC, 2011. *Assessing climate change impacts and vulnerability, making informed adaptation decisions*. United Nations Framework convention on Climate Change, ed.

UNFCCC, 2013. *Non-economic losses in the context of the work programme on loss and damage*.

UNISDR, 2009. 2009 *Global Assessment Report on Disaster Risk Reduction. Risk and poverty in a changing climate: Invest Today for a Safer Tomorrow.*

UNISDR, 2015a. Making Development Sustainable: The Future of Disaster Risk Management. *Global Assessment Report on Disaster Risk Reduction*. Geneva, Switzerland.

UNISDR, 2011. Revealing Risk, Redefining Development. *2011 Global Assessment Report on Disaster Risk Reduction*. Available at: http://www.preventionweb.net/english/hyogo/gar/2011/en/bgdocs/GAR-2011/GAR2011_Report_Prelims.pdf

UNISDR, 2015b. The Sendai Framework for Disaster Risk Reduction 2015-2030: the challenge for science. *Royal Society Meeting Note*, p.9. Available at: https://royalsociety.org/~/media/policy/Publications/2015/300715-meeting-note -sendai-framework.pdf

United Nations, 2014. *World Urbanization Prospects 2014*.

Varduhn, V., Ralf-Peter Mundani & Ernst Rank, 2015. Multi-resolution Models: Recent Progress in Coupling 3D Geometry to Environmental Numerical Simulation. *Geotechnical, Geological and Earthquake Engineering*, 16, pp.55–69.

Villegas, N., 2009. *Análisis de valor en la toma de decisiones aplicado a carreteras*. Universidad Politecnica de Cataluña.

Viñolas, B., 2011. *Aplicaciones y avances de la metodología MIVES en valoraciones multicriterio*. Universidad Politécnica de Cataluña.

Viñolas, B. et al., 2009. MIVES: modelo integrado de valor para evaluaciones de sostenibilidad. In C. I. de M. N. en I. (CIMNE), ed. *Congrés Internacional de Mesura i Modelització de la Sostenibilitat*. Barcelona, pp. 1–24. Available at: http://hdl.handle.net/2117/9704

Visser, H., Petersen, A.C. & Ligtvoet, W., 2014. On the relation between weather-related disaster impacts, vulnerability and climate change. *Climatic Change*, 125(3-4), pp.461–477. Available at: http://link.springer.com/10.1007/s10584-014-1179-z

Wamsler, C., Brink, E. & Rivera, C., 2013. Planning for climate change in urban areas: from theory to practice. *Journal of Cleaner Production*, 50, pp.68–81. Available at: http://linkinghub.elsevier.com/retrieve/pii/S095965261200652X

Wang, L. & Liu, H., 2006. An efficient method for identifying and filling surface depressions in digital elevation models for hydrologic analysis and modelling. *International Journal of Geographical Information Science*, 20(2), pp.193–213. Available at: http://www.tandfonline.com/doi/abs/10.1080/13658810500433453

Wang, Y.-M. & Elhag, T.M.S., 2006. Fuzzy TOPSIS method based on alpha level sets with an application to bridge risk assessment. *Expert Systems with Applications,* 31(2), pp.309–319. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0957417405002174

Webster, C.J., 1994. GIS and the scientific inputs to planning. Part 2: prediction and prescription. *Environment and Planning B: Planning and Design*, 21(2), pp.145–157. Available at: http://epb.sagepub.com/lookup/doi/10.1068/b210145

Webster, J., 2007. The Canadian Urban Archetypes Project: a tool facilitating the integration of energy-related information into urban planning decision making. *43rd ISOCARP Congress* 2007, pp.1–12.

Zavadskas, E.K. et al., 2014. Multi-criteria analysis of Projects' performance in construction. *Archives of Civil and Mechanical Engineering*, 14(1), pp.114–121. Available at: http://linkinghub.elsevier.com/retrieve/pii/S1644966513000903

ANNEX I

REFERENCE	BUILDING ID	STREET	NUM.	YOC	STATE OF CONSERVATIO N	WATER DAMAGE	GROUND FLOOR TYPOLOGY	EXISTENCE OF BASEMENT	OPENINGS GROUND FLOOR	ROOF TYPE	FAÇADE MATERIAL	USE	STRUCTURAL MATERIAL	EXISTENCE OF ADAPTIVE SYSTEMS	DRAINAGE SYSTEM CONDITIONS	PREVIOUS INTERVENTION S	NUM. DWELLINGS	SOCIO_ECONO MIC STATUS	CULTURAL VALUE
8297001	2486	GENERAL JAUREGI	14	1895	0.00	0.00	1.00	1.00	1.00	1.00	1.00	0.69	1.00	0.00	1.00	1.00	10.00	0.62	0.27
8297002	2480	GENERAL JAUREGI	16	1890	0.00	0.00	1.00	1.00	1.00	1.00	1.00	0.69	1.00	0.00	1.00	0.00	8.00	0.62	0.27
8297003	2471	GENERAL JAUREGI	12	1900	0.00	0.00	1.00	1.00	1.00	1.00	1.00	0.69	1.00	0.00	1.00	0.00	12.00	0.62	0.27
8297004	2470	GENERAL JAUREGI	10	1895	0.18	1.00	1.00	1.00	1.00	1.00	1.00	0.69	1.00	0.00	1.00	1.00	12.00	0.62	0.27
8297005	2456	EUSKAL HERRIA	7	1900	0.00	1.00	1.00	1.00	1.00	1.00	1.00	0.69	1.00	0.00	1.00	0.00	11.00	0.62	0.27
8297006	2446	GENERAL JAUREGI	8	1900	0.18	1.00	1.00	1.00	1.00	1.00	1.00	0.69	1.00	1.00	1.00	1.00	13.00	0.62	0.27
8297007	2447	GENERAL JAUREGI	6	1900	0.18	1.00	1.00	1.00	1.00	0.00	1.00	0.69	1.00	1.00	1.00	0.00	13.00	0.62	0.27
8297008	2472	GENERAL JAUREGI	4	1900	0.18	1.00	1.00	1.00	1.00	0.00	1.00	0.69	1.00	1.00	1.00	0.00	6.00	0.62	0.27
8297009	2474	GENERAL JAUREGI	18	1895	0.18	1.00	1.00	1.00	0.49	0.00	1.00	0.69	0.60	1.00	1.00	0.00	6.00	0.62	0.27
8297010	2466	EUSKAL HERRIA	5	1900	0.00	1.00	1.00	1.00	1.00	0.00	1.00	0.69	1.00	0.00	1.00	0.00	14.00	0.62	0.27
8297011	2457	SALAMANCA, PS DE	7	1900	0.00	0.00	1.00	1.00	0.49	1.00	1.00	0.69	0.60	0.00	1.00	1.00	16.00	0.62	0.86
8297013	2455	EUSKAL HERRIA	9	1900	0.00	0.00	1.00	1.00	0.49	0.00	1.00	0.69	0.60	0.00	0.78	0.00	26.00	0.62	0.27
8297014	2451	EUSKAL HERRIA	1	1900	0.18	1.00	1.00	1.00	0.49	0.00	1.00	0.69	0.60	0.00	0.78	1.00	12.00	0.62	0.27
8297015	2452	ALDAMAR	22	1900	0.00	0.00	1.00	1.00	1.00	0.00	1.00	0.69	0.60	0.00	1.00	1.00	11.00	0.62	0.27
8297016	2484	ALDAMAR	24	1986	0.00	1.00	1.00	1.00	1.00	0.00	1.00	0.69	1.00	0.00	1.00	1.00	12.00	0.62	0.27
8297017	2476	ALDAMAR	26	1900	0.00	1.00	1.00	1.00	1.00	1.00	1.00	0.69	1.00	0.00	1.00	1.00	12.00	0.62	0.27
8297018	2473	ALDAMAR	28	1900	0.00	1.00	1.00	1.00	1.00	0.00	1.00	0.69	1.00	0.00	1.00	0.00	12.00	0.62	0.27
8297020	2475	SALAMANCA, PS DE	8	1900	0.00	0.00	0.50	1.00	0.49	1.00	1.00	0.69	0.60	0.00	1.00	1.00	7.00	0.62	0.27
8297021	3461	GENERAL ETXAGUE	1	1965	0.00	0.00	1.00	1.00	1.00	1.00	0.00	0.69	0.60	0.00	1.00	1.00	17.00	0.62	0.00
8297024	2449	SALAMANCA, PS DE	5	1900	0.18	1.00	1.00	1.00	0.49	0.00	1.00	0.69	1.00	0.00	1.00	0.00	19.00	0.62	0.27
8297032	2468	EUSKAL HERRIA	14	1890	0.18	1.00	1.00	1.00	0.49	0.00	1.00	0.69	0.60	0.00	0.78	0.00	13.00	0.62	0.27
8297034	2485	EUSKAL HERRIA	8	1900	0.18	1.00	1.00	1.00	1.00	1.00	1.00	0.69	1.00	0.00	1.00	0.00	11.00	0.62	0.27
8297035	2467	EUSKAL HERRIA	3	1900	0.18	1.00	1.00	1.00	1.00	1.00	1.00	0.69	1.00	0.00	1.00	1.00	10.00	0.62	0.27
8297044	3456	ALDAMAR	12	1900	0.73	1.00	1.00	1.00	1.00	0.00	1.00	0.69	1.00	0.00	0.29	0.00	11.00	0.62	0.27
8297045	3457	ALDAMAR	14	1900	0.00	0.00	1.00	1.00	1.00	0.00	1.00	0.69	1.00	0.00	1.00	1.00	14.00	0.62	0.27
8297046	2442	ALDAMAR	16	1900	0.18	1.00	1.00	1.00	1.00	0.00	1.00	0.69	1.00	0.00	0.78	0.00	11.00	0.62	0.27
8297047	2450	EUSKAL HERRIA	12	1900	0.00	0.00	1.00	1.00	1.00	0.00	1.00	0.69	0.60	0.00	1.00	0.00	18.00	0.62	0.27
8297082	2454	EUSKAL HERRIA	4	1890	0.00	0.00	1.00	1.00	1.00	0.00	1.00	0.69	1.00	0.00	1.00	1.00	6.00	0.62	0.27
8297117	2493	GENERAL ETXAGUE	15	1970	0.00	0.00	1.00	1.00	1.00	0.00	0.00	0.69	0.60	0.00	1.00	0.00	25.00	0.62	0.00
8297159	2440	GENERAL ETXAGUE	7, 9	1900	0.00	0.00	1.00	1.00	1.00	1.00	1.00	0.69	1.00	0.00	1.00	0.00	20.00	0.62	0.00
8297166	3394	ALDAMAR	4	1900	0.00	0.00	1.00	1.00	1.00	0.00	1.00	0.69	1.00	0.00	1.00	0.00	10.00	0.62	0.61
8297168	3390	ALDAMAR	6	1886	0.18	1.00	1.00	1.00	1.00	0.00	1.00	0.69	1.00	0.00	1.00	0.00	13.00	0.62	0.61
8297169	3439	GENERAL ETXAGUE	2	1900	0.18	1.00	1.00	1.00	1.00	0.00	1.00	0.69	1.00	0.00	1.00	0.00	12.00	0.62	0.61
8297171	3449	ALDAMAR	2	1900	0.00	1.00	0.00	1.00	1.00	0.00	1.00	0.69	1.00	0.00	1.00	0.00	9.00	0.62	0.61
8297172	2441	GENERAL ETXAGUE	11	1900	0.73	1.00	0.00	1.00	1.00	1.00	0.00	0.69	1.00	0.00	0.29	1.00	12.00	0.62	0.00
8297173	3391	GENERAL ETXAGUE	4	1908	0.00	0.00	1.00	1.00	1.00	0.00	0.38	0.69	1.00	0.00	1.00	1.00	14.00	0.62	0.27
8297174	3468	GENERAL ETXAGUE	5	1900	0.00	0.00	0.50	1.00	1.00	1.00	0.00	0.69	1.00	0.00	1.00	0.00	12.00	0.62	0.27
8297175	3472	GENERAL ETXAGUE	3	1900	0.73	1.00	1.00	1.00	1.00	1.00	0.00	0.69	1.00	0.00	1.00	0.00	12.00	0.62	0.27
8297176	2479	EUSKAL HERRIA	10	1900	0.18	1.00	1.00	1.00	1.00	0.00	1.00	0.69	1.00	0.00	1.00	0.00	7.00	0.62	0.27
8297177	2443	EUSKAL HERRIA	6	1900	0.00	0.00	1.00	1.00	1.00	1.00	1.00	0.69	1.00	0.00	0.78	0.00	10.00	0.62	0.27
8297178	2453	EUSKAL HERRIA	2	1900	0.18	1.00	1.00	1.00	1.00	0.00	1.00	0.69	1.00	0.00	1.00	1.00	7.00	0.62	0.27
8297186	3397	GENERAL ETXAGUE	8	1900	0.00	1.00	1.00	1.00	1.00	1.00	1.00	0.69	1.00	0.00	1.00	1.00	13.00	0.62	0.27
8297193	3448	REINA REGENTE	2	1900	0.00	0.00	1.00	1.00	1.00	0.00	1.00	0.69	1.00	0.00	1.00	0.00	8.00	0.62	0.61
8297194	3454	REINA REGENTE	3	1900	0.00	1.00	1.00	1.00	1.00	0.00	1.00	0.69	1.00	0.00	1.00	1.00	8.00	0.62	0.61
8297195	3453	REINA REGENTE	4	1900	0.18	1.00	1.00	1.00	1.00	0.00	1.00	0.69	1.00	0.00	1.00	1.00	9.00	0.62	0.61
8297197	3409	REINA REGENTE	5	1900	0.00	1.00	1.00	1.00	1.00	0.00	1.00	0.69	1.00	0.00	1.00	0.00	11.00	0.62	0.61
8297199	3425	GENERAL ETXAGUE	10	1890	0.00	0.00	1.00	1.00	1.00	1.00	1.00	0.69	1.00	0.00	1.00	1.00	10.00	0.62	0.27
8297201	3396	GENERAL ETXAGUE	6	1900	0.00	0.00	1.00	1.00	1.00	1.00	0.38	0.69	1.00	0.00	1.00	0.00	12.00	0.62	0.27
8297202	3408	REINA REGENTE	6	1886	0.00	1.00	1.00	1.00	1.00	0.00	1.00	0.69	1.00	0.00	1.00	1.00	10.00	0.62	0.61
8297203	3450	REINA REGENTE	7	1984	0.00	0.00	1.00	1.00	1.00	0.00	1.00	0.69	1.00	0.00	1.00	1.00	14.00	0.62	0.61
8297204	3444	SALAMANCA, PS DE	2	1900	0.00	0.00	1.00	1.00	0.49	0.00	1.00	0.69	0.00	0.00	1.00	0.00	20.00	0.62	0.61
8297205	3429	GENERAL ETXAGUE	14	1976	0.00	0.00	1.00	1.00	1.00	0.00	0.38	0.69	0.60	0.00	1.00	0.00	35.00	0.62	0.00
8297212	3424	GENERAL ETXAGUE	12	1900	0.00	0.00	1.00	1.00	1.00	1.00	1.00	0.69	1.00	0.00	1.00	0.00	11.00	0.62	0.27
8297575	3571	USANDIZAGA	7	1910	0.18	1.00	1.00	1.00	1.00	1.00	1.00	0.69	0.60	0.00	0.78	1.00	12.00	0.62	0.27
8297576	3516	RAMON MARIA LILI, PS	2	1922	0.00	1.00	1.00	1.00	1.00	0.00	1.00	0.69	0.60	1.00	0.78	0.00	16.00	0.62	0.86
8297579	2515	ZURRIOLA, AV DE	6	1910	0.00	1.00	1.00	1.00	1.00	1.00	1.00	0.69	0.60	0.00	0.78	0.00	14.00	0.62	0.27

8297584	3528 PEÑA Y GOÑI	5	1926	0.18	1.00	1.00	1.00	1.00	1.00	1.00	0.69	0.00	1.00	0.78	1.00	12.00	0.62	0.27
8297585	2524 PEÑA Y GOÑI	3	1920	0.00	0.00	1.00	1.00	1.00	1.00	1.00	0.69	0.60	0.00	1.00	0.00	26.00	0.62	0.27
8297586	3491 PEÑA Y GOÑI	4	1920	0.00	1.00	1.00	1.00	1.00	1.00	1.00	0.69	0.60	0.00	0.78	0.00	20.00	0.62	0.27
8297587	3573 USANDIZAGA	5	1900	0.00	1.00	1.00	1.00	1.00	1.00	1.00	0.69	0.60	0.00	0.78	1.00	17.00	0.62	0.27
8297588	2522 ZURRIOLA, AV DE	12	1925	0.00	0.00	1.00	1.00	1.00	1.00	1.00	0.69	0.60	1.00	1.00	1.00	12.00	0.62	0.27
8297589	2523 PEÑA Y GOÑI	1	1926	0.18	1.00	1.00	1.00	1.00	1.00	1.00	0.69	1.00	0.00	0.78	0.00	15.00	0.62	0.86
8297590	2539 PEÑA Y GOÑI	2	1912	0.00	0.00	1.00	1.00	1.00	1.00	1.00	0.69	0.60	1.00	0.78	1.00	14.00	0.62	0.27
8297600	3515 USANDIZAGA	3	1920	0.18	1.00	1.00	1.00	1.00	1.00	1.00	0.69	0.60	0.00	0.78	1.00	23.00	0.62	0.86
8297602	3539 RAMON MARIA LILI, PS	1	1915	0.00	1.00	1.00	1.00	1.00	0.00	1.00	0.69	0.60	1.00	0.78	0.00	35.00	0.62	0.86
8297603	3538 ZURRIOLA, AV DE	4	1910	0.00	1.00	1.00	1.00	1.00	0.00	1.00	0.69	0.60	0.00	0.78	0.00	17.00	0.62	0.27
8396057	8957 SIERRA DE ARALAR	3	1944	0.00	0.00	0.00	1.00	0.49	0.00	0.00	0.69	0.60	0.00	1.00	0.00	6.00	0.54	0.00
8396157	9003 MATXIÑENE	12, 14	1933	0.00	0.00	1.00	1.00	0.49	0.00	0.38	0.69	1.00	0.00	1.00	1.00	4.00	0.54	0.00
8396351	9016 URBIA	5, 6	1985	0.00	0.00	1.00	0.00	0.49	0.00	0.38	0.69	0.60	0.00	1.00	0.00	3.00	0.54	0.00
8396352	9140 MATXIÑENE	6	1927	0.00	0.00	1.00	0.00	0.49	0.00	0.38	0.69	1.00	0.00	1.00	1.00	2.00	0.54	0.00
8396353	9141 MATXIÑENE	8	1920	0.18	1.00	1.00	0.00	0.49	0.00	0.38	0.69	0.60	0.00	1.00	1.00	5.00	0.54	0.00
8396354	9021 MATXIÑENE	11, 13	1933	0.00	0.00	1.00	1.00	0.49	0.00	0.38	0.69	1.00	0.00	1.00	0.00	4.00	0.54	0.00
8396355	9134 MATXIÑENE	3, 5	1933	0.00	0.00	1.00	1.00	0.49	0.00	0.38	0.69	1.00	0.00	1.00	0.00	4.00	0.54	0.00
8396356	9019 MATXIÑENE	9	1933	0.18	0.00	1.00	1.00	0.49	0.00	0.38	0.00	1.00	0.00	1.00	0.00	4.00	0.54	0.00
8396364	9011 URBIA	2, 3, 4	1972	0.00	0.00	1.00	1.00	1.00	0.00	0.38	0.00	0.60	0.00	1.00	1.00	3.00	0.54	0.00
8396367	9006 URBIA	17, 18, 19	1933	0.00	1.00	0.50	0.00	0.00	0.00	0.38	0.69	0.60	1.00	0.78	0.00	5.00	0.54	0.00
8396368	9009 URBIA	26	1930	0.00	1.00	0.50	0.00	0.49	0.00	0.38	0.00	0.60	0.00	0.78	0.00	2.00	0.54	0.00
8396369	9010 URBIA	25	1918	0.00	0.00	0.50	1.00	0.49	0.00	0.00	0.69	0.60	1.00	1.00	0.00	2.00	0.54	0.00
8396370	9025 URBIA	24	1918	0.00	0.00	0.50	1.00	0.49	0.00	0.00	0.69	0.60	1.00	1.00	0.00	2.00	0.54	0.00
8396371	9040 URBIA	23	1940	0.73	0.00	0.50	1.00	0.49	0.00	0.38	0.69	1.00	0.00	1.00	0.00	3.00	0.54	0.00
8396372	9033 URBIA	20, 21, 22	1933	0.73	1.00	0.50	0.00	0.49	0.00	0.38	0.69	0.60	0.00	0.78	0.00	4.00	0.54	0.00
8396373	9022 URBIA	10	1933	0.00	0.00	0.50	0.00	0.49	0.00	0.38	0.69	1.00	1.00	0.78	0.00	3.00	0.54	0.00
8396374	9041 URBIA	9	1933	0.18	1.00	0.50	0.00	0.49	0.00	0.38	0.69	1.00	0.00	0.78	0.00	3.00	0.54	0.00
8396375	9023 URBIA	11	1930	0.00	1.00	0.50	0.00	0.49	0.00	0.38	0.69	1.00	1.00	0.78	0.00	3.00	0.54	0.00
8396376	9036 URBIA	13, 14	1933	0.00	1.00	0.50	0.00	0.49	0.00	0.38	0.69	1.00	1.00	0.78	0.00	2.00	0.54	0.00
8396419	9031 MATXIÑENE	10	1933	0.18	1.00	1.00	1.00	0.49	0.00	0.00	0.69	1.00	0.00	0.78	0.00	4.00	0.54	0.00
8397200	2536 RAMON Y CAJAL	6	1925	0.73	1.00	1.00	1.00	1.00	1.00	1.00	0.69	0.00	0.00	1.00	1.00	13.00	0.62	0.27
8397242	2526 USANDIZAGA	17	1925	0.00	0.00	1.00	1.00	1.00	1.00	1.00	0.69	0.60	0.00	1.00	1.00	13.00	0.62	0.27
8397337	2534 ZURRIOLA, AV DE	16	1945	0.00	0.00	1.00	1.00	1.00	0.00	0.38	0.69	0.60	1.00	1.00	1.00	7.00	0.62	0.27
8397338	2521 MIGUEL IMAZ	4	1944	0.00	0.00	1.00	1.00	1.00	0.00	0.38	0.69	0.60	1.00	1.00	1.00	14.00	0.62	0.27
8397339	2519 MIGUEL IMAZ	6	1944	0.00	0.00	1.00	1.00	1.00	1.00	0.38	0.69	0.60	1.00	1.00	1.00	15.00	0.62	0.27
8397340	2520 MIGUEL IMAZ	8	1925	0.18	1.00	1.00	1.00	1.00	1.00	1.00	0.69	0.60	0.00	0.78	0.00	12.00	0.62	0.27
8397341	2529 USANDIZAGA	19	1925	0.18	1.00	1.00	1.00	1.00	1.00	1.00	0.69	0.60	0.00	0.78	0.00	12.00	0.62	0.27
8397363	2506 RAMON Y CAJAL	4	1953	0.73	1.00	1.00	1.00	1.00	0.00	0.38	0.69	0.60	0.00	1.00	1.00	14.00	0.62	0.27
8397364	2528 ZURRIOLA, AV DE	22	1952	0.00	0.00	1.00	1.00	1.00	0.00	0.38	0.22	0.60	1.00	1.00	1.00	14.00	0.62	0.27
8397365	2508 USANDIZAGA	21	1924	0.00	0.00	1.00	1.00	1.00	1.00	1.00	0.69	0.60	0.00	0.78	1.00	26.00	0.62	0.61
8397366	2509 MIGUEL IMAZ	5	1919	0.00	1.00	1.00	1.00	1.00	1.00	1.00	0.69	0.60	0.00	0.78	0.00	13.00	0.62	0.27
8397367	2498 MIGUEL IMAZ	3	1932	0.00	1.00	1.00	1.00	1.00	1.00	1.00	0.69	0.60	0.00	0.78	0.00	12.00	0.62	0.27
8397369	2502 ZURRIOLA, AV DE	18	1936	0.00	0.00	1.00	1.00	1.00	1.00	0.38	0.69	0.60	0.00	1.00	1.00	15.00	0.62	0.61
8397377	2499 MIGUEL IMAZ	1	1940	0.00	0.00	1.00	1.00	1.00	1.00	0.38	0.69	0.60	0.00	1.00	1.00	12.00	0.62	0.61
8397380	2504 USANDIZAGA	27	1925	0.18	1.00	1.00	1.00	1.00	1.00	1.00	0.69	0.60	0.00	1.00	0.00	12.00	0.62	0.27
8397383	2505 USANDIZAGA	25	1923	0.00	1.00	1.00	1.00	1.00	1.00	1.00	0.69	0.60	0.00	0.78	1.00	12.00	0.62	0.27
8397384	2510 USANDIZAGA	23	1923	0.00	1.00	1.00	1.00	1.00	1.00	1.00	0.69	0.60	0.00	0.78	0.00	12.00	0.62	0.27
8397389	2503 ZURRIOLA, AV DE	20	1906	0.00	1.00	1.00	1.00	1.00	1.00	0.38	0.69	0.60	0.00	1.00	1.00	7.00	0.62	0.27
8397390	2507 ZURRIOLA, AV DE	22	1931	0.00	1.00	1.00	1.00	1.00	0.00	0.38	0.69	0.60	0.00	1.00	1.00	7.00	0.62	0.27
8397716	2537 USANDIZAGA	13	1920	0.18	1.00	1.00	1.00	1.00	1.00	1.00	0.69	0.60	0.00	1.00	1.00	12.00	0.62	0.27
8397717	2516 ZURRIOLA, AV DE	14	1925	0.00	0.00	1.00	1.00	1.00	1.00	1.00	0.69	0.60	0.00	1.00	1.00	12.00	0.62	0.27
8397718	2527 ZURRIOLA, AV DE	16	1949	0.00	0.00	1.00	1.00	1.00	1.00	0.38	0.69	0.60	1.00	1.00	1.00	9.00	0.62	0.27
8397719	3486 USANDIZAGA	11	1925	0.00	0.00	1.00	1.00	1.00	1.00	1.00	0.69	0.60	0.00	1.00	0.00	12.00	0.62	0.27
8397720	2525 USANDIZAGA	15	1924	0.00	1.00	1.00	1.00	1.00	1.00	1.00	0.69	0.60	0.00	1.00	1.00	12.00	0.62	0.27
8397728	3487 USANDIZAGA	9	1900	0.00	0.00	1.00	1.00	1.00	1.00	1.00	0.69	0.60	0.00	1.00	1.00	13.00	0.62	0.27
8496055	9108 SIERRA DE ARALAR	15	1940	0.73	1.00	1.00	0.00	0.49	0.00	0.38	0.22	1.00	0.00	0.29	0.00	1.00	0.54	0.00
8496065	9136 SIERRA DE ARALAR	17	1900	0.18	1.00	1.00	0.00	0.00	0.00	1.00	0.00	1.00	0.00	0.78	1.00	0.00	0.54	0.00