UNIVERSITAT DE BARCELONA

Public space design for flooding:
Facing the challenges presented by climate change adaptation

Maria Cabral Matos Silva Aires Pereira

Universitat de Barcelona

Programa de Doctorado Espacio Público y Regeneración Urbana.
Arte, Teoría, Conservación del Patrimonio
Facultat de Belles Arts. Universitat de Barcelona

Public space design for flooding

Facing the challenges presented by climate change adaptation

Maria Cabral Matos Silva Aires Pereira

Directores: Doctor João Pedro Teixeira de Abreu Costa,
Doctora Mª Cristina da Fonseca Ataíde Castel-Branco

Tutor: Doctor Antoni Remesar

Tesis Presentada para la obtención del grado de doctor | Septiembre, 2016

Apoyo:

FCT Fundação para a Ciência e a Tecnologia
MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E ENSINO SUPERIOR

Programa de Doctorado Espacio Público y Regeneración Urbana: Arte, Teoría, Conservación del Patrimonio
Facultat de Belles Arts
Universitat de Barcelona

Public space design for flooding:

Facing the challenges presented by climate change adaptation

Maria Cabral Matos Silva Aires Pereira

Directores:
Doctor João Pedro Teixeira de Abreu Costa
Doctora Mª Cristina da Fonseca Ataíde Castel-Branco

Tutor:
Doctor Antoni Remesar

Tesis Presentada para la obtención del grado de doctor

Septiembre, 2016

This work was supported by the individual doctoral grant provided by the Portuguese Foundation for Science and Technology (SFRH / BD / 76010 / 2011) as part of the POCH - Human Capital Operational Programme in conjunction with the European Social Fund and National Funds of the Ministry of Education and Science.

HONRA TEUS AVÓS

Abstract

The urban phenomenon of floods is recurrent and is expected to be aggravated in the near and distant future, not only in light of climate change projections, but also if flood management approaches continue the path of "business as usual".

Facing this problem-matter, this research proposes the design of public spaces as a key component in the adaptation to current and expected urban flood events.

Climate change adaptation endeavours have already entered the urban agenda and are influencing urban planning and public space design approaches. This emerging tendency is further prompting new flood management paradigms that acknowledge the practice of integrating ecosystems and the natural water cycle.

This research develops a solution-directed process, which is particularly attentive to design and envisions a direct application in contemporary practice. Its main objective is to develop a conceptual framework of flood adaptation measures applicable in the design of public spaces. A framework that aims to offer a wide range of systematized conceptual solutions, in order to promote and facilitate the initial stages of a public space project with flood adaptation capacities. Its relevance and applicability are tested in the case of the municipality of Lisbon.

Overall, by approaching the subject of urban flooding through public space design, conventional responses, practiced through singular and segregated disciplinary approaches, are confronted with the rich and wide-ranging and interdisciplinary benefits brought by public space.

Keywords

Public Space, Flood Management, Climate Change Adaptation, Urban Planning, Lisbon.

Resumen

El fenómeno urbano de las inundaciones es recurrente y se espera que se agrave en el futuro cercano y lejano, no sólo a la luz de las proyecciones de cambio climático, pero también si los enfoques de la gestión de inundaciones continúan el camino de "*business as usual*".

Enfrentando esta temática, la investigación propone el diseño del espacio público como un componente clave en la adaptación a los eventos de inundación urbana actuales y estimados.

Los esfuerzos de adaptación a los cambios climáticos ya han entrado en la agenda urbana y están influyendo en el planeamiento urbano y en el diseño del espacio público. Esta tendencia emergente está también impulsando nuevos paradigmas de gestión de inundaciones que reconocen la práctica de la integración de los ecosistemas y del ciclo natural del agua.

La tesis desarrolla un enfoque dirigido a la práctica, prestando una especial atención al diseño y previendo una aplicación directa en el proyecto contemporáneo. Su objetivo principal es desarrollar un marco conceptual de las medidas de adaptación a inundaciones aplicables en el diseño de los espacios públicos. Un marco que ofrezca una amplia gama de soluciones conceptuales sistematizadas, con la finalidad de promover y facilitar las etapas iniciales de un proyecto de espacio público con las capacidades de adaptación a inundaciones. Su relevancia y aplicabilidad son testadas en el caso del ayuntamiento de Lisboa.

En síntesis, al abordar el tema de las inundaciones urbanas a través del diseño del espacio público, las respuestas convencionales, practicadas aisladamente en ámbitos disciplinares estrictos, se enfrentan a los beneficios amplios e interdisciplinarios aportados por el espacio público.

Palabras clave

Espacio Público, Gestión de Inundaciones, Adaptación a los Cambios Climáticos, Urbanismo, Lisboa.

Resumo

O fenómeno urbano das inundações é recorrente e espera-se que se agrave num futuro próximo e distante, não só à luz das alterações climáticas estimadas, mas também se as aproximações da gestão de inundações continuarem o caminho do "*business as usual*".

Enfrentando esta questão, a investigação propõe o desenho do espaço público como um componente chave na adaptação aos eventos de inundação urbana atuais e estimados.

Os esforços de adaptação às alterações climáticas já entraram na agenda urbana e marcam presença no planeamento urbano e no desenho do espaço público. Esta tendência emergente está também a impulsionar novos paradigmas de gestão de inundações que reconhecem a prática da integração dos ecossistemas e do ciclo natural da água.

A tese desenvolve uma abordagem orientada para a prática, prestando especial atenção ao desenho e prevendo uma aplicação direta no projeto contemporâneo. O seu principal objetivo é desenvolver uma matriz conceptual de medidas de adaptação a inundações aplicável no desenho dos espaços públicos. Um quadro que forneça uma ampla gama de soluções conceptuais, sistematizadas, com vista a promover e facilitar as etapas iniciais de um projeto de espaço público com capacidades de adaptação a inundações. A sua relevância e aplicabilidade são testadas no caso do município de Lisboa.

Em síntese, ao abordar o tema das inundações urbanas através do desenho do espaço público, as respostas convencionais, praticadas isoladamente em âmbitos disciplinares estritos, são confrontadas com os benefícios amplos e interdisciplinares oferecidos pelo espaço público.

Palavras-chave

Espaço Público, Gestão de Inundações, Adaptação às Alterações Climáticas, Urbanismo, Lisboa.

Acknowledgements

I would firstly like to express my gratitude to my advisor Professor João Pedro Costa, who has been a great mentor. I would like to thank him for encouraging and promoting my research, for allowing me to develop as a researcher and in my teaching experience, and for showing understanding and patience whilst at the same time providing important critique throughout these years.

Furthermore, I would like to thank my co-advisor Professor Cristina Castel-Branco, whose guidance and advices dates back over many years; and Professor Antoni Remesar, for being my tutor. I am particularly grateful for the many conversations with Professor Pedro Brandão who has helped me question concepts and assumptions throughout the unfolding of this dissertation, therefore raising the standards of the ongoing reasoning process. I would like to extend my appreciation to all the doctorate's committee members, Professor Sergi Valera, Professor Nuria Ricart, Professor Joana Cunha Leal and Professor Lino Cabezas, for their yearly assessments and insights regarding my research. Finally, I would like to thank the availability and generosity of Professor José Saldanha Matos and Eng. Silva Santos, who have shared their thoughts and experiences particularly in relation to Lisbon's Drainage Master Plan.

The importance of Polis Research Centre and Universitat de Barcelona in the course of this investigation must be additionally acknowledged. I am also particularly grateful to the Faculty of Architecture at the University of Lisbon, and to its Research Centre for Architecture, Urbanism and Design (CIAUD), in providing the opportunity for me to complete my research there.

This research would not have been possible without the funding from the Portuguese Foundation for Science and Technology, for which I am also very thankful.

From Barcelona to Lisbon, new colleagues became new friends and made this journey even more enjoyable. A particular thank you goes to André Nouri, who was kindly supportive in the final efforts.

Last but not the least, I dedicate this thesis to all my old friends, who have always been there for me, and to my dearest family. To my grandparents for their ever wise advices. To my parents and my parents-in-law for their loving availability helping with family management. To my sister who always reminds me of the value of rigor and intellectual honesty. To Tomás, my beloved husband, for being the strength that stimulated and sustained this professional goal, and to our cherished daughter Luísa who, fortunately, obliged me to live beyond this research.

Contents

Introduction

Floods are a recurring phenomenon that disrupts our cities on a regular basis; they can cause environmental damages, displace population and even the loss of lives. Floods can also seriously compromise economic activities and economic development.

Quite recently in this year (2016), devastating floods have occurred in São Paulo, Brazil, in March; also in Oklahoma and Texas, in the United States during May; in several European regions from May to June (mostly in Germany, France and the United Kingdom); in Maryland, United States in July and; more recently, in Louisiana, United States in August (The Flood Observatory 2016). According to Centre for Research on the Epidemiology of Disasters (CRED), more specifically its Emergency Events Database (EM-DAT), the number of recorded flood events has been expressively increasing, particularly in the past decades (Jha et al. 2012).

Changing this rising tendency is a massive challenge, particularly when considering the continued research that has been consolidating knowledge on climate change projections, pointing towards an even greater number of flood events per year. Considering, for instance, the findings from the Intergovernmental Panel on Climate Change (IPCC), flood events are likely to increase not only due to projected sea level rise (SLR) but also due to the projections which indicate more intense and frequent extreme precipitation events in many regions (IPCC 2014).

Bearing in mind that conventional flood management infrastructure is mostly designed in accordance to statistical recurrence criteria, originating from available historic meteorological data, the same method may not be able to cope with the expected unprecedented flood events.

Indeed, projections have indicated a tendency towards an increase in the intensity of the precipitation events together with a decrease of the return period for some regions (EEA 2012). As such, although we have always lived and will continue to live with a changing climate, our cities and infrastructure are not prepared to face the projected exceptional changes for the next 100 years (Schiermeier 2011), which makes most of the existing infrastructure inadequate. On the other hand, altering the existing flood management systems from one moment to another in order to follow the predicted climate change scenarios would involve unreasonable investments, that are very likely unaffordable for the municipalities in the near future. Adaptation to projected flood events is therefore gaining relevance as one of the biggest challenges of the next century.

With much controversy, reinforced by the irrefutable fact regarding the uncertainty about the future, the concern about climate change impacts, and the consequent need to act upon them, is high on the international political agenda[1].

In the 2016's Global Risks Report, presented at the World Economic Forum, the "failure of climate-change mitigation and adaptation" is stressed as the major "global risk of highest concern" for the next 10 years, being furthermore considered to have greater potential damage than "weapons of mass destruction" placed as the second most important risk before "water crisis" in third (WEF 2016). The thesis question derives precisely in the face of this widespread concern, specifically tackling the threat of future urban floods and the adaptation action.

Recognizing that present flood management infrastructures are not sufficient to respond to the scale and speed of estimated flooding impacts, flood management practice is currently facing an urging need to reassess and improve current methods. The challenge put forward by climate change, that is putting infrastructure to its limits, is forcing flood management practices to move beyond modernist/sectorial paradigms and welcome multidisciplinary and interdisciplinary approaches. It is in this line of reasoning that the design of public spaces finds a niche of potentiality for climate change adaptation.

In general terms, the present relationship between urban planning and flood management infrastructure consists on punctual actions,

[1] Referring just a few statements made during the near-universal Leaders Event at the Paris Climate Change Conference (COP 21): Ban Ki-moon mentioned that "Bold climate action is in the national interest of every single country represented at this conference"; Barak Obama expressed his concerns on how "the growing threat of climate change could define the contours of this century more dramatically than any other" and that the biggest enemy to be fought at the conference was "the notion we can't do anything about climate change"; also Angela Merkel highlighted that "This (agreement) is a question of both ecological necessity and economic common sense. It is a question of intergenerational equity. It is a question of our humanity, and on it depends the future of the human race" United Nations, 2015. *Statements made during the Leaders Event at the Paris Climate Change Conference - COP 21 / CMP 11* [online]. United Nations Framework Convention on Climate Change. Available from: http://unfccc.int/meetings/paris_nov_2015/items/9331.php [Accessed 18th August 2016].

manipulated by political priorities, and where potential solutions are carried out only when complications are already in a severe state. This type of approach is particularly deceptive in light of future projected scenarios.

Estimated projections are indicative rather than definite, yet they are reliable as such. The fundamental ideas that infrastructure should be integrated into urban planning (Meyer 1999) and that urbanism should better consider estimated projections as drivers of change (Costa 2013) are not new. What is here proposed, is that by specifically introducing public space design in all planning stages of flood management infrastructures, it may be possible to achieve significant developments in the agenda of urban flood adaptation.

Public spaces are here understood as multifunctional spaces, with a central social, political and cultural significance (Ricart and Remesar 2013). They are distinguished by their long-lasting permanence as a structuring urban space and they have an interdisciplinary nature. Implicitly, they are considered as a common entity of shared concerns, which may also accommodate civic purposes.

Public spaces are among the most vulnerable areas to climatic hazards, particularly flooding events, simultaneously they may show specific characteristics that are particularly relevant for adaptation efforts (CABE 2008). Indeed, both local know-how and locally-driven design should always be considered as added value for adaptation endeavours (Ruddell et al. 2012). Moreover, both people and communities can be perceived as more than susceptible targets and be professed as active agents in the process of managing urban vulnerability (Pelling 1997, IPCC 2012). Through a medium that is more accessible to people, climate change literacy may likely endorse an increased common need for action (Sheppard 2015) and the consequential pursuit of suitable solutions.

Specifically with regards to the physical capabilities of public spaces as flood risk management infrastructures, empirical evidence shows that through the design of public spaces, floodwaters can be namely 1) conveyed, 2) infiltrated, 3) harvested, 4) stored, 5) avoided or 6) tolerated (Figure 0.1).

By integrating flood management practices into the design of public spaces, what was previously strictly seen through an engineering perspective is embraced at the core of an interdisciplinary design process.

Figure 0.1 - Left (1): Old city centre of Banyoles, Girona, Spain. Image credits: Adrià Goula.
Right (2): Can Caralleu, Barcelona, Spain. Image source: (Vidiella and Zamora 2011, p.160).
Left (3): Green facade at the Caixa Forum plaza, Madrid, Spain. Image credits: Maria Matos Silva, 2014.
Right (4): Benthemplein square in Rotterdam, The Netherlands. Image credits: Maria Matos Silva, 2014.
Left (5): Coastal defence promenade in Blackpool, United Kingdom. Image credits: © Dixi Carillo, 2008.
Right (6): Floating square over the wetland of Yongning River. Image credits: Kongjian Yu/Turenscape.

One may identify a wide range of current and past situations where a public space is combined together with one or more flood risk management measures (examples may be found namely in Quintino 2011, and Prominski et al. 2012). One may furthermore witness more recent examples where public spaces and flood risk management measures are explicitly integrated within climate change adaptation purposes (Matos Silva 2014). These examples can be seen as encouraging and promoters of new thinking, new solutions and, eventually, new paradigms (Matos Silva and Costa 2016).

However, there is still a considerable amount of unconnected information between the interrelated fields of adaptation, knowledge and public space design. A particularly weak point is shown by the frail link between theoretical scientific findings and professional exercise of comprehensive application. In continuation from the R&D project "Urbanized Estuaries and Deltas" (Costa et al. 2013), the question remains on "how" to expand this matter into practice.

Although not as a focal issue, flood adaptation measures applied in the design of public spaces have been sporadically discussed by a range of diverse literary examples, which can be seen in various scientific journals, books, research reports, conference proceedings and workshops. Particularly for those involved in the design of public spaces that incorporate flood adaptation efforts, analysing the existing knowledge is crucial. Nevertheless, analysing the existing knowledge must be done in a systematic way, otherwise it may present unsatisfactory results when considering the time frame of one design proposal.

As such, in order to increase the rate of successful flood adaptation endeavours, fulfil municipal goals for more adaptive cities and facilitate the initial brainstorming phases of a design process, this research aims to provide a Conceptual Framework of urban flood adaptation measures applicable to the design of public spaces. A Conceptual Framework for those dealing with a public space design project or flood adaptation purposes, one which they can easily understand and manage. A Conceptual Framework that anticipates to further aid its users by presenting a wide range of options, which are identified and characterized through a simple vocabulary and organized in a flexible and straightforward layout.

Overall, the Conceptual Framework's main goal aims at offering a different approach to tackle the urgent problem of urban flooding. Through a different perspective, one that highlights the importance of public space design in adaptation action, traditional flood risk management practices are confronted and potentially improved. What is commonly framed in the sphere of few and singular disciplines is here integrated within the multidisciplinary and interdisciplinary scope of public space design.

This research is therefore expected to contribute to the Public Space and Urban Regeneration thinking, as well as to Urbanism. By focusing the investigation upon Design, this research further aims to contribute to all the professional practices having involvement in the design of public spaces, reinforcing its interdisciplinary character, from urban planners to landscape architects, architects or engineers.

Hypothesis and objectives

This research is based on the hypothesis that **the design of public space is a key component on the urban adaptation to current and expected flooding events.**

In light of the proposed hypothesis, one main objective and five secondary objectives are proposed:

Main objective

- To create a Conceptual Framework that identifies, defines and organizes different types of urban flood adaptation measures applicable in the design of public space.

Secondary objectives

- Highlight how the climate change agenda is influencing urban planning and in particular, the design of public spaces;
- Highlight the contemporary need for a change of paradigm in flood risk management practices, reinforcing interdisciplinarity;
- Reason the importance of public spaces in climate change adaptation endeavours;
- Reason the potential benefits of integrating public space design in present and future flood risk management undertakings;
- Assess the relevance and applicability of the proposed Conceptual Framework upon the specific case of the city of Lisbon, Portugal.

Research approach

This research follows a deductive approach following the classic three stages approach 1) to deepen the problematic, 2) to demonstrate the hypothesis and 3) to assess overall findings of the developed research.

The stage "to deepen the problematic" is tackled in Part I of this thesis, entitled "Exploration". In this first part, the investigation dwells upon the inter-related implications of the two core subject-matters that have motivated this research – anthropogenic climate change impacts and current flood risk management practices – focusing on their relation with the design of public spaces.

The second stage, aiming "to demonstrate the hypothesis", is tackled in Part II of the dissertation entitled "Experimentation". This part intends to evidence the specific advantageous characteristics of public space under the impending need for urban territories to adapt when facing the potential impacts of future flood events. It further aims to propose the Conceptual Framework, which is expected to systematize and organize a wide range of existing types of flood adaptation measures applicable in the design of public spaces.

Finally, the third stage, which envisions the "assessment of the overall findings", is tackled in Part III and it is entitled "Evaluation". As the name suggests, it is targeted at assessing the pertinence and applicability of the proposed Conceptual Framework in a specific context such as the city of Lisbon.

Recalling Umberto Eco, it is recognized that studying contemporary issues is always more difficult and more risky than studying past or circumscribed subjects in time. Whereby for the latter, it is likely that there are solid references to which one can refer, in regards to present-day matters, those are found in a developing field of knowledge full of conflicting findings. Umberto Eco additionally highlights how the researches' critical capacity to analyse a modern subject may be distorted by the lack of perspective (Eco 2010[1977]).

Assuming the aforementioned risks, this research choses the path of pragmatism and its associated knowledge claims that arise out of actions, situations, and consequences (Creswell 2008). A research approach that values different and various perspectives directed at the present and the future, with the goal to answer the question "what works"? A "problem-centred" and "solution-directed" research approach that foresees direct application in contemporary practice. In light of this abstract basis, a mixed methods approach, with different forms of data collection and analysis, is undertaken. In another perspective, it can be understood as a research orientated towards Design.

Thesis structure

The core of this thesis is composed by three parts that entail two chapters each.

Part I – Exploration comprises: **chapter 1**, which focuses on how anthropogenic climate change is prompting the emergence of new urban approaches that are influencing the design of public spaces; and **chapter 2**, which aims to evidence how flood risk management practices are being reassessed in light of the adaptation agenda and how this anticipated paradigm shift may be supported and enriched by public space design.

Part II – Experimentation includes: **chapter 3**, which delves into the subject of local flood adaptation action through public space design, empirically evidencing and characterizing a wide range of examples; and **chapter 4** where different types of flood adaptation measures are systematized and organized in a Conceptual Framework.

Part III – Evaluation entails: **chapter 5**, which aims to highlight the relevance of the proposed Conceptual Framework within the particular context of the city of Lisbon; and **chapter 6**, which is targeted at a practice-based analysis that subsequently evaluates the applicability of the adaptation measures specifically highlighted by the Conceptual Framework for the city of Lisbon.

Each part and each chapter encompass a brief introductory note, and each chapter has concluding discussions. Considering that some of the matters presented in the thesis include specialized and sometimes complex terms, a glossary, as well a list of abbreviations and acronyms, is further provided in order to facilitate the reading.

Methodology

Although the used methods will differ for each part of the thesis, there are some methodological aspects that are common throughout the research's approach. The first includes the goal to enrich overall findings with continuous contacts with experts. For this purpose, ongoing public dissemination of research findings were undertaken[2] together with the involvement in national and international networks[3]. In the same line of reasoning, this investigation was developed in English. An option that privileged the expanded reach of the international language of

---

[2] For each research stage, more or less evidenced by each chapter, there was an effort to disseminate research findings. Corresponding outputs, presented in the form of publications, are identified in the beginning of each chapter.

With regards to the present section on the research's methodology, ongoing developments were namely disseminated in following publication:

Matos Silva, M. and Costa, J. P., Urban flood adaptation through public space design. A contribute to a conceptual framework. EFLA Regional Congress 2011- Mind the Gap. Landscapes for a new era. , 2011 Tallinn, Estonia, Acta Architecturae Naturalis ISSN: 2228-1320. [Conference proceedings]

[3] As a result of the presented public dissemination of research findings, it was further possible to share and discuss the subject matters with international experts in related fields, such as Jan Gehl and Antje Stokman (at EFLA Regional Congress 2011, Tallin), Han Meyer (at Water & the City Workshop 2012 and Climate Change Adaptation in Urbanised Estuaries: Lisbon and the Tagus Conference), Jack Ahern (at ECLAS 2014, Porto) or José Saldanha Matos (Instituto Superior Técnico (IST), Lisbon). From the participation in the research project "Urbanized Estuaries and Deltas" (2013), additional contacts with experts were facilitated. The project developed a national and international networking on the subject, resulting in new collaborations with several distinguished scientists and institutions, namely with Filipe Duarte Santos and the Portuguese research centre CCIAM (Climate Change, Impacts, Adaptation and Modelling research group). As such, the debate of ideas among professors and colleagues who shared connecting fields of research was not only facilitated, but also encouraged. It is further important to highlight the network of experts provided by the enrolment in this PhD Program "Espacio Público y Regeneración Urbana: Arte, Teoría, Conservación del Patrimonio" and previous experience under the Master Degree "Disseny Urbà: Art, Ciutat, Societat". Both courses at Universitat de Barcelona, which provide a solid background of knowledge regarding the design and construction of public space from interdisciplinary perspectives (territory, society, art, environment). Lastly, through the research period at the research centre CIAUD (Faculty of Architecture of the University of Lisbon) it was possible to further expand academic networks.

scholarship, over potential constraints that the author is not a native English speaker.

In addition, considering the matter under study, there is a strong emphasis given to the so called "grey literature". The term grey literature, refers to governmental, academic or scientific literature that is not formally published, namely technical reports from government agencies or scientific research groups, working papers from research groups or committees or white papers. The majority of grey literature is considered primary literature as they comprise original writings on a subject.

The methodological aspects that are specific to each part of the thesis are subsequently described.

Part I – Exploration

The first stage of the dissertation follows from the developed works of the R&D project "Urbanized Estuaries and Deltas" (2013) and seeks to specifically deepen the interconnected implications between anthropogenic climate change and flood risk management practices upon the sphere of public space. This highlighted problem-matter is substantiated through a theoretical discussion based on burgeoning technical, scientific and grey literature on the subjects of climate change, adaptation and flood risk management practices. Primary references essentially refer to original documents, original research, technical reports as well as legal rules or regulations.

Considering the elected scope of the thesis, which is mostly practice oriented, the conducted research develops from an exploitative content of a panoramic nature. As such, and in light of the developed bibliographical review, the dissertation begins by exploring the matter of global anthropogenic climate change as a trigger for a new urban agenda. It then scrutinizes the concept of climate change adaptation and questions the urgency to act in the face of uncertainty. It further analyses three international cases (namely the Netherlands, United States and the United Kingdom), which have been particularly proactive in the implementation of climate change adaptation strategies in their cities, more specifically with regards to the adaptation towards the expected impacts of increased flood occurrences. This combined analysis is intended to showcase if new paradigms, instigated by the need to tackle climate change and its projected impacts, are emerging within contemporary urban approaches, and in public space designs in particular.

At the same time, flood determinants and intensifying factors are generically analysed, including the expected influence of climate change projections emanating from scientific literature. The historic evolution of flood management practices are also concisely analysed and contrasted with the contemporary *avant-garde* practices embraced by the cities of Rotterdam, New York and London. These tasks are envisioned to explore and question a potential tendency concerning a shift of paradigm in conventional flood management practices. A change towards a new approach triggered by climate change projections, which is potentially reconfiguring the relationship between the city and water.

Part II – Experimentation

The second part of the dissertation is targeted at demonstrating the enhanced role of public spaces when facing local adaptation action, and to develop a Conceptual Framework that identifies, defines and organizes different types of urban flood adaptation measures, which are applicable in the design of public spaces.

These goals are approached through systemic assessments of scientific, grey and technical literature reviews, together with data collection, data analysis and field trips. Primary references will essentially entail original documents, original research, technical reports and direct observation.

Conceptual Framework construction – a specific methodology[4]

The goal to create a Conceptual Framework of urban flood adaptation measures applicable to the design of public spaces is essentially directed at assisting anyone involved in the process of designing a public space with the capacity to integrate flood adaptation responses. It is further based on the premise that it is not up to the investigator to decide what the best solution for a specific place is, but rather to enumerate, organize and characterize a range of different possible solutions.

The Conceptual Framework's overall resulting output is therefore intended to be: (1) of a generic nature, yet capable of including an amplified range of alternatives; (2) simple in form and content, so that users find it easy to work and rationalize with; and (3) flexible to change in light of newly discovered information. The framework is further aspired to include a specific vocabulary that eliminates mainstreamed

---

[4] This section was developed from the following publication:

Matos Silva, M. and Costa, J. 2016. Flood Adaptation Measures Applicable in the Design of Urban Public Spaces: Proposal for a Conceptual Framework. *Water,* 8(7), 284.

redundancies (i.e., different names given to the same type of measure) while adding new concepts emanating from contemporary designs.

Referencing Amos Rapoport, Rilley clarifies that "a theory explains, a model predicts, and a framework organises. A framework can be judged on its reasonableness and its utility, but claims no exclusivity vis-à-vis other frameworks." (Riley 1990, p.49). The proposed Conceptual Framework is therefore a specifically systematized conceptual organization that supports and encourages flood adaptation measures to be integrated in the design of public spaces.

The framework's construction is supported by three main tasks. The first two are parallel and endorse each other. As illustrated in Figure 0.2, these two tasks include: an empirical data collection, here named "portfolio screening", corresponding to a specific database of examples; and a particularly targeted literature review focused on external research findings related to previously developed frameworks on adaptation measures. **Task 1** supports the initial conceptual identification of categories of flood adaptation measures applicable in the design of public spaces. **Task 2**, alongside, enables the identification of the subsequent types of flood adaptation measures applicable in the design of public spaces. Both of these mentioned tasks are specifically sustained by scientific, grey and technical literature, data analysis, networking, site visits, empirical observations and simplified/interpretative sketches.

Task 3 consists on materializing the envisioned Conceptual Framework through a particular classification process, which analyses the previously identified categories and types of flood adaptation measures applicable in the design of public spaces.

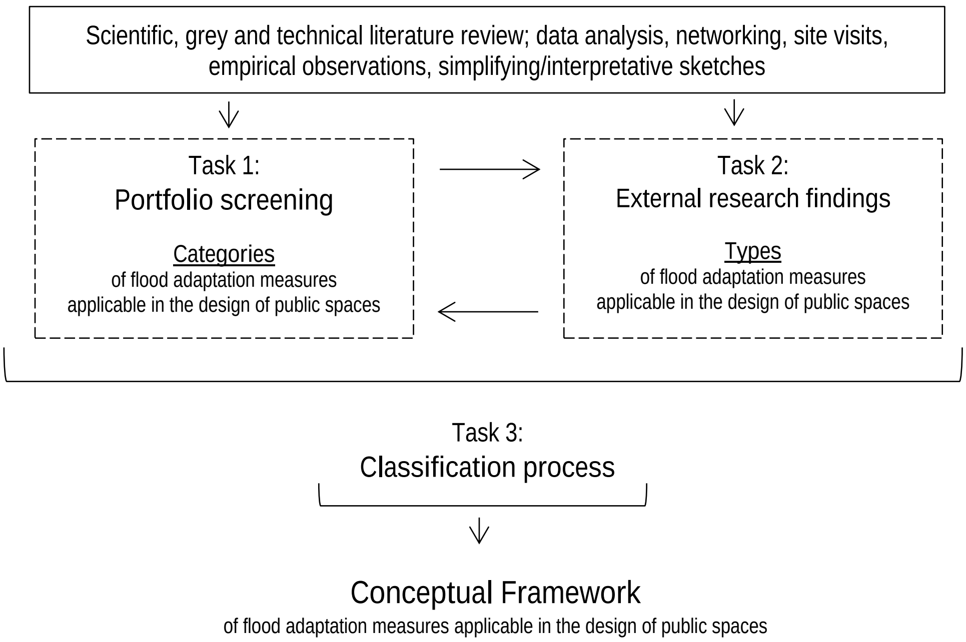


Figure 0.2 – Methodological scheme for the construction of the Conceptual Framework.

Task 1

The portfolio screening consists of an empirical data collection of existing examples of public spaces with flood adaptation purposes. This specific analysis is based on comprehensive case studies highlighted in research projects and also on further bibliographical reviews, networking and in onsite visits. Besides including main or secondary functions related to flood vulnerability reduction, the chosen range of examples also aims to unveil intellectual treasures from existing designs and select "good quality" cases (PPS 2003) among a comprehensive group of public space typologies (such as in Brandão 2011).

The examples that form part of the portfolio screening are progressively identified throughout the dissertation. Ideally, the assembled range of cases would provide a geographically representative scope, however, the projects with greater dissemination and improved access to information are privileged. Regardless, the portfolio screening is not developed as an end to itself, and should not be considered comprehensive, but rather a significant sample of real-case situations that support and enrich the conceptual classification process. More importantly, it serves to show case examples that can be applicable to different contexts and with different purposes, hence providing further valuable information that may assist the decision-making throughout the design processes.

In light of the gathered examples, which are considered as solid grounds for the assessment of flood adaption action, it is proposed an initial conceptual identification of **categories** of flood adaptation measures applicable in the design of public spaces.

Task 2

Following on from task 1, the second task entails a targeted literature review focused on external research findings related to previously developed frameworks on adaptation measures. This task starts off by identifying and analysing previously-developed research endeavours that have proposed comprehensive frameworks, which included, or could be related to, climate change adaptation measures specifically related to urban flooding; in other words, flood risk management measures from the viewpoint of climate change projections.

Most of the identified comprehensive frameworks encompassed structural strategies and concomitant measures, which are not only related to urban stormwater systems (or urban drainage systems), but are also related to flood defences, embankment systems or building design.

In this line of reasoning, besides the requirements to identify 1) flood-related climate change adaptation measures that are 2) applicable to the design of public spaces, the selection process from the findings of previously-developed frameworks followed the additional criteria 3) to be relevant to urban contexts and 4) to include solely structural operational measures, that is, those which include technical design[5].

Most of the identified comprehensive studies are related to R&D projects and reports ordered by national or international governing entities. These projects, which have an average duration of three years, generally comprise vast and multidisciplinary teams and often involve international collaborations. Envisioning the best possible result, significant contributions, such as empirical observations and further research findings, are also considered in the Conceptual Framework's construction. Ultimately, information regarding the types of flood adaptation measures applied in the design of public spaces, gathered through the analysis of external research findings and empirical observations, started to provide repetitious results, which confirmed to be unnecessary the scrutiny from other sources.

Through a systematization process based on the outputs from the analysed studies and empirical observations, different **types** of flood adaptation measures applicable in the design of public spaces are specifically highlighted, simplified and compared with the help of multiple spreadsheets.

In the undertaken systematization process, common perspectives and redundancies are identified, specifically in the given nomenclature. In order to choose the most appropriate vocabulary for the scope of this research, a semantics analysis is also conducted; permitting further conceptual clarifications.

Based on a scientific, grey and technical literature review, as well as in data collection, networking, site visits and empirical observations, a synthetized characterization of each category and type of measure is advanced.

[5] This last criteria specifically aims to distinguish approaches that use design as a basic tool to face potential vulnerabilities, such as the ones associated with the projected increase of flood hazards. As a result, this separates the aforementioned criteria from those that are non-structural and more strategic, institutional, regulatory or political, such as forecasting, warning, information, evacuation, aid services, building codes or shared risk and compensations.

Lastly, drawn schemes of each type of measure are also developed, namely as a tool that facilitates the reasoning process behind the proposed typification and conceptualization.

Task 3

The Conceptual Framework is materialized once the categories and types of measures are classified in accordance to a specific subject-matter. Among the possible analysis are the classifications resulting from several questions: 1) for which type of flood is the measure most appropriate (pluvial, fluvial, groundwater, artificial drainage, coastal)?; 2) To which infrastructural strategy does the measure primarily relate to (harvest, store, infiltrate, convey, tolerate, avoid)?; 3) In what areas of the watershed are the measures applicable?; 4) What is the physical extent of the benefits provided by each measure (on-site; downstream, upstream, off-stream)?; 5) What is the estimated scale of the investments (building, neighbourhood, small town, urban regional)?; among others. Various frameworks can therefore be proposed after being subjected to a particular classification process. The range of possible organizations is as wide as the potentially numerous classifications of the identified types of measures and their corresponding examples.

In order to construct a Conceptual Framework of prompt utility, which directly evidences its potential practical use, it is chosen to classify the identified categories and types of measures in accordance with their infrastructural capacities. Each category and type of measure is therefore associated with one main and/or one or more secondary infrastructural purposes. Several concepts may describe various possible infrastructural strategies, yet the following comprehensive group is hereby used: harvest, store, infiltrate, convey, tolerate and avoid. By approaching the matter with the chosen commonly-used vocabulary and familiar technical notions, the communication and exchange of know-how are facilitated.

The classification process is primarily based on the analysis of the portfolio screening. More specifically, each classification dwells upon each specific public space example, and is based on empirical observations, as well as bibliographical information. As such, results must be revisited in light of new examples or new information about each substantiated situation. All measures are classified in accordance to their specific characteristics. There is no unjustified judgment of value and no particular disciplinary background is privileged. The more examples that are classified, the more accurate of an assessment can be made for each category and type of measure. Most analyses can lead to multiple classifications. Moreover, contributing to the complexity of the process, provided classifications are also likely to be intimately interlinked. Undeniably, the utility of each measure is highly dependable upon different circumstances. In order to further facilitate the understanding of the conceptual organization and provide enhanced transparency, the classification analysis will accompany the presented results.

Lastly, a visual output of the framework's contents is further anticipated. This output is specifically intended to be simple and easy to disseminate and communicate with, as well as capable to improve and be re-adjusted in light of new learnings. The proposed Conceptual Framework must therefore be designed in a forever open format, enabling reclassifications as well as the addition of new categories and types of measures. Bearing in mind the continuous and evolving knowledge inherent to the scope of this research, every result (categories and types of measures as well as the classification analysis) was constantly revisited throughout the investigation processes.

Part III – Evaluation

The third part of this dissertation is specifically focused on assessing the relevance and applicability of the proposed Conceptual Framework in a particular municipal context. The city of Lisbon, as a working case[6], is chosen for this purpose.

The suitability of the proposed Conceptual Framework is specifically assessed through the identification of Lisbon Municipality's recognized vulnerabilities and (re)actions in the face of past, present and projected future flooding events.

If using the Conceptual Framework is justified, its applicability is therefore assessed. More specifically, additional adaptation measures potentially highlighted by the Conceptual Framework, are subsequently evaluated through a practice-based analysis upon specific public spaces. In this sense, three illustrative preliminary designs are tested for three specific public spaces within the city of Lisbon, more specifically within the Alcântara Upper Basin. In order to assess the infrastructural relevance of the additionally proposed measures in a way that could be comparable

[6] This research acknowledged the difference between "case study" and "working case" as proposed by João Pedro Costa in his doctoral thesis (Costa, J. P., 2007. *La Ribera entre Proyectos. Formación y transformación del territorio portuario, a partir del caso de Lisboa.* PhD Thesis. TU Catalonia, Barcelona Technical Superior Scholl of Architecture.). Specifically, while the "case study" guides the overall investigation, the "working case" serves to introduce a contrast or materialize an idea or hypothesis.

with conventional engineering approaches, quantifiable estimates regarding source control volume capacity together with projected implementation scenarios are further developed.

Throughout the conducted research, it is intended to reinforce the contents of the Conceptual Framework in light of the municipal undertakings in adaptation research and applied examples, as well as to prompt new discussions specifically regarding current municipal flood management approaches and their relation with public space regeneration processes.

All the above mentioned goals are developed through essential scientific, grey and technical literature review; field reconnaissance; preliminary study designs; spatial analysis and quantitative analysis. While AutoCAD software was used in the development of the preliminary study designs, ArcMap software served the quantitative spatial analysis. Primary references essentially entail original documents, original research and technical reports.

Lisbon is selected as a "working case" taking into account the fact that it is a city that frequently suffers from urban flooding, a phenomenon which is potentially aggravated in light of climate change projections. Lisbon is also a large city in terms of area and population and, as a capital, it is a strategically important city within the region and country. Regarding the characteristics of the available information, Lisbon has additional value. More specifically, it is a city with a recently approved master plan (2012) in which climate change adaptation strategies and measures are particularly envisioned. It further corresponds to the same case study as the R&D project "Urbanized Estuaries and Deltas" from which this research emerged. Lastly, the access to the necessary information is facilitated in order to conduct the proposed research.

Following the same methodology, more working cases would serve to contrast results and thus enable more solid conclusions. Yet findings from the developed analysis are sufficient to evidence the relevance and applicability of the proposed Conceptual Framework, as well as to raise similar questions related to other contexts.

Regarding other limitations identified in the presented methodology, one may highlight: 1) the greater emphasis given to three occidental "developed" countries, 2) the latent subjectivity of the overall empirical analysis or 3) the undetailed quantifiable data (spatial and hydrological) used in the exploratory content of the final chapter of this dissertation.

Different approaches and types of measures could be highlighted by other, maybe less developed, countries. Yet the pragmatic approach conducted in the research focused on the international cases with already recognized best practices in adaptation undertakings.

Without doubt, the empirical analysis could also be improved by more field trips that would encompass all the identified examples, yet this improvement would have involved greater investments, both in time and money, unnecessary in the scope of this research.

Lastly, although the final chapter of the dissertation is openly exploratory in search of new questions, improved hydrological estimations with upgraded quantifiable data could be achieved namely through experimentation in a pilot project. Also a more detailed set of spatial data could be accomplished, namely if considering a more circumscribed study area that is interpreted through detailed field analysis.

Part I

Exploration

The first part of the thesis sets out to explore the two principal motives that have instigated the research, along with their associated relationship to the practice of public space design. More specifically, the subject-matter of global anthropogenic climatic change and by way of in its inter-related approach to flood risk management.

Chapter one focuses on how anthropogenic climate change is prompting the emergence of new urban approaches that inevitably influence the interdisciplinary practice of public space design. Subsequently, Chapter two aims to portray how conventional flood risk management methods are being reassessed in light of the emerging adaptation agenda. Also enclosed in this chapter, the role of public space, and their respective design, is assessed in terms of their potentiality to enrich and support such a paradigm shift within the contemporary city.

Chapter 1

Climate change adaptation as a trigger for new approaches on public space design

---

Parts of this chapter were disseminated in the following publications:

Matos Silva, M. and Nouri, A., 2014. Adaptation measures on riverfronts, an overview of the concepts. *In:* Costa, J. P. and Sousa, J. F. d. eds. *Climate Change Adaptation in Urbanised Estuaries Contributes to the Lisbon Case.* Óbidos: Várzea da Rainha Impressores, 131-150 ISBN: 978-989-98628-1-4. [Book Section]

Costa, J. P., *et al.* 2014. Climate change adaptation and urbanism: A developing agenda for Lisbon within the twenty-first century. *URBAN DESIGN International,* 19, 77-91. [Journal Article]

Nouri, A. S. and Matos Silva, M., 2013. Climate change adaptation and strategies: an overview. *In:* Helena Bártolo, *et al.* eds. *Green Design, Materials and Manufacturing Processes.* Lisbon: Taylor and Francis, 501-507 pp. ISBN: 978-1-138-00046-9. [Book Section]

The first chapter of the thesis explores the present-day issue of global anthropogenic climate change and its resulting influence as a trigger for new urban approaches, which are particularly influencing the design of public space.

It begins by evidencing the contrasting need to act in the face of uncertainty, namely within urban territories. Concurrently, cities can be seen as, on the one hand, major contributors to the exacerbation of the projected climate change phenomenon; and on the other, as contexts in which mitigation and adaptation efforts find their niche in counterbalancing such anthropogenic connotations. This chapter also further analyses the particular concept of climate change adaptation, ranging from its very definition, to the consequential jeopardies of maladaptation. Lastly, it focuses upon solid examples of adaptation efforts held within the international arena, such as those presented within the Netherlands, the United States of America, and the United Kingdom.

The developed analyses enabled the confirmation that the instigation associated to the climate change adaption agenda has led to the emergence of new urban paradigms and opportunities. For this reason, a contemporary challenge can thus be identified, one in which the interdisciplinary duties surrounding the practice of urbanism are reinforced namely through public space design.

1.1. Global anthropogenic climate change: the urgency to act in the face of uncertainty

It is better to be vaguely right than exactly wrong

Carveth Read [19/20th century British philosopher and logician].
Read, C., 2012(1898). Logic, Deductive and Inductive. Tredition Classics, p.351.

Time-frames of significant climate variability have occurred since the earth's origin and through its habited ages. Humans, often characterised as the most adaptable of animal species, have always been able to successfully adapt to altered climates. Moreover, throughout the vast majority of human history, we had a residual interference in the earth's natural systems. At least until the Industrial Revolution.

There have been several authors that since the modern environmental conservation movement, have argued that the period commonly identified as the Industrial Era, may be the cause of radical climatic changes. Among them are: George Perkins Marsh, who wrote "The Earth as Modified by Human Action" (1882), a pioneering book on conservation science; Nathaniel Shaler's book "Man and the Earth" (1905); Rachel Carsons' "Silent Spring" (1962); among others (Hebbert and Jankovic 2013) (Figure 1.1).

In 1975, Wally Broecker specifically engaged with the matter of anthropogenic global warming. Through his paper "Climatic Change: are we on the brink of a pronounced global warning?", Broecker was one of the first to argue that by the first decade of the XXI century, global temperatures would be warmer than any in the antecedent millennium (1975).

Later by the 1980s, sociologists Ulrich Beck and Anthony Giddens termed the concept of "risk society" when reflecting upon modernity, and in particular, the growing environmental concern. For Giddens, a risk society is "a society increasingly preoccupied with the future (and also with safety), which generates the notion of risk" (Giddens 1999a, p.3). At the same time, Beck describes risk as "a systematic way of dealing with hazards and insecurities induced and introduced by modernisation itself" (Beck 1992, p.21).

The severe ecological disruptions that have resulted from the industrial society, such as the climatic changes emphasized by the authors firstly mentioned, served as a key pillar for this analysis of the modern period. For Beck, environmental risks have become recurrent rather than exceptional. The author further argues, that this occurrence is a result of "manufactured constraints", or, in other words, the result of pressures that are significantly determined by human actions (Beck 1992). In order to clarify the difference between external or "natural" risks and "manufactured risks", Giddens elucidated that, "At a certain point, however – very recently in historical terms – we started worrying less about what nature can do to us, and more about what we have done to nature" (Giddens 1999b, p.3).

More recently, one of the most important reflections on this matter, may be the suggestion made by Nobel Laureate Paul Crutzen and Eugene Stoermer in 2000, that we have entered a new geological Era ahead of the Holocene. They coined the Era as the Anthropocene and defined it as an unprecedented age, in which humans are not just mere spectators, but the primary forces shaping the world (Crutzen and Stoermer 2000).

In 2002, Crutzen developed from his original article with a commentary in the journal Nature, the "Geology of Mankind", stating that "The Anthropocene could be said to have started in the late Eighteenth century when analysis of air trapped in polar ice showed the beginning of growing global concentrations of carbon dioxide and methane" (Crutzen 2002, p.23).

Looking into what is known about the earth's geological time scale, one may be a bit reluctant to accept the fact that the human species, which has existed for less than 1% of its history, could have had such a significant impact. However, the surprise diminishes, when recognizing that human action that has re-shaped the planet, is far faster than that of natural geological change. Among others, Crutzen and Stoermer' argue that: humankind has exhausted 40% of the known fossil fuels in only a few generations; nearly 50% of the land surface has been transformed by direct human action, from the dams holding sediment by the gigatonne, to the forests' devastation; more nitrogen is now fixed synthetically for fertilisers, than is fixed naturally in all terrestrial ecosystems; there are now less than 50% of mangroves protecting Coastal wetlands; Fisheries remove more than 25% of the primary production of the oceans, and more than half of all accessible freshwater is used for human purposes (Crutzen and Stoermer 2000).

Although the names given to the different geological Eras are of little interest to the core matter of the thesis, the case of the argued transition onto the Anthropocene entails further implications. It is an evolution connoted with the emergence of a clear awareness of an unbalanced relationship between people and their planet. As such, it further implies that a new way of thinking and acting is urgent. This inflicted existential analysis goes in line with the concept of "modern reflexivity", also widely argued by Beck and Giddens. For Beck, the key feature of "reflexivity" is the process of society examining itself and acting accordingly: "what was made by people can also be changed by people" (Beck 1992, p.157).

In 1988 the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) established the Intergovernmental Panel on Climate Change (IPCC), which is a scientific body of experts specialised in providing "a clear scientific view on the current state of knowledge in climate change and its potential environmental and socio-economic impacts" (IPCC 2015, p.1). Since then, this entity has been producing, at regular intervals, assessment reports (AR) on the state of knowledge on climate change, namely the 1990 First Assessment Report (FAR), 1995 Second Assessment Report (SAR), 2001 Third Assessment Report (TAR), 2007 Forth Assessment Report (AR4) and 2013-14 Fifth Assessment Report (AR5). During an assessment experience of a quarter of a century, there were substantial progressions among the published results. Experts contributing and assessing these reports also substantially increased in number. While the FAR had the contribution of ninety-seven authors, the AR4 received contributions from over 3500 experts, from more than 130 countries (IPCC 2015) (Figure 1.1).

Presently, there is a 97% consensus rate among climate experts in regards to anthropogenic global warming (Cook et al. 2013). The remaining 3% not only question the consensus of climate scientists, but also the consensus of evidence, which is mostly argued by the uncertainty associated to climate research.

Sources of uncertainty have been namely identified as arising from: measurement errors; aggregation errors; natural climate variability; future emissions of greenhouse gases (GHG); limited climate models; complexity in interaction of climatic and non-climatic factors; future changes in socio-economic, demographic and technological factors as well as in societal preferences and political priorities (EEA 2012a). Other concerns include the vulnerability of systems and regions, the conditions that influence vulnerability and particular attributes of adaptation, such as costs of implementation and maintenance, effectiveness and significance (Burton et al. 2001). For example, while the potential contribution of ice sheets to sea level rise (SLR) is very large, there are still many incomprehensible processes concerning their dynamics. As stressed by Michael Oppenheimer regarding this matter, "uncertainty is still large, and is unlikely to ever be reduced" and "it is also likely that, despite the enormous progress, the phenomena of the 21st century will anticipate their proved predictions" (2010, p.12). Arguments that not only question the existence of forthcoming perfect models, but that also highlight our present unpreparedness in regards to projected impending weather events.

Whilst in theory, some uncertainties may be reduced by further research, others simply cannot, as they are related to the future. Indeed, there is no way around uncertainty in climate change research. There is no way around the fact that no research will never be exact about the future. Scientists will only be capable of proposing ranges of partial or imperfect information that indicate approximate tendencies. By way of example, when projections on global mean temperatures present an uncertainty range between 2 and 4.5 °C, this means, that in spite of not being able to forecast exactly how many degrees the temperature will rise, it is virtually certain that the planet will continue to warm (EEA 2012a).

Regardless, "climate sceptics" will always haunt climate change action. According to Lourenço et al., up until recently, three basic approaches on adapting to an uncertain climate have been followed when analysing a significant number of real-life cases, namely: 1) It is necessary to reduce uncertainties before making a decision on how to proceed; 2) Uncertainties are considered too large and act either as a barrier to decisions or as a motive to postpone them or; 3) is possible to deal with uncertainties and act in spite of their existence (Lourenço et al. 2014).

While the option of doing nothing could occasionally prove to be the most correct option, several authors and near-universal agreements[7] have

[7] Among the most recent public demonstrations supporting the imperative need for climate change response is the papal encyclical letter Laudato Si'. Throughout his letter, Pope Francis appeals for a renewed discussion about the future of our planet particularly considering that "Never have we so hurt and mistreated our common home as we have in the last two hundred years" Pope Francis, 2015. *Encyclical letter Laudato Si' of the Holy Father Francis* [online]. Vatican: Vatican Press. Available from: http://w2.vatican.va/content/vatican/en.html [Accessed 5th October 2016]. Moreover, without once mentioning the word "capitalism" there is a clear point of view regarding the limits of our current economic system that, through the intensive use of fossil energy, has greatly developed and enriched only part of the world at the expense of the whole planet's health. Although recognizing the lack of culture needed to confront this crisis, Pope Francis does not give up hope that "humanity at the dawn of the twenty-first century

strongly argued on the need for countries to invest on increasing their capacity to cope with uncertainty, rather than to increase risk from the use of ambiguous impact studies or no action (IPCC 2012). As stated by the British philosopher and logician Carveth Read, "It is better to be vaguely right than exactly wrong" (Read 2012[1898], p.351).

Acknowledging that uncertainty about future weather events is a sure certainty, the ultimate question relies on how can we prepare and manage for our future? Particularly in regards to the transposition of this problem-matter upon Urbanism, and in light of the concept of Ulrich Beck's "Risk society", François Ascher was one of the first to argue that urban planning had to deal with uncertain risks and global impacts (Ascher 2010[2001]). As stated by Richard Marshall, "Our cities have changed faster than we have been able to adjust our thinking (…). Our problem is not one of memory; it is one of adjusting our ideas of what is an appropriate urban form to be in line with the current reality of our culture and society. What is needed in urban design today, above all else, is a re-calibration of our ideas to the currency of our time" (Marshall 2001, p.3). For Lister, "if uncertainty and regular change are inevitable, then we must learn to be flexible and adaptable in the face of changes" (Lister 2005, p.21). Following this line of reasoning, Jack Ahern further argued that uncertainty must be reconceived as an opportunity to "learn by doing" (Ahern 2006). In accordance with these arguments, designers and planners, which operate in the "real world", cannot be tied up until there are no more climate sceptics or the hopelessness of no more uncertainties.

In line with the research project Urbanised Estuaries and Deltas (Costa et al. 2013), however uncertain, climate change projections provide a sufficiently stable range of possible futures that serve to test available options. The methodological difference upon the planning process, relies mainly on the shift from the search for the one optimal solution, into the pursuit of various adequate alternatives.

---

will be remembered for having generously shouldered its grave responsibilities" ibid. In order for this change to happen, social vices for comfort and superficially, which tendentiously assume that nothing serious will happen, must be inverted.

Counterbalancing this tendency, 2015 United Nations Climate Change Conference (COP 21 Paris) marked a new threshold for climate action. This was an important undertaking particularly considering the number of parties evolved. More specifically, 195 world nations have agreed to sign the so-called "Paris Agreement" as opposed to the 114 parties of the previous Copenhagen accord. The only counties that did not cover the agreement are North Korea and Syria for comprehensible reasons. It is therefore considered a legal universal agreement against climate change, with great prospects of effectively reduce or eliminate the consumption of coal, oil and gas as energy sources that have feed human societies since the XVIII century.

1.1.1. The underlying role of urban territories

Cities are confined in only two percent of the world's area, yet they are held accountable for major contributions to climate change. More specifically, not only are cities the key drivers of GHG emissions but are also the greater consumers of global energy (IPCC 2014).

In addition, in light of experienced hazards[8], cities are among the most vulnerable areas as to the impacts of climate extremes. That is namely because most cities are predominantly located in vulnerable areas such as coastline's, mouths of major rivers or low-lying areas of estuaries and deltas. As a direct cause of their physical location, these cities are at a greater risk from climate hazards such as coastal storms, cyclones, flooding and coastal erosion.

---

[8] The three recent climate-hazard occurrences, namely of New Orleans and the 2005 hurricane Katrina, the 2005 cyclone in Mumbai and the 2007 heavy rains in Jakarta, exemplify how the urban context contributed to the severity of the climatic impact.

1. The most severe portion of Katrina did not pass through the city of New Orleans as expected. However, it created an extreme storm surge that challenged man-made infrastructure until it surpassed its limits. As a result, drainage and navigation canal levees suffered about fifty breaches. This physical failure together with an expected austere weather, triggered the well-known tragic disaster, flooding over 80% of the city and killing more than 1800 people.

2. Mumbai's geographical situation includes large reclaimed areas just above sea level and below high-tide level. If high tides are coincident to extreme rain events, natural runoff is impossible. This phenomenon occurred in the July 2005 event, a month before Katrina, where an unusual amount of rainfall combined with high tide levels led to the saturation of the whole drainage system. Most of the affected area corresponded to dense informal settlements, which specifically contributed to the severity of this disastrous event, leading up to more than 1000 perished people. The flood made rubbish and human waste circulate around the slums, leading to epidemic outbreaks and wide-spread insalubrity.

3. Jakarta is also a city within a flood prone area. It is a 10 million people city located in a low flat basin in which 40% is below sea level. Moreover, and in similarity with New Orleans albeit in a much larger scale, the city is built on what was once a swamp and thus severely suffers from land subsidence. As a result of heavy rains, a major flood occurred in 2007, covering about 70% of Jakarta's total area. Contributing factors include clogged sewerage pipes and waterways with debris. This disaster led to 57 deaths, over 300.000 evacuees and at least 190,000 people have fallen ill (WorldBank, 2011. *Jakarta - Urban Challenges in a Changing Climate. [Mayors' Task Force On Climate Change, Disaster Risk & The Urban Poor]*. Washington, DC, Report number: 65018. 45 pp.).

These three previous examples of urban climate related hazards illustrate how rare, albeit not unpredictable, intense weather events, coupled with obsolete or poorly maintained infrastructure, can lead to massive destruction of life and property. Each case may additionally serve to highlight how particularly vulnerable are underprivileged social groups.

Cities are also particularly vulnerable, as they are where most people live and where most of the world's built assets and economic activities are held. According to the Global Health Observatory (GHO), the 21st century marks the first time in history, when the proportion of the world's urban population has surpassed rural population, evidencing a tendency that is very likely to continue. United Nations World Urbanization Prospects estimate that by 2050, urban population will double (United Nations 2014). This forecast indicates that more people and more assets will be exposed to the multiple urban climatic risks, with billions of dollars in infrastructure located in highly exposed areas (Munich Re Group 2004, Kraas et al. 2005 and Wenzel et al. 2007 in IPCC 2012). The rapid unplanned urbanization in low and middle-income countries, further accelerates the number of highly vulnerable urban communities.

It should be further noted, that urban climate vulnerability is also exacerbated by less evident circumstances. According to Allan Lavell, among the specific urban contexts that may increase vulnerability and disaster risk are: "1) The synergic nature of the city and the interdependency of its parts; 2) The lack of redundancy in its transport, energy, and drainage systems; 3) Territorial concentration of key functions and density of building and population; 4) Mislocation; 5) Social-spatial segregation; 6) Environmental degradation; 7) Lack of institutional coordination; 8) The contrast between the city as a unified functioning system and its administrative boundaries, that many times impede coordination of actions" (Lavell 1996 in IPCC 2012, p.78). Other factors, such as the gradual reduction of fresh water or the gradual increase of air pollution, are as unnoticeable and as worrisome.

In addition to these factors, which intensify urban vulnerability towards climatic extremes, are the consequences that climate change prospects upon cities and its citizens. While floods, landslides, storms, heat waves and wild fires are part of the history of urban settlements, the characteristics of these events, and their climate drivers, are projected to change and increase dramatically in frequency and intensity. In light of global climate change projections and impacts, not only are cities facing higher temperatures, but also a climatic shift towards more extreme events, such as heat waves or severe precipitation, (Kovats and Akhtar 2008 and Satterthwaite 2008 in IPCC 2012). On the one hand, the projected rising of temperatures will intensify the Urban Heat Island effect (UHI), leading to more intense heat waves. On the other hand, heat waves increase heat-related health problems among the most socially vulnerable, such as the elderly and children. Heat stress may furthermore impact renewable water resources, endangering water supply. Lack of water may consequently promote water-related diseases, as well as affecting food production. Other extreme events such as cyclones, sea-level rise, storm surges or heavy rainfall, will most likely lead to increased flood occurrences, that will push the boundaries of urban infrastructure and governance as we know it. A fact that increasingly threatens human lives and livelihoods, as the pressure for urban areas to expand onto flood plains and coastal strips continues (McGranahan et al. 2007 and Nicholls et al. 2011 in IPCC 2012). Also the sudden expenses from the recovery of climate change impacts, may induce financial disruptions in the cities and country capitals.

On the positive side, cities are as vulnerable as they are powerful, in the sense that, as centres of communication, commerce, innovation and culture, they are the economic drivers of their respective country and major authorities for future agendas.

Despite previous difficulties[9], and namely as a consequence of improved global climate research, the climate agenda is now emerging, and growing within the urban agenda, with new information and reinforced arguments. Overall, it is widely suggested that cities and their decision makers are well aware of global climate change. Cities are also well informed by the scientific community that, "Delaying adaptation action will most probably increase costs at a later stage, or measures will come too late" (EEA 2012b, p.7).

In line with the examples that will be analysed next, some cities have been actively applying climate change research in their planning endeavours. Yet that is not the case for most of the cities, which are still largely unprepared to face the projected changes in climate for the next 100 years

---

[9] Since the mid twentieth century, research in urban climatology has attempted to reach decision makers through global intergovernmental networks and NGOs, challenging cities to assume responsibility for their part as "co-partners of their climate" (Hebbert, M. and Jankovic, V. 2013. Cities and Climate Change: The Precedents and Why They Matter. *Urban Studies,* 50(7), 1332-1347). However, until recently, the scientific community was constantly disappointed as it was unable to transmit and transpose their knowledge about urban climates into urban planning. In order to understand the reasons for this failure to communicate, some authors have argued that it was a discipline only relevant for "cases of major expansion, urban redevelopment or new town design" (ibid. p.1339). Other authors indicated as the main hindering cause, the difficulty of translating the language used by urban climatologists, which was essentially expressed in the form of mathematical understandings.

Before the turn of the century, few where the implemented urban planning examples that incorporated local urban climatology findings. Among them are the public housing projects for the city of Munich by Camillo Sitte's disciple Theodor Fischer, or Frederick Olmsted's "Emerald Necklace" (1989) in Boston, USA. Both projects which aimed to integrate the general principles of modern town planning that envisioned to bring ecological processes into the city.

and more. Contrastingly, humankind is strongly dependent on what is done and not done in the cities within the next century.

If our "urban nature"[10] has changed the way the world works, than we must also learn hotesw to live and adapt with the inferred changes. As argued by Ulrich Beck "what was made by people can also be changed by people" (1992, p.157). At the same time that urban territories are major contributors to the climate change phenomenon, they are also the most decisive for its counterbalance; namely through mitigation and adaptation endeavours.

[10] With regard to (and influenced by) the Anthropocene concept, the sixth edition of the International Architecture Biennale Rotterdam (IABR) 2014, curated by the Dutch Landscape Architect Dirk Sijmons, was themed "Urban by Nature".

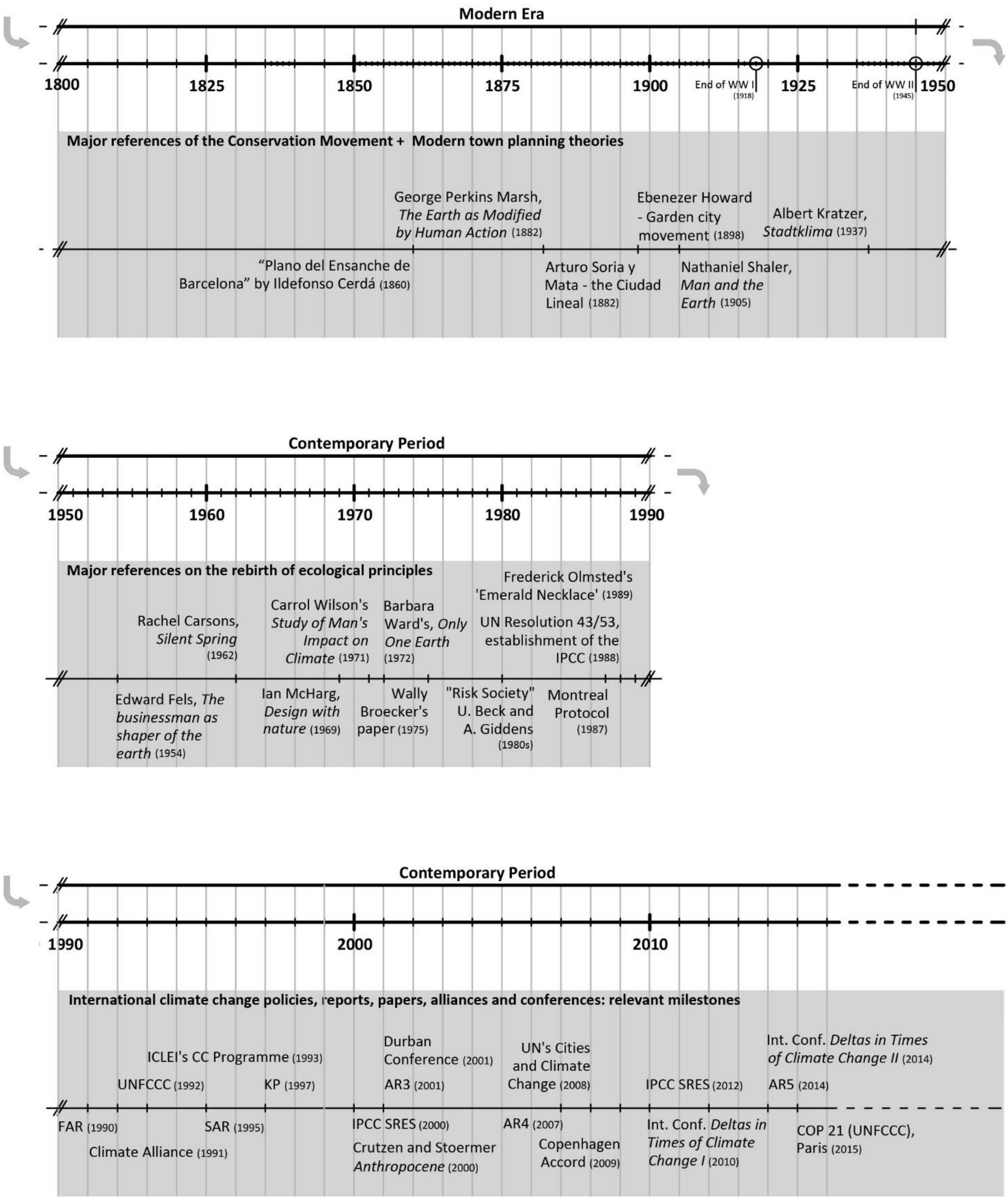


Figure 1.1 - Mentioned references compiled in a timeline. Above: 1800-1959, Conservation Movement and Modern town planning theories; Middle 1950-1990: Rebirth of ecological principles; Bellow: 1990-present, International climate change policies, main reports, papers, alliances and conferences. Source: developed by the author.

1.2. Climate change adaptation in the contemporary urban agenda

While mitigation reduces greenhouse gas emissions, so that impacts do not grow exponentially, adaptation is vital when considering the impacts that are no longer preventable. On the other hand, while mitigation results are associated with great inertia, both in international agreements and in the climatic system, adaptation is capable of producing immediate local results.

As mitigation and adaptation endeavours are driven by the same difficulty to face anthropogenic climate change, they are dependent on each other. As such, a successful global response could only include the two interrelated strategies of mitigation and adaption, together with the implementation of a wide variety of correspondent measures. Whereas an isolated mitigation strategy is irrelevant as it is already incapable of avoiding considerable climate change, an isolated adaptation strategy will become more expensive and less efficient as the amplitude of changes remains unaltered (Bierbaum et al. 2013).

Although the interdependency and complementarity of both types of endeavours has always been recognised in theory, mitigation was the primer and a stronger political and institutional goal in the first practical initiatives facing anthropogenic climate change.

Two decades ago, particularly for Europe, which strongly ventured and led the path of mitigation, adaptation strategies, together with the uncertainty alibi, were generally considered, as a recognition of the inability or lack of results from the coordinated actions to reduce greenhouse gas emissions. By contrast, the USA has always been primarily committed towards adaptation strategies that, albeit more expensive, would not compromise the country's economic adverse effects by any consequent restriction on fossil energy. Also, as if knowing that mitigation alone would be insufficient to tackle climate change impacts.

Yet since the turn of the century, adaptation grew in importance and reliability, becoming not only a legitimate, but a fundamental aspect within the broad international climate change agenda (Roggema 2009). As Verschoor stated, "adapting to climate change will become part of everyday policy making" (Verschoor 2009, p.26). It will consist on a challenge that is expected to evolve and progress in time and that will not to cease to exist.

Urban planning also initially followed the path of mitigation, being somewhat hindered by the uncertainties of climate change associated projections. Among the discussed and applied mitigation strategies and measures, are the reinforcement of "carbon sinks" through the protection or development of ecological areas, the improvement of urban pedestrian and bicycle traffic, together with public transport or the different types of "sustainable communities", from the singular buildings to the neighbourhood or the city, in the search for a local balance. The ultimate concern was essentially focused on the foundation of a low-carbon future.

However, as the research project Urbanised Estuaries and Deltas aimed to explore (Costa et al. 2013), there is the opportunity to complement the practice of urbanism with climate change adaptation endeavours, without the need of exceeding each of their disciplinary realms of practice. Indeed, as evidenced by the international examples analysed next, Urbanism is a promising platform for a symbiotic integration between both strategic efforts of mitigation and adaptation, catalysing the objectives of each strategy, while retrieving important co-benefits. The junction between these two complementary spheres of climate change response, requires proactive thinking amongst the public sector, agencies, and investigation centres. It is a vital priority, that synergies are contemplated and rehearsed between those agents, as complex as it might be. Irrespective of their professional area, be it urban planning, architecture, geography or engineering, there must always be an unyielding commitment to consider their role in preparing for a changing climate (Costa 2013).

While climate change is already taking its toll on contemporary cities, bigger impacts are projected to occur in the medium to long term scales within the enfolding of the twenty-first century. As argued by some authors, such as Solomon et al. (2009) and Rahmstorf (2007), even if mitigation fulfilled all its goals, several climatic changes would still occur for centuries. Not only because it is a recent agenda, with too few leading successful examples, but most importantly, because every year the urgency of the matter is reinforced, climate change adaptation is presently an undeniable deliberation, which is inseparable from the agenda of urbanism. It is within this pursuit of effective adaptation strategies and measures, that urbanism and urban planning is facing one of its greatest challenges.

The following sub-chapters will encompass a comprehensive analysis upon the concept of climate change adaptation, in order to better understand its meaning, as well as how it should or should not be applied in practice.

1.2.1. Literature review on the concept of adaptation

Although adaptation to global anthropogenic climate change is a recent phenomenon, the same cannot be said for human adaptation to environmental change as well as human inferred alterations in microclimates for its benefit. Even if not always successful, adaptation to the encircling climate has accompanied the evolution of Mankind as a species since its existence on the planet. From the igloo ice shelters that have served to protect from the extreme cold, to the stilt houses that have served to protect from periodic flooding; or from the microclimatic manipulation of the Inca settlements for food production, to the shallow water pools of Roman atriums that provide a cooling effect from water evaporation in hot weather. Although with different perspectives, many are the disciplines that have dwelled upon the concept of adaptation, including anthropology, archaeology, biology, ecology, geography, political ecology and psychology (Schipper 2007). What essentially differentiates the standpoint of global environmental climate change science, is the speed of its development and the implication of unprecedented weather regimes as it's multiple and interrelated consequences.

The general definition of the term "adapt", according to dictionaries, implies making adjustments or modifications in order to make a given requirement or condition suitable. Yet, as Guillaume Simonet highlights, "adaptation remains a prisoner of its etymology" (Simonet 2010, p.2). More specifically, it refers at the same time to the process of adaption (an action) and to the state of being adapted (a finality) (Smit et al. 2000), a terminological duality between "adaptation state" and "adaptation process" that has been formerly discussed by Piaget (1967, in Simonet 2010). It may therefore occur for a same situation to become adapted and to continuously change and adapt through time.

When discussed in particular disciplines, the term "adapt" implies different specific connotations. For example, "natural" biologic adaptation is referred to changes in which organisms or species become fitted into a different environment (Lawrence 1995, Abercrombie et al. 1977 in Smit et al. 2000) whereas within the social sciences, adaptation is referred to adjustments by individuals to the collective behaviour of socio-economic systems (Denevan 1983, Hardesty 1983 in Smit et al. 2000)

Besides the different definitions of adaptation among various concerned disciplines, within climate change literature, the adaptation concept has recently had a significant amount of attention. This is reflected namely in the sheer amount of articles and scientific reports devoted to the understanding of the concept of adaptation, which according to Bassett and Fogelman, have doubled between 2007 and IPPC AR4 (2013). Among the analysed references, the presented definitions of climate change adaptation are countless and apparently distinct. It seems that there is still no standard characterisation assumed among the scientific community, and that most likely, there never will be as "the framing of adaptation differs among different communities of practice and across different local contexts" (McEvoy et al. 2013, p.283).

A comprehensive range of definitions from the climate change scientific discourse was therefore gathered with the aim to grasp an overall accepted meaning of the climate change adaptation concept and its constituent components. More specifically, Table 1.1 develops from definitions mentioned in three conceptual reviews (namely Smit et al. 2000, Schipper 2007, Bahinipati 2011), and adds other missing definitions (namely for the years: 1994, 2001, 2004, 2005, 2007, 2009, 2011 and 2012) that are present in referenced literature.

As a critical document on climate change for both scientists and policy makers, UNFCCC inaugurated the definition of climate change adaptation, stating that it is an "adjustment to natural or human systems in response to actual or expected climate *stimuli* or their effects, which moderates harm or exploits its beneficial opportunities" ((UNFCCC 1992) in Bahinipati 2011, p.7). Since then, the concept has been open to discussion among the scientific community. The most commonly used definitions belong to the IPCC, namely the definition present within the IPCC TAR from Burton et al. (2001), which detailed further conceptual descriptions "…This term refers to changes in processes, practices, or structures to moderate or offset potential damages or take advantage of opportunities associated with changes in climate. It involves adjustments to reduce the vulnerability of communities, regions, or activities to climatic change and variability"(Burton et al. 2001, p.881). Forthright versions of the definition arrived later, such as UK's Adaptation Sub-Committee (ASC), which summarized adaptation as "any adjustment of behaviour to limit harm, or exploit beneficial opportunities, arising from climate change" (ASC 2011, p.92). Or the 2012 definition from the IPCC "Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation", which re-joins the keywords of "process" and "opportunity".

This literature review started to present redundant results by the year 2012, as much similarity was identified among the differenced expressed conceptualizations on climate change adaptation.

Table 1.1- Climate Change Adaptation Concepts – A summary of descriptions. Developed from the bibliographical reviews presented in (Smit et al. 2000, Schipper 2007, Bahinipati 2011).

Source	**Description**
(UNFCCC 1992)	Adaptation to climate change is the adjustment to natural or human systems in response to actual or expected climate *stimuli* or their effects, which moderates harm or exploits its beneficial opportunities.
(Burton 1993)	Adaptation to climate change is the process through which people reduce the adverse effects of climate on their health and well-being, and take advantage of the opportunities that their climatic environment provides.
(Smit 1993)	Adaptation involves adjustments to enhance the viability of social and economic activities and to reduce their vulnerability to climate, including its current variability and extreme events as well as longer term climate change.
(Stakhiv 1993)	The term adaptation means any adjustment, whether passive, reactive or anticipatory, that is proposed as a means for ameliorating the anticipated adverse consequences associated with climate change.
(IPCC 1994, p.32)	Adaptation is concerned with responses to both the adverse and positive effects of climate change. It refers to any adjustment, whether passive, reactive or anticipatory, that can respond to anticipated or actual consequences associated with climate change.
(Smith et al.1996)	Adaptation to climate change includes all adjustments in behaviour or economic structure that reduce the vulnerability of society to changes in the climate system.
(Watson et al, 1996)	Adaptability refers to the degree to which adjustments are possible in practices, processes, or structures of systems to projected or actual changes of climate. Adaptation can be spontaneous or planned, and can be carried out in response to or in anticipation of change in conditions.
(IPCC 1996) – SAR	Adaptation to climate change includes measures that serve the dual purpose of (a) reducing the damages from climate change; and (b) increasing the resilience of societies and eco-systems to the impacts of the climate change.
(Downing et al. 1997)	Adaptation is synonymous with "downstream coping".
(Burton et al. 1998)	Adaptation refers to all those responses to climate change that may be used to reduce vulnerability.
(Smit et al. 2000)	Adaptation as adjustment in ecological-social-economic systems in response to actual or expected climatic stimuli, their effects or impacts.
(Burton et al. 2001, p.881) IPCC – TAR	Adaptation is the adjustment in ecological, social and economic systems in response to actual or expected climatic stimuli and their effects or impacts. This term refers to changes in processes, practices, or structures to moderate or offset potential damages or take advantage of opportunities associated with changes in climate. It involves adjustments to reduce the vulnerability of communities, regions, or activities to climatic change and variability.

(Pielke 1998)	Adaptation refers to adjustments in individual, group and institutional behaviour in order to reduce society's vulnerabilities to climate.
(Scheraga and Grambsch 1998)	Adaptive actions are those responses or actions taken to enhance resilience of vulnerable systems, thereby reducing damages to human and natural systems from climate change and variability
(UNDP 2002)	Adaptation is a process by which strategies to moderate, cope with and take advantage of the consequences of climatic events are enhanced, developed and implemented
(Easterling et al. 2004, p.6)	A successful adaptation is defined as one that follows a climate change causing adverse impacts and maintains a system at approximately the same level of welfare or services as was provided before the change in climate. If the adaptation can completely offset the loss from climate change, it is successful.
(EEA 2005, p.10)	Adaptation: policies, practices, projects for moderating damages, and/or realising opportunities
(IPCC 2007, p.869) – AR4	Adaptation as adjustments to reduce vulnerability and enhance resilience in response to observed or expected changes in climate and associated extreme weather events.
(Magnan et al. 2009, p.17)	Adaptation is a continuous learning process.
(ASC 2011, p.92)	Adaptation is any adjustment of behaviour to limit harm, or exploit beneficial opportunities, arising from climate change.
(IPCC 2012, p.556)	Process of adjustment to actual or expected climate and its effects in order to moderate harm or exploit beneficial opportunities.

Having undertaken an initial analysis of the assembled definitions, it can be noted that there is a general accordance of what is the core interpretation of the analysed concept. More specifically, the majority of definitions within the range of the presented examples refer to societal adaptation instead of natural biological adaptation; an evidence that acknowledges adaptation not only as exclusive to the autonomous and reactive natural developments of plants and animals, but also as a concept for guiding social policy and actions to confront climate change (Schipper 2007). In addition, among the most clear conceptual consensus between the different definitions are the ideas of 1) adjustment processes, 2) vulnerability reduction and 3) beneficial opportunities.

According to Magnan et al., the concept of "adjustment" is intimately related to the concept of flexibility (2009). In turn, flexibility if often referred to the action that is able to change the structure of systems and its processes alongside inflicted disturbances. When considering the idea of "vulnerability reduction", an inverse correlation can be presented at the outset: "the less vulnerable an area is, the more it could be considered as "adapted"; conversely, a high degree of vulnerability would translate as a low adaptation capacity" (Magnan et al. 2009, p.17). Regardless, it is important to note that the inverse situation is not always correct, i.e. a reduced adaptation capacity is not necessarily the result of a high degree of vulnerability and an adapted area is not necessarily free of vulnerabilities. Lastly, regarding the idea to take advantage of "beneficial opportunities", it is commonly recognized that adaptation, while reducing the vulnerabilities that instigate adverse projected impacts, is also able to capitalize new and emerging opportunities. Assumed as an ongoing learning process, which must be continuously assessed and revisited, adaptation entails the capacity to generate experience while dealing with change (Berkes et al. 2003), consequently endorsing creativity and engaging with uncertainty.

Adaptation for vulnerability reduction

Returning to the idea of vulnerability reduction, there is a general agreement that adaptation to climate change should not be primarily focused on the expeditious reduction of the impending impacts but rather on the reduction of the vulnerabilities towards them. A concern that is primarily related with the uncertainties concerning climate projections.

As highlighted by McEvoy et al., the reduction of vulnerabilities, before being integrated into development policy, should explicit adaptation strategies towards expected results. More specifically, if a city is already vulnerable to present climate conditions, then efforts should be initially directed to reduce these vulnerabilities, rather than those of future potential hazards. Moreover, priorities should be directed to where vulnerabilities are higher. Once initial vulnerabilities are reduced, then impacts can be minimised and adaptation can find favourable circumstances to emerge (Schipper 2007, McEvoy et al. 2013). In this line of reasoning, it is important to emphasize the importance of considering different approaches when facing different geographical connotations. For example, while European cities may be more focused with planning for the long term consequences of climate change, developing countries have no other option, but to expeditiously integrate development, disaster risk reduction and right-of-way climate change adaptation (McEvoy et al. 2013).

Besides addressing climate change, adaptation is also perceived a process that, through implemented strategies and measures, comprises responses to many other factors, such as evolving planning experiences and actions, as well as risk perception (IPCC 2012). By way of example, and specifically regarding risk perception, one may compare the two different flood risk management measures of dikes and *non ædificandi* flood plains. While the first may efficiently reduce flood episodes, it is also bounded by the so-called "levee effect" that consists on a false sense of protection as its eventual rupture would highly increase the impacts that were firstly aimed to be prevented. Contrastingly, changes in the land use of urbanised areas that would promote the punctual welcoming of flood waters, may paradoxically enable the reduction of vulnerabilities as the flood processes are revealed and perhaps most of all, expected.

Adaptation as an adjustment process

Extensive literature has explored the role of the adjustment process of learning as a key element within the presented dynamic notion of climate change adaptation. Adaptation to projected anthropogenic weather events has been namely described as the process of "paying attention to learning about past, present, and future climate threats, accumulated memory of adaptive strategies, and anticipatory action to prepare for surprises and discontinuities in the climate system" (Nelson et al. 2007 in IPCC 2012, p.443). It has been further characterized, as the ability to reflect upon mistakes (Adger 2003 in Tschakert and Olsson 2005) and to generate experience in dealing with change (Berkes et al. 2003), both of which are inherent characteristics of learning.

It is no coincidence that the definition of the abstract subject of climate resilience has been changing in recent times. At first, it was generally argued that climate resilience was based on the capacity of social-ecological systems to tolerate shocks and still maintain the reliability of functional relationships. Yet new claims suggest that climate resilience definition should rather comprise the capacity of social-ecological systems to learn, reorganise, renew and develop, and to utilize disturbances as opportunities for innovation and evolution of new paths to improve the system's ability to adapt (Folke 2006, IPCC 2012).

Learning through adaptation processes can be namely approached through the continued monitoring and assessment of implemented actions. An ongoing evaluation that not only enhances the adaptation process itself, but that also enriches, practical state of the art knowledge suitable to be extensively shared (EEA 2012b). Moreover, the fact that climate change adaptation is characterized by being a dynamic, ever evolving and revaluated approach, makes it a process unhindered by the need to succeed and where adjustments are a constituent part of the process. As adaptation measures are accepted as an ongoing learning process in which failure is a part, creativity and continued improvement is particularly supported (Howe et al. 2011).

Adaptation in search for beneficial opportunities

Climate change adaptation is a learning continuous adjustment process aimed at reducing vulnerabilities. Still, adjacently, it can further capitalise new and emerging opportunities. As pointed out by Jack Ahern, multiple possibilities can namely be entailed within learn-by-doing or safe-to-fail design experiments (2011). Among safe-to-fail design adaptation measures are: win-win options, no-regrets options, low-regrets options and reversible and flexible adaptation options (IPCC 2012, EEA 2013). These options are generally distinguished by its cost-effectiveness and by its given beneficial consequences in light of present and future climate. Specifically, win-win options are referred as cost-effective measures that besides reducing climate risks include side benefits in social, economic or environmental sectors. No-regrets options are also associated to cost-effective measures that are advantageous regardless of future climate conditions. Low-regret options entail measures of relatively low costs in which benefits, although essentially envisioned for future climate projections, are wide-ranging. Lastly, flexible and reversible options are those that encompass the capacity to be altered in the future as climate changes. The encouragement to be more water efficient may be an example of a win-win measure, while the promotion of good agricultural practices, such as the dissemination of techniques that reduce soil erosion, may be considered as an example of no-regret measure. The investment to extend the capacity of a small drainage system may be considered an example of a low-regret measure, while the design of a retention and infiltration basin so that it can be increased in the future can be considered as a flexible measure.

1.2.2. Adaptation strategies and the threat of maladaptation

In the attempt to understand the "anatomy of adaptation", Smit et al. concluded that his assembled definitions were connected and differentiated by three key questions: Who or what adapts? Adaptation to what? And how does adaptation occur? For Smit et al., in addition to the identification on the subject it refers to, i.e. if natural or socio-economic systems, adaptation is also dependent on the "timing", i.e. if it is reactive, anticipatory or passive; on the "degree of spontaneity", i.e. if it is autonomous and takes place through unmanaged systems or planned and it is consciously undertaken by humans; and finally on the "target", i.e. on the different climate related stimulus (Smit et al. 2000).

In light of the conducted bibliographical review on the different types of climate change adaptation strategies (which can be consulted in Matos

Silva and Nouri 2014), even though many authors have distinguished various adaptation typologies and identified frameworks as bases for their characterization, most authors emphasise the need for planned adaptation. Schipper, for instance, states that "the main difference in biological adaptation and climate change adaptation is the level of planning and consciousness by which adjustments are carried out" (2007, p.4). In 1996, Ian Bruton gave six reasons to choose planned adaptation from other approaches: 1) Climate change cannot be totally avoided; 2) Anticipatory and precautionary adaptation is more effective and less costly than forced, last-minute, emergency adaptation or retrofitting; 3) Climate change may be more rapid and more pronounced than current estimates suggest. Unexpected events are possible; 4) Immediate benefits can be gained from better adaptation to climate variability and extreme atmospheric events; 5) Immediate benefits also can be gained by removing maladaptive policies and practices; 6) Climate change brings opportunities as well as threats. Future benefits can result from climate change (Burton 1996). Six reasons that are still presently pertinent.

The majority of academics further supports an anticipatory approach, namely given the strong limitations of "optimal" autonomous or reactive adaptation that are generally associated to limited information and access to resources, adaptation costs, and residual damages (Smith et al. 1996, Reilly 1998, Tol 1998, Fankhauser et al. 1999, Bryant et al. 2000, Schneider et al. 2000 in Burton et al. 2001). Moreover, although research on adaptation experiences has proved that humans have the capacity to spontaneously adapt to long-term mean climate conditions, the same cannot be said when adapting to extremes and year-to-year variations in climate (Burton et al. 2001, IPCC 2012). This fact, *per se*, evidences the need to differentiate natural adaptation to climate from the adaptation to anthropogenic climate change, particularly as confidence grows regarding the great impact of extreme weather events.

While the most attractive adaptation strategies are usually those which offer development benefits in the short term and reductions of vulnerabilities in the long term, extensive literature has been highlighting that not all adaptation responses are benign. Among others, the IPCC in its report "Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation" states that "there are trade-offs, potentials for negative outcomes, competing interests, different types of knowledge, and winners and losers inherent in adaptation responses" (2012, p.443).

Selecting the optimal adaptation strategy or measure for a particular situation is therefore neither easy nor straightforward. This determining process is particularly complicated given the specific ramifications and secondary impacts related to adaptation processes. In some cases results can be critical, namely when adaptation does not fulfil its designated objective and ultimately leads to increased vulnerability. This phenomenon is generally called Maladaptation, which can be described as "action taken ostensibly to avoid or reduce vulnerability to climate change that impacts adversely on, or increases the vulnerability of other systems, sectors, or social groups" (Barnett and O'Neill 2009 in IPCC 2012, p.55).

Maladaptive action may therefore bring short term benefits but lead to unwanted consequences in the medium to long-term. As synthesised by Barnett and O'Neill, there are five types of maladaptation: 1) Increasing emissions of greenhouse gases, an action that is in direct conflict with the mitigation efforts; 2) Disproportionately burdening the most vulnerable, promoting actions with unequal benefits across society; 3) High opportunity costs; 4) Reduce incentive to adapt and 5) Path dependency that limits the choices of future generations (2010).

Situations of maladaptation occur when, for instance, cross-scale management is not a concern. The large dams that area planned to be built in Amazonia, can be used to exemplify this issue. While the dam may offer significant benefits on the national and regional level, it may lead to substantial social and environmental disruptions at the local level. Other types of maladaptation can be associated to the choice of strategies and measures to be applied regardless of the situation or contexts at hands. For example, a bioswale[11] with the right combination of phyto-purification plants that are placed in the wrong location, may not only be an unnecessary expenditure, a lesser effect is that they may give rise to stagnant water that can be very dangerous to public health (namely through exposed untreated contaminants and mosquito breeding) (Figure 1.2). Other examples include: the promotion of energy intensive cooling or water supply technologies; using ground water for irrigation in a region with low and decreasing groundwater levels; prevention from climate change induced diseases only for unaffordable prices or storm surge of flood protection infrastructure that disturbs the natural dynamics of coastal or river systems (European Commission 2009).

Unlike mitigation, long-term benefits of proactive adaptation are more dependable on the accuracy of regional socio-economic, climate and impact projections which are additionally inseparable to substantial uncertainty. A careful analysis of the situation in hand, should therefore always precede the choice of strategies and measures to be applied, as

[11] See Chapter four – "Overall characterization of the proposed types and categories of measures" / "Bioretention" for the description of the "Bioswale" measure.

there will never be a universal solution. Accordingly, to prefer any strategy or measure in anticipation is more likely to lead to maladaptation than when opting to choose from a wide range of assessed options.

It is therefore essential to recognise, that alongside the process of planned adaptation, lies the constant threat of maladaptation. Yet maladaptation cannot be considered as a hindering factor supporting "business as usual," as it can be minimized through the ongoing adjustments of continuous assessment. Any adaptation response should therefore imply learning from monitored and assessed actions.

Figure 1.2 - A failed Bioswale as illustrated in this image is an example of maladaptation. Source: (Urban 2008).

Although the need to identify and analyse successful examples of adaptation strategies and measures is every year reinforced. According to Magnan, there is still a wider range of bibliographical information discussing existing risks that offer different solutions (2009). In counterbalance, the overall unfolding of the thesis, will aim to evidence specific international practices and some of its implemented adaptation strategies and measures. From the conducted analysis, it was further possible to identify how climate change is influencing the landscape of urban territories, namely their public spaces.

1.3. International examples of urban adaptation action

When compared to practical mitigation endeavours to reduce greenhouse gas emissions, adaptation is still in its infancy. Regardless, it is an agenda that is progressing at a fast pace. Not only is climate change adaptation presently recognized as inevitable, but it is also in the core interest of each individual country. In accordance, the number of national, regional and local adaptation strategies supported by public or private initiatives, increases every year.

This sub-chapter will aim to explore some examples of adaptation undertakings held within the international cases of the Netherlands, United States of America and the United Kingdom.

1.3.1. The Netherlands

Given its geographical situation, with over two thirds of the country below sea level, the Netherlands has a very experienced planning and land management culture that is particularly knowledgeable in regards to "water works".

After the catastrophic storm flood on the night of the 31st of January 1953, a Delta Works Commission was created almost immediately (18th February 1953) with the goals not only to study the causes, but also to propose solutions to avoid similar future hazards. It took eight years for the committee to present its final report, which became known as the Delta Project. For the first time, this project based the flood safety level, on the contrasting analysis between the cost of reinforcing coastal defence and the economic damage from its infrastructural failure (d'Angremond 2003). In accordance with its guidelines, coastal engineering design around the most populated areas would have to sustain extreme surge levels of very low probability such as "once in 10,000 years" events. This Delta Project was considered as a landmark in coastal defence, which supported the closure of inlets, the construction of new extremely strong dikes and the reinforcement of the older ones.

Since the end of the 1990's and the early part of 2000's, several occurrences prompted the need for an updated Delta plan in the Netherlands. Other concerns included the high water occurrences registered in the Dutch rivers in 1993 and 1995 and the 2005 Katrina incident in New Orleans, which destroyed over 80% of the city, due primarily to an infrastructural failure of flood defences. According to Meyer et al. "Hurricane Katrina was a harsh wake-up call for all urbanized deltas. In the Netherlands, Katrina reinforced out awareness of the need to maintain effective flood defences and water-management practices" (Meyer et al. 2010, p.x). In accordance, a new (second) Delta Commission was appointed in 2006, while the formulation of the first Dutch National Adaptation Strategy[12] was being developed.

This second Delta Commission was specifically appointed to look at the next 200 hundred years, and consider projected climate change impacts such as flood risk. Their work gave rise to the Delta Programme of 2008 entitled "Working Together with Nature – A living land builds for its future" (Deltacommissie 2008). As the name indicates, this report introduced radical changes in comparison to its precedent. As stated by the Dutch Ambassador Renée Jones-Bos "Our old "higher dikes" approach is no longer sustainable or affordable. Whether we like it or not, we are learning to adapt, to live with water, and not to always fight against it. Our collective DNA is mutating away from flood resistance at any cost, to flood accommodation wherever possible" (2012). This advocated "working with nature" approach does not disregard hard infrastructure, but rather reinforces the need for it to be used with moderation and in complementarity with "natural" design solutions. This approach further emphasises the negative counterpart of being highly dependable upon hard infrastructure, as its potential failure could imply an even more severe aggravation of the very risk it was created to neutralize.

As will be latter specified, this particular "working with nature" approach supported and endorsed actions and programmes, which established specific solutions based on the benefits and services provided by nature. That is namely the case of the Ruimte voor de Rivier (Room for the River) program and the Sand Engine or Zandmotor beach nourishment natural mechanism.

The ultimate goal of the 2008 Delta Program, was to "climate-proof" the Netherlands. Within this agenda, the cities of Rotterdam and Amsterdam stand out for their fearless approach and ongoing results, having turned the threatening challenge of climate change into opportunities.

"Rotterdam Climate Proof" adaptation programme, also created in 2008, envisioned "Rotterdam climate resilient by 2025". Through the use of avant-garde solutions, this programme aimed at enhancing the safety and the quality of life in the city, whilst reinforcing the economic potential for the entire region (RCI 2009, RCI 2010, RCI 2013b). In this specific municipal strategy, adaptation action is essentially approached through four main objectives: 1) "Maintaining and strengthening the basics", such as the dikes and storm surge barriers, while pursuing for improved and innovative ideas; 2) "Making use of the entire urban environment",

[12] The first Dutch National Adaptation Strategy "Make Space for Climate" was only adopted in 2007 and it was primarily focused on mitigation.

making the city more resilient and less vulnerable through the implementation of flexible measures that are in harmony with the natural dynamics of the delta such as tidal parks, floating developments, floodable quays, among others; 3) "working together and linking in with other projects in the city", sharing responsibilities with other parties and stakeholders, providing information for citizens, taking action through small-scaled adaptive measures led by empowered inhabitants and businesses, linking climate change adaptation measures to other urban programs in order to capitalize resources, and initiating and facilitating initiatives within the community; and 4) "Added value for the environment, society, economy and ecology", exploiting opportunities provided by the implementation of adaptation measures; namely more public spaces, more biodiversity, better water quality, increase in property values, among others (RCI 2013a, p.7).

So far, resulting achievements include: the reinterpretation of the dike concept, such as the development of multifunctional defences; adaptive buildings, namely with embedded flood gates, or dry proof constructions; the goal to accommodate water through the construction of reservoirs, water plazas, extended systems of canals, water robust streets and infrastructure such as bioswales, water butts or green courtyards; the implementation of floating houses and developments; and the development of networks of green roofs, green walls and blue roofs. As can be expected, these applied measures, which are planned to grow in number and extension, are significantly transforming Rotterdam's urban spaces and its public space in particular (Figure 1.3).

Figure 1.3 - Overview of Rotterdam's Climate Change Adaptation Strategy. Among the identified measures within this illustration are: green roofs, green facades, blue roofs, tidal parks, collective gardens, water plazas, multifunctional dike reinforcement, floatings developments, bioswales. Source: (RCI 2013a, p.127).

In regards to the case of Amsterdam, the WATERgraafsmeer programme is worth mentioning. The Watergraafsmeer is an attractive residential area albeit being the lowest part of Amsterdam, circa 5.5m below sea level. It is therefore an area particularly vulnerable to flooding and its associated climate change projections.

In order to face the challenges presented by climate change, this initiative envisioned to improve and adapt existing residential areas, as well as new urban developments through community based projects based on an integral approach across sectors and stakeholders. It evolved more than 100 associates, from knowledge institutes, industry, governments to inhabitants. Ultimately, their goal consisted in changing the attitudes and behaviours of the overall community in order to promote adaptation endeavours.

Having started in January 2010, the program has encouraged and enabled projects and activities that adopt ongoing experimentation and learning about potential practical measures to be implemented in their specific urban contexts. One of its projects, located at Jerusalem, is essentially targeted to set up small scale adaptation measures directed towards making the neighbourhood more waterproof for now and in the future. These measures are intended to impose a minimal claim on public space and aim to make water more visible in order to increase its perception. Approximately, the project has been implemented across 80% of the Jerusalem neighbourhood. Among the proposed and implemented measures are: green roofs, permeable pavements on bicycle lanes, rain harvesting systems such as rain barrels, and rain water discharge enhancement through the design of more channels[13]. Although the project is only expected to be concluded in 2018, it has been continually evolving Watergraafsmeer stakeholders, encouraging and promoting critical thinking about new possible sustainable ideas that can adapt to the projected upcoming climate.

One other interesting contribution suppoted by the Netherlands worth mentioning, is the collaborative platfrom of “Dutch Dialogues” [14] which arose as a result of the disastrous event across New Orleans incited by Hurricane Katrina.

The first of the Dutch Dialogues were held in March 2008, starting as a series of interdisciplinary discussions and workshops, that aimed to discover whether Dutch adaptation strategies and measures applied to water management, landscape architecture, flood protection and overall urban design, were of use to the city of New Orleans in its recovery. Works were primarily held between Dutch engineers, urban designers,

[13] www.watergraafsmeer.org/projects/jeruzalem
[14] www.dutchdialogues.com

landscape architects, urban planners and soils/hydrology experts and their Louisiana counterparts.

Their interactions had an intentional effect on territorial studies, that allied with projected climate change scenarios, promoted theoretical and practical advances around the themes of Climate Proof Cities, Living with Water or Resilience Approaches. Through this initiative, the debate of climate change adaptation was further extended by an active platform of knowlege sharing.

1.3.2. United States of America

The North American approach to its national climate change agenda has followed a very different path than the European Union countries. As previously mentioned, while Europe initially preferred a "global government" solution targeted on mitigation endeavours, the USA rather initially pursued a market-based solution to develop adaptation actions. Indeed, while the USA stands out for not having signed the Kyoto Protocol (KP) for opposing to its envisioned efforts to reduce greenhouse gas emissions, it had an early-born and an ever growing adaptation agenda with a significant presence both in national and local scales. One might argue that the US is therefore more experienced and more advanced in the adaptation agenda, and thus eventually more prepared for what climate change may bring.

In 1989, the U.S. Global Change Research Program (USGCRP) was established by Presidential Initiative and mandated by Congress in the Global Change Research Act (GCRA) of 1990 to develop and coordinate federal research on global environmental changes. It further required a report to Congress every four years on the health, environmental, safety and economic impacts of climate change. Under GCRA, the first National Climate Assessment was published in 2000[15].

The years following 2005 Katrina incident also demonstrated a clear progression in the U.S. climate change agenda: "If Hurricane Katrina taught us anything, it is that the worst-case can happen. For the first time in human history, science has given us the ability to peer into a crystal ball of numbers and models and see what kind of a climate we'll be living in by mid-century if we continue to emit carbon at our current levels." (Cullen 2010, p.xvii). Succeeding Katrina´s "wake up call", the second National Climate Assessment report Global Climate Change Impacts in

[15] This report was subject to considerable controversy. One of the biggest accusations was that information was being suppressed, and the expected impacts where much more serious than what was transmitted.

the United States[16] was published in 2009. While the core of this report relied on the identification and assessment of climate change impacts as its title reveals, it also initiated reflections on how society can respond to the upcoming climate challenges in both mitigation and adaptation actions.

Given the pressing need for adaptation approaches, as emanated by the aforementioned reports, President Barack Obama ordered the preparation of federal recommendations for climate change adaptation. It is in this context that the "Interagency Climate Change Adaptation Task Force" (ICCATF) was formed in the same year (2009) with the goal to recommend actions in support of a National Climate Change Adaptation Strategy. Its first progress report, published in 2010, established eight primary principles: "1) Adopt integrated approaches; 2) Prioritize the most vulnerable; 3) Use best-available science; 4) Build strong partnerships; 5) Apply risk-management methods and tools; 6) Apply ecosystem-based approaches; 7) Maximize mutual benefits and 8) Continuously evaluate performance" (ICCATF 2010, p.10). The second progress report, published in 2011, provided an update on Federal Government adaptation strategies including: building resilience in local communities, safeguarding critical natural resources such as freshwater, and providing accessible climate information and tools to help decision-makers manage climate risks (ICCATF 2011).

Following the abovementioned Federal guidelines, the U.S. Army Corps of Engineers published a report in the same year, which recommended for all civil works to consider, with immediate effect, a projected SLR of 2m (Department of the Army 2011).

Although the "Third National Climate Assessment" (ICCATF 2014) verified that the adaptation strategy began to play a strong role in the political agenda within the Federal Government, most adaptation actions have occurred on regional and local scales, in cities of different sizes and locations, independently from federal guidelines. A fact that specifically highlights the distinctive character of the United States adaptation

[16] The report's finding were resumed in ten straightforward facts: "(1) Global warming is unequivocal and primarily human-induced; (2) Climate changes are underway in the United States and are projected to grow; (3) Widespread climate-related impacts are occurring now and are expected to increase; (4) Climate change will stress water resources; (5) Crop and livestock production will be increasingly challenged; (6) Coastal areas are at increasing risk from sea-level rise and storm surge; (7) Risks to human health will increase; (8) Climate change will interact with many social and environmental stresses; (9) Thresholds will be crossed, leading to large changes in climate and ecosystems; (10) Future climate change and its impacts depend on choices made today" GCRP, 2009. *Global Climate Change Impacts in the United States.* New York, US: Global Change Research Program, Cambridge University Press.196 pp.

approach that is strongly associated with proactive "bottom-up" initiatives held in dynamic municipalities. As verified by the research project "Urbanized Estuaries and Deltas" (Costa et al. 2014), cities such as New York, San Francisco, Chicago and Philadelphia have played a particularly significant role in the United States adaptation agenda.

Particularly regarding the case of New York City, in August 2008 Mayor Michael Bloomberg summoned a Climate Change Adaptation Task Force that, with the support of the Rockefeller Foundation, originated a group of climate change impact and adaptation scientists and engineers named the New York City Panel on Climate Change (NPCC). More importantly, underlying this political choice lied the beginning of an original sustainability and climate strategy called the PlaNYC.

When looking into the existing initiatives presented in the PlaNYC since 2007, it can be observed that the adaptation approach has grown in importance when compared to the mitigation approach. For example, in the chapter dedicated to climate change within the last updated PlaNYC of 2011, among the thirteen stated initiatives only two are related to mitigation (City of New York 2011, p.153-159). Among the presented initiatives is the "Million Trees NYC" that, with the goal to increase NY's urban forestry by 20 percent, envisions to enhance the air quality, improve flood resilience and reduce the heat island effect[17].

Emanated from the initial versions of PlaNYC is the equally ambitious NYC Green Infrastructure plan, which essentially promotes the use of unconventional "soft" measures to manage stormwater, namely raingardens, bioswales, permeable pavements or engineered wetlands, among others (City of New York 2010).

In response to Hurricane Sandy, which impacted the city in an unprecedented way, the 2013 version of the PlaNYC arose. In light of the presented recommendations of this plan, entitled "A Stronger, More Resilient New York", it is clear how a bigger importance is given to adaptation measures when compared to mitigation measures that are left for other endeavours. Adaptation is the core "motive" of this Master Plan, the overall and ultimate objective.

Within this plan, the strategy for the adaptation of existing buildings is worth highlighting, as it is mainly related with the transformations in the built environment. Particularly in regards to the improvement of buildings resilience towards coastal flooding, the strategy was organised in two parts: 1) To strengthen new and substantially improved buildings to meet the highest possible standards; and 2) to protect existing

[17] www.milliontreesnyc.org

buildings by encouraging targeted retrofits over time (City of New York 2013b, p.78).

Considering the numbers of existing buildings, the latter strategy entails a bigger challenge. Within this strategy it is advocated for existing buildings to be improved into "flood resistant buildings" by flood proofing their ground floor, or by elevating the entries above projected flood levels. As this transformation may have negative consequences on the streetscape, building access, public safety and so on. The Department of City Planning developed a range of urban design principals in order to guide the designs of building retrofits (City of New York 2013a). Among other components, these guidelines suggested 1) visual connectivity, 2) façade articulation, 3) design for inviting access and 4) enhancement of neighbourhood character (Figure 1.4).

Figure 1.4 - Example of "Do's" and "Don'ts" in regards to "Façade Articulation" (above) and "Inviting Access" (below). Source: (City of New York 2013a).

It is important to note that in New York City, as in most North American cities, there is a clear differentiation in the urbanistic approach when in public or private domain. In an adaptation strategy that is primarily focused on the resilience of existing urban areas, urban planning is essentially directed to vital infrastructure, transportation systems and public spaces. By contrast, it is the insurance industry which motivates private buildings to adapt through time. For example, after 2012, Hurricane Sandy hit New York and in light of the revised federal flood maps that extended the flood prone zones, as well as the impacts of its associated flood risks, insurance companies started to significantly raise the households flood insurance bill if houses were not raised up to their respective security levels.

Other adaptation projects have been developed with the support of tax abatement, grant programs or community-based alliances. This is the case of some of the implemented green and blue roofs such as the ones at Bishop Loughlin High School in Brooklyn and at the Osborne Association in the Bronx or Lenox Hill Neighbourhood House in Manhattan, as well as the tidal park at Pier 42 along the East River (currently under construction) or initiatives such as the new-born Brooklyn Greenway Initiative[18].

1.3.3. United Kingdom

Focussing now on the case of the United Kingdom, one is presented with a country that has been one of the pioneers in climate change adaptation, namely when considering: 1) the United Kingdom Climate Impacts Programme (UKCIP) established in 1997[19], which has supported several adaptation endeavours; 2) the UK Climate Change Programme launched in the year 2000 and updated in 2006, which envisioned the development of a national adaptation approach, that would define political priorities for internal and external action; 3) the 2008 publication from the Department for Environment, Food and Rural Affairs (DEFRA) which grouped UK's national adaptation strategies from diverse existent initiatives (2008); 4) the Climate Change Bill, also from 2008, which established a national legislative framework that defined the need to adopt a program to address climate change associated risks (Swart et al. 2009); and 5) the Nottingham Declaration, launched in 2000 and signed by more than 300 English Councils, which recognized the central role of local authorities in the impending challenge of facing climate change and committed parties involved to address and prepare their community for its impacts.

From these first mentioned efforts, UK's climate change adaptation action grew in maturity and number of actions. Among the current most relevant undertakings is their National Adaptation Programme (NAP)

---

[18] www.brooklyngreenway.org
[19] www.ukcip.org.uk

(HM Government 2013), which specifically evidences the "embedding of adaptation in policies and planning" as the first of its three key areas of action.

Other achievements that are worth highlighting are 1) "Climate UK" network[20] constituted in 2011, which gathers a wide range of organisations and individuals supporting local climate change action; and 2) the "Climate Local" initiative from the Local Government Association (LGA) launched in 2012 in light of the Nottingham Declaration on Climate Change. More specifically, the role of "Climate UK", essentially consists of promoting and assisting bottom-up climate change action as a nationwide effort, joining together and sharing know-how from all the UK about local circumstances, local risks and local opportunities. In parallel, "Climate Local" supports councils' endeavours on climate change response. By choosing to sign up to the "Climate Local" initiative, councils are required to undertake climate change adaptation and mitigation efforts at a local level and share their findings.

In addition to the importance given to local "bottom-up" climate change action, the English case stands out for its proactivity in the search for flexible adaptation measures and an overall precautious approach. This point can be namely exemplified by the achievements from the "Building Futures" think tank of the Royal Institute of British Architects (RIBA)[21] together with the Institution of Civil Engineers (ICE), namely its publication on "Facing up to Rising Sea-Levels: Retreat? Defend? Attack?" (2009). More specifically, this consortium decided not only to assess the impact of the projected extreme scenarios, but also to equate possible strategies and measures to be implemented in the most affected urban areas. According to Robinson et al. "This is a think piece – designed to provoke longer-term thinking across a wide audience … Our proposals are extremes; and they need to be in order to tackle the scale of the problem" (Robinson et al. 2009, p.2). Further within this report, focusing on the situations of Kingston-Upon-Hull and Portsmouth, as the report's title indicates, three strategic options are launched in order to face the scenario of a two meter sea level rise. The presented strategies include: 1) Retreat – the abandonment of urbanised areas and affected infrastructure, and relocation to hazard-free areas; 2) Defend – the employment of new improved defence infrastructure in order to avoid flooding in the prone areas; and 3) Attack – the advancing into the water, reflecting upon international approaches such as the Dutch concept of floating structures.

[20] http://climateuk.net/

[21] www.buildingfutures.org.uk

As can be noticed in Figure 1.5, all the proposed strategies imply a significant change in the pre-existing urban layout. Changes that further imply the rethinking of public spaces and their design. In the Retreat strategy there is namely the opportunity to build submergible parks in wetlands or flood prone areas; in the Defend strategy it is possible to construct multifunctional dikes or embankments with sightseeing settings suitable for promenades or esplanades; and in the Attack strategy ancient floating urban agriculture can be reinvented alongside networks of paths or bicycle lanes.

Figure 1.5 - Three broad approaches to future coastal management. Source: Adapted from (Robinson et al. 2009).

Aside from speculative theory, the English case further developed guidelines that are specifically applied to the adaptation of buildings and the adaptation of public spaces. In regards to the adaptation of buildings, one must mention the document "Your Home in a Changing Climate. Retrofitting Existing Homes for Climate Change Impacts" (Three Regions Climate Change Group 2008) as well as the continuous findings from the research centre CURBE - Cambridge University Centre for Risk in the Built Environment. In regards to the adaptation of public spaces one must refer the works of CABE Space, and in particular their report "Adapting public space to climate change" (CABE 2008), as well as the "Susdrain" community[22] that is particularly focused on the delivering knowledge in the form of practical implemented examples of sustainable urban drainage systems (SUDS) throughout the country.

[22] www.susdrain.org

1.4. Discussion

When considering future horizons, it is consensually established that the subject of climate change will always have to cope with issues of uncertainty and the resulting incongruity between scientists. Nevertheless, there is considerable evidence on how anthropogenic activity has influenced global climate change since the industrial Era, and how it will very likely continue to affect societies in the long term (AMS 2012, Min et al. 2011).

As a consequence of the Human activities since the late Eighteenth century, Crutzen and Stoermer further argued that we are one Era ahead the Holocene, coining it as the Anthropocene, and defining it as an unprecedented age in which humans are not just mere spectators, but are the primary forces shaping the world (2000). This is a recognition that reaches mankind far beyond natural science, it implies a profound reflection about the relationship between people and their planet. Indeed, adapting to unprecedented climate change is one of the biggest contemporary challenges (WEF 2016), as will be the processes of learning how live and cope with established uncertainty.

Among contemporary literature, urban territories are recognized both as major contributing agents of greenhouse gas emissions as well as particularly vulnerable targets to the impacts of projected climate change; namely for being where most people live and most assets rely (Hebbert and Jankovic 2013). Coastal cities in particular, which represent 90% of the world's urban areas, are a major concern, as they are at high risk from some of the most severe climate change impacts such as SLR and storm surges. Other climate related impacts that specifically affect urban territories are wide-ranging, such as the projected rising of temperatures. This specific impact will intensify the UHI effect and its associated heat-related health problems, as well as impact renewable water resources endangering water supply and food production among other consequences. Yet cities are as vulnerable as they are powerful. In addition to being held as the most accountable in regards to the projected unprecedented climate change impacts, urban territories have a privileged position to significantly influence counteractions to the expected climatic changes. It may even be realistic to state that our future relies in our cities.

It is widely recognized that cities should approach expected climate change through both mitigation and adaptation actions as one common endeavour. It is also clearly evidenced that mitigation strategies have been well established within national governments since before the turn of the century. By contrast, climate change adaptation has only reinforced its urban agenda in recent years. This fact is particularly associated to the inevitability of climate change impacts, which has progressively been recognised among climate scientists. In addition, as present times prove, mitigation strategies have not been as successful as previously anticipated. Every year, the progression of Mankind is diverging further from the goals that were initially set by the Kyoto Protocol (KP). Today, climate change adaptation is a deliberation that is inseparable from the agenda of urbanism. Additionally, it is within the pursuit of effective adaptation strategies and measures that this agenda stands before one of its greatest challenges.

Climate change adaptation is still a fairly recent subject, albeit progressively growing as a matter of extreme importance and immediate necessity within the core goals of global scientific and political arenas. In light of the developed bibliographical review, climate change adaptation is generally considered as an adjustment process, which aims to reduce climate related vulnerabilities while looking for beneficial opportunities. In addition, as a dynamic and ever evolving process, climate change adaptation embraces continuous and adjoining learning from monitoring and assessments. By further enabling constant improvements throughout the process, adaptation is unhindered by the need to be an immediate success and the threat of maladaptation is reduced.

While climate change adaptation presents similar perspectives to some of the approaches emanated from sustainability planning, such as when considering the value of ecosystem services, or the need to promote energy efficiency, there is a particular characteristic which significantly differentiates both. In brief, while sustainability planning supports decision-making by the analysis of past trends, climate change adaptation planning bases its options on the recognition of possible future climates through projections and simulations. Adaptation can therefore also be considered as a tool to manage uncertainty. Uncertainty that despite having always been present in the evolutionary processes of cities (Brandão Estêvão 2015) has only recently been accepted, in part due to climate change projections, as part of the way we manage and plan our cities.

In 2007, Füssel distinguished anthropogenic climate change from previous types of adaption by essentially highlighting the "unprecedented" characteristic of the first, namely unpreceded climate conditions, unprecedented rate of change; unprecedented knowledge, unprecedented methodological challenges; new actors and new measures (Füssel 2007). Nowadays a wide range of climatic data is at our disposal, enabling us to better prepare and plan for the future. Traditional climate-sensitive risk methodologies are not prepared to manage the complexity and uncertainty of global climate change, prompting the need for new methodologies to be developed. Adaptation to climate change will therefore challenge established professions, which previously assumed climate was generally stationary. Areas such as water planning, forest management, urban planning or tourism management will need to evolve, bearing in mind a rapidly changing climate. Alongside these developments, climate change adaptation will bring new approaches and measures into the frontline of innovation.

In light of the analysed international examples, one can witness the increasing ambition amongst decision makers and designers, to diminish the gap between theory and practice with regards to adaptation action. Unlike mitigation, adaptation must be differently outlined for each country, requiring specific national, regional and local understanding on the foreseeable impacts. Regardless, it was possible to evidence how climate change adaptation is prompting new urban planning approaches, which are further influencing public space design and the urban form as we know it.

Aside from different processes that have led each country to carry out adaptation endeavours, the overall resulting outcomes evidence a number of similarities. Among the most relevant common characteristics identified in the analysed international examples of urban adaptation action is the importance given to:

- Community-based, from the "bottom-up" projects;
- Interdisciplinary and collaborative processes that involve actors form across sectors and stakeholders;
- Long-term comprehensive approaches coupled with small-scaled interventions;
- Reliability in a wide range of possible solutions instead of a "one size fits all" approach;
- Search for synergies with other urban programmes in order to get the most out of resources;
- Search for new and innovative approaches through collaborative "think tanks" and knowledge sharing platforms

Even though adaptation action is emerging at a fast pace and happening at multiple levels of government, as well as private and non-profit sectors, most cities are still largely unprepared to face the projected climate change. Yet, contrastingly, humanity is strongly dependent on what is done and not done in the cities within the next century.

Ultimately, adaptation action is bounded by Political willingness and institutional capacity

New opportunities for urbanism to evolve are presented by the need for climate change adaptation action. Processes that are associated within (re)-generation, (re)-urbanization, and (re)-infrastructural interventions are now interwoven with longer timescale reflections. The challenge in the search for new and innovative approaches and practices, instigates the reinforcement of both the old and new interdisciplinary duties surrounding the practice of urbanism, including the design of public space.

Chapter 2

Towards a shift of paradigm in conventional stormwater management practices

---

Parts of this chapter were disseminated in the following publications:

Matos Silva, M., New approaches on water management infrastructure. *Soil Bioengineering and Land Management - New Challenges: Sustaining Our Land, Water and Life in Changing Climate*, 2012 Cascais, 88-97 pp. ISBN: 978-989-20-4788-1. [Conference Proceedings]

Costa, J. P., Matos Silva, M. and Oliveira, D., 2012. A adaptação às alterações climáticas, os processos ecológicos e o desenho da infraestrutura de gestão das inundações urbanas. *In:* AEAULP ed. *Palcos da Arquitectura*. Lisboa: Academia de Escolas de Arquitectura e Urbanismo de Língua Portuguesa, 506 - 515 pp. ISBN: 978-972-9346-27-0. [Book Section]

Urban flooding is an old and recurrent urban phenomenon, that every year disturbs our cities, and in some cases quite severely. Climate change research, while evidencing that floods may become more frequent and intense, alerts us of the fact that flood management cannot continue the path of "business as usual". These two arguments, widely present within scientific discourse, prompt the urgency and need for a new way of thinking; possibly, a new way to look upon the relationship between the city and (its) water.

The next chapter will focus upon general flood determinants and intensifying factors, including the influence of expected climate change projections. It will further analyse the evolution of flood management practices throughout history, giving a special emphasis to contemporary avant-garde practices adopted in the cities of Rotterdam, New York and London.

Through the conducted analysis, it is possible to highlight an emerging shift of paradigm in conventional flood management practices, which is namely triggered by the need to reassess traditional approaches. It is further evidenced, how alternative flood management measures are being integrated into the design of public spaces and how this matter is gaining relevance among some municipal endeavours.

2.1. General flood determinants and intensifying factors

Flooding is the most common natural hazard, and third most damaging globally after storms and earthquakes (Wilby and Keenan 2012). It can be generally defined as the overflowing of the normal confines of a stream or other body of water, or the accumulation of water over areas not normally submerged. Floods are mostly related with extreme hydrologic phenomenon's that vary in frequency and intensity, which can be induced by both natural and anthropogenic factors. When water exceeds the acceptable thresholds, these events may additionally encompass serious threats for communities.

A particular flood can result from many combinations of meteorological, hydrological and human factors (Table 2.1). As such, floods do not solely result from the variance of meteorological factors such as rain, snow, snow melt or storm surges, but may also result from the combination with other hydrological determinants, such as the drainage basin conditions and the coastal or estuarine configurations (Smith and Ward 1998). In addition, floods may be aggravated by human induced factors such as the implementation of human settlements into flood prone areas.

Table 2.1 – Summary of factors contributing to flooding. Source: (EEA 2012, p.37).

Meteorological factors	**Hydrological factors**	**Human factors aggravating natural flood hazards**
• Rainfall • Storm surges • Temperature • Snowfall and snowmelt	• Soil moisture level • Groundwater level • Presence of impervious cover • Channel cross-sectional shape and roughness • Topography, slope, basin geometry • Presence or absence of over bank flow, channel network • Synchronisation of run-offs from various parts of watershed • High tide and heavy swell impeding drainage • Presence of strong ice cover on rivers	• Land-use changes (e.g. surface sealing due to urbanisation, deforestation) • Inefficiency or non-maintenance of sewerage system; river margins clearing • Building in flood-prone areas • Reducing/cutting off retention areas

Precipitation may vary in intensity, duration, amount, timing, and phase (rain or snow). A natural drainage basin may vary in its water level, channel cross-sectional shape and roughness, topography, slope, basin geometry, presence of strong ice cover on rivers, vegetation, soil type and status (frozen or not, soil moisture content and vertical distribution) (Bates et al. 2008). A drainage basin may be further affected by the synchronisation of run-offs from various parts of the watershed, high tide or heavy undulation that impedes outflow drainage (EEA 2012). When a drainage basin is urbanized, additional factors may lead to the propensity for flooding. Among others are the circumstances that accentuate flood peaks such as dikes, dams, reservoirs, artificial defences or underground drainage infrastructure ruptures, as well as the extension of impervious surface area.

Types of floods

Floods are generally typified according to their cause or source (Figure 2.1). They can be divided in (1) fluvial, (2) pluvial, (3) coastal, 4) groundwater, (5) artificial drainage floods. Other authors further evidence the type of floods associated to (6) glacial lake outbursts (Bates et al. 2008). In addition, severe fluvial floods and costal floods can push man made flood defence infrastructure, where they exist, up to unsafe thresholds (1a, 3a). When costal defences rupture, fluvial and costal floods are significantly exacerbated.

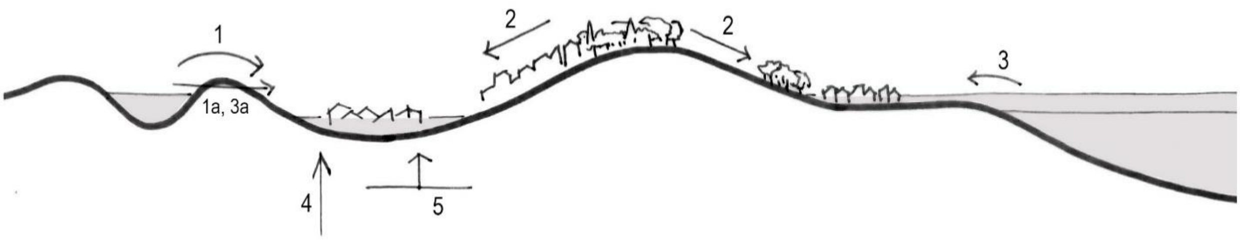


Figure 2.1 - Illustration of the different types of floods: 1) fluvial, 2) pluvial, 3) coastal, 4) groundwater flood, 5) artificial drainage flood, 1a, 3a) flood defence rupture. Image: author's design, 2015.

1. Fluvial or river floods occur when the surface water runoff exceeds the capacity of natural or artificial channels and overflows into the adjacent and low-lying floodplain areas. Progressive floods are a particular subtype of fluvial floods.

   As an example of a fluvial flood, one may consider the 1998 flood event in the Yangtze River Basin in Southern China (Jha et al. 2012). Natural progressive floods, such as the floods at the Nile in northern Africa or in the Mississippi in northern America, periodically occur among parts of the flood plain areas. The city of Coimbra, in Portugal, is also repeatedly affected by the named progressive floods of Mondego River; one of the greatest registered episodes occurred on 29th, January 1948 (Dias et al. 2015).

2. Pluvial floods, which are also known as overland floods, are resultant from rainfall or snowmelt that has not infiltrated into the ground and is forced to flow overland. The affected area will continue flooded until water is drained outwards and into drainage systems or watercourses. Flash floods, which occur due to a rapid rise and fall of water levels, usually after intense rainfall episodes, are particularly common within urbanized areas.

   Pluvial floods usually affect large areas and for an extended period. Recent 2015 floods in the northwest of the UK (in Lancashire and Yorkshire, among other places) are an example of pluvial floods. Flash floods have a more localized impact. They are generally characterized by having a peak in volume of torrential stormwater after a short time period (generally six hours), and can be particularly hazardous as they are difficult to predict. The 1967 drastic flood episode in Lisbon and its local surrounding area, is an example of a flash flood.

3. Coastal floods occur from the incursion of water from the sea or the ocean. These floods are mostly associated with an unusual extreme increase in sea level caused by tsunamis or severe storms and storm surges.

   While storm surges are a phenomena that are physically bounded within the coastal areas, tsunamis propagate through the deep oceans and strike the coastlines (Nirupama and Murty 2012). Both occurrences can cause great losses in low-lying coastal areas, particularly when urban. The 2005 flood episode in New Orleans caused by Hurricane Katrina is one among many other examples of a costal storm. This particular case also evidences the exacerbated consequences of the failure of an artificial system, such as a flood wall.

4. Groundwater floods occur when subsurface water emerges from the ground. It often takes place in low-lying areas underlain by permeable rocks. This type of flood is usually the result of persistent rainfall that exceeds the aquifer capacity until its water reaches the surface level. In other cases, namely in semi-permanent flood situations, this type of flood may be associated with areas that lie below sea level or where the water table is very close to surface. Considering its characteristics, this type of flood usually takes longer to dissipate.

Groundwater flooding may occur in places such as the city of Mumbai, India. This city is situated in an area with large reclaimed terrains, just above sea level, and below the high-tide level. One of the most severe flooding episodes to occur in Mumbai, was in July 2005.

5. Artificial drainage flooding is the result of a failure in the artificial drainage infrastructure. This type of flooding is a recurrent hazard among most cities, particularly the ones that have an old and deteriorated artificial drainage system. Occasionally, these systems may burst when exceeding their capacity after an extreme precipitation event to cause flooding in lower-lying urban areas, and can be seen with a sewer overflow. The failure of an artificial system is often associated with a rapid outbreak of water at high pressure and velocity, aggravating the possible impacts. While, expectedly, low-lying areas nearby, which are nearby obsolete drainage systems (or adjacent to fragile engineered defences that may exacerbate coastal flooding) are more vulnerable, this type of flood is usually omitted from the flood plain hazard zones commonly mapped (RIBA 2010).

   Among the many possible examples of artificial drainage flooding, one may highlight the event of February 18th of 2008 in Lisbon. On a day that experienced low tide values in the Tagus Estuary, this flood occurrence was primarily dictated by the combination of heavy rainfall with pressures and consequent rupture of obsolete underground drainage infrastructure.

6. A glacial lake outburst flood is a type of "megaflood" (i.e. high-magnitude and low-frequency) that occurs when the dam containing a glacial lake fails. For example, in south-eastern Alaska, glacial lake outburst floods can occur every year.

2.1.1. Expected influence of climate change upon flood events

There is no doubt that a change in the climate physically changes several factors that affect floods, and may thus change the characteristics of floods (IPCC 2012). Although there are many other contributing factors that may lead to a change in the frequency and intensity of flood episodes, such as engineering structures or specific land uses, this sub-chapter will specifically focus upon the changes in floods that might be associated to changes in climate, that is, that are climate-driven.

Among the most important climate-driven changes that may lead to more flooding episodes are: 1) the increase of global precipitation; 2) the greater amplification in the frequency and intensity of precipitation extremes; 3) the increase of storm surge magnitudes and 4) the increase of average sea levels.

The aforementioned changes however, are expected to vary significantly between regions. For example, in light of most climatic projections emanated by the specialized disciplines, there is a general agreement that a rise in both mean and extreme precipitation is expected for northern Europe (Semmler and Jacob 2004; Frei et al. 2006; Nikulin et al. 2011 in Soares et al. 2015), while for the Mediterranean area most authors suggest a reduction in mean precipitation and an increase in extreme events (Alpert et al. 2002 and Rajczak et al. 2013 in Soares et al. 2015).

It is important to bear in mind that climate models are unable to fully grasp the complexity of the water cycle. Indeed, most scientific studies related to climate change consider water as a stable element on the atmosphere when it is general common ground that water interacts with the whole ecosystem through various inter-related processes. As argued by recognized statistician George E.P.Box, “All models are wrong, but some are useful" (1987)[25]. As a point of fact, models will never be able to replicate reality as a whole but rather analyse parts of its intricacy. For Kharin et al, intermodal differences, rather than sampling errors, are what mostly dominates the uncertainty in changes regarding precipitation extremes (Kharin et al. 2007). Any model will never be entirely correct, yet findings that may arise from their analysis are important thresholds that must not be neglected.

As a result of such a complex understanding one often finds contradictory studies, particularly among research focused on rainfall extremes. Jacobeit et al, which have analysed several studies regarding the particular case of the Mediterranean, conclude that, within this region “temperature related estimates are more reliable than those related to rainfall, and estimates of mean conditions are more reliable than those of extremes” (2014, p.1903).

At a global scale, Groisman et al found that both the empirical evidence, from the period of instrumental observations and model projections of a greenhouse-enriched atmosphere, indicate an increasing probability of intense precipitation events for many extratropical regions (2005). In 2011, two studies published in Nature Magazine concluded that climate warming is already causing extreme weather events that affect the lives of millions. One of the studies consisted on the “first formal identification

[25] Box, George E. P.; Norman R. Draper (1987). *Empirical Model-Building and Response Surfaces*, p. 424, Wiley. ISBN 0-471-81033-9.

of a human contribution to the observed intensification of extreme precipitation" (Min et al. 2011, p.380). This former study also highlighted that "extreme precipitation events may strengthen more quickly in the future than projected and that they may have more severe impacts than estimated" (Min et al. 2011, p.380). The other study links climate change to a particular event: the damaging foods in England and Wales in the year 2000. From this study it was possible to conclude that anthropogenic climate change may have almost doubled the risk of the extremely wet weather that caused the mentioned flood (Pall et al. 2011).

In 2012, the IPCC argued that, although there is limited evidence that anthropogenic climate change affects the magnitude or frequency of floods, it is possible to detect climate change influences upon several components of the hydrological cycle, such as precipitation and snowmelt that may impact flood trends. More specifically, according to their report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation, "there is medium confidence that projected increases in heavy rainfall, would contribute to increases in rain-generated local flooding, in certain catchments or regions" (IPCC 2012, p.178).

Additional research presented less conservative results than the above-mentioned. Coumou and Rahmstorf, for instance, have argued that there are many lines of evidence, from statistical analysis of observed data to climate modelling and physical reasoning, that strongly indicate that some types of extreme events, namely precipitation extremes, will significantly increase in a warming climate and, moreover, have already done so (Coumou and Rahmstorf 2012).

Findings from the recent Assessment Report of the IPCC (AR5) evidenced observed changes in many extreme weather and climate events since around 1950. Some of these changes include an increase in the number of extreme precipitation events in several regions (IPCC 2014). Regarding projected changes, the report mentions that "extreme precipitation events will become more intense and frequent in many regions" (IPCC 2014, p.61), while also highlighting that "Changes in precipitation in a warming world will not be uniform" (IPCC 2014, p.64). Data that consequently implies greater risks of flooding in regional scales, a statement that the IPCC declares with "medium confidence" (IPCC 2014, p.8).

Regarding changes in sea levels, highly influenced by weather conditions, coastal areas are among the most vulnerable territories. Flooding in these areas has resulted predominantly from intense storms, which in turn have caused high sea levels. In many situations different phenomenon's occurred at the same time, such as storm surges and high tides or even river outflows, which aggravated the problem (Kress 2007). Considering the expected increase of SLR, as well as man-made pressures upon coastal regions, the risks upon these areas are expected to be amplified.

In 2011, a 20 year investigation evidenced that the ice in Greenland and Antarctica is losing mass at a faster pace than what was expected by the IPCC in 2007 (Rignot et al. 2011). This improved research implied significant consequences for the rise of sea levels. According to the IPCC projections of 2007, a sea level rise of about half a meter until the end of the 21st century was estimated (IPCC 2007). In addition, recent research conducted by Schaeffer et al. demonstrated that, in accordance with the strong inertia of large ice sheets and the deep ocean, when facing the impacts of climate change, it is physically expected for sea level to physically rise slowly and along an extended timeframe.

This study further specifically indicates that the influence of past emissions has already contributed to about half of the twenty-first century SLR, concluding that "even an abrupt switch to zero emissions, would have practically no effect on sea level over the coming 50 years and only a moderate effect on sea level by 2100" (Schaeffer et al. 2012, p.870). In a dramatic perspective, if ultimately the Greenland icecap melts, the consequence would be a SLR of 7 meters (Kress 2007).

According to the latest studies from the IPCC, there is high confidence that "Coastal systems and low-lying areas will increasingly experience submergence, flooding and erosion throughout the 21st century and beyond, due to sea-level rise" (IPCC 2014, p.74). The same report specifically indicates that all Representative Concentration Pathways scenarios (RCPs) project a SLR in a range extending from 0.26 to 0.82 m.

Lastly, and on a parallel note, one must highlight that apart from a future with more extreme weather events, climate projections also point towards a rise in temperature. There is either too much water from punctual, albeit more frequent and intense, storms or an overall diminishing of the water resource. In some situations, namely in the Mediterranean region, both scenarios (of abundancy and scarcity of water), albeit almost antagonistic, show concurring projections.

2.1.2. The main concerns of urban flooding

How you choose to live each day, whether you regard or disregard me doesn't really matter to me. One way or the other, your actions will determine your fate, not mine. I am nature. I will go on. I am prepared to evolve. Are You?

www.natureisspeaking.org

Every year, floods disturb our cities. As mentioned earlier, in an urbanized drainage basin, there is a greater tendency for flooding, namely by the circumstances that accentuate flood peaks. Among them is the extension of the impervious area, which significantly alters the natural water cycle (Figure 2.2). According to the well-known study of Thomas Schueler, "The Importance of Imperviousness", the impervious coverage in residential areas increases from approximately ten percent in low-density suburban areas, to over fifty percent in multi-family communities; in industrial and commercial areas coverage rises above seventy percent and in dense metropolises, it is over nighty percent (Schueler 2000). When compared to a natural watershed, urban territories have therefore greater runoff flows with increased velocities, less infiltration rates and the consequent reduction in groundwater recharge, as well as less evapotranspiration rates. Furthermore, when considering the cities' ongoing extensive underground works, such as metro lines or building's basements, sub-surface drainage is also significantly disturbed, consequently contributing in a greater extent to the upper ground area flooding.

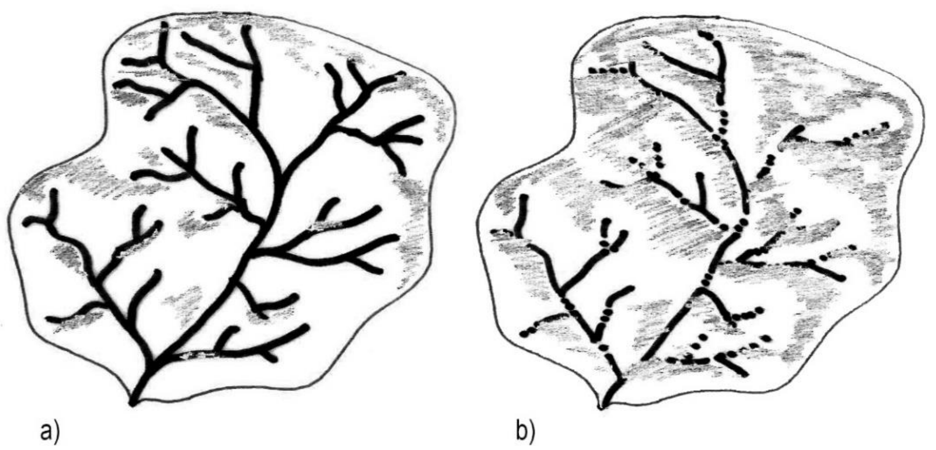


Figure 2.2 - Sketch of a) natural water basin *versus* b) an urbanized water basin (severely altered with cancelled stream sections). The smudge represents the human settlements. Source: adapted from (Watson and Adams 2010, p.89).

The most common types of flood in urban areas are: river floods, flash floods, coastal floods, urban drainage floods and groundwater floods.

Among the most severe urban flood impacts are the loss of life and health hazards, which can result from the exposure to contaminated waters. Other impacts include, displaced population and environmental damage, as well as material loss including the devastation of infrastructure or public and private property. Floods may also seriously compromise economic activities and economic development, namely through the failure of services (transport, communication, electricity) and the loss of jobs. A more comprehensive analysis on the most frequent impacts of urban flooding is presented in Table 2.2.

Table 2.2 - Potential flood impacts in urban areas include material, economic, health and emergency assistance impacts. Adapted from EEA (2012) and Andjelkovic (2001).

Material impacts
• Recurring basement backups from surcharged sanitary sewers; • Inflow of stormwater into sanitary sewers; Municipal waste water treatment plant by-passing; • Delays in public transportation; • Disruption of services such as water supply, sewerage and power supply;
Economic impacts
• Flooding of housing, commercial and industrial properties; • Flooding of streets, intersections and transportation systems, causing traffic disruption; • Damage to public and personal property; • Economic losses; • Disruption of electricity and communication networks; • Loss of business.
Environmental impacts
• Disturbance of wildlife habitats; • Combined sewer overflows and associated pollution of receiving water bodies.
Health impacts
• Loss of human life; • Spilling the surcharged sewers content into streets; • Citizens' experience of all relevant impacts in a flood event — post traumatic stress disorder due to dislocation and loss; • Health hazards due to contact with contaminated flood water.
Emergency assistance impacts
• Clean-up demands; • Hazards in fire department, policy department, sewer management and water board services.

Specifically regarding urban stormwater management, as this subject will be further discussed, drainage systems have been implemented within cities throughout history. These systems have been improved over time and are increasing in scale and complexity. Most cities have relied in these systems as they are particularly efficient in the rapid collection of stormwater and effectively draining it away from the city. Nonetheless, current stormwater management practice still faces several problems, which go in parallel with the current priorities and concerns. More specifically, as it is increasingly mentioned and evidenced within academia, some of the negative effects produced by these systems, paradoxically, exacerbate flooding within urban territories.

According to Howe et al., the most urgent matters that need to be tackled in the current practice of urban stormwater management, encompasses eight main issues: 1) combined sewerage overflows; 2) diffuse pollution; 3) decreased base flow; 4) heat island effect; 5) erosion and sedimentation; 6) downstream flooding; 7) costs; and 8) waste of a valuable resource (Howe et al. 2011, p.102).

More specifically, during the periods of heavy rainfall, drainage systems may exceed their capacity and cause overflows. This phenomenon is particularly serious when it occurs within combined sewerage systems, whereby the treatment plant has reached its limit, thus discharging polluted waters into receiving water bodies.

Diffuse pollution, unlike the pollution of industrial and sewerage treatment plants, has multiple sources. It generally results from rainfall or snowmelt that moves though the roofs and grounds, bringing along pesticides, herbicides, oils and solid materials such as mud, litter, leaves, branches, among others (Figure 2.3).

Figure 2.3 - Left: A street in Lisbon with visible petroleum hydrocarbons pollutants. Image credits: Tiago Cunha Ferreira, 2014. Rigth: Litter clogging the gutter at a street in Lisbon. Image credits: Leonor Klettenberg, 2014.

Most of the traditional drainage systems bury and seal runoff within a network of pipes, which further contributes to the disruption of the already disturbed urban water cycle. As such, the reduced rates of infiltration, evaporation and groundwater recharge are exacerbated. By reducing natural discharge and infiltration, aquifers are depleted, as is the availability of drinking water. Alongside this, because stormwater is rapidly removed from urban areas, evapotranspiration is reduced. This fact, albeit less obvious, leads to hotter urban microclimates, which further contribute to the aggravation of the urban heat island effect (UHI) (Alcoforado and Andrade 2008).

The increased velocities that are intensified by the percentage of impervious areas within the urban watershed, leads to the erosion and increased sedimentation in the receiving estuaries, rivers or streams. The fast conveyance and disposal of stormwater into receiving water bodies further increases the risk of downstream flooding. This is particularly the case of waterfronts that are simultaneously affected by tides of great amplitude, such as in the Lisbon case.

The problem of costs is particularly associated with the scale of investment in maintaining and retrofitting the existent system. Especially in the case of consolidated urban fabrics, the construction and maintenance of these systems is known to be extremely expensive and extremely time-consuming. In addition, the "end-of-pipe" treatment system is energy intensive.

The last abovementioned unsolved matter concerns the counterproductive action of lightly wasting the valuable resource of rain water which would be otherwise useful. More specifically, non-drinkable water from rain storms may serve for several purposes such as watering gardens, cleaning streets, among others. The use of this water will consequently diminish the consumption of drinkable water, which is a vital resource. An evidence that despite being relatively unnoticed, must not be disclaimed from our common concerns.

To all the aforementioned factors, one must add the previously highlighted projected scenarios pointed out by climate change research. Overall, there is high confidence that urban areas exacerbate the exposure to climate change and the impacts upon the local scale. Indeed, most urban areas create unique microclimates due to their change from natural to artificial surfaces, a fact that affects "air temperature, wind direction and precipitation patterns, amongst others" (EEA 2012, p.13).

Yet, while "urbanization itself is not always a driver for increased vulnerability" (IPCC 2012, p.79), the result of inadequate planning and governance are. Bicknell et al. namely refers that the urbanization of some localities is considered to be of much reduced vulnerability to extreme weather events (2009).

As most urban disasters related to extreme climatic events are understood as unusual events - paradoxically, usually referred to as "natural events" - orthodox urban planning and governance does not usually dwell into the matter. However, when disasters are caused or exacerbated by urban development, then urban research must not ignore them (Bicknell et al. 2009).

Bearing in mind that conventional stormwater management infrastructure, is mostly designed in accordance to statistical recurrence criteria, originating from available historic meteorological data, the same may not be able to cope with the expected unprecedented flood events. Milly et al have already argued that traditional engineering solutions based on the assumptions of a stationary climate are no longer applicable (Milly et al. 2008). Howe et al. are also assertive when claiming that the majority of stormwater drainage infrastructure "lacks the flexibility to adapt when design parameters are no longer applicable for the local climate" (2011, p.103). According to Myles Allen "what has been considered a 1-in-100-years event in a stationary climate, may actually occur twice as often in the future" (in Schiermeier 2011, p.2), which makes most of existing infrastructure barely adequate. Yet adapting the existing stormwater drainage systems from one day to another in order to follow the predicted climate change scenarios would involve unreasonable investments, that are very likely unaffordable for the municipalities in the near future.

Many other factors offer daily defiance to contemporary urban stormwater practice, some of which also reasonably uncertain, from governance strategies to emerging technologies, from population growth or decline to energy use. One must bear in mind that the lifestyle of developed countries and its cities, is leading to a narrower societal range of overall tolerance with floodwaters, which further leads to increased vulnerabilities.

Although total protection from urban flooding is an impossibility, improvements within our physical managing systems can be made, particularly when acknowledging impending weather events. Estimated projections are drivers for change, they are indicative rather than definite and are reliable as such. The challenge relies on our ability to adapt existing infrastructure, so that they can continuously cope with various and changing possible scenarios.

2.2. The evolution of flood management practices

2.2.1. An overview of flood management practices throughout history [26]

Whoso neglects learning in his youth,
Loses the past and is dead for the future.

Euripides - Greek tragic dramatist (484 BC - 406 BC)

Strolling through history, one can identify differing approaches concerning flood management practices, and begin to understand why and how paradigms and attitudes towards urban stormwater have changed over time. Ultimately, through an overall analysis, one may further risk to speculate about future potential approaches, namely by questioning if we are presently on the verge of a new paradigm shift, one that reassesses contemporary conventional practices. Indeed, as argued by Euripides, most future facts are based on those in the past.

In order to ensure food and water, the early settlements of mankind were developed in mild climates near rivers or waterfronts. The first archaeological records of water projects, such as dams and irrigation systems, date from the Neolithic Age (ca. 5700 – 3200 BC) (Angelakis et al. 2014). These systems were developed namely in Mesopotamia and Egypt in order to benefit from the seasonal flooding of their nearby rivers of Tigris–Euphrates and the Nile, respectively. For these notable ancient civilizations, floods were no nuisance but rather an advantage as they naturally enriched the river plain soils with minerals and thus increased their fertility. Only through time, as these communities grew and these developments expanded into cities, did floods began to be less and less welcomed. The benefits of floods started being surpassed by the negative consequences and disturbances they caused.

Besides taking advantage of the best quality farmland, early societies from the Neolithic age also developed techniques to store and preserve stormwater. As Mumford recalls, one should mark how much the city owns technicality to the village, "…the irrigation ditch, the canal, the reservoir, the moat, the aqueduct, the drain, the sewer…" (1989[1961], p.16). Between the end of 4000BC and the beginning of 3000 BC, initial Mesopotamian villages had networks for storm and waste water (Angelakis et al. 2014).

[26] The brief historical overview may be accompanied by the developed timeline presented in Annex I - Relevant milestones regarding the evolution of flood management practices.

Mohenjo-daro, a planned city built around 2450 BC in the Indus Valley, is an example of the early attention given to sewer and drainage infrastructure (Angelakis and Zheng 2015). From the ruins of its systems it was possible to identify the use of simple sanitary sewers as well as drains to convey stormwater off the streets. A particularly interesting feature of their tailored technique was the use of a “cunette” for the conveyance of reduced flows (Matos 2003). Developments in cities such as Ur or Babylon from the Mesopotamian Empire, also represented great advances in civilization (see Annex I - Relevant milestones regarding the evolution of flood management practices). Specifically in regards to the hydraulic matters, archaeological works confirm the advanced technical know-how of its sanitary and stormwater systems, including baked brick and asphalt arched sewers and domestic sewers (Burian et al. 1999).

Knossos palace in Crete, dating from circa 2000 BC, had three distinct water management systems: one for water supply, another for waste water and one for water runoff. Aqueducts, cisterns, covered pipes, open channels, fountains, dams, polders, levees, rainwater harvesting from rooftops and courts, catchment basins and manholes were some of the techniques used by the Minoans. As the palace was on top of a hill that was regularly hit by torrential precipitation, stormwater management was specifically addressed. Among the practiced rainwater drainage techniques in this palace, one may highlight the advanced stairway runnel onto which rainwater is directed (Figure 2.4-Left). Through this system, the use of the stairway is undisrupted by superficial drainage. A drainage technique that, just like most others, was latter used and reinterpreted for infrastructural and/or aesthetic purposes (Figure 2.4-Right). In addition, not only did the Minoans engendered ways to collect water in order to help the removal of waste water and stormwater, but they were also able to keep the water pure for later consumption (Burian et al. 1999). Indeed, the long-term sustainability of Minoan cisterns has been acknowledged, namely in light of their contemporary presence and utility in the rural areas of Crete (Angelakis and Zheng 2015).

In the first Chinese urban establishments, which emerged circa 700 – 100 BC, techniques were developed and projects were implemented with the aim to fulfil the needs of irrigation, flood control, water supply, among others. Both large scale and small scale interventions were applied. While cisterns for the collection of rain water were frequently small scale, for domestic and irrigation usage, large scale interventions comprised mostly of aqueducts, dams, dykes or canals. According to Angelakis and Zheng, by this time, cisterns did not only play an important role in water supply but also in flood protection when serving as stormwater sluices (2015).

Currently, this technique is best known as stormwater regulation reservoirs.

Figure 2.4 - Left: Drainage canal built-in a stairway and corresponding catch basin at the Knossos Palace in Crete built in 2000BC. Source: (Angelakis et al. 2012). Right: Detail of water canal built-in a stairway at Granada - Generalife gardens built in late XIII century. Image credits: Maria Matos Silva, 2014.

By 600 BC, among the Etruscan civilization, Marzobotto city is known for its drainage system which used the natural topographical conditions to its advantage (Matos 2003). Paved streets and stepping stones were used in order to keep the city dry and the people safe from the nuisances of strong runoffs.

Most of the techniques developed in these times are used in the current days. Nonetheless, regardless of their advanced knowhow on water management, these notable civilizations eventually collapsed. Particularly regarding the Minoans, Mycenaean and Etruscan, researches still argue whether or not their failure is associated with water related hazards.

The Romans inherited Greek techniques and developed them further. Not only did they increase the extension of water projects, implementing them in almost every large city, but they also increased the scale of each project due to their high engineering competence. An often-mentioned example of Ancient Roman excellence in the implementation of robust sewage and drainage infrastructure is the Cloaca Maxima, one of the first (and largest) covered sewerage system built around 600 BC (see Annex III - Relevant milestones regarding the evolution of flood management practices).

Roman water management practices also envisaged small scale systems. Specifically regarding stormwater management, Roman cities such as Pompeii (79 AD), adopted the Etruscan techniques of stepping stones in roads, which additionally served to store and convey stormwater. As mentioned by Burian et al., most Roman streets "… were paved, with raised sidewalks and stepping-stones at street crossings to protect pedestrians against stormwater and overflow from the aqueducts" (1999, p.4). Roman drainage structures additionally included "occasional curbs and gutters to direct surface runoff to open drainage channels alongside roadways" (Burian et al. 1999, p.4).

In addition, by this period, it was common for Greek and Roman houses to have rainwater harvesting and storing systems. One of the techniques was to collect rainwater from roofs and store it in cisterns, which were usually placed under the building. Variants of this system include the "impluvium" technique that essentially corresponds to a sunken artificial basin of an inner atrium, into which rainwater drained from rooftops was directed. The basin, or better said, the "impluvium", is further composed by a porous pavement surface in order to filter water before it is percolated into the underground cistern for storage. This technique, in addition to collecting, filtering and storing rainwater, also serves as a cooling system of the surrounding spaces.

All the aforementioned techniques have helped cities develop and endure for thousands of years. Aside from the technical quality of these systems, the reason they have surpassed historical hindrances or regressions is often associated to the permanency of written records that scientifically explained each technology. Among these works are the widely recognized treatises of Vitruvius, *De Architectura* and in particularly, its eight chapter regarding water supplies and aqueducts, or Sextus Julius Frontinus *De aquaeductu urbis Romae*. Besides the exposure of technical and engineering knowledge, Vitruvius treatise further assessed and argued on the nature of elements, namely water. It specifically stated that "all things depend upon the power of water" (Introduction, Book VIII in Maciel 2009).

Earliest documented in the 13th century, Freiburg Bächle is a notable reference of ancient water supply techniques. In essence, it consists on a network of small canals that divert water from the river into and city, and again, out of the city. Besides the purpose to distribute water for consumption and agriculture, these canals were further used to help combat fires and to convey all sorts of waste out of town during the night-time (Figure 2.5-Left). However, in general, water management techniques did not progress much during the period between the end of the Roman Empire and the Eighteen century, as most urban developments paid little attention to the need for waste and stormwater management. Existing systems became progressively insufficient for the increasing population. There was an evident decline in the urban hygiene and cleanliness, which thus increased surges of epidemics. Historical accounts mention extremely poor salubrity conditions. One can experience a glimpse of these agonising moments in history through the descriptions included in Peter Hall's "City of the dreadful night" chapter, namely the sentimentalist testimony named "The Bitter Cry" provided by Andrew Mearns on the life within a Victorian slum (Hall 2014[1932]).

In order to tackle the aforementioned unsanitary conditions, Europe started to cover its pestilent drainage channels throughout the city. A simple strategy that apparently solved the sewage and drainage problem only by removing it from sight. Although the first planned sewerage is said to have been built on 1370 in Paris, London only constructed a planned sewer in the 1600s and most of Paris continued to rely on open sewers until the 1700s (Burian et al. 1999).

Only in the 1600s did the theoretical knowledge on fluid mechanics advance enough to allow sewer systems to be developed based on rational considerations (Niria 2009). An important laboratory for the advancement of this knowledge, and particularly the techniques related to piped water supply and hydraulics, was the garden of Versailles, built between 1664 and 1685. For the proper functioning of the numerous fountains of this immense garden, several engineers and scientists came from all over and presented innovative solutions in light of the presented hydraulic hindrances. In this place, empirical hydraulic knowledge therefore gave rise to scientific and applied know-how (Figure 2.5-Right).

Figure 2.5 - Left: A street of Freiburg Bächle today. Image credits: © Jessica Spengler, 2012. Right: The Latona Fountain, the central element of the Grand Perspective of the garden of Versailles. All the remaining fountains depend totally on Latona for their water supply. Image credits: Maria Matos Silva, 2005.

Marked as the advent of modern engineering hydraulics and hydrology, large scale sewerage systems were constructed in the 1800s, together with the regulation of river flows through the implementation of dams, embankments, sluices, among others. Through the course of time, visible forms of water became rare. Gradually, a vast network of underground pipes replaced unhealthy and dangerous water courses existing within cities.

Stormwater runoff was additionally seen as a nuisance for the proper functioning of the industrial city "machine", and efforts were therefore targeted at conveying water flow excesses out of the city as efficiently and as fast as possible. In theory, benefits from water resources were increased and hazards to human life and property diminished. Overall, such actions were considered a great progress in the fields of engineering and urban planning.

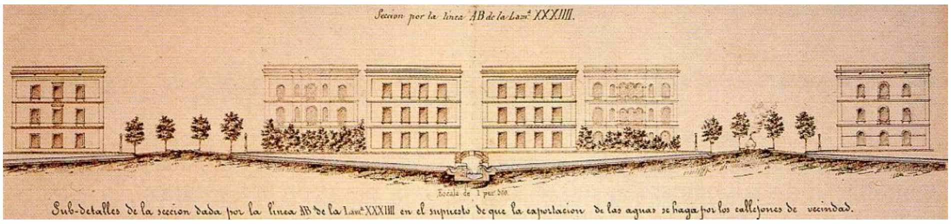
One of the urban planning highlights of this era, which followed the lines of the sanitarian movement, is Ildefonso Cerdá's "Plano del Ensanche de Barcelona" of 1860. Among the invisible qualities of the "Ensanche" plan, is the attention given to stormwater drainage, which was carefully considered and included in some of the plan's design details. Not only was the aboveground design of the streets carefully thought out, with considerations about the type of lamps and pavement, but also the underground sewer galleries, with their own designed configuration served the city unnoticed (Figure 2.6-Above).

Cerdá's plan is a good illustrative example of the transition between the city whose major water infrastructure was linked to water supply and the city, which began to also include sewerage infrastructure and with a greater extension. In this particular transition, a great respect upon the antecedent land use and natural morphology conditions is evident, namely in order to facilitate the gravitational flow of rainwater, both in surface and in underground.

According to Busquets, the great floods that occurred in Barcelona's plain, greatly influenced Cerdà's proposal. In light of Cerdà's detailed knowledge of Barcelona's territory[27], a particular attention was given to the existing groundscape. His understanding from this analysis led to the "adaptation" of the "Ensanche" itself to the NW-WS orientation in order to facilitate drainage runoff. His description was very precise: "What the topographic study from all locations teaches us, is that by transposing edification of a rural state into an urbanization, …, drainage outflows from the first urban roads had to be the same as those already existing in rural land, or are the runnels and streams that are the natural form of

[27] In 1855, Ildefonso Cerdà was part of a team that developed Barcelona's topographical map (Tarragó, F., 1996. *Cerdà. Ciudad y Territorio. Una visión de futuro.* 3rd ed. Madrid: ELECTA. 381 pp. ISBN: 84-8156-069-3.).

rainwater in its fall and flow"[28] (Cerdà 1867, p.308, author's translation) (Figure 2.6-Middle and below).



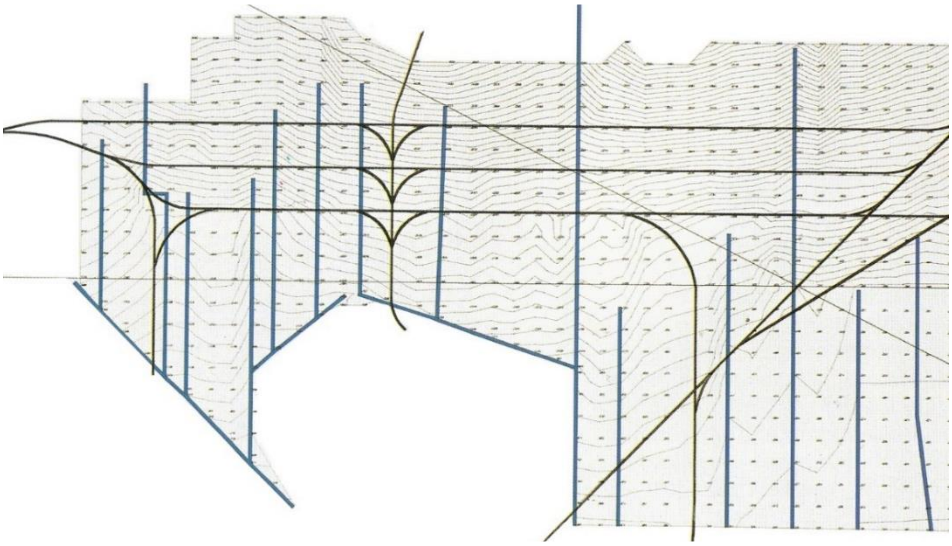


Figure 2.6 - Above: Section of the grouping of blocks "M" with neighbourhood street. Detail of the sewerage galleries' configuration. Source: Atlas del Anteproyecto de Ensanche de Barcelona, 1855 in (Tarragó 1996, p.190).

Middle: Ildefonso Cerdá's "Plano del Ensanche de Barcelona" over pre-existing buildings and agricultural plots. Source: (Corominas and Busquets 2009, p.38)

Below: Sanitation and drainage network (in blue) deduced by Francesc Magrinyà over Barcelona's topographic lines. Source: (Magrinyà 1996, p.244).

[28] Original text: *"Lo que el estudio topografico de todas las localidades nos ensena, es que al pasar la edificacion del estado rural al de urbanizacion, es decir, al agregarse casas a casas, estableciendo entre si una combinacion cualquiera, que siempre hubo de ser asaz imperfecta, los desagues de las primeras vias urbanas hubieron de ser los mismos que tenía ya el terreno en su estado rústico ó rural, ó sean los regates y arroyos que forman naturalmente las aguas pluviales en su caída y corriente."*.

While a comprehensive drainage master plan was only finalized in 1891 by the Engineer, Garcia e Faria, it was developed according to the guidelines left by Cerdà. His manuscripts and Master Plan further acknowledged the need to build a great street-collector ("Ramblar Colector") that would store and divert stormwater from the Collserola Mountains before it reached the "Ensanche" (Tarragó 1996). As will be further analysed in the third part of the thesis, a similar strategy, to store and deviate stormwater flows through great underground tunnels, was recently proposed in the actualization of Lisbon's drainage Master Plan (2016-2030).

By this time, most urban areas expanded and improved their sewerage system's networks at the same time that new questions arose, such as the debate regarding combined versus separate sewerage systems. Arguments in favour of the Separate Sewerage Systems (SSS) came namely from the English Engineers Edwin Chadwick and John Philips (Matos 2003), yet Combined Sewerage Systems (CSS) generally prevailed (Tarr 1979 in Burian et al. 1999) (see Annex I - Relevant milestones regarding the evolution of flood management practices).

Indeed there are intricate links between water, wastewater, and stormwater management and the urban water cycle as a whole. Each part can significantly influence another. As mentioned by Howe et al., "these influences may be negative, such as overflows from combined sewer networks, but may also be positive, such as when recycling water provides an additional source of water supply for a city" (Howe et al. 2011, p.69). In accordance, and on a parallel note, one must not forget that opportunities can found even in likely obsolete implemented infrastructure.

Around the 1900s, other pioneering urban planning models were developed with the same ambition to improve the quality of life of urban dwellers, namely the "Ciudad Lineal" of Arturo Soria and the "Garden city movement" of Ebenezer Howard. These emerging concepts included the attempt to bring ecological processes into the city (Magalhães 2001) and are generally considered as the collective response to the underlying consequences of a carbon based industrialization. As argued by Patrick Geddes in the beginning of the twentieth century, the clean energy "Neotechnic" city was replaced by the black pollution and physical concentration of the "Paleotechnic" capitalism (Geddes 1915 in Hebbert and Jankovic 2013).

In the 20th century a different paradigm emerged that disregarded the integrative approach introduced by the formerly mentioned visionaries. After the Second World War, infrastructure had to be built in order to support the previously devastated and now rapidly growing cities. This objective was essentially tackled though functional separation and the independent allocation of different activities regardless of any ecological principle (Ferreira and Leitão 2006). As argued by Magalhães, generalist and integrative thinking lost all influence to specialization and analytical thinking (2001).

In accordance with the modern perspective to segregate functions and activities, technical expertise such as civil engineering and urban design also worked both separately and autonomously. This fact is particularly evident in 19th and 20th century Dutch civil engineering, which developed great mono-functional, nation-wide scale, infrastructural works. For example, the great Zuiderzee works for the closure to the dam of Afsluitdijk, built between 1927 and 1932 (Figure 2.7). These works were largely guided by the Netherlands' internationally recognized and acclaimed policies of "Dredge, drain e reclaim" (Veen 1962[1950]). According to Han Meyer, "the advances in the technology of hydraulic engineering, had offered the prospect of controlling the physical structure of the country – and by that, creating the conditions for urbanisation and industrialisation of this delta area, all by diminishing the danger of flooding" (Meyer 2010, p.1).

In light of this epoch, one could argue flood related paradigms evolved from the defensive approach to protect from flood hazards, to an offensive approach, which assumed that floods and overall nature, were a controllable phenomenon.

Figure 2.7 - Left: First days of The Afsluitdijk of the Zuiderzee Works. North Sea is on the left and the IJsselmeer on the right. Source: (Veen 1962[1950], p.126). Right: The Afsluitdijk as it is today. Image credits: © David van Mill, 2010.

Only in the 1960s did ecological principles began to be woven back into urban planning disciplines as a result of an increased environmental awareness motivated by general environmental degradation and increasing urban sprawl into the countryside (Roberts and Roberts 1984 in Ferreira and Leitão 2006). One of the benchmarks that has contributed for this change is Ian McHarg's book "Design with nature". Among the book's highlights, the author mentions the theoretically obvious notion of the unreasonableness to build within areas that are inhospitable to man, such as earthquake areas, hurricane paths, floodplains and alike, while also recognizing that in contrast, the most common approach is to ignore prudency (McHarg 1992[1967]).

As water continued to prove its strength, by periodically surpassing the boundaries imposed by man-made infrastructure and eventually leading to disastrous consequences, it was progressively recognized that landscape cannot be totally shaped to the benefit of Man. In contrast, it began to be gradually accepted that human intervention must be determined by Nature itself. As Caldeira Cabral recalled "*Ars cooperative naturae*", the art to convince nature to collaborate with us (Cabral 1961 in Andresen 2001).

Surpassing the useless and irresponsible goal of total flood control, the next overall purpose was to "at least" manage floods. Although the use of specialized engineering measures such as embankments, dikes, sea walls and channels, where these were greatly recognised and preferred in the 80s and the 90s, "soft" measures, with parallel purposes started to be considered, namely the Rhine-flood warning centre in the state of Rheinland-Pfalz at the Netherlands that exists since 1986 (Karin de Bruij et al. 2009). Yet the main strategic objective was still to reduce flood probability.

Only by the end of the century did we comprehend that it was just as impossible to manage any natural system in it's entirely, and floods in particular (Figure 2.8). As stated by Kay and Schneider when arguing on the complexity of ecosystems such as the water cycle, "our traditional managerial approaches, which presume a world of simple rules, are wrong-headed and likely to be dangerous" (Kay and Schneider 1995, p.49).

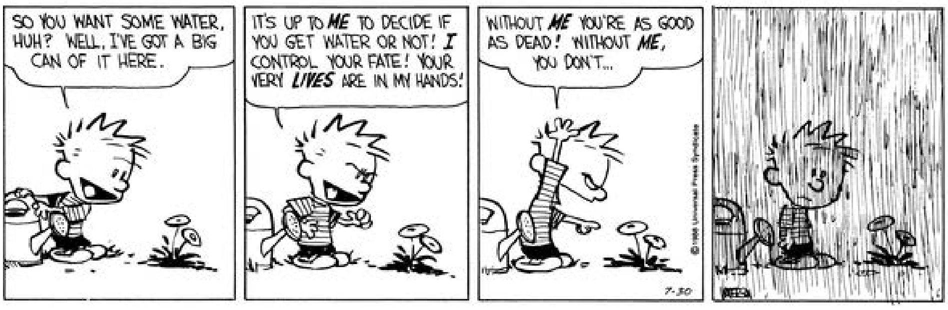


Figure 2.8 - Bill Watterson elucidating us on how Man can be powerless in the face of nature. Credits: *Calvin & Hobbes* - Bill Watterson, Universal Press Syndicate, 2009.

Among the most important milestones that have possibly propelled this new understanding are: the First Assessment Report (FAR) of the IPCC published in 1990; and the Dublin Principles presented at the

International Conference on Water and the Environment held in 1992, which gave rise to the Integrated Water Resources Management (IWRM) approaches. While the debate on anthropogenic global warming has been around since Wally Broecker's paper (1975), FAR was the first widely disseminated comprehensive study on climate change. Not only did this former report alert about the potential threats of future climate, but it also raised the challenge of working with everlasting uncertainties. Adjacently, IWRM was envisioned to substitute the existing disjointing approach on water resources and management, which generally led to unsustainable actions. In brief, IWRM is based on the premise that water resources are a central constituent of the ecosystem with social and economic value.

Thereafter, a progressive change towards the reintegration of environmental and social needs began. Accordingly, instead of wanting to manage floods the focus shifted towards managing its risks. Instead of aiming to reduce the probabilities to experience floods, approaches turned into actions to be primarily targeted at reducing the vulnerability of people and goods, thus giving rise to the currently advocated approach of Flood Risk Management.

Gradually, it became the common practice for countries and its cities to have ongoing assessment studies and updated management plans for the risks to which they were more vulnerable to, namely floods. Current and past trends are evaluated in order to anticipate hazards and to develop strategies to adress them. Likewise, it also became common practice for cities to have emergency response plans for the eventful ocassion of a disaster taking place.

In order to support comprehensive approaches based on entire river basins, the European Union adopted the directive on Risk Assessment and Floods Management in 2007 (2007/60/EC) requiring Member States to plan and prepare for the prevention and protection of flood hazards. The same directive also reinforced the rights of the public to the access information and to be included in the planning and decision processes. It additionally recognised the need to take climate change into consideration, substantially reinforcing the already present need for a change of practices. Overall the EU floods directive aimed reinforced the acknowledged need to work towards living with nature, "creating more sustainable water systems and to look for synergies while implementing flood protection measures in cities" (Stone et al. 2012, p.292).

By adding climate change to the equation, new perspectives and approaches inevitably infiltrate flood risk management endeavours. This fact is essentially prompt by the intrinsic characteristic of climate change science to be based on the analysis of possible future climates through projections and simulations, while sustainability and risk management planning rather support decision-making by the analysis of past trends. In other words, while the field of disaster risk management commonly learns from “ex post” activities, climate change adaptation processes are mainly associated with “ex ante” actions (IPCC 2012). While the former focuses on the moment or past situations and questions constraints and survival, the latter focuses on the future and supports any opportunity for learning and reinventing.

Recalling upon the fact that climate change projections point towards a future with more extreme weather events, either more severe precipitation or severe droughts, and the consequent endangerment of water as a resource, new approaches are trying to figure out ways to make cities safe *with* water. That is, to improve cities in order to benefit not only from the conveying of stormwater (from precipitation, sea level rise, storm surge) but also from its harvesting and storing. For Kravčík et al., “The draining of the land is like living on debts. Water falling from the large water cycle is like a state subsidy. It comes for free but not regularly, often to wrong recipients and in the wrong amounts. It sometimes brings more harm than good” (Kravčík et al. 2007, p.71). Other authors are also assertive that, “in the near future, urban stormwater will become again a precious resource for man's survival” (Andjelkovic 2001, p.6). Fact is, water is an increasingly endangered global resource, precious for human survival (Wada et al. 2010). Moreover, the presence of water can significantly diminish temperature related impacts such as UHI.

In this line of reasoning, new strategies and measures have started to emerge in contemporary practices related to flood risk tackling. These recent and revised approaches, broadly integrated within climate change adaptation undertakings, not only aim to reduce vulnerabilities, but also aim to enhance adaptive capacity and build resilience through the acknowledgement of stormwater as an advantage.

As will be scrutinized in the second part of the thesis, among these strategies are the source control measures or the flow attenuation and infiltration techniques, which can be applied throughout all the city and whenever opportunities arise. Approaches that largely integrate on comprehensive, multi-scaled, decentralized and interdisciplinary practices.

Although examples such as “Rotterdam Climate Proof” adaptation programme, “New York Green Infrastructure plan” or the English “Susdrain” community, are expected to stimulate other cities to embark on similar paths, flood risk adaptation endeavours are still very far from being the most commonly used approach. Our common practice still relies mainly on robust mono-functional engineering infrastructure that typically offers isolated and centralized systems, which dissociate any human perception and experience of the water-related ecological processes of landscape in exchange for a "theoretical" maximum efficiency (Figure 2.9). Theoretical in the sense that, as oversized systems that disfavour redundancy, they are particularly vulnerable to major collapse with little or no recover capacity (Ahern 2014), and should thus be complemented with other, more adaptive, strategies.

Figure 2.9 - Left: New Orleans London Ave Canal Wall. Image credits: © Chris Adams, 2015. Right: Girls peeking to see over London Ave Canal Wall in New Orleans. Source: (Papacharalambous et al. 2013, p.15).

Indeed, as argued by Han Meyer, "climate change is not the only reason for the search for new approaches in urban design and engineering: it is literarily, in terms of time, the *last* reason" (Meyer 2010, p.2). Regardless of the distinguishable progresses in contemporary planning practices, such as the more often assessments and revisions of implemented plans, flood management planning still follows the lines of doctrinaire and layered modern paradigms. Long term developments or integrated and sustainable practices aren't yet fully tackled, and neither is any attention given to the natural water cycle as a resource and service provider. Issues which alone are sufficient and significant as motors of intense discussion and will to change.

Altogether, how our cities have been dealing with floods throughout the years, is intimately related with the perception of water as a resource, which is also naturally influenced by the intricacies of history and urban planning paradigms. As illustrated in Figure 2.10, first we were predisposed to live with floods; secondly, we took advantage of floods; whereby in a third stage, we indented to control floods; and more recently, we aim to reduce vulnerabilities.

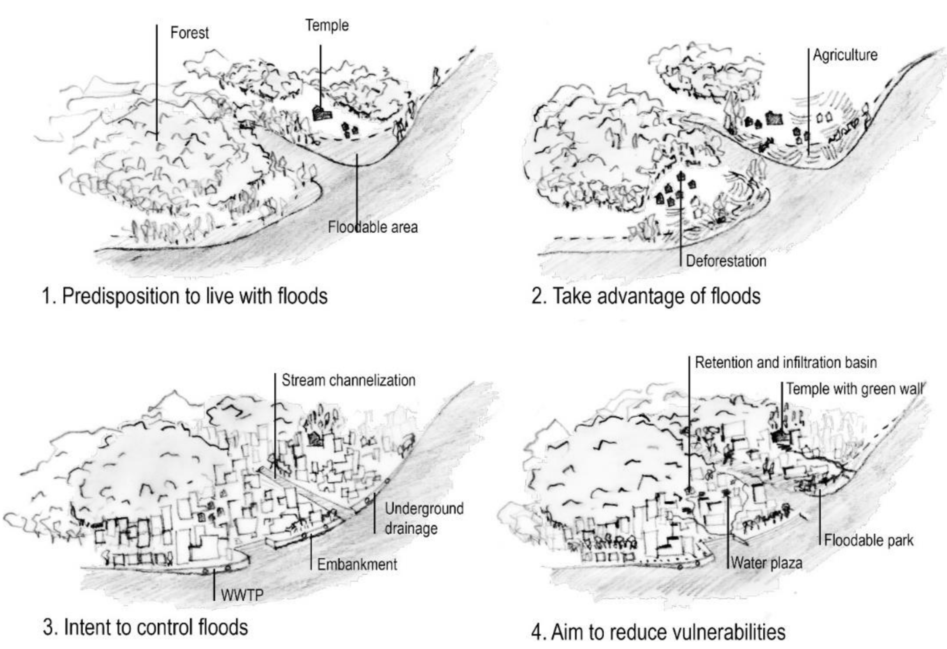


Figure 2.10 - Four stages synthesis on the historical evolution of the city's relationship with the floods. Source: author's design, 2014.

According to Saraiva, there are four main evolutionary stages that characterize our overall approach towards water as a resource: 1) the "harmony" period, where human activities adapted to the natural water cycle; 2) the "domination" period, where humans thought it was possible to control water; 3) the "degradation" period, corresponding to the phase in which the human damages onto the environment became visible and 4) the "sustainability" period, where there was an invigorated awareness of the environmental, ecological, cultural, social, economic and symbolic value of water (Saraiva 1999).

Also Brown et al. identified six different stages of how our cities managed water, namely the stages titled 1) Water Supply City, 2) Sewered City, 3) Drained City, 4) Waterways City, 5) Water Cycle City and 6) Water Sensitive City. Water Supply City corresponds to the time when concerns were essentially focused on providing a good quality and quantity of water for a growing number of urban population. The time when large quantities of water where extracted by means of large dams, pipe systems and aqueducts. Sewered City is the period that arose as a consequence of public health concerns. The key focus of this Era relied on the conveyance of dirty waters outside city boundaries, often in natural watercourses. The Drained City stage corresponds to the period in which the main goal generally consisted on providing the most rapid and efficient system of stormwater conveyance out of cities in order to facilitate urban expansion after the Second World War. It is the time when waterlines were extensively channelized and floodplains drained. Resources were assumed as never-ending and with inherent and infinite auto-purifying mechanisms. The Waterways City is the period that emerged together with the global social movement of environmental awareness in the late 1960´s. A stage that can be characterized by having brought new values set around the need to protect Earth's natural resources. Wastewater discharges started to be regulated in treatment plants at the same time that new technologies were developed, such as different kinds of bio-filtration systems. In the Water Cycle City period, the limits on natural resources are clearly recognized. It is a stage that further envisions that the management of the water cycle is to be shared by the government and its communities, and also that the associated risks should be diversified. Lastly, Brown et al. envisions that our future will encompass the Water Sensitive City stage. A desired future that, for the authors, encompasses a multifunctional, integrated and adaptive management of the whole water cycle, that would bear in mind the precautionary principle instigated by climate change ongoing projections.

Comparing the aforementioned research together with the conducted study on how our cities have related and dealt with floods, a prospect upon our future approach is triggered: are we on the fringe of a new flood management paradigm, one that is targeted at fully integrating risk and uncertainty? (Figure 2.11).

Indeed, it seems as if the first IPCC AR published in 1990, determined an important milestone in the flood management practices, namely by adjoining the goal of "adaptation" and thus questioning the adequacy of conventional structural and rigid measures. As the overall goal in the face of urban floods shifted from reducing the probability of hazard experience, to the reduction of society's vulnerability, we must no longer rely solely on inflexible strategies and measures, but rather welcome the incorporation of new measures, more flexible and adaptable, in our practices.

Yet, when adding adaptation measures to contemporary flood risk management undertakings, a far wider number of factors must be interrelated. As a consequence, its practice becomes even more complex. Prompted by the need and urgency to change, this complexity encourages new perspectives and approaches. In addition to the fact that climate change will force us to contemplate far wider timescales in future, which consider the next 50 to 100 years and, in some cases, the next 200 years[29],

[29] In the Netherlands, the Deltacommisse project "Working Together with Nature – A living land builds for its future", works for the future timeframes 2100 and 2200. "Rotterdam Climate Proof" adaptation programme envisions "Rotterdam climate resilient by 2025".

these new perspectives will also necessarily comprise a change in the relationship between the city and (its) water.

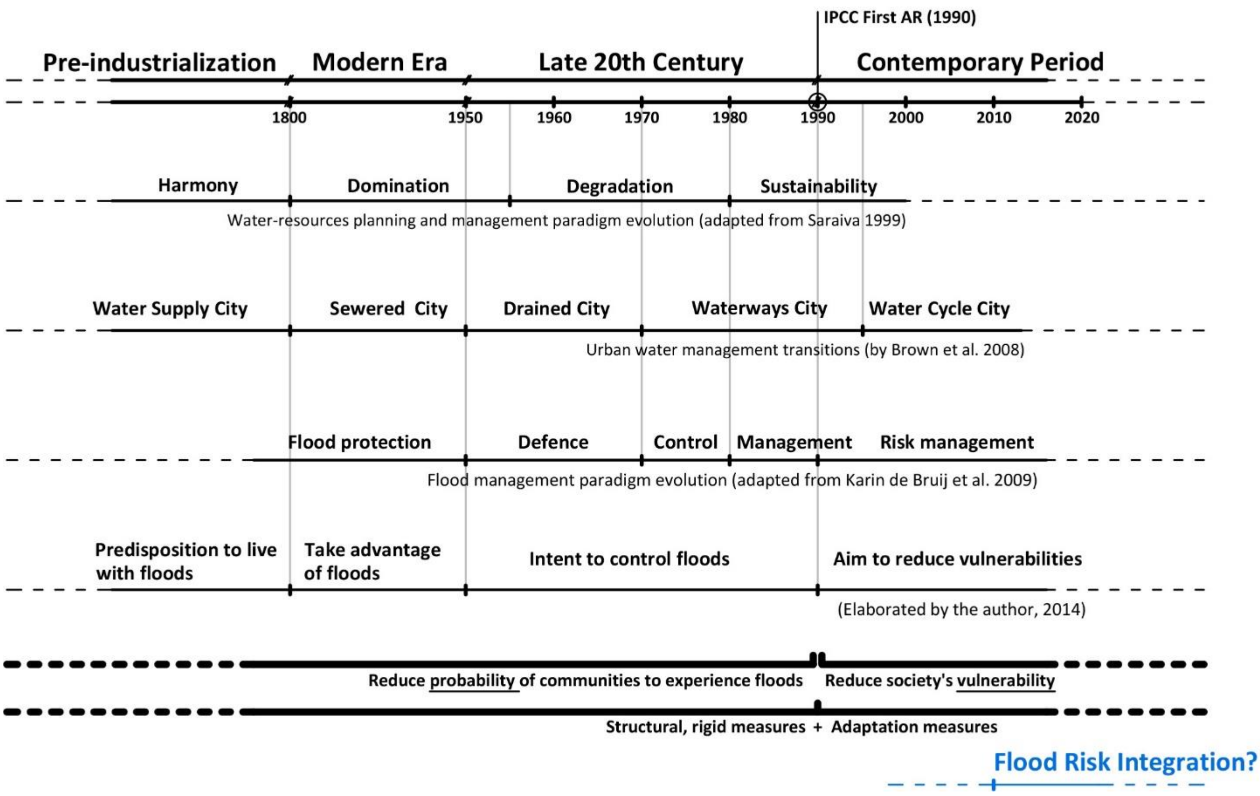


Figure 2.11 - Diachronic analysis: flood management paradigms evolution adapted from Karin de Bruij et al., compared with water management paradigms evolution by Saraiva and Brown et al. Source: compiled by the author.

Several authors have long argued on the inclusion of complexity in decision making processes (Morin 1974, Kay and Schneider 1995, Magalhães 2001, Berkes et al. 2003). Others further excluded the need for collective consensus when reasoning on the need for a more flexible planning, one that alternatively searches for compromises and embraces uncertainty, namely Nuno Portas who has suggested the inclusion of a "maybe" in the decision processes in contrast with the strict "yes" and "no" (Portas 2012).

To work with the water cycle, and namely the prospective practice of flood risk integration, is not only inherently complex but will also be forever accompanied by an unpredictable future. The challenge therefore relies on being able to integrate and acknowledge its associated complexity and uncertainty as a constituent component among our

---

In the United States of America, the Interagency Climate Change Adaptation Task Force works for the next 50 to 100 years. The city of New York, for example, considers the same future timeframes for the development of their adaptation strategies.

In the United Kingdom, the Environment Agency's Thames Estuary programme for example, is developed for the next 100 year. Royal Institute of British Architects (RIBA) also develops adaptation research, namely for the future 25 / 50 / 75 and 100 years.

planning practices. An approach that must be strategic enough to highlight the long-run, including the distant future, and flexible enough to incorporate learnings throughout the processes of action. Conventional flood management engineering and natural systems, such as the water cycle, are therefore envisioned to be integrated in one common endeavour that, through design, is adaptable in the face of uncertainty.

2.2.2. *Avant-garde* international practices: on the verge of a paradigm shift in stormwater management practices

Looking into the international cases briefly analysed in chapter one, it is notorious that climate change is not only influencing changes in urban planning approaches and in the design of public space, but that it is also influencing and altering, to some extent, conventional flood management practices.

New approaches can be identified namely in cities such as Rotterdam, New York or London. All of which have specifically acknowledged that rigid infrastructure can no longer be the sole solution for a dynamic climate, that is expected to drastically and rapidly change in its extremes. As a result, these cities are actively searching for new flexible planning and management strategies that, while recognizing the value but also the limitations of mainstreamed practices, further consider adaptation measures.

The Netherlands and the city of Rotterdam

In 2008, the Delta Commission of the Netherlands launched the Delta Programme entitled "Working Together with Nature – A living land builds for its future" (Deltacommissie 2008). This programme was a turning point for Dutch flood management policy and practice as it reassessed and restructured a two hundred year old paradigm of hard infrastructural defensive engineering by adding further considerations, such as local and regional identity as well as climate change and increasing vulnerabilities. In essence, this national Dutch plan proposed 1) the reinforcement of the defensive infrastructures by taking into consideration possible conceptual reinventions and 2) the pursuit to work with nature.

In light of the challenges presented by the aforementioned Delta Programme, projects that strive to live with water instead of fighting it started to emerge. That is namely the case of the projects, The Sand Engine and Room for the River. The first, The Zandmotor[30], basically consists of a beach nourishment technique that builds the coast with nature alone without the disruption of the vulnerable seabed. The second, the Ruimte voor de Rivier programme, started off by envisaging the double objective to 1) accommodate greater discharge volumes in the lands along the rivers Rhine, Meuse, Waal, IJssel and Lek, and to 2) improve of the overall spatial quality of the riverine area (Rijke et al.

---

[30] www.dezandmotor.nl

2012). In order to fulfil these goals, space for water was provided through measures, which included among others, dike relocation, the lowering and excavation of flood plains (Figure 2.12). Although this approach marked a very important milestone in hydraulic engineering and practice – namely as it recognized the know-how of landscape architects, ecologists and environmentalists, who started to have a privileged influence on the design of the new river landscapes – it was mostly applied in rural areas of relatively straightforward social and economic complexity. Efforts are still being made on the challenge to apply these new concepts in urban design within metropolitan areas (Meyer 2010).

Figure 2.12 - "Room for the River" Programme applied in the urban waterfront of the Oude Maas River. Image credits: © Joop van Houdt, 2009.

In consonance with the 2008 Delta Program, the "Rotterdam Climate Proof" adaptation programme was launched the same year. Particularly regarding flood management response, this program pursued a wide range of exemplary solutions, some of which are briefly mentioned in the following section.

When aiming to protect old vulnerable developments from storm surges or sea level rise, the city of Rotterdam has promoted initiatives that include reinterpretations of the concepts of dikes and flood walls. As an example, one may refer to the multifunctional dike of Boompjes, protecting Waterstadt historical waterfront, or the levee at Hilledijk area that is envisioned to expand onto a multifunctional terraced dike, which includes a city park that connects two urban districts. In combination with the robust flood defence system, the "working with nature" paradigm is also proposed through the creation of a tidal park envisioned for the river Meuse. Particularly for the outer-dike areas, measures of adaptive building and design are also reinforced, such as the local raising of property and quays or the introduction of floating buildings.

Again, when considering the design of new developments, floating techniques applied for houses, infrastructures or districts are among the selected suggestions. This option is likely associated to the purpose of providing the ultimate resilient urban design, prepared to face the projected climate change impacts, without disturbing its ongoing functioning. Having already gained experience through the Rijnhaven floating pavilion as a pilot project (2010)[31], Rotterdam has completed in 2011, a list of possible locations for floating communities (RCI 2013).

Within inner consolidated urban developments, the city has invested in measures that accommodate water that arrives either from precipitation or higher water levels. Reservoirs, water plazas, the extension of the system of canals, water robust streets and infrastructure, such as bioswales, water butts and green courtyards are some of the conducted investments. Related examples, which are already implemented, include: the multifunctional water plaza at Benthemplein, finished during 2013; the underground water storage under Museumpark car park (10,000 m3) in operation since 2011; or the reopened Westersingel canal which can store extra water on a lower-lying sculpture terrace, among others.

Other measures that have been applied throughout the entire city include green roofs, green walls, blue roofs or collective gardens. Among the existing examples one may highlight the circa 130,000 m2 of existing green roofs, namely the new large scale Roof Park, located between Hudsonstraat (residential street) and Vierhavensstraat, named the Dakpark, or the 5000 m2 Green wall at Westblaak car park (2010).

United States and the city of New York

Although North American federal recommendations on climate change adaptation action arrived only in 2010[32], since the turn of the century many states and cities embraced the adaptation agenda and tried to autonomously understand and respond to the impending climatic threats. That is namely the case of New York City.

Through the strategic vision of New York's City Hall Mayor Michael Bloomberg, an original sustainability and climate strategy called the PlaNYC was launched. This plan was firstly released in 2007, updated in

[31] www.drijvendpaviljoen.nl

[32] Earliest international undertakings include, for instance, United Kingdom's Climate Change Programme launched in the year 2000 and updated in 2006, which envisioned the development of a national adaptation approach that would define political priorities for internal and external action.

2011, and put to the test by Hurricane Sandy in 2012 and again updated in 2013.

Among the critical components of the primary PlaNYC are the improvement of the City's water quality as well as the reduction of urban vulnerabilities in the face of flooding events. Bearing in mind the existing climatic projections while simultaneously acknowledging the fact that NY's existing drainage is already overloaded, the hazards associated with increased runoff therefore arose as a key concern. As a result, in order to avoid damages associated with combined sewerage overflow (CSO) events and reduce overall vulnerabilities towards flood events, the NYC Green Infrastructure plan was launched in 2010.

In essence, this plan aimed to offer a more sustainable alternative to the conventional "grey" infrastructure by proposing ecosystem-based solutions such as: rooftop detention, green roofs, subsurface detention and infiltration, swales; street trees, permeable pavement, rain gardens, engineered wetlands, among others. The plan's overall ambition consists on managing 10% of the runoff from impervious surfaces by 2030. When considering the citywide Costs of CSO Control Scenarios, the cost of the mentioned 10% of storm water capture through "green means" is expected to cost approximately $2.4 billion, which is "far less than the $3.9 billion for Potential Tanks, Tunnels, and Expansions, which provide few if any sustainability benefits" (City of New York 2010, p.30).

Through this strategic plan, NYC Department of Environmental Protection (DEP) has been continuously developing and implementing green infrastructure in Priority CSO Tributary Areas. More specifically through public on-site retrofit projects, such as "right-of-way bioswales", as well as in public-private partnerships such as green infrastructure in schoolyards or green infrastructure grant programs (DEP 2013) (Figure 2.13).

The subsequent version of the PlaNYC "A Stronger, More Resilient New York" (2013), included more than 250 specific recommendations to further fortify the city against the predicted climate events.

Regarding the coastal protection strategy, the plan specifically focused on 1) fortifying the defence infrastructure and 2) expanding natural protections. More specifically, though the following strategies and measures: 1) Increase coastal edge elevations, such as beach nourishment, armour stone (revetments), bulkheads (walls at the water's edge) and tide gates/drainage devices; 2) Minimize upland wave zones such as: dunes, offshore breakwaters, wetlands, reefs, and living shorelines and groins; 3) Protect against storm surge namely through integrated flood protection systems, floodwalls/levees, local storm surge barriers and multi-purpose levees; and 4) Improve coastal design and governance.

Figure 2.13 - Left: Green infrastructure public property retrofits - Playground at JHS 218K, East New York, Brooklyn – Before. Image credits: © NYC Water, 2012.

Right: Green infrastructure public property retrofits - Playground at JHS 218K, East New York, Brooklyn – After. Image credits: © NYC Water, 2013.

Among the coastal protection projects under development is the East Side Coastal Resiliency Project, with construction targeted to begin in late 2017. The idea that guides this plan emerged from the international competition "Rebuild by Design" sponsored by the U.S. Department of Housing and Urban Development. It essentially encompasses around 3.54 km (2.2 miles) of leveed waterfront, from Montgomery Street to East 23rd Street, which reinforces flood defence through the combination of enhanced natural areas, improved public space and facilitated littoral access (Figure 2.14). It further seeks for effective public engagement, regularly promoting public workshops and outreaches (Figure 2.15). Overall, this project envisions to benefit from the combined opportunities to improve physical, social and economic conditions while reducing the risk of flooding.

Figure 2.14 - Above: Design "vision" for the East Side Coastal Resiliency Project. Source: (City of New York 2016).

Figure 2.15 - Conducted public engagement activities. Source: (Rebuild By Design 2013).

United Kingdom and the city of London

Among the current most relevant undertakings of the United Kingdom on climate change adaptation action, is their National Adaptation Programme (NAP) (HM Government 2013).This particular strategy highlights specific tasks for local authorities, such as: the requirement to develop and apply Local Flood Risk Management Strategies, Area Drainage Plans and Surface Water Flood Maps that incorporate evidence of future climate change; the requirement to ensure that Local Plans include measures to proactively plan to adapt to climate change; and the added responsibility to become "Sustainable Urban Drainage Systems (SUDs) Approval Bodies" being enabled to decide on the adequacy of sustainable drainage proposals for new developments (LAAP 2013).

Looming into the case of London, one must highlight the "London Climate Change Partnership"[33] as the centre of expertise on climate change adaptation and resilience. Among its case studies is the "Drain London Programme", which consists of a partnership group, with the Mayor of London, Environment Agency, London Councils and Thames Water, which is responsible for managing surface water, flood risk and drainage assets.

Although climate change was not the prime trigger for this initiative, but rather a contributing factor for the increasing need to tackle existing problems, adaptation options started to be equated namely for the most vulnerable areas. These options ranged from the reinforcement of conventional infrastructure, to other more sustainable approaches that deal with rainwater through measures that are closely related to natural systems, namely through Sustainable Urban Drainage (SUD) techniques.

---

[33] http://climatelondon.org.uk/

In accordance, in light of the Drain London Programme, the London Sustainable Drainage Action Plan was developed in 2015. Overall, this plan includes the vision that "By 2040, London will manage its rainwater sustainably to reduce flood risk and improve water security, maximising the benefits for people, the environment and the economy". An expectation that is to be accomplished through the main goal to achieve a "1% reduction in surface water flows in the sewer network each year for 25 years, resulting in a 25% reduction in flows by 2040" (GLA 2015, p.5).

This action plan is particularly targeted at delivering sustainable drainage through new developments, through domestic and local neighbourhood measures, as well as through overall retrofitting across London. Funding opportunities and regularity incentives are further envisaged, as well as continued motoring.

Adjacently, as part of the London Plan of 2015, CIRIA (Construction Industry Research and Information Association) will develop an updated National SUDs Manual, which will greatly contribute to the compilation of encompassing evidence on the benefits and constraints of sustainable drainage, that will not only be helpful for all the United Kingdom, but also for other countries. Previous versions, of clear technical quality, include: "Sustainable drainage systems. Hydraulic, structural and water quality advice" of 2004; "The SUDS manual" of 2007; "Planning for SUDS – making it happen" of 2010; "Water Sensitive Urban Design in the UK" of 2013; among others.

Among the already implemented adaptation actions within the city of London, which put great emphasis on sustainable drainage systems, are the urban retrofit at the eastern end of Derbyshire Street dead end (Figure 2.16-Above) and the urban regeneration project at Australia Road, White City (Figure 2.16-Below). Many other examples of applied SUDS in London and all around the UK, of various scales and range of complexity, can be consulted in the database of susdrain.org.

Figure 2.16 - Above: Derbyshire Street Pocket Park. A project that turned a parking lot into a community garden encompassing sustainable urban drainage measures such as permeable pavement and bioretention planters. Source: (Susdrain 2012), 2014.

Below: Australia Road regeneration project, which had strong community involvement and sustainable urban drainage at its heart. Image credits: © Robert Bray Associates, 2015.

One other interesting approach regarding flood management is the Thames Estuary 2100 Plan, which adopts a particularly conservative estimate of 1.90m sea level rise scenario for the 2100 horizon. In essence, this plan assesses the flood risk within urbanised areas for the 2100 horizon, distinguishing three different areas of action: 1) priority areas for evacuation and shelter provision; 2) areas to develop flood resilient buildings; and 3) areas to develop flood resistant buildings (EA 2009). Moreover, it proposes a particularly interesting adaptable approach for the Thames Barrier defensive infrastructure, which takes into account different possible sea level rise scenarios through "decision pathways" (see figure 3.7 in EEA 2012, p.90). Overall, one may consider this strategic plan as an exemplary case on the adoption of the precautionary principle, as it assumes that the consequences of the failure of this specific infrastructure are much more damaging for the city than the consequences of failing by excessive caution.

Lessons learned

Considering the mentioned international and contemporary undertakings concerning urban flood tackling, it is possible to identify a range of common approaches that are distinguishable from previously established practices. Among these shared characteristics between the analysed cases, the following are worth highlighting:

- Hard structural engineering is not dismissed, but was rather reconsidered in light of new hydraulic concepts, which namely favour more water in the city;
- Ecosystem-based approaches, or approaches that “work with nature”, are particularly favoured (and institutionalized) and envisioned to be applied whenever possible;
- Undertakings are outlined as holistic processes targeted for citywide implementation, yet through de-centralized small-scaled interventions;
- Opportunities are explored, namely in a tailored combination of multiple benefits and in the potential synergies arising out of other urban projects;
- Strong and comprehensive value is given to local approaches, which favour community engagement and involvement;
- Continued assessment and monitoring of implemented measures is acknowledged as vital, namely for the encouragement of continued improvement;
- The use of Design to connect scales, sectors and ambitions (from individuals or of a common good).

It is no surprise that the above mentioned prominent characteristics regarding the stormwater management practices of the studied international cases, are in consonance with their countries and municipality’s respective adaptation strategies as highlighted in the former chapter.

From these mentioned approaches it is clear that a new tendency on how to manage urban floods is emerging. “Living with nature” has become a common requisite in developed countries, which has propelled a new relationship between humankind and its surrounding environment, one that is no longer obsessed by its control but is rather focused on living in harmony with it. Indeed, natural systems have already revealed themselves as particularly resilient to hazards, presenting robust developments through time (Figure 2.17).

Figure 2.17 - Miracle pine single tree that survived 2011 tsunami in Rikuzentakata, Iwate Prefecture, Japan, turned into monument. Image credits: © AP, Per-Anders Pettersson/Corbis.

The precedent goal to effectively and rapidly avoid or convey stormflows is therefore being gradually replaced by the goal to incorporate stormwater within the city, through the enhancement of the whole water cycle and not just part of its components. Contemporary responses to urban floods are, in this way, starting to consider not only the risks, but also the opportunities that stormwater may bring for a better-quality and more adapted city.

In other words, the excess of water seen as a threat, is progressively changing into being seen as an opportunity. In the building of a new relationship between the city and water, opportunities may specifically include: the process of learning how to live in constant change, the potential to connect people with change, the chance to improve urban territories throughout change, among others. Opportunities that are giving rise to new perspectives and practices in urban planning and landscape and architecture design, which are connecting objectives and benefiting from synergies.

This change of attitude, triggered by present uncertain times and uncertain projected climates, is particularly important in the design of our cities and namely in the design of public spaces, particularly when considering the reduction of hard infrastructure dependence and the corresponding need of expensive readjustments. A new approach that may prove to be an important advantage in the medium and long run, as it diminishes risk and overall vulnerabilities by expanding alternative practices and relying less on one sole plan.

What was previously a matter of a few or sole disciplines, such as hydraulic engineering, is becoming a matter that must integrate other competences, such as urbanistic, environmental, economic and sociological, in order to better face the challenges concerning the safety against present and future expected flooding. Yet, not only is a predominantly mono-disciplinary practice becoming an interdisciplinary discipline, but present endeavours, entailed within this new mind-set, are also giving rise to multifunctional projects.

Most of the highlighted projects are further grounded and enriched by local know-how and community involvement, which has proved to be particularly advantageous, not only for the quality and overall success of the results, but also in regards to citizen awareness and empowerment of proactive behaviours. Regarding this matter, Jacqueline Hoyer et al. have argued that there is still much to be done in regards to social and aesthetic considerations, which are generally only present at the level of academic and policy rhetoric. For the author "too few sustainable stormwater management systems have been applied in a manner that is appreciated by the public" (Jacqueline Hoyer et al. 2011, p.5). Indeed, social and aesthetic considerations are particularly critical in the influence of the public perception and acceptance of the water system. While water is present in everyday life, in cities with conventional drainage systems, people only experience its presence (or absence) in exceptional events of floods or droughts. In these situations, people are less likely to understand, accept and acknowledge the water system. By contrast, if people are to live closely with water they are more likely to contribute as potential active managers of change.

In light of an overall analysis, public space and public space design may therefore be considered as effective and rich interfaces for the implementation of adaptation measures, namely measures particularly related to flood adaptation. Besides the benefits that may emerge from an interdisciplinary practice, multifunctional results and community involvement, the evidenced shift of paradigm in flood management practices will significantly alter the urban landscape as we know it. For instance, by welcoming more water in the city, new spaces must be provided for this purpose. Among these spaces, the one that mainly stands out from the previously analysed examples, is Public Space as in the founder and structuring element of the urban form (Martin 2007, Portas 2003). Public space is also the space for people and thus where community involvement may more easily emerge and develop.

Measures that form part of this new flood management approach may be applied in many urban situations, namely in areas that are hereby understood as different to what is considered as a public space, such as underground reservoirs below building or raingardens within an open space of a large scale shopping centre. Regardless, chapter three will aim to further understand the advantages of using such measures specifically in the design of public space.

2.3. Challenges in the reassessment of conventional flood management approaches

A change in mainstreamed practice on flood management is needed and is already tentatively taking place in some countries and cities. Once floods are a persistent phenomenon, which in light of climatic projections is expected to become even more frequent and intense, the faster this change is implemented the more positive outcomes can be achieved. Yet most cities are still far from addressing this matter and updating their established approaches.

Several factors that are hindering adaptation processes have been identified by various authors. In regards to the mismatch between the urgent need to face impending extreme weather events and overall number of climate change adaptation efforts, G. Robbert Biesbroek has argued that it is primarily due to the "temporal discordance between the long term impacts of climate change and the short-termism in politics and decision making" (2014, p.137).

Other authors relate erroneous assumptions being greatly responsible for the misconceptions regarding climate change projections, which in turn lead to the postponement attitude towards climate action. In a survey conducted by Sterman and Booth Sweeney ("Cloudy skies: assessing public understanding of global warming"), some subjects were unwilling to take urgent and expensive actions in response to climate change as they believed that keeping CO2 emissions at current rates would stabilize CO_2 concentration, and that reducing CO_2 concentration would immediately stabilize global temperature (Sterman and Booth Sweeney 2002 in Chen 2011). However, as stated by Xiang Chen, climate change cannot be treated as a bounded object as "it is a dynamic process with temporal totality and inertia" (Chen 2011, p.31), two fundamental aspects for the understanding of climate change. For the author, in order to break hindering constraints, there must be a clear acknowledgement of the basic differences between objects and processes.

Other researches lean initially to consider communication barriers between scientists and the general public, namely decision makers, to be at the centre of climate adaptation inaction. Although climate change awareness and the imperativeness to act is considered by the authors as widely recognized, the overall limited understanding of the causes of climate change and scientific projections is still identified a problem (Lorenzoni and Pidgeon 2006) that confuses, prolongs and burdens decision processes. When scientific findings and discussed consensus do not reach the general public and decision makers, adaptation action loses its significance. More specifically, scientists often mislead the public through the use of particular terms that are only correctly comprehended among their peers. Researchers Richard Somerville and Susan Hassol have identified some of these terms and have also suggested corresponding alternatives. For example when scientists say "positive feedback" the public understands "good response, praise" while a better choice of words would be "vicious cycle, self-reinforcing cycle". When scientists say "error" the public understands "mistake, wrong, incorrect" while a better choice of words would be "difference from exact true number. Or, when scientists say "manipulation" the public understands "illicit tampering" while a better choice of words would be "scientific data processing" (Somerville and Hassol 2011, p.51).

Also as a communication problem, yet of a differentiated perspective, other authors, namely of the scientific field of phycology, have argued that it is partially due to the present inability to connect climate change to people that social barriers to action on climate change persist to exist. One of the identified gaps between society and climate change has been identified as being the related intangibility of greenhouse gases (GHGs) and overall climate change processes. Just as McKibben states "it is hard to picture climate change, because carbon dioxide is invisible – if it were brown, we would have stopped producing it long ago" (McKibben, W. 2012 in Sheppard 2012, p.vi). As will be tackled with more detail in the next chapter, with regard to this specific outlined communication problem, public space and their design offer particular advantages. Not only can public space serve as local communication platforms but they can also offer, through their design, the possibility to reduce the risk of disaster (Matos Silva and Costa 2016).

Particularly in regards to flood adaptation actions, these are intrinsically related to the overall magnanimity of the economics. It is not a new idea that every strategy of action is extremely volatile in the brises of economic trends. As most current flood risk management strategies are almost entirely publicly funded, during a financial crisis and consequent severe reductions in budgets and public resources, the priority for flood risk adaptation actions is likely disregarded. In addition, the choice between actions often favours economic concerns over others, such as social or environmental concerns. On top of this, it might be interesting to consider that most comprehensive studies on the risks to people and property are often sponsored by insurance companies, which indirectly influence the results to be mainly focused on the economic impacts that may influence their service (assets such as buildings, farms, machinery, etc). These types of studies are frequently conducted in North American cities, as well as European cities such as Lisbon who's most current and comprehensive study on flood risk impact was sponsored by the Portuguese Association of Insurance companies (APS) in 2014.

Uncertainty is furthermore used as an alibi for the lack of investment in the adaptation or improvement of traditional flood management infrastructure. In fact, it is likely the most significant hindering factor in action for change. Bearing in mind that "Infrastructure for water, urban drainage and flood protection has a typical lifetime of 30–200 years" (Gersonius et al. 2013, p.411), any investment is only amortized after many years and in dependency of a future climate that is expected to be particularly variable in its extreme regimes. One must additionally consider the associated physical extent of the existing infrastructural networks together with the implicit difficulty and prolonged process of execution.

Yet in light of the constraint of uncertainty, the search for additional infrastructural alternatives lies strengthened. As highlighted among current existing international practices, our future does not solely rely on the renovation and modernization of existing drainage infrastructure. Indeed, as highlighted, there is a growing number of examples with advanced technical expertise, namely on stormwater source control measures. One might therefore argue that the challenge for change is not technical-related, but rather depends in decision making, as argued by Howe and Mitchell "… the impediments to progress do not seem to always arise from the unavailability of technological solutions and scientific knowledge, but rather the failure to manage the social and institutional change progress that would enable the implementation of techno-scientific solutions in practice" (Howe and Mitchell 2012, p.37).

It seems to be very difficult for today's society to reach a consensus in any field of action. Most commonly, it is generally only after great hazards that priorities are rearranged and unanimity is met. As can be noted throughout history, breakthroughs in water related disciplines were intimately associated with severe unbearable situations. More specifically, droughts, thirst or the difficulty in extinguishing fires within consolidated urban neighbourhoods, leading to the need to improve water supply systems; major epidemic surges prompt sewerage improvements; water quality began being monitored when extensive pollution started killing life in water courses; and stormwater management systems were improved after major flood events (Andjelkovic 2001).

Bearing in mind the climatic projections mentioned beforehand, this commonly conducted reactive approach manifested in our governing practices, may lead to severe consequences. In anticipation of what could be considered as the unreasonable approach to "do nothing" when facing carefully analysed impacts, there are many authors who argue in favour of an approach that is focused on precautionary and proactive principles (Smit et al. 2000, Ahern 2006, Wilby and Keenan 2012). Fundamentally, these authors believe that uncertainty must not be a reason to postpone actions that face the challenges presented by climate change.

As such, the adaptive planning and management approach is gaining recognition is various areas, namely when it is possible to consider and connect a range of options and results. Examples that have pursued this approach, include much of the previously mentioned, namely the management of Thames Barrier flood defence or the Dutch "Room for the River" approach. According to Jack Ahern "the adaptive approach reconceives uncertainty as an opportunity to 'learn by doing'" (Ahern 2006, p.128). While traditional management only applies new policy decisions in the face of proof of efficacy obtained through long and short-term empirical studies, adaptive management is a "hands-on" method where projects are assumed as experimental laboratories from which continuous learning is expected (Ahern 2011). However dependent of continuous monitoring and consequent recurrent costs to the public and private sector, at least Wilby and Keenan are imperative to state that "adaptive management currently offers the best hope of reducing flood risk in an uncertain social and physical climate" (2012, p.361).

Lastly, one might consider the current overwhelming amount of information about "climate change adaptation" and "adaptation measures" as one other fact that is stalling action. There are numerous overlapping studies, which offer an extensive range of purposes and interpretations alongside the common theme of adaptation or flood adaptation. As it is a relatively new subject, existing possible measures haven't yet been organised and analysed in a comprehensive manner, which would combine all findings in one common understanding easily used by the subjects involved. This missing link to standardize typologies, so that they can be used together with other established urban planning practices, is envisioned to be addressed in this research. More specifically, the second part of the thesis that begins in chapter three, will dwell upon the analysis of urban flood adaptation measures that are applicable in the design of public space.

2.4. Discussion

Through the course of time, watersheds have been progressively redefined by Man's land occupation processes. In early times, these changes in the landscape were essentially driven by the need to efficiently use natural resources, as well as the need to resist the damaging power of natural events. Related water infrastructure techniques accompanied these changes and developed accordingly, from water collection strategies to flood protection or stormwater storage measures.

History is made of continuous and consecutive loops, it goes back for inspiration in order to move forward. Findings from past achievements or misfortunes in flood management practices are therefore crucial for the understanding of our current situation. While every occurrence is highly context specific, efforts should be made in order not to repeat former mistakes, and also not to waste time on "reinventing the wheel" (Castel-Branco and Ishikawa 2016). As such, ancient water technologies are more than historical relics, but rather potential models for current and future practices (Angelakis and Zheng 2015). Indeed, the way several early societies have lived in harmony with nature constitutes an important intelligence patrimony from which we can learn and actively develop. From the ancient civilizations knowledge section evidenced in this chapter, one may identify the three following key principles: 1) City planning must include both water and wastewater infrastructure as well as essential flood protection strategies, such as the avoidance to establish settlements in flood prone areas; 2) Water as resource should not be wasted even in periods of water adequacy; and 3) Large scaled measures should be combined with small scaled measures. Angelakis et al. further highlighted the reclaimed guidance to 4) regard the safety and security of water supply, namely when considering war periods (2014).

While first human societies were predisposed to live with floods, including both its disadvantages as well as its benefits, latter civilizations changed perceptions and floods started to be mostly seen as a phenomenon that brought more harm than good. As societies became progressively more threatened by floods, efforts were therefore mainly targeted at avoiding and controlling this unwanted hazard. Only lately, and greatly influenced by climate change science and projections, did we shift our focus from the goal to reduce the probability to experience floods, to the aim to reduce society's vulnerabilities.

Human activity from the industrial period is said to have influenced the world's climate in unprecedented ways. Following up-to-date climatic projections, this change points towards an increased frequency and greater intensity of storms (precipitation and storm surges), together with a rise in sea level (Min et al. 2011). These changes in the climate regime are expected to increase the number of floods as well as strengthen their devastating effect on society and in the environment.

The importance of tackling climate change is presently recognized among most political agendas (Swart et al. 2009), namely when considering the estimated impacts of exacerbated urban flood events. By recognising that the climate is changing in exceptional ways, current flood management endeavours started to additionally include the probabilities of future climate change projections besides the analysis of past trends. Present times further recognize that floods encompass different interrelated factors besides the obvious climatic aspect. In accordance, when facing the need to analyse the probability of occurrence of a flood phenomenon the need to consider social, economic and institutional vulnerabilities was added. As such, the importance to include and engage with a wide range of scientific disciplines is further recognized; from the technical and natural sciences, to the social and governance disciplines.

The adaptation of urban areas to "unprecedented new extremes" (Coumou and Rahmstorf 2012, p.5) is considered by many to be one of the biggest challenges of the next century (Jones et al. 2012). In fact, although we have always lived and will continue to live with a changing climate, we are not prepared, our cities and infrastructure are not prepared to face the projected changes in climate for the next 100 years.

The 2016 report of global risks further substantiates these matters when highlighting "extreme weather events" as the second most important risk in terms of likelihood. In regards to the analysis on the potential impacts over the next 10 years this report stresses that the top risk is "failure of climate-change mitigation and adaptation", which is considered to have greater potential damage that "weapons of mass destruction" placed as the second most important risk before "water crisis" in third (WEF 2016).

Experts in climate science are increasingly agreeing that, to some extent, the extreme changes in climate induced by Man, can no longer be completely stopped. Moreover, there is a growing consensus that these changes are already being felt. It is therefore an urgent matter to move beyond mitigation and adaptation rhetoric, and act before this challenge, namely in regards to flood management infrastructure "…if only, because the infrastructure we build today locks us into patterns of behaviour for many years to come" (Bicknell et al. 2009, p.292). Innovating in applied flood risk management infrastructure and being in the cutting edge of long term planning entails great opportunities for the development of our future cities.

When analysing an overview of the flood risk management practices throughout history, it was possible to verify how climate change science and projections are shifting the focus from the goal to reduce the probability to experience floods, to the aim to reduce society's vulnerabilities. Moreover, that the goal to tackle social vulnerability might be related with the integration of risk and uncertainty in flood management practices, namely by fully acknowledging and welcoming the processes of the natural water cycle amongst public space. A perspective that will inevitably change the relationship between the city and (its) water.

Assuming the relevance of a change of paradigm in current flood risk management practices, cities such as Rotterdam, New York and London have matured their relationship with water, namely the relationship between society and flood risk management infrastructure. In brief, the conventional simplistic arrangement to effectively and rapidly avoid or convey stormwater is, in these examples, being gradually replaced by the inclusion and permanence of stormflows within the city and the overall enhancement of the natural water cycle. As such, part of the envisioned solutions within these plans has focused on "more comprehensive, not purely engineering" (Hartmann and Driessen 2013, p.6) measures, with the goal to attenuate the maximum flood flow instead of rapid discharge, including so-called "source control" measures such as detention and retention ponds, permeable surfaces, infiltration trenches, porous pavements, and green roofs, among others. Although hard structural engineering is not dismissed, ecosystem-based approaches are therefore privileged. Undertakings are targeted for citywide implementation and there is an active search for synergies among other urban projects in development. Moreover, local "bottom-up" approaches are considered of critical value, as well as continued assessment and monitoring of implemented measures. In other words, the importance of learning mentioned in chapter one, i.e. reflecting upon mistakes and generating experience while dealing with change (Berkes et al. 2003), is reinforced in light of the presented examples.

Regardless, much is yet to be researched in terms of urban adaptation to floods. The abovementioned approaches are still far from being established policy among most of our cities. There are still some hindering factors that must be surpassed and among them is how to deal with the uncertainty of climate projections that, in light of long-term and highly costly flood management infrastructure considerations, gains an even bigger dimension.

In the face of impending weather events, which will affect not only precipitation regimes, but also a rise in sea-level, "source control" measures are not the only envisioned solutions. Floating structures (Zevenbergen et al. 2008) are, in this context, a paradigmatic example of "out-of-the-box" thinking. Moreover, many adaptation measures are particularly difficult to implement within consolidated city neighbourhoods. Evidence of this difficulty has led to an additional need to present alternatives. Along this line of reasoning, public space design is of significant importance, not only because it may influence global climate (Kravčík et al. 2007) but also because public perceptions entail immediate repercussions on the reduction of a society's vulnerability (Ruddell et al. 2012).

In light of the vast amount of evidence, that elucidates on how uncertainty must be acknowledged as an inevitable factor, that must and can be taken into consideration in the way we plan our cities (Ascher 2010[2001], Lister 2005, Brandão Estêvão 2015, among others), the claim for adaptive management approaches lies enhanced. That is, an approach that tackles the future through tailored adjustments, whose teachings from continued assessments will serve and encourage to further improve interventions. The adaptive management approach is therefore not intended to directly respond to flood risk events, but rather to face future uncertain climate extremes as they unfold.

What if we welcome and integrate the uncertain dynamics of extreme events alongside other urban dynamics? What if stormwaters with high risk connotations are also, by contrast, recognised as a fundamental and beneficial resource for the endurance of our cities? The challenge presented by these questions is not related to technical difficulties or technical stagnation of knowledge, as evidenced by the aforementioned examples or by authors such as Howe and Mitchell (2012). The current most important challenge when facing the constraints against action for the reassessment of conventional flood management practices is, first and ultimately, political will.

As argued by Jack Ahern, "Planners operate in the 'real world' where there is an imperative to act. The world doesn't stop or wait while planners work to collect data to reduce uncertainty. Planning operates on a target that is, by definition, moving." (Ahern 2006, p.128). Bearing this in mind, and in order to contribute to break the chains of decision making, the next chapter aims to evidence how the specific enhancement of public space design stands as a key factor in the success of adaptive flood management strategies. How, through public space, a new communion with the water element and stormwater in particular may protrude. To see water, to touch water or to taste water; to play with water, to respect and assume water with precaution; to enhance the whole water cycle and to know vulnerabilities in first-hand (Figure 2.18); all this and more can be achieved through public space and its design.

Figure 2.18 - Bill Watterson elucidating us on how what is commonly considered as a nuisance can be turned into an opportunity or on how an object that is initially thought and designed to fulfil a particular purpose may serve another. Credits: Calvin & Hobbes - Bill Watterson, Universal Press Syndicate, 2009.

Part II

Experimentation

The second part of the thesis aims to evidence the specific characteristics of public spaces and public space design under the recognized need for cities to face the projected climatic challenges, and flood events in particular. It further aims to highlight the existing experimental types of opportunities in a Conceptual Framework of flood adaptation measures applicable in the design of public space.

Chapter three focuses upon local scale adaptation initiatives and argues upon a new and enhanced role of public space. Mostly through an empirical analysis, chapter three will further evidence an initial organization in different categories of flood adaptation measures applied in the design of public spaces, as well as explore the potential benefits enclosed within the recognized characteristics of public space.

Chapter four will extend the developed empirical analysis with an in-depth literature review, specifically directed at identifying and defining the different types of adaptation measures within the previously identified categories. Combining and analysing the results obtained, chapter four will additionally develop the proposed Framework of flood adaptation measures applicable in the design of public space.

Chapter 3

Local climate change adaptation through public space design

Parts of this chapter were disseminated in the following publications:

Matos Silva, M. and Costa, J. P., 2016. Climate Change and Urbanism. A new role for public space design? *In:* A.Remesar ed. *The Art of Urban Design in Urban Regeneration. Interdisciplinarity, Policies, Governance, Public Space.* Barcelona: Publicacions i Edicions de la Universitat de Barcelona, 62 - 86 ISBN: 978-84-475-3781-5. [Book Section]

Chapter three is principally focused upon local flood adaptation action through public space design. Besides exploring the potentiality of public spaces when facing adaptation endeavours, this chapter evidences and characterizes wide ranging examples of public spaces with specific flood adaptation purposes. Through an empirical analysis based on the collective cases, it is possible to propose an initial organization into different categories of flood adaptation measures applied in the design of public space. In addition, this chapter highlights the potential benefits that may specifically arise from the inherent characteristics of public space. Lastly, this chapter specifically argues that, through public space, which provides the opportunity to integrate and reveal the complex intermingling connections between natural, social and technical processes, traditional flood management practices may be reassessed to the contemporaneity of our time.

3.1. Climate change adaptation through local, "bottom-up", initiatives

Cultures and climates differ all over the world, but people are the same. They'll gather in public if you give them a good place to do it.

Jan Gehl - www.gehlarchitects.com

Climate change has mostly been evaluated through global models, more specifically, through General Circulation Models (GCM) -, in order to anticipate climate change scenarios. Whereas many authors strongly support scientific evidence, claiming that "changes in climate are happening at multiple scales from global to regional to local and that there are independent anthropogenic drivers of change at each scale" [IPCC 2007; Oke 1997; Stedman 2004 *in* Ruddell et al. (2012, p.584)]. As a result, regionalised models (RCMs, Regional Climatic Models) started being used. These models derive from the downscaling of the GCM's and cover a limited area of interest, such as Europe or an individual country. As a consequence of being based on an incomplete model *per se*, these regionalised models reinforce eventual errors and insufficient data. As started by Hebbert and Webb "[climatic] effects cannot be downscaled from a regional weather model, they are complex and require local observation and understanding." (2007, p.125). Global as well as regional models, particularly when considering the necessary combination of overwhelming information about all the natural and changing processes, are therefore further distanced approximations of reality.

In addition, although it is commonly recognized that great driving forces function at a global scale, such as greenhouse gas rates or financial dynamics, it is also widely acknowledged that various local phenomenon's influence global climate (Wilbanks and Kates 1999), from micro-environmental processes to demographic variations or resource use undertakings, such as deforestation or coral mining. The Urban Heat Island effect (UHI) in particular, as a clear indication of significant acceleration of temperature changes in most existing cities world-wide, imposes direct repercussions upon global climate.

Other authors have further argued that, although the frequently mentioned greenhouse gas emissions unequivocally contribute to global warming, the witnessed disturbance of the small water cycle is a bigger catalyst on future climate extremes (Kravčík et al. 2007). While most investigations analyse the impacts that climate change will have on the water cycle, Kravčík et al. question the reverse influence that an unbalanced water cycle may have on the exacerbation of climatic change. In light the research presented by these authors, saturating the small water cycle through the conservation of rainwater on land would be a revolutionary solution to the given problems of anthropogenic climate change.

For a long time, carbon mitigation and/or adaptation to global warming have formed part of several international agendas, with monthly initiatives being disseminated throughout the global scientific community. Although these global endeavours are imperative, it has been argued that it is frequently "focussed [on] the exposure of cities to hazards that have a huge impact but low frequency. It has little to say about the high-frequency and micro-scale climatic phenomena created within the anthropogenic environment of the city" (Hebbert and Webb 2007, p.126). Contrastingly, as it may be endorsed by some of the examples that will be highlighted next, this tendency has been counterbalanced by the various local initiatives that have emerged more or less quite recently[35]. These initiatives essentially confront the systematic assumption of realism in science (as highlighted by Beck 1992), deciding not to rely solely on justifications from global projections in order for adaptation to be advanced in cities. Rather than being restrained or expectant of downscaled or locally applied models, a wide range of cities have recognized the need to take action now in order to prepare for the future (Carmin et al. 2012).

In this line of reasoning, Jaap Kwadijk and others (2010) have identified two main approaches on climate adaptation policy: 1) a predictive top-down approach and 2) a more from the bottom-up resilience approach. While the first is essentially guided by global models, the second is

[35] Besides specific local scale flood adaptation endeavours applied in public spaces, which will be analysed next, one may mention further examples such as the water saving projects in Zaragoza, the establishment of community-based early warnings against flash floods in northern Bangladesh or the neighbourhood's action against the impact of urban heat islands in Portland, Oregon. (IPCC, 2012. *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation.* Field, C. B., *et al.* eds. Cambridge, UK, and New York, NY, USA: Cambridge University Press. 582 pp.).

relatively independent of "justifications from atmospheric science" (Ruddell et al. 2012, p.601) and its associated uncertainties. Moreover, instead of reducing impacts, the latter rather focuses on reducing vulnerability by improving the resiliency of a system exposed to particular climate change risks (Te Linde 2011 in Veelen 2013).

Local scales are particularly sensitive to every climatic change, be it sporadic or ongoing (Figure 3.1). According to the IPCC, there is "high agreement" and "robust evidence" that "disasters are most acutely experienced at the local level" (IPCC 2012, p.293). When analysing the risks of extreme events, the IPCC further highlights that while most events will not become severe enough to cause a disaster of national of international magnitude "…they will create ongoing problems for local disaster risk management" (IPCC 2012, p.297). The degree of the impacts is also strongly linked with the existing social and physical local vulnerabilities "…including the quality of buildings, the availability of infrastructure, urban forms and topographies, land uses around the urban centre, local institutional capacities" (Bicknell et al. 2009, p.362).

Figure 3.1 - "We all hate you Sandy" printed over a wall in New Jersey after the hurricane effects in 2012. It recalls us how most significant impacts will always relate to the human scale. Image credits: Henk Ovink.

Furthermore, as locals are the first to experience and respond to hazards, they retain local and traditional knowledge that is not only aware of these hazards and existing vulnerabilities, but also knows how to cope and work with them (IPCC 2012). In accordance, Ruddell et al. states that "It is critical to ground support for climate adaptation and mitigation initiatives within local contexts of shared experiences" (2012, p.601). In other words, local know-how should always be considered as added value for adaptation action, particularly when considering a known or often repeated hazard. Societal processes are thus critical for the success adaptation action. Ultimately, and regardless of national and reginal efforts, without a local approach that integrates the human scale, adaptation endeavours will fail their purpose.

On the other hand, projected scenarios and the increased record of more frequent extreme events (Coumou and Rahmstorf 2012) will likely lead to unprecedented situations for which localities have no previous experiences. As corroborated by the IPCC, "extreme weather and climatic events will vary from place to place and not all places have the same experience with that particular initiating event" (IPCC 2012, p.297). As such, local action should not be dissociated from a global and more encompassing scale in which scientific knowledge of future climate projections is crucial. For example, bearing in mind that local initiatives rely more on weather, ecology and social media; events such as cold summers or heavy rains may be wrongly interpreted as evidence that there will be no global warming or long term droughts (Ruddell et al. 2012).

In accordance, under the risk of not contributing effectively to the achievement of community expectations, and the safeguard public interests and collective resources, not only local but also global and regional strategic views must be taken into consideration. In other words, both global "top-down" and local "bottom-up" strategies must be seen as equally significant drivers for successful adaptation action. In the same line of reasoning, in the final conference of the R&D project "Urban Deltas" (Costa et al. 2013), Han Meyer has raised the question of how to take advantage of the arising numerous local initiatives spread out through the Netherlands. In his view, local actions that are not structured in one global and general strategy get lost in the overall scale and will ultimately lose their significance and value. Whilst acknowledging the importance of local scale responses, these should always be accompanied by a global strategy in order to fulfil their objectives.

Indeed, in light of the international examples previously analysed in Part I, agile municipalities, which often have close relationships with their citizens, enterprises and institutions, are quicker and more effective in the implementation and monitoring of local adaptation solutions. Recalling Borja, "it is not possible to decouple urban claims from the strength and innovation of local and proximity governance" (Borja 2003, p.31, author's translation). On the other hand, for Bicknell, to ensure adaptation to extreme weather events is a characteristic of well governed cities (2009). Hebbert and Jankovic further stated that "Cities which understand and manage their local climate have a head start in responding to global climate change" (2013, p.1345). A "municipalism in action" that strengthens the social, physical and economic backbones of the city (RCI

2009), but that is also inseparable to local competences and political autonomy.

In addition, as it has been argued by many authors, there is a strong relation between the quality of cities and the quality of its public space. This relation can be acknowledged in both sides of the spectrum, i.e. that the quality of cities can be measured by the quality of its public space and that the quality of public space largely influences the quality of cities. More specifically, for John Ruskin, "The measure of any great civilisation is in its cities, and a measure of a city's greatness is to be found in the quality of its public spaces, its parks and its squares" (Cowan 2005, p.314) and for Jordi Borja "The assessment of urbanism is the public space"[36] (Borja 2003, p.176, author's translation). On the other hand, Jordi Borja also emphasized that "Public space defines the quality of the city, because it reveals people's quality of life and the quality of citizenship for its inhabitants"[37] (Borja 2003, p.135, author's translation). Furthermore, Brandão et al. argued that "Quality public spaces can help cities to create and maintain sites of strong centrality, environmental quality, economic competitiveness and sense of citizenship"[38] (Brandão(Coord.) et al. 2002, p.17, author's translation). Other widely recognized authors have considered that the city "is" the public space itself (Lynch 1996[1960], Jacobs 1992[1961], Portas 2011[1968]); "the city is the public space, place of social cohesion and exchanges"[39] (Borja 2003, p.119, author's translation).

What came to be known as the Barcelona Model is a widely recognized example of a successful urban regeneration process that is essentially focused on the improvement of local scaled public spaces. As evidenced by its greatest mentor, Oriol Bohigas, the main focus was on the improvement of the quality of public spaces, either as a result of public or private initiatives. Following the general approach of "cleaning the centre and monumentalize the periphery" (Bohigas 1986, p.20), any intervention was primarily based on the (re)qualification of public spaces or on the building of new ones. From the PERI projects (Special Plans for Interior Reforms) (1980-1986) to the Olympic project (1982), the Barcelona Model gave rise to a new form of planning based on the importance and dignity of public space. It was the emergence of the Barcelona after Franco. In the first democratic urbanism projects, public space started to

[36] Original text: *"La prueba del urbanismo es el espacio publico".*
[37] Original text: *"El espacio publico define la calidad de la ciudad, porque indica la calidad de vida de la gente y la calidad de la ciudadanía de sus habitantes".*
[38] Original text: *"Os espaços públicos de qualidade podem ajudar as cidades a criar e manter locais de forte centralidade, qualidade ambiental, competitividade económica e sentido de cidadania".*
[39] Original text: *"la ciudad es el espacio publico, lugar de la cohesión social y de los intercambios".*

be something belonging to all citizens, that everyone needs and that everyone must have access to.

Eventually, one may identify a current "flip side" to the successes achieved in the eighties and the nineties, namely as a result of the negative consequences of an over-growth of the tourism sector and overall "globalization" (Remesar 2005). Yet, what made the case of Barcelona a Model was the generalized perception of the ideal to base urban regeneration process on interventions made with public money in order to create new public spaces for its citizens. As mentioned by Balibrea, from the moment that public intervention obeys the institutional relations logic of the local situation of global markets, and not of those institutions with the needs and desires of the local population, the meaning of public space undermines itself and its continued evocation can turn out to be only a rhetorical speculation (Balibrea 2003).

As previous research evidenced (Matos Silva 2011), it is interesting to note how nowadays one can still verify reminiscences of the mentioned early democratic urbanism ideals, namely in the management of the cities' floods. Similarly to most developed cities, what were formerly open and exposed water courses, which crossed Barcelona's plain, parallel to each other into the sea, are now underground interconnected channels. As the urbanised impermeable areas increased, the drainage system progressively became insufficient to manage the experienced heavy rains. Consequently, Barcelona increasingly suffered from recurrent flooding episodes.

In addition, besides the torrential precipitation common to Barcelona's Mediterranean geographic condition, the topographical situation of the city is also a significant and inevitable contributing factor for the occurrence of periodic flash floods, namely the steep slopes of the Collserola Mountain and the cities' extended plain surface in-between the mountain and the sea. While the steep slope doesn't allow infiltration, the extended plain does not favour gravity drainage. As a consequence, there is a rapid concentration of rainwater into the lower lands and a subsequent difficulty to discharge stormflows to the receiving water body[40].

Nowadays, most of Barcelona operates in a combined sewer system (CSS). In dry weather and during light to moderate rainfall, the system conveys wastewater and stormwater flows to the wastewater treatment facility. However, during periods of heavy rainfall, the capacity of the

[40] Recall how 1860 Cerdá's plan took this matter into consideration and "adapted" the "Ensanche" itself to the NW-WS orientation in order to facilitate drainage runoff.

CSS and its treatment plant can be exceeded and combined sewerage is diverted onto a receiving water body. This phenomenon is called a Combined Sewerage Overflow (CSO), which not only contributes to the occurrence of floods but also directly impacts receiving water body with untreated polluted waters.

In order to tackle this matter, several retention tanks were proposed in the 1997 "Plan Especial de Alcantarillado de Barcelona" (PECLAB) and were later constructed by CLABSA (Clavegueram de Barcelona, S.A.). These great regulation tanks or underground reservoirs had the primary function to retain vast quantities of stormwater during heavy rains. Once large amounts of stormwater are retained, they can be subsequently evacuated little by little and the system is ready to receive them. Through such process, untreated outflows into the beaches and rivers is also avoided.

In 2011, Barcelona had eleven reservoirs that together could store around 415 000 cubic meters of stormwater (Matos Silva 2011). An investment that greatly reduced the flood episodes within the city. Yet, what makes Barcelona's reservoirs particularly different from the others implemented in many European cities, such as Berlin (Germany), Bolton (United Kingdom) or Bordeaux (France) (ChiRoN et al. 2006), is their integration with cities' public spaces.

Barcelona is often highlighted as being the European city whose drainage strategy was invested in the most, through construction of these underground reservoirs. However, the city should also be recognized for its capacity to integrate such great infrastructures in compact urbanized areas as well for its capacity to combine synergies in order to offer more public spaces for its citizens.

As further developments within this chapter will evidence, namely in the analysis of Escola Industrial example, most of the constructed underground reservoirs entail plazas, sports fields, parking lots or gardens on their surface. Through the construction of these reservoirs, Barcelona has shown that infrastructures may aspire more than to only serve the objective they were built to accomplish. In contrast with other cities that look into infrastructure as an isolated and untouchable urban element, the project and implementation of such reservoirs interconnected several disciplines, from urban planning to drainage engineering and landscape design. A transversal and interdisciplinary approach that explored the benefits and opportunities of common understandings. In 2003, Jordi Borja had already emphasised that "infrastructures have been considered as an inevitable aggression to the citizen's public space or have not been treated for other uses besides the specifics of their roles: network services (energy, water, telephone, etc.), infrastructures and collective transport systems (from train stations to bus stops", but that "one needs to see these elements as opportunities and not obstacles in the development of the city and its quality of life"[41] (Borja 2003, p.137).

It thus appears that the importance given to public space, as a distinctive feature of the Barcelona Model, is latent in contemporary sectorial strategies and not only in the past initial direct intent of urban regeneration. It may be further argued that the Barcelona Model therefore remains a pioneer urban approach, namely on its combined integration between flood adaptation measures and public space design. Although Barcelona's reservoirs were not conceived with specific adaptation purposes, they are undoubtedly connected to a particular kind of public space that shares the additional function to tackle floods. Through their public spaces, people are connected with the dynamics of a particular system or infrastructure. More specifically, physical elements such as ventilation chimneys or placards evidence the presence and performance of the below-ground infrastructure. This connection process connection between people and the flood management infrastructure, which will be developed in the following pages, can lead to an improved common understanding and engagement.

Lastly, recalling upon the previously exposed advantages of locally driven adaptation action, it is argued that just as specific public space interventions can rise the standard for good quality cities, so too will local adaptation measures applied in public spaces be particularly relevant in the quality of our future cities.

[41] Original text *"… las infraestructuras, … han sido consideradas agresiones inevitables al espacio publico ciudadano o no han estado tratadas para otros usos que el especifico de su función: redes de servicios (energía, agua, teléfono, etc.), infraestructuras y sistemas de trasporte colectivo (desde las estaciones hasta las paradas da autobús). … Es necesario ver en estos elementos oportunidades y no obstáculos para el desarrollo de la ciudad y da la calidad de vida.".*

3.2. The key role of Public Space in adaptation endeavours

To live together in the world means essentially that a world of things is between those who have it in common as a table is located between those who sit around it; the world, like every in-between, relates and separates men at the same time. / The public realm, as the common world, gathers us together and yet prevents our falling over each other, so to speak.

Arendt, H., 1998[1958]. *The Human Condition*. 2nd Edition ed. Chicago University of Chicago Press, p.52

The idea of public space may be apprehended by a set of two meanings: 1) a conceptual meaning commonly used in political and social science, in which public space, as characterized by Innerarity, "brings together all the processes that configure the opinion and collective will" (2006, p.10, author's translation) and 2) a physical meaning, commonly used in urban planning and design, where the previous actions are developed (Borja 2003, Cowan 2005).

In old Greece, "public space" had specific boundaries. It was called "Ágora" whose literal meaning is a "gathering place" for discussion. Innerarity has argued that this traditional meaning of public space, in which public matters are expressed and represented in a bounded physical area, has disappeared. However, the author additionally claims the need of a space "for" the public (Innerarity 2006). More specifically, a space that enables and promotes community life, such as streets, sidewalks, plazas, coffee shops, parks or museums, and that potentially offers wide-ranging benefits such as place-making, sense of place or local identity. Likewise, other authors have additionally highlighted pubic space as multifunctional space, with a central social, political and cultural significance (Ricart and Remesar 2013). In regards to its physical characteristics it has been particularly argued on the long-lasting permanence of public space as a structuring urban space (Martin 2007, Portas 2003) of interdisciplinary nature (Madanipour 1997[1972], Brandão 2004). Overall, public space may be defined by Hanna Arendt's communal table: it "gathers us together and yet prevents our falling over each other, so to speak." (1998[1958], p.52).

The present chapter embraces all these previously mentioned facets of public space and, in addition, it aims to discuss their specific role in urban adaptation processes. More specifically, it will be argued that through the application of effective adaptation measures in public spaces, communities are facilitated to comprehend, learn, engage and mobilize for climate action.

As argued in chapter one, the distinctiveness of urban territories as major centres of communication, commerce, culture and innovation, is what may empower successful processes and outcomes of the climate change adaptation agenda. In addition, recalling Jordi Borja, the cities' interchange processes of products, services and ideas "need, are processed and expressed in their public spaces" (2003, p.120, author's translation).

As argued by Banerjee, there has been an increasing tendency for people to gather in order to improve a common liveability, often ending up enhancing the overall quality of the urban environment (Banerjee 2001). Banerjee additionally evidences that most of these shared public actions happen in existing public spaces, such as streets, plazas or school amphitheatres, therefore "reasserting the role and sustenance of the public realm" (Banerjee 2001, p.15). Not only do people want to be the main actors in the urban space, but also want to be at the centre of space design concerns. As Jane Jacobs pointed out, "Dull, inert cities, it is true, do contain the seeds of their own destruction and little else, (…) lively, diverse, intense cities contain the seeds of their own regeneration, with energy enough to carry over for problems and needs outside themselves" (Jacobs 1992[1961], p.448). Indeed, what is regularly overlooked in large scale planning and policy – often guided by questionable interests – is a community's inherent resilience (Figure 3.2).

Figure 3.2 - Regular summer day in a street of Lisbon. Two kids facing a 29 C temperature with a bath in an inflatable swimming pool filled with water, which is placed near their front door yet outside in the public street. Image credits: Paulo Henrique, 2016.

Climatic hazards such as flooding, potentially aggravated by climate change, are an increasing threat that affects all the people in a community, particularly the most vulnerable (elderly, children, poor, among others). Considering public space as a communal space, a collective entity of shared concerns, a new claim for climate change adaptation is presented, the claim that public space may therefore additionally serve as social beacons for change.

In light with Pelling's findings, people and communities are not only targets but also active agents in the management of vulnerability (Pelling 1997). Ulrich Beck also highlighted that "what was made by people can also be changed by people" (Beck 1992, p.157). Correspondingly, not only it is in the public space where hazards become tangible to a community, but it may also be where adaptation initiatives may strive. It therefore comes as no surprise that a new variety of insurgent citizenship is arising within public spaces as the urgent matter of climate change adaptation is recognized among our societies (Figure 3.3). Regardless, bearing in mind the potential severity of the projected impacts that are expected to become increasingly more unavoidable, many authors agree that our society is still not responding accordingly (IPCC 2014).

Figure 3.3 - Provocative "tag" at the Regent's canal in north London in which the words "Global Warming" were intentionally cut in half as if suggesting the sea level had already risen. This manifesto was made right after the end of the inconclusive Copenhagen climate conference by the graffiti artist Banksy in 2009. Source: www.banksy.co.uk, accessed: 19th March 2015.

Some societies have shown to be reluctant of the need to face impending threats of climate change. It seems as if there is no common understanding of what is the "common good". Hesitant communities may be driven by the fact that climate change is still a much politicized issue or by the fact that adaptation is still a fairly recent strategy of response. Regardless of the causes in climate change suspicions, some cases evidence an inclination to prioritize other values.

Even within developed countries that have already suffered direct consequences of severe climate impacts, some communities have rejected initiatives towards a more adapted urban environment. That is namely the case of the New Orleans local society, which reacted against the construction of an adaptation plan proposed by a group of experts after the Katrina incident of 2005:

> *"On a Friday morning in ravaged New Orleans, Louisiana, Joe Brown learned just how fiercely people value their homes. Along with several dozen other disaster experts, the veteran urban planner had been recruited by Urban Land Institute in Washington D.C., to develop a rebuilding plan for the city, which had been devastated by Hurricane Katrina in August 2005 (…) about a quarter of the city lay in utter ruin and remained at high risk of flooding. Brown displayed diagrams that suggested turning some blocks, for the time being, into open space.*
>
> *Reaction was swift and harsh. A council member accused Brown of aiming to 'replace these fine neighborhoods with fishes and animals' he recalls. A couple of audience members rose up and declared, 'All we want to do is get back our homes'. The planners were startled. 'We got shock and amazement to what, to us, were fairly obvious truths', Brown says" (Couzin 2008, p.748).*

Regardless that the practice of several construction techniques, such as flood resilient buildings, was met by a distinguishable positive impulse within local society, through the experience of Joe Brown, Couzin alerts the scientific and professional community about the various possible disparities between science and social understanding.

Other communities, in other situations, also did not initially welcome adaptation actions. That is namely the case of the first attempt to implement the currently internationally recognized concept of the Water Plaza, which can be briefly characterized by being a low-lying square that is submerged only during storm events. Despite a promising start – with an idea that, within the report "Rotterdam Water City 2005", had won the first prize of the 2005 Rotterdam Biennale competition – the first pilot project failed. Conflicts emerged from several sources, from prior conflicts with the municipality, which decided to conduct the pilot project, to the uncertainties associated to an experimental project of this nature. Risks, such as of children drowning, triggered strong emotional reactions from local citizens who started naming the idea as the "drowning plaza" (Biesbroek 2014, p.121/122).

Having wisely learned from the encountered barriers that prevented the implementation of the first project, the second pilot project had, not only a new location, but, more importantly, a new approach towards technical criteria and social participation. This second attempt was successfully built and is currently considered an exemplary case of concrete climate change adaptation in a highly urbanised area.

Both mentioned cases evidence that social, cultural and emotional factors can be more valued and respected than the need of physical safety or ecological services of public spaces. This fact is one that strengthens the importance of continual community evolvement alongside additional and distinct methods for the dissemination of scientific knowledge with within the agenda of climatic adaptation.

According to Van Der Linden, persuasive communication about climate change is only successful when based on an integrated acknowledgement of the psychological processes that control pro-environmental behaviour (2014). In order to reach this goal, the author specifically claims three criteria to be met: 1) the need to combine and integrate cognitive-analytical reasoning (knowledge/information), experiential (affective processing) and social-normative aspects of human behaviour in the design of a message; 2) the need to make the climate change context explicit and 3) the need to target specific behaviours and their psychological determinants that need to be changed (Van Der Linden 2014).

The role of public space as a mediator for social proactivity towards adaptation seems to have been insufficiently addressed in overall climate change discourse. In the cases where the local scale is considered, approaches often disregard context-specific features of communities and neighbourhoods, to which people more likely connect, and are rather more oriented towards the policy role of municipalities. Yet public spaces seem to offer what Van Der Linden considered as fundamental for climate change adaptation engagement. Through public spaces and public space design, local aspects of climate change can be made visible and thus meaningful for citizens and their livelihoods. In his keynote speech at "2010 Deltas in Times of Climate Change Conference", the design director for Arup Urban Design, Malcolm Smith, expressed similar concerns when stating the need to "make visible the invisible" in climate change adaptation designs (Smith 2010).

Furthermore, public spaces provide a differentiated source of knowledge and information (besides the mainstreamed sources of science and media) that may be apprehended an autonomous and independent process. A process that may count with direct learning experiences, based on deep-rooted traditional experience and know-how, in a public domain that is naturally subject to social control. In other words, public spaces may provide extended opportunities for experiential learning that are influenced by specific contexts and social pressures. Through a medium that is closer to people, "climate change literacy" may more likely endorse a common need for action and search for solutions. According to CABE Space (Commission for Architecture and the Built Environment), a leading advisor of the UK Design Council, the adaptation of cities to climate-driven threats is strongly dependent on "well-designed, flexible public spaces"(CABE 2008, p.2). Others believe that "the best way to predict the future is to design it" (Buckminster Fuller in Brinke et al. 2010, p.2).

When integrating local expertise as well as scientific and technical knowledge in a flexible and clear-cut design, public spaces are not only able to promote adaptation action and reduce risk of disaster, but also improve awareness on climate change.

The physical and the social components combined make public spaces favoured interfaces for adaptation action. In public spaces people may "be" as well as "become" both producers and managers of adaptation action. People may "be" producers and managers of adaptation through autonomous, individual or collective involvements - from art manifestations to community based projects. And people may also "become" both producers and managers of adaptation when awareness is raised through the direct consequence of the formerly mentioned processes or through institutional endeavours such as the design of a particular public space, by the message of a public art (Figure 3.3) or by informative signage (Figure 3.4). In this line of reasoning, the design of public space sees itself enhanced in the face of impending weather events, being here considered as determinant for the adaptation of urban territories when facing climate change.

In regards to the particular matter of flood adaptation, public spaces entail further specific connotations besides those previously explored. Their particular features will next be identified through an empirical analysis based on a gathered range of examples. Underlying this assessment lies the argument that public spaces support the new emerging tendency on urban flood management claimed in the former chapter, where the precedent goal to effectively and rapidly avoid or convey stormflows is being gradually replaced by the goal to incorporate stormwater within the city and through the enhancement of the whole natural water cycle. In other words, that public space, comprised with flood adaptation measures, helps promote a change of paradigm for more flood-adapted cities that aim to reduce vulnerabilities while integrating environmental, social and economic concerns.

Figure 3.4 - Thames Water Tower. This glass and stainless steel tower is not only an art installation designed to mask an enormous and unsightly surge relief pipe. It further entails the function of an amplified electronic barometer, which forecasts the weather to the passing traffic while acting as an important local landmark within the public realm. Communication of other sectorial needs has been suggested for towers similar to the one here illustrated, namely the visual expression of cities' water consumption. Source: www.reform-architects.london.

3.3. Public space design for flood adaptation

It is not enough to seek the beauty of design. More precious still is the service we offer to another kind of beauty: people's quality of life, their adaptation to the environment, encounter and mutual assistance.

Pope Francis,2015
Papal Encyclical Letter Laudato Si' "On care for our common home"

Given that urban climate change adaptation can be considered a relatively recent subject, initiatives are still faced with numerous challenges. Most common barriers to adaptation can be associated to "short term thinking of politicians and long term impacts of climate change", "little finance reserved/available for implementation", "conflicting interests between involved actors", "more urgent policy issues need short term attention" or "unclear social costs and benefits of adaptation measures" (Biesbroek 2014, p.139). However, every day successful examples grow in number, and as argued by Howe and Mitchell, it is increasingly important to see more empirical studies of adaptation examples rather than just dwell on the barriers to change (2012). An emergent tendency of new and innovative adaptation projects that can be exploited as a creative laboratory, which proposes, assesses and monitors solutions through an ongoing learning process in order to serve and inform future decisions and reduce generalised hindering constraints.

Pursuant to the methodology presented in the introductory part of the dissertation, next lines, and Table 3.1 in particular, advance an empirical analysis that gathered existing examples of public spaces with additional flood adaptation purposes. The presented analysis is based on comprehensive case studies highlighted in research projects, bibliographical reviews, interviews with specialists, networking or in site visits. Besides including main or secondary functions related to flood vulnerability reduction, the chosen range of examples also aimed to select "good quality" cases among a comprehensive group of public space typologies. This research approach is here named as "Portfolio screening".

For Jan Jacob Trip public space may be the element of urban development that is most difficult to plan and design as it relates to so many intangible qualities inherent to the quality of place itself (Trip 2007). Although, there is no imposing formula that would define the quality of a public space design, it is commonly accepted that a good design must develop from a sensible understanding of its situation and all its encompassing contexts: environmental, cultural, social, economic and political (Brandão(Coord.)

et al. 2002). For Borja, “the quality of public space can be largely evaluated by the intensity and quality of the social relations that it generates, by the force to encourage the mixture of groups and behaviours, and by the ability to stimulate the symbolic identification, expression and cultural integration”[42] (Borja 2003, p.124). A good public space design therefore is likely to result in a place that is valued and used and that stimulates a communities’ sense of belonging (1996[1960]). Based on an exhaustive evaluation of thousands of public spaces worldwide, the non-profit organisation Project for Public Spaces (PPS) evidences that “great places” generally share four principal attributes, namely: sociability, uses and activities, access and linkages and comfort and image. They further developed “The Place Diagram” as a tool to assist the analysis of any place, good or bad. Intended as an all-inclusive generalist approach, the mentioned diagram also evidences the “intangibles” and “measurements” inherent to the presented principal attributes. Great public spaces that entail flood adaptation measures are likely to include at least one of the PPS intangible qualities of being “vital”, “useful”, “sustainable” or “safe”. The portfolio screening presented next, i.e. the range of empirically collected examples, was therefore based on the aforementioned references and emphasised attributes.

The portfolio screening further aimed to encompass a comprehensive range of public space typologies. For this purpose, the typology of public spaces identified by Brandão was used, namely the differentiation regarding “Layout spaces” (plazas, streets, avenues), “Landscape spaces” (gardens, parks, belvederes, viewpoints), “Itinerating spaces” (stations, interfaces, train-lines, highways, parking lots, silos), “Memory spaces” (cemeteries, industrial, agricultural, services, monumental spaces), “Commercial spaces” (markets, shopping malls, arcades, temporary markers, kiosks, canopies) and “Generated spaces” (churchyard, passage, gallery, patio, cultural, sports, religious, children's, lighting, furniture, communication, art) (Brandão 2011b, p.35). As a result, and as may be consulted with more detail in Annex II - Examples of public spaces with flood adaptation purposes classified in light of the Public Space Typologies presented by Brandão (2011), the range of examples presented next cover all the aforementioned types of public spaces.

The examples that form part of the presented database have been progressively identified throughout the unfolding of the dissertation. The

---

[42] Original text: *“la calidad del espacio público se puede evaluar sobre todo por la intensidad y la calidad de las relaciones sociales que facilita, por la fuerza con que fomenta la mezcla de grupos y comportamientos y por la capacidad de estimular la identificación simbólica, la expresión y la integración culturales”.*

gathered range of cases aimed to further provide a geographically representative scope, yet, inevitably, the projects with greater dissemination and improved access to information were privileged. More specifically, the examples presented in Table 3.1, involve 19 countries and 72 cities. Together, they are not meant to offer an exhaustive collection but rather a significant sample of designed solutions that endorse further reliable research and decision-making.

Table 3.1 – Portfolio screening: examples of public spaces with flood adaptation purposes.

#	Project name	Location**		Coordinates	Construction
1	Caixa Forum plaza	ES	Madrid	40°24'39.43"N - 3°41'35.36"W	2006
2	Westblaak' car park silo	NL	Rotterdam	51°54'58.63"N - 4°28'36.90"E	2010
3	Woolworths Shopping playgr.	AU	Walkerville	34°53'43.37"S - 138°37'2.52"E	2013-2014
4	North Road	GB	Preston	53°46'3.25"N - 2°42'12.18"W	2009
5	Expo Boulevard	CN	Shanghai	31°11'9.45"N - 121°29'16.85"E	2010
6	Jawaharlal Planetarium Park	IN	Karnataka	12°59'3.93"N - 77°35'23.74"E	2013
7	'Water Table / Water Glass'	US	Washington	47°36'59.36"N - 122°21'8.31"W	2001
8	Whole Flow'	US	California	34° 8'17.36"N - 118° 8'51.48"W	2009
9	Dakpark	NL	Rotterdam	51°54'31.25"N - 4°26'17.00"E	2009-2014
10	Promenade Plantée	FR	Paris	48°50'51.54"N - 2°22'30.06"E	1993
11	European Patent Office	NL	Rijswijk	52° 2'19.65"N - 4°20'14.48"E	2001
12	Womans University campus	KR	Seoul	37°33'39.71"N - 126°56'47.03"E	2008
13	High Line Park	US	New York	40°44'51.32"N - 74° 0'17.71"W	2006-2009
14	Waltebos Complex	NL	Apeldoorn	52°12'42.67"N - 5°56'11.12"E	2000-2007
15	Stephen Epler Hall	US	Portland	45°30'46.04"N - 122°41'16.42"W	2001-2003
16	Parc de Diagonal Mar	ES	Barcelona	41°24'28.11"N - 2°12'49.34"E	2002
17	Parc del Poblenou	ES	Barcelona	41°23'40.76"N - 2°12'14.32"E	1992
18	Benthemplein square	NL	Rotterdam	51°55'40.13"N - 4°28'36.29"E	2012-2013
19	Tanner Springs Park	US	Portland	45°31'52.18"N - 122°40'54.97"W	2005
20	Parc de Joan Miró	ES	Barcelona	41°22'36.98"N - 2°8'52.88"E	2003
21	Escola Industrial *	ES	Barcelona	41°23'13.77"N - 2° 8'53.20"E	1999
22	Potsdamer Platz	DE	Berlin	52°30'33.69"N - 13°22'31.47"E	1994-1998
23	Museumpark car park	NL	Rotterdam	51°54'48.81"N - 4°28'17.26"E	2011
24	Place Flagey	BE	Brussels	50°49'39.9"N - 4°22'20.8"E	2005-2009
25	Stata Center	US	Massachusetts	42°21'41.26"N - 71° 5'24.05"W	2004
26	The Circle	US	Illinois	40°30'33.35"N - 88°59'3.85"W	2010
27	Georgia Street	US	Indianapolis	39°45'51.50"N - 86° 9'40.24"W	2010-2012
28	Parque Oeste	PT	Lisbon	38°46'46.53"N - 9°9'13.40"W	2005-2007
29	Qunli park	CN	Haerbin	45°43'33.84"N - 126°32'45.68"E	2009-2010
30	Emerald Necklace	US	Boston	42°19'20.70"N - 71° 7'3.84"W	1860s
31	Quinta da Granja	PT	Lisbon	38°45'7.99"N - 9°11'27.73"W	2011
32	Parque da Cidade	PT	Porto	41°10'9.20"N - 8°40'40.44"W	1993
33	Trabrennbahn Farmsen	DE	Hamburg	38°45'7.99"N - 9°11'27.73"W	1995-2000

34	Elmhurst parking lot	US	New York	40°44'16.71"N - 73°52'48.47"W	2010
35	Ecocity Augustenborg	SE	Malmö	55°34'50.19"N - 13° 1'27.49"E	1997-2002
36	Museum of Science	US	Portland	45°30'28.49"N - 122°39'52.14"W	1990-1992
37	High Point 30th Ave	US	Seattle	47°32'44.43"N - 122°22'13.42"W	2001-2010
38	Moor Park	GB	Blackpool	53°50'52.78"N - 3° 2'5.08"W	2008
39	Ribblesdale Road	GB	Nottingham	52°59'31.70"N - 1°8'42.24"W	2013
40	South Australian Museum	AU	Adelaide	34°55'15.06"S - 138°36'11.58"E	2005
41	Columbus Square	US	Philadelphia	39°55'58.09"N - 39°55'58.09"N	2010
42	Derbyshire Street	GB	London	51°31'34.40"N - 0° 3'40.45"W	2014
43	Onondaga County	US	New York	43° 3'1.51"N - 76° 8'53.51"W	2010
44	Edinburgh Gardens	AU	Melbourne	37°47'14.68"S - 144°58'58.19"E	2011-2012
45	Taasinge Square	DK	Copenhagen	55°42'36.27"N - 12°34'4.53"E	2014
46	Australia Road	GB	London	51°30'39.58"N - 0°13'57.73"W	2013-2015
47	East Liberty Town Square	US	Pittsburgh	40°27'40.91"N - 79°55'31.25"W	2013-2014
48	Can Caralleu	ES	Barcelona	41°24'3.81"N - 2°6'48.02"E	2006
49	Zollhallen Plaza	DE	Freiburg	48° 0'38.00"N - 7°50'52.36"E	2011
50	Green park of Mondego	PT	Coimbra	40°12'0.63"N - 8°25'29.25"W	2000-2004
51	Bakery Square 2.0	US	Pittsburgh	40°27'24.57"N - 79°55'2.75"W	2015
52	Praça do Comércio	PT	Lisbon	38°42'27.05"N - 9°8'11.04"W	2010
53	Percy Street	US	Philadelphia	39°56'22.15"N - 75° 9'29.52"W	2011
54	Greenfield Elementary	US	Philadelphia	39°57'7.26"N - 75°10'40.30"W	2009-2010
55	Etna Butler Street	US	Pittsburgh	40°29'47.05"N - 79°56'38.82"W	2014
56	Community College	US	Philadelphia	39°58'3.51"N - 75°23'30.76"W	2005
57	Elmer Avenue Neighbourhood	US	Los Angeles	34°12'39.39"N - 118°22'36.70"W	2010
58	Green streets design manual***	US	Philadelphia		pilot
59	Ribeira das Jardas	PT	Sintra	38°46'7.10"N - 9°18'2.34"W	2001-2008
60	Ahna	DE	Kassel	51°19'20"N - 09°30'24"E	2003-2004
61	River Volme	DE	Hagen	51°21'33.27"N - 7°28'33.55"E	2006
62	Promenada	SI	Velenje	46°21'38.60"N - 15° 6'55.55"E	2014
63	Catharina Amalia Park	NL	Apeldoorn	52°12'39.29"N - 5°57'38.18"E	2013
64	Kallang River	SG	Bishan Park	1°21'47.63"N - 103°50'37.96"E	2009-2012
65	Alb	DE	Karlsruhe	48°59'58.04"N - 8°22'16.95"E	1989-2004
66	Westersingel	NL	Rotterdam	51°55'5.95"N - 4°28'19.52"E	2012
67	Thornton Creek	US	Seattle	47°42'6.65"N - 122°19'26.72"W	2003-2009
68	Cheonggyecheon River	KR	Seoul	37°34'10.73"N - 127° 0'14.32"E	2003-2005
69	Soestbach	DE	Soest	51°34'28.42"N - 8° 6'24.34"E	1992-2004
70	Banyoles	ES	Girona	42°7'5.10"N - 2°45'53.48"E	1998-2008
71	Freiburg Bächle	DE	Freiburg	47°59'42.95"N - 7°51'10.06"E	13th century
72	Roombeek	NL	Enschede	52°13'51.62"N - 6°53'26.81"E	2003-2005
73	Solar City streets	AT	Linz	48°15'27.00"N - 14°21'37.31"E	2004-2006
74	Pier Head	GB	Liverpool	53°24'14.47"N - 2°59'47.09"W	2009
75	Olympic park	GB	London	51°32'48.85"N - 0° 0'59.27"W	2012
76	Kronsberg	DE	Hannover	52°20'30.73"N - 9°50'23.01"E	1998-2000
77	Renaissance Park	US	Tennessee	35° 3'42.91"N - 85°18'37.41"W	2006

78	21st Street	US	Paso Robles	35°38'10.15"N - 120°41'23.27"W	2010-2011
79	West India Quay	GB	London	51°30'24.03"N - 0°1'21.07"W	1996
80	Ravelijn Bridge	NL	Bergen op Zoom	51°29'54.64"N - 4°17'27.85"E	2013-2014
81	Yongning River Park	CN	Taizhou	28°39'36.51"N - 121°14'53.08"E	2002-2004
82	Landungsbrücken pier	DE	Hamburg	53°32'42.28"N - 9°58'9.48"E	1980?
83	Spree Bathing Ship	DE	Berlin	52°29'52"N - 13°27'13"E	2004
84	Leine Suite	DE	Hannover	52°22'21"N - 09°43'49"E	2009
85	Rhone River Banks	FR	Lyon	45°45'26"N - 04°50'24"E	2004-2007
86	Parque fluvial del Gallego	ES	Zuera	41°51´59"N - 00°47'07"E	2000-2001
87	Rio Besòs River Park	ES	Barcelona	41°25'25.14"N - 2°13'28.84"E	1996-1999
88	Buffalo Bayou Park	US	Houston	29°45'42.10"N - 95°22'55.68"W	2006
89	Parc de la Seille	FR	Metz	49° 6'15.97"N - 6°11'6.91"E	1999
90	Park Van Luna	NL	Heerhugowaard	52°38'21.74"N - 4°47'59.69"E	1997-2003
91	Passeio Atlântico	PT	Porto	41° 9'56.62"N - 8°41'19.25"W	2001-2002
92	Quai des Gondoles	FR	Choisy-le-Roi	48°45'48"N - 02°25'03"E	2009
93	Elster Millraces	DE	Leipzig	51°20'00"N - 12°22'15"E	1996
94	Terreiro do Rato	PT	Covilhã	40°16'39.35"N - 7°30'40.72"W	2003-2004
95	Waterfront promenade	ES	Bilbao	43°15'55.24"N - 2°55'32.76"W	?
96	Tagus Linear Park	PT	Póvoa de Sta. Iria	38°51'42.79"N - 9° 3'7.39"W	2013
97	Elbe promenade	DE	Hamburg	53°32'39.12"N - 9°58'43.62"E	2006-2012
98	Dike of 'Boompjes'	NL	Rotterdam	51°54'51.32"N - 4°29'13.40"E	2000-2001
99	Zona de Banys del Fòrum	ES	Barcelona	41°24'29.36"N - 2°13'34.69"E	2004
100	Molhe da Barra do Douro	PT	Porto	41° 8'49.16"N - 8°40'31.05"W	2004-2007
101	Jack Evans Harbour	AU	Tweed Heads	28°10'7.46"S - 153°32'43.06"E	2011
102	Schevenigen	NL	The Hauge	52° 6'25.53"N - 4°16'14.08"E	2006-2009
103	Sea organ	HR	Zadar	44° 7'2.50"N - 15°13'11.39"E	2005
104	Main riverside	DE	Miltenberg	49°42'12"N - 09°15'26"E	2009
105	Blackpool Seafront	GB	Blackpool	53°48'9.83"N - 3° 3'24.10"W	2002-2008
106	Westhoven	DE	Cologne	50°53'47.95"N - 7° 1'30.11"E	2006
107	Waalkade promenade	NL	Zaltbommel	51°48'53.79"N - 5°14'54.49"E	1998
108	Kampen waterfront	NL	Kampen	52°33'31.88"N - 5°55'1.41"E	2001-2003
109	Landungsbrücken building	DE	Hamburg	53°32'44.14"N - 9°58'2.96"E	2009?
110	Corktown Common	CA	Toronto	43°39'14.60"N - 79°21'6.12"W	2006–2014
111	Westzeedijk	NL	Rotterdam	51°54'36.12"N - 4°28'21.16"E	12th century
112	Anfiteatro Colina de Camões	PT	Coimbra	40°11'49.33"N - 8°26'5.51"W	2008

= project number

* Barcelona is provided with several other similar underground reservoirs with encompassing public spaces in its corresponding aboveground areas. The inclusion of all these reservoirs would therefore provide redundant information in this database. Additional information regarding the other existing reservoirs may be consulted in (Matos Silva 2011).

** Countries acronyms in the location column, presented before the name of the city, follow ISO 3166, which is a standard published by the International Organization for Standardization (ISO) that defines codes for the names of countries. Specifically, the codes used in Table 3.1 correspond to the following countries: AT – Austria; AU – Australia; BE – Belgium; CA – Canada; CN – China; DE – Germany; DK – Denmark; ES – Spain; FR – France; GB – United Kingdom; HR – Croatia; IN – India; KR – South Korea; NL – Netherlands; PT – Portugal; SE – Sweden; SG – Singapore; SI – Slovenia; US – United States.

*** This is the only example, among the presented group, which is still considered as a pilot project.

In several of the presented examples that enabled this analysis, adaptation measures were unrecognized as such. The existing functional qualities of some cases were rather associated to other, more prevailing, conceptual approaches such as sustainability or flood protection. Yet, in light of the findings from chapter one, namely in regards to the concept of adaptation, all presented examples are considered as adaptation measures. Not only do all examples entail the transposition of uncertainty, and its apparent impediments, into public spaces of multifunctional qualities, but also all examples serve as solid grounds for the assessment of adaptation action.

As such, in light of the 112 gathered examples, different categories of flood adaptation measures started to be identified. More specifically, from an empirical analysis, it is possible to organize the aforementioned examples in 16 different categories, namely: A. Urban greenery; B. Urban furniture; C. Rooftop detention; D. Reservoirs; E. Bioretention; F. Permeable paving; G. Infiltration techniques; H. Stream recovery; I. Open drainage systems; J. Floating structures; K. Wet-proof; L. Raised structures; M. Coastal defences; N. Floodwalls; O. Barriers and P. Levees.

Although each presented example may be encompassed within one or more of the highlighted categories of flood adaptation measures, examples were associated to their more prominent category.

3.3.1 Categories of flood adaptation measures applicable in the design of public spaces

For each of the sixteen identified categories of flood adaptation measures, one example from the portfolio screening will be briefly analysed, namely the following:

A. Urban greenery - Caixa Forum plaza, Madrid, Spain;
B. Urban furniture - Jawaharlal Planetarium Park, Karnataka, India;
C. Rooftop detention – Dakpark, Rotterdam, Netherlands;
D. Reservoirs - Escola Industrial, Barcelona, Spain;
E. Bioretention - Parque Oeste, Lisbon, Portugal;
F. Permeable paving - Can Caralleu, Barcelona, Spain;
G. Infiltration techniques - Elmer Avenue, Los Angeles, U.S.;
H. Stream recovery - Cheonggyecheon river, Seoul, South Korea;
I. Open drainage systems - Pier Head, Liverpool, United Kingdom;
J. Floating structures - Yongning River Park, Taizhou, China;
K. Wet-proof - Rio Besòs River Park, Barcelona, Spain;
L. Raised structures - Elster millstream, Leipzig, Germany;
M. Coastal defences - Molhe da Barra do Douro, Porto, Portugal;
N. Floodwalls - Blackpool seafront, Blackpool, United Kingdom;
O. Barriers- Kampen waterfront, Kampen, Netherlands;
P. Levees - Corktown Common, Toronto, Canada

A. *Urban greenery*

- Example 'Project name': Caixa Forum plaza
- Example number #: 1
- Location: Madrid, Spain
- Coordinates: 40°24'39.43"N - 3°41'35.36"W
- Construction date: 2006
- Design: Patrick Blanc
- More information: www.verticalgardenpatrickblanc.com

Figure 3.5 - Green facade at the Caixa Forum plaza, Madrid, Spain. Image credits: Maria Matos Silva, 2014.

One of the façades of the entrance plaza of the Madrid Caixa Forum is a green wall implemented in 2006. It is four storeys high and it includes over 15000 plants from 250 different species.

This "living wall" not only contributes to the climatic amenity of the adjacent plaza but also to the reduction of the heat island effect, which is particularly present in a city such as Madrid that is warmed by continuous sun in the summer. Its capacity to harvest rain water also contributes to the amelioration of floods while the diversity of plant species constitutes an oasis for several types of birds and other animals.

Besides the environmental benefits, the design of the green wall may have additional aesthetic characteristics, particularly if considering it as an art project. In this example, designed by Patrick Blanc, one can identify a studied pattern of colours and textures that combine art, architecture and botany. For all these reasons, this plaza, highlighted by this wall, has currently become another drawing card in the heart of the Madrid's cultural district already surrounded by famous museums.

Among the many other examples of public spaces with greenery, such as roads with tree alignments or small neighbourhood gardens, one may further highlight the public spaces next to the green walls of Musee du quai Branly in Paris or the Rubens Hotel in Victoria, London, for their generous expression.

B. *Urban furniture*

- Example 'Project name': Jawaharlal Planetarium Park
- Example number #: 6
- Location: Karnataka, India
- Coordinates: 12°59'3.93"N - 77°35'23.74"E
- Construction date: 2013
- Design: Vinod Heera Lal Eshwer
- More information: (Mital 2013)

Together with the McCann Company that funded this initiative, Vinod Heera Lal Eshwer built a permanent art installation at Jawaharlal Nehru Planetarium Park in India, in order to raise awareness on the process of collecting rainwater by making it visible (Mital 2013).

Figure 3.6 - Permanent rainwater catching installation at Jawaharlal Planetarium Park in India. Image credits: © Shreya Pareek, 2013.

Located at the centre of the children's park, this simple object clarifies the process of rainwater harvesting that is sometimes understood as a complicated term for the younger generations.

When it rains, a large funnel collects water into a see-through rectangular-shaped tack. Inside the tack there are some fish swimming, further recalling how life may be sustained by harvesting rain-water.

Visibly highlighted, the headline "catchtherain.org" is written in the tank. With this information, one may connect to a website with further information, namely a video and a free game for children, which reinforce the importance of collecting rainwater.

Other examples of urban furniture applied in a public space, which besides fulfilling its main purpose of communication or utility also contribute to flood adaptation, include, for instance, the inverted umbrella implemented in Woolworths Shopping playground in Walkerville, Australia.

C. *Rooftop detention*

- Example 'Project name': Dakpark
- Example number #: 9
- Location: Rotterdam, Netherlands
- Coordinates: 51°54'31.25"N - 4°26'17.00"E
- Construction date: 2009 - 2014
- Design: Buro Sant en Co
- More information: www.santenco.nl

Figure 3.7 - Prespective of the Dakpark. Image credits: © Buro Sant en Co, 2014.

Dakpark is a roof park not far from the centre of Rotterdam. The project programme consisted on building a dike in the so called Four Harbours strip that would also integrate offices, shops, schools and a public park. While the services were designed for the lower ground, the public park was planned as the roof of the whole structure. This project is thus representative of what it is meant by intensive spatial use or multiple ground use. Also fulfilling the function of a multifunctional dike, this roof park has a higher side that is around 8 meters above the ground level. The design further divides the park into two other intermediate levels. At its centre, there is a generous stairway, which connects the high and the low levels, with a particular stairway-water design.

Among the project's limitations are the constructional requirements associated to a green area being implemented over a roof and the attention that must be given to tree planting location or roof waterproofing, among others. Another limitation is the safety concern related with its height. In accordance, the park encompasses a physical boundary of fences and gates, and is closed off between sunset and sunrise.

Other examples of public spaces that encompass rooftop detention as a flood adaptation category, namely include the Promenade Plantée in Paris, France or the Stephen Epler Hall in Portland, U.S.

D. Reservoirs

- Example ‘Project name’: Escola Industrial
- Example number #: 21
- Location: Barcelona, Spain
- Coordinates: 41°23'13.77"N, 2° 8'53.20"E
- Construction date: 1999
- Design: CLABSA – Clavegueram de Barcelona, S.A.
- More information: (CLABSA)

Figure 3.8 - Detail of the football filed area above the underground reservoir at Escola Industrial, Barcelona. Note the presence of the grey chimneys part of the reservoir’s ventilation system. Image credits: Maria Matos Silva, 2011.

This underground reservoir is situated on the intersection of Viladomat and Rosselló streets, underneath the football field of the Escola Industrial de Barcelona. According to CLABSA’s records, the reservoir has a total capacity of 27.000 m3, which is equivalent to ten Olympic swimming pools. Over the reservoir, a football field was installed covering more or less the same surface area of 94 by 54 meters with artificial grass. Among the infrastructural requirements, which needed to be included within the aboveground public space, are a ventilation system, an entrance to the machinery and control room and the necessary expansion joints. In this case, the ventilation system comprised chimneys, expansion joints where camouflaged below the grass and the entrance to the control room was made in connection to Carrer Rosselló. In this particular example, the entrance further included placards with detailed information about the technical characteristics of the reservoir as well as tri-dimensional schemes of its structure and integration with public space.

As previously mentioned, other reservoirs were implemented throughout Barcelona, such as the cases of the reservoirs at Joan Miró Park, Bori I Fontestà garden, Doctors Dolsa plaza, among others. All of which entail the common characteristic of including a certain type of public space over it, and thus conferring to this infrastructure the benefit of encompassing additional purposes such as plazas, parking lots or gardens besides sports fields.

E. Bioretention

- Example 'Project name': Parque Oeste
- Example number #: 28
- Location: Alta de Lisboa, Lisbon, Portugal
- Coordinates: 38°46'46.53''N - 9°9'13.40''W
- Construction date: 2005 - 2007
- Design: Isabel Aguirre de Urcola
- More information: sgal.altadelisboa.com

Figure 3.9 - Parque Oeste / Oeste Park, Alta de Lisboa, Portugal. Image credits: Maria Matos Silva, 2014.

The new urban development of Alta de Lisboa neighbourhood is bound by Parque Oeste (West Park). This urban park comprises a wet retention basin that, given the known lack of capacity of the downstream drainage network, essentially serves to regulate the increased amounts of superficial rain water flows from the newly constructed developments. Besides the potential to store significant amounts of rain water, this system also controls and reduces the velocity of the upstream flow, minimizing the influx at critical points. If provided with appropriate vegetation, the marginal areas of the basin would additionally serve for water purification.

The retention basin of Parque Oeste comprises a lake with 17.500 m2 of maximum water surface. The limits of the lake consist of small "beaches" of grass or sand, concrete walls or gabions. From what it is known, no water is reused from the retention lakes. Up until know it could be said that it is a park with a very low affluence of users. However, this fact is more likely related with the complexities evolving other urban matters (particularly social matters and the uncompleted neighbourhood construction) than to the design of the park itself.

Other examples that comprise the Bioretention category of flood adaptation measures include the bioswales at Elmhurst parking lot in New York, U.S. or the rain gardens at the Edinburgh Gardens in Melbourne, Australia, among others.

F. *Permeable paving*

- Example 'Project name': Can Caralleu
- Example number #: 48
- Location: Barcelona, Spain
- Coordinates: 41°24'3.81"N - 2°6'48.02"E
- Construction date: 2006
- Design: Bagursa, Barcelona Gestió Urbanística. Sector Urbanisme
- More information: (Vidiella and Zamora 2011)

Figure 3.10 - Detail of Can Caralleu Parking lot and street. Different pavements were used. Almost half of the total area of intervention includes permeable pavement. Source: (Vidiella and Zamora 2011, p.160).

This project essentially consists on the enlargement of Carrer Major de Can Caralleu, turning a two-way road into a street with two downhill lanes and one uphill lane. Among its characterizing aspects are its situation of topographical asymmetry (steep road and bottom plain basin) and the use of permeable pavement as a design tool. More specifically, two types of porous pavement were used: grass, which naturally promotes the micro harvest, retention and infiltration of rainwaters; and gravel reinforced with recycled plastic cells over sub-layers with different sizes of aggregates. The lower areas of the pavement function both as a parking lot and as rainwater retention areas collected through the permeable pavement's porosity. Under the parking area, in its lowest point, a cistern was additionally included. As the spillage risk of oils is high in parking lot areas due to the fact that vehicles may remain still for long periods of time, the proposed design furthermore works as an intermittent purifying filter based on the rain patters. Overall, the permeable area corresponds to around 45% of the total area (4.062.30m2) while the impermeable area corresponds to around 55% (5.021.70 m2) (Vidiella and Zamora 2011).

There are many other examples of public spaces that encompass permeable paving; among the examples highlighted in this research's portfolio screening, one may mention the Greenfield Elementary in Philadelphia, U.S. or Praça do Comérico in Lisbon, Portugal.

G. *Infiltration techniques*

- Example ‘Project name’: Elmer Avenue neighbourhood
- Example number #: 57
- Location: Los Angeles, United States
- Coordinates: 34°12'39.39"N - 118°22'36.70"W
- Construction date: 2010
- Design: Stivers & Associates, Inc.
- More information: (Robinson and Hopton 2011)

Figure 3.11 - Elmer Avenue after retrofit with bioswales, native plants and trees, and grand infiltration trench bellow the centre of the avenue. Image credits: Council for Watershed Health, 2011.

As part of Los Angeles Basin Water Augmentation Study (WAS) initiated in 2000, Elmer Avenue Neighbourhood was selected as demonstration project in order to test and monitor state-of-the-art of Sustainable Urban Drainage Systems (SUDS). Among the implemented measures along the sidewalks and private residential gardens are: bioswales, permeable paving surfaces (including permeable concrete and permeable pavers), rain barrels and high-efficiency drip irrigation. Yet the most distinguishing feature of this project is the underground infiltration gallery below Elmer Avenue that is capable of capturing 750,000 gallons of runoff (Robinson and Hopton 2011). This project regenerated an important avenue of a neighbourhood that initially had no flood management infrastructure and was thus vulnerable to recurrent flooding. Now, through an intervention area of 1.6 hectares, this projected started to manage the first flush rainwaters from the surrounding 16.2 hectare-area. Through this public space retrofit the aesthetic qualities of the street improved, increasing resident satisfaction with their block’s walkability from less than 2% of survey respondents in 2006 to 92% in 2011 (Belden and Morris 2011). Moreover, through workshops, meetings, volunteer events and maintenance manuals, participation and project ownership was promoted. Other examples of public spaces that have incorporated infiltration techniques include, among others, Etna Butler Street in Pittsburgh, U.S. or Community College in Philadelphia, U.S.

H. Stream recovery

- Example 'Project name': Cheonggyecheon river
- Example number #: 68
- Location: Seoul, South Korea
- Coordinates: 37°34'10.73"N - 127° 0'14.32"E
- Construction date: 2003-2005
- Design: Seoul City Government
- More information: (Kwon 2007, Novotny et al. 2010)

Figure 3.12 - Cheonggyecheon river promenade, Seoul, South Korea. Image credits: © riNux, 2005.

For over three decades, Cheonggyecheon river was confined underground, over which passed a multi-lane roadway and an elevated highway. By the year 2000, strong structural fragilities of the speedway viaduct were identified. The costs for its recovery were considerable and as such Seoul City Government reasoned the alternatives. In a political venture, the mayor Lee Myung-bak proposed not to invest in the renovation of the traffic infrastructure but rather on the restoration of the river's flow. In two years, the river was exposed and turned into a 5.8 km of linear park which now crosses the city centre. Among the resulting benefits is the improved capacity to sustain a flow rate of 118mm/hr and flood protection for up to a 200-year flood event (Kwon 2007).

What was formerly a source of congestion, pollution and aridity is now a blooming and environmentally healthy public space. Today, Cheonggyecheon river is a very popular park among the city residents, with clean water where people can swim and more than a few natural habitats. Sites of historic and cultural significance were also renewed, further contributing to a rehabilitated social identity.

Other public spaces that have resulted from stream recovery projects include: Kallang River at Bishan Park, Singapure; Ribeira das Jardas at Sintra, Portugal; Catharina Amalia Park at Apeldoorn, Netherlands; amongst others.

I. Open drainage systems

- Example ‘Project name’: Pier Head
- Example number #: 74
- Location: Liverpool, United Kingdom
- Coordinates: 53°24'14.47"N - 2°59'47.09"W
- Construction date: 2009
- Design: AECOM Design + Planning
- More information: (AECOM 2016).

Figure 3.13 - Extended channel at Pier Head, Liverpool. Image credits: © AECOM Photography, 2010.

Pier Head is very important to Liverpool’s sense of identity. In light of its status as a World Heritage Site and under the opportunity of Liverpool’s 2008 European Capital of Culture, Pier Head embarked on an ambitious programme to renew and regenerate its public space. More specifically, the central docks and the area in front of the Three Graces historic waterside buildings. Together with Liverpool Vision, AECOM coordinated the regeneration master plan, which encompassed the new landmark Museum of Liverpool Life, as well as a mixed-use development of homes, shops and offices along with a remodelling of Mersey ferry terminal (AECOM 2016). Yet the main focus of this prominent project was the creation of a channel extension linking the Leeds and Liverpool Canal to the north with dockland water basins adjacent to King's Waterfront to the south. It is the first major canal extension in the UK in a generation, with 650 meters in length (Landscape Institute 2014). With the Three Graces as a background, this 2.5 hectare public plaza facing the River Mersey combined sunken water basins with open-air amphitheatres for cultural events. This public space was further designed to achieve a long life through the selection of robust materials and careful detailing.

Other examples of public spaces that contain open drainage systems as a category of flood adaptation measures include, for instance, the 13th century channels of Freiburg Bächle in Germany or the public spaces of Banyoles in Girona, Spain.

J. Floating structures

- Example 'Project name': Yongning River Park
- Example number #: 81
- Location: Taizhou, China
- Coordinates: 28°39'36.51"N - 121°14'53.08"E
- Construction date: 2002 - 2004
- Design: Turenscape
- More information: www.turenscape.com

Figure 3.14 - The floating square over the wetland of Yongning River enables the fruition of the site during the flood season. Image credits: Courtesy of Kongjian Yu/Turenscape.

Before 2002, the riverbanks of the Yongning River were made of concrete. In order to further control flood and storm waters, the idea to completely channelize the river was under progress. Yet the local authority was persuaded by the proposition of a less costly and equally effective solution. The alternative solution comprised an ecologically sane while culturally and historically rich urban tidal park.

With the purpose of meeting the mentioned objectives, this project aimed at the confluence of two main systems: the ecological system that can serve floods and wildlife, and the social system of public spaces that can serve people and tourists. While the ecological system essentially comprises the wetland and its inherent natural characteristics, in the social system the concept of floating structure emerged. While the ground layer is frequently flooded for the benefit of its natural habitats and vegetation, the floating "human layer" is composed of a path network that extends from the urban fabric down towards the park and a matrix of squares and groves of native trees. The enjoyment of this site is now available all year round through the use of floating structures, which further allow visitors to fully acknowledge the surrounding natural processes of seasonal flooding without compromising their safety.

Other examples of public spaces in floating structures include swimming pools, kiosks, sports fields or bridges, namely the pedestrian bridge at the London Docks, connecting Canary Wharf with West India.

K. Wet-proof

- Example 'Project name': Rio Besòs River Park
- Example number #: 87
- Location: Barcelona, Spain
- Coordinates: 41°25'25.14"N - 2°13'28.84"E
- Construction date: 1996 - 1999
- Design: Consortium for the Defense of the river Besòs, Barcelona City Council, City of Santa Coloma de Gramanet, Council of Sant Adrià del Besòs, City of Moncada i Reixac
- More information: (Margolis and Robinson 2007, Santacruz 2012)

Figure 3.15 - Besòs River Park. Image credits: Maria Matos Silva, 2011.

Rio Besòs River Park is located along the last five kilometres of the Besòs River before it reaches the Mediterranean Sea. It is one of the two rivers that bounds Barcelona Metropolitan area, Lobregat River in the south-west and Besòs River to the northeast. Under the influence of a torrential rain pattern, characteristic of Mediterranean areas, water flows in Besòs River typically shift from being reduced in the dry season into raging torrents in the rainy season.

After the severe floods of 1962, which caused around 800 casualties and widespread property damage (Margolis and Robinson 2007), the river's walls were reinforced up to a 4m height with concrete walls. Although such an approach was considered as the most effective flood control response, it reinforced this area as an unattractive space which became gradually neglected and environmentally deteriorated.

In 1996 the European Union sponsored the rehabilitation of the River Besòs margins, subsidizing 80% of the project's value under the Cohesion Fund. By this time the river was considered one of the most polluted in Europe (Margolis and Robinson 2007). The project for the Besòs River Park was developed by the Consortium for the defence of Besòs river basin, formed by a collaborative process that evolved government and citizen groups as well as inter-municipal cooperation agreements.

Overall, the project recognized that the future urbanistic and ecological success of the river and its margins depended on the active use and care of its neighbours. As such, besides the objectives to improve wastewater treatment through the implementation of wetlands and to expand the hydraulic capacity of the river, it further entailed the creation of wet-proof public spaces for leisure and recreation alongside the river's margins.

During severe rain events, stormwater may rise up the channel walls and flood the park areas. In order to allow users a safe access to the flood prone margins within the river channel, electronic placards were placed in the park's entrances. In accordance with the variation and severity of the stream flows, which is monitored through data collected by river-wide sensors, satellite and weather radar information, as well as river footage of the river-banks, this system of placards serves to inform potential users if they can or cannot enter the park. If the situation is particularly dangerous, sirens and loudspeakers are also used. It is a particularly efficient communication system as it is able to rapidly inform sudden and intense flood surges (Prominski et al. 2012).

In order to manage runoff flows, the innovative solution of inflatable dams were also implemented throughout the course of Besòs River. This flexible infrastructure is able to rapidly inflate in order to detain water and, also in a matter of minutes, deflate in order to release water. This type of technology is particularly adequate for small to medium sized streams and are suitable for a wide range of purposes, from groundwater recharge to tidal barriers and recreation.

Other examples of "wet-proof" public spaces include, among others, Passeio Atlântico at Porto, Portugal; Buffalo Bayou Park at Houston, US; or Parc de la Seille at Metz, France.

L. Raised structures

- Example 'Project name': Elster millstream
- Example number #: 93
- Location: Leipzig, Germany
- Coordinates: 51°20'00''N - 12°22'15''E
- Construction date: 1996
- Initiative: 'Neue Ufer' ('New Shores')
- More information: (Prominski et al. 2012)

Figure 3.16 -Uncovered Elster millstream with suspended pathways along its course. Image credits: © Gabriele Seelemann, 2004.

In the sixties, Elster Millrace was conveyed underground, stripping the city of Leipzig from its former urban landscape of squares, pathways and homes by the riverside. Although the revitalization projects for the Elster millstream, as well as for the Pleiße millstream, were initiated in 1991, the continuation of the works along the years that followed were greatly instigated by the "Neue Ufer" (New Shores) initiative funded in 1996. Since 1996, it was possible to uncover around 1.200m of stream (Neue Ufer 2013). Financial sources that allowed the regeneration project to be developed included fund raising, donations, flood water protection resources, the city of Leipzig as well as financial corporations through town planning contracts with neighbours and adjacent owners of the river (Seelemann 2015). Throughout the millstream, some areas were completely redesigned while in other areas a complete intervention was constrained by the availability of space, namely along the busy roads previously implemented over the vault of the culverted course (Prominski et al. 2012). In these situations, contemporary materials and knowhow was used in order to provide raised structures, such as cantilevered pathways, floating piers, amongst others. In these, more limited, interventions along millstream, the regeneration project had little ecological recovery, yet it greatly improved the surrounding urban spaces. Other examples of public spaces that have included raised structures within their design include Terreiro do Rato in Covilhã, Portugal or the waterfront promenade at Bilbao, Spain.

M. Coastal defences

- Example 'Project name': Molhe da Barra do Douro
- Example number #: 100
- Location: Porto, Portugal
- Coordinates: 41° 8'49.16"N - 8°40'31.05"W
- Construction date: 2004-2007
- Design: Carlos Prata Arquitecto and Fernando Silveira Ramos
- More information: www.carlosprata.com

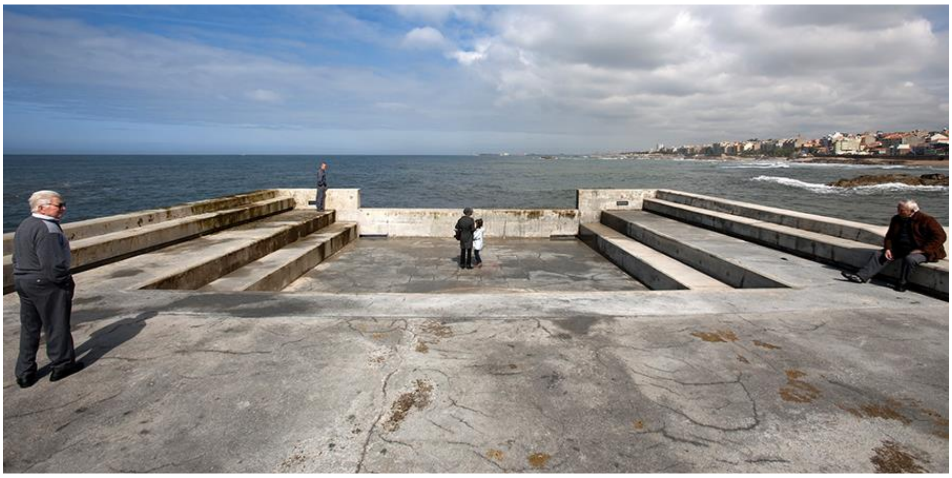


Figure 3.17 - Plaza viewpoint at Molhe da Barra do Douro, Passeiro Alegre, Porto, Portugal. Image credits: © João Ferrand, 2005.

The primer purpose of this project, located at the north side of Douro's river mouth, encompassed the need to ensure navigation safety conditions in the entrance of the river. Conventionally, the programme to build a jetty of considerable dimensions would have been undertaken solely by engineers, with a very specialized perspective on marine dynamics, coastal protection and navigability. Yet this project entailed further ambitions, namely the goal to integrate the necessary infrastructure as a constituent part of the "urban realm", as in public space that is owned and controlled by the city.

With a built area of 9000m2, this linear corridor extends more than 600m into the ocean. Pedestrians may stroll through the infrastructure, both above ground or through an interior gallery that was envisioned to function as a restaurant and a passageway to the lighthouse in days of storms. Different situations mark this public space along its length, enhancing the experience of new views that connect the city to its sea. It is a living and lived in space, highly dependable on the dynamics of waters and used by people in multiple and reinvented ways.

Other projects that integrate costal defence infrastructure with public space design include, among others, the Zona de Banys del Fòrum in Barcelona, Spain or Jack Evans Harbour at Tweed Heads, Australia.

N. Floodwalls

- Example 'Project name': Blackpool seafront
- Example number #: 105
- Location: Blackpool, United Kingdom
- Coordinates: 53°48'9.83"N - 3° 3'24.10"W
- Construction date: 2002-2008
- Design: AECOM / Jerde Partnership
- More information: (AECOM 2011)

Figure 3.18 - Coastal defence in Blackpool, UK. Image credits: © AECOM Photography by Dixi Carillo, 2008.

Before this contemporary intervention, Blackpool seafront was composed by traditional defensive coastal infrastructure such as steep embankments and tall vertical walls. Connections to the Sea or entrances to the beach were very few and made out of narrow and precipitous stairways.

The Blackpool Promenade project regenerated this seafront with the multipurpose to respond to the threats of sea level rise and more frequent and extreme storm surges, and to provide an extended and improved waterfront public space. Reinventing the traditional concept of floodwall, this eight hectare project integrates infrastructure and art while connecting people throughout and across the designed space. In a design that conceptually attempts to mimic nature through its undulating form, concrete stairs separate the town from the water and fulfil the apparently contradictory goals to protect and connect people with water.

Other representative examples of public spaces with reinvented floodwalls, include the cases of Main riverside in Miltenberg, Germany or the case of Westhoven in Cologne, Germany.

O. Barriers

- Example 'Project name': Kampen waterfront
- Example number #: 108
- Location: Kampen, Netherlands
- Coordinates: 52°33'31.88"N - 5°55'1.41"E
- Construction date: 2001-2003
- Planning and construction: City of Kampen
- More information: (Prominski et al. 2012, Voorendt 2015).

Figure 3.19 - Pulled down flood gate crossing a small street to be raised vertically when needed. Image credits: © Mark Z. Voorendt, 2015.

Kampen city, located at the lower reaches of the river IJssel, is an old Hanseatic city in Dutch province of Overijssel. In Kampen, the combination of strong winds and flood waters flowing downstream, can make the sea level rise up to 3 m in just three hours (Prominski et al. 2012). In order to protect the town from flooding and, at the same time, maintain the city's traditional character, various measures have been implemented, integrating flood defence with other purposes. For example, in order to provide extra height, "stoplogs" were integrated in the existing quay wall. The historic city wall, as well as several private gardens and buildings, were also improved with additional demountable barriers (Voorendt 2015). In an emergency setting barriers are raised and gates are closed, namely with mobile aluminium elements. These elements are stored in a large warehouse and can be totally installed by a 200-person-strong floodwater team (reserved members included) within three hours (Prominski et al. 2012). In some situations, the flood defence line crosses small streets or bigger roads. Overall, Kampen's flood defence strategy comprises public spaces that additionally integrate the functions of transport, parking, and historical preservation, among others.

Other examples of Barriers applied within public spaces, specifically demountable barriers, may be seen in the Waalkade promenade in Zaltbommel, Netherlands, or in the doors of Landungsbrücken building in Hamburg, Germany.

P. Levees

- Example 'Project name': Corktown Common
- Example number #: 110
- Location: Toronto, Canada
- Coordinates: 43°39'14.60"N - 79°21'6.12"W
- Construction date: 2006–2014
- Design: Michael van Valkenburgh Associates
- More information: (WATERFRONToronto 2009, mvvainc 2012)

Figure 3.20 - Detail of the levee at Corktown Common Park in Toronto, Canada. Image credits: © Dushanj, 2013.

Corktown Common is a 6.5 hectare park in a post-industrial area left as a brownfield. Located in the West Don Lands district of Toronto, this park currently offers a wildlife-filled marsh, athletic fields, playgrounds and a generous area of open lawns (WATERFRONToronto 2009). Yet this park is also a flood defence infrastructure. Designed by Michael van Valkenburgh Associates partnered with Arup, the Corktown Common Park not only serves residents across Toronto but also encompasses a levee whose structure is hardly distinguishable. According to the designers, the levee embedded within the park is robust enough to protect vulnerable areas against a 500 year flood (mvvainc 2012).

Placed over gentle slope banks, this levee-park protects the new West Don Lands community from flooding, including Toronto's financial district. Albeit it is a constructed landscape, it is a particularly ecological one, with a great number of native trees and scrubs, an extensive marsh with developing and enriching biodiversity, among others. This project further stands out for its flood management approach, which enables the collection and treatment of rainwater within the constructed marsh, subsequently storing it for irrigation (mvvainc 2012).

Other examples of public spaces integrated within levees are particularly common in countries such as the Netherlands.

3.3.2 Potential advantages of applying flood adaptation measures in the design of public spaces

In light of the identified examples in Table 3.1, including the examples previously illustrated, the following analysis focuses upon the identification of the particular benefits offered by pubic space itself on the way towards more adapted cities. In other words, a range of common characteristics that evidence how public spaces may offer particular advantages for the application of flood adaptation measures, is subsequently emphasized.

Among the distinguishable characteristics present within the range of aforementioned examples, potential benefits may specifically arise by 1) public spaces favouring interdisciplinary design, 2) by the possibility of public spaces to embrace multiple purposes, 3) by how community engagement and interaction may be promoted through the design of public spaces, 4) by public spaces being comprehended within extensive physical structure, 5) by the possibility to expose and share value through public space and 6) by the opportunity to diversify and monitor flood risk through public spaces.

Each of these features will be scrutinized in the following pages and further reinforced by the association with additional identified cases from the portfolio screening.

Interdisciplinary design

Acknowledging that public space "is of everyone", its design is therefore "not a matter of one sole profession, entity or interest group" (Brandão(Coord.) et al. 2002, p.19, author's translation). Likewise, Madaninpour argues that public spaces should be created by different professionals from different disciplines of the built, natural and social environments or by any professional with multi-disciplinary concerns and awareness (Madanipour 1997[1972]). As Lefébvre acutely states, "ultimate illusion: to consider the architects, urbanists or urban planners as experts in space, the greatest judges of spatiality..."[43] (in Brandão 2013, p.30, author's translation).

Recalling Horacio Capel's argument, since the nineteenth century, the subject of urbanism has been excessively controlled by a fierce competition between engineers on the one side and architects on the other. While the first would define and design major infrastructures, the

[43] Original text: "*Suprême illusion: considerer les architectes, urbanistes ou planificateurs comme experts en espace, juges suprêmes de la spatialité…*"

latter would define and design interventions in streets, buildings or green areas. However, as the author highlights, "all this should be at the service of social needs" (Capel 2005, p.92, author's translation). In other words, all urban endeavours should firstly account for people and communities, and if necessary, should be able to surpass professional interests and the limitations of specialized expertise.

Back in the 1870s, Frederick Law Olmsted designed Boston´s Emerald Necklace (#30)[44] with the goal to resolve engineering problems of drainage and flood control together with the fulfilment of the increasing social needs for leisure and recreation opportunities in a growing population. Simply put, Olmsted demonstrated that it was possible to integrate complex connections between natural and technical processes together with and improvement on the quality of life of the surrounding populations. For Cynthia Zaitzevsky "Olmsted foresaw that such a comprehensive approach embraced planning, engineering and architecture and that, to bring the disciplines together to create the best solution, needed the unifying instincts of the new profession of landscape architecture" (2001, p.43). Today, Emerald Necklace parks include land and water features, engineering structures, public buildings and ecological designs that are merged together in a rational and balanced design.

From the Barcelona Model, further examples of interdisciplinary public space designs emerged. As previously mentioned, it was likely due to Barcelona's urban regeneration grounding ideals from the 80's that, in the beginning of the twenty first century, the city decided to integrate the infrastructural construction of underground reservoirs underneath different types of public spaces (#20, #21). An interdisciplinary approach that required for multiple professional areas to share their expertise throughout all procedural planning stages. By contrast, other municipalities have chosen to solely focus on one technical discipline. As a result, similar infrastructures were designed as isolated monofunctional facilities fenced from its surroundings (Matos Silva 2011). Through Barcelona's integrated approach it was further possible to enclose parallel advantages from a grand urban intervention, namely the creation of more public spaces. Putting it simply, Barcelona turned the constraint of a required great drainage improvement into the opportunity to build more public spaces for its citizens and all its potential succeeding side-benefits.

[44] Henceforth, the mentioned examples will be additionally identified with their corresponding number presented in Table X in order to facilitate the access to further information. Emerald Necklace, for example, is number 30 and so it is identified within the text by #30.

Other successful public space, particularly known for its interdisciplinary design that further entailed multiple purposes, is Postdamer Platz in Berlin (#22) (Figure 3.21). Situated in an important area of the city, near the Berliner Philharmonie and the Berlin State Library, Postdamer Platz has an approximate area of 1.2 hectares. Its design, composed of a series of urban pools, revels an integrated approach between ecological, aesthetical and civil-engineering functions. The large water features are feed uniquely by rainwater. In summer, water surfaces lower the ambient temperature and improve microclimates. Roofs from the surrounding buildings capture rainwater and store it in underground cisterns. The collected water is then used for topping up the pools, flushing toilets and for irrigating green areas (Pötz and Bleuzé 2012).

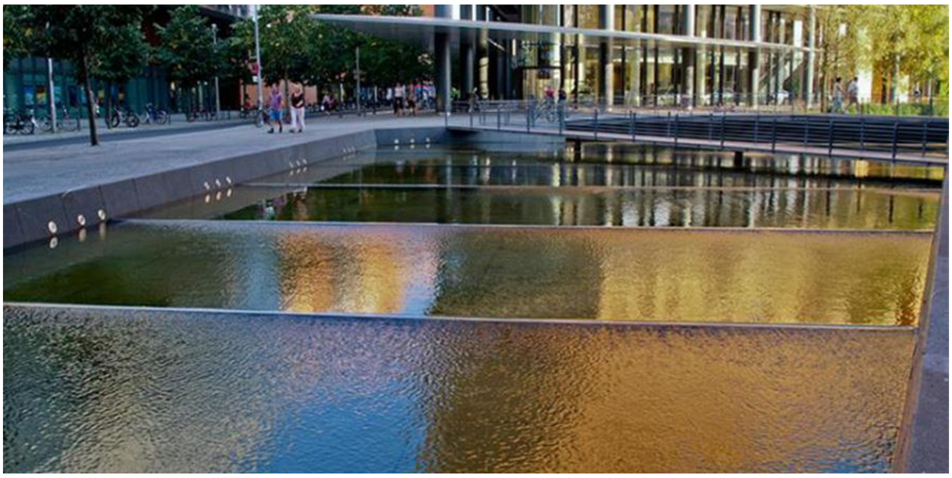


Figure 3.21 - Detail of the Postdamer Platz in Berlin. Image credits: Dreiseitl, 1998.

One can further evidence a growing tendency for interdisciplinary design, specifically when interventions consider the need for climate change adaptation. One of the most recent examples of urban realm to have been created in light of the disseminated projections is the Olympic Park (#75), more precisely "Queen Elizabeth Olympic Park" in London (Figure 3.22). In accordance, the Park's landscape design priorities included "Great amenity; Improved micro-climate; Biodiversity; Integrated water management; Energy generation; Resource management; Waste management and minimization; Local food production; …" (LLDC 2016, p.1), among others. Priorities which involved the inclusion of additional and uncommon disciplines actively involved in the design process.

Solutions arising from interdisciplinary designs are very diverse and combine the use of a wide range of approaches such as technical, social, economic, ecological, among others. With regards to adaptation there is much we can learn from our civilizational past, which has surpassed other great turbulences. We must also humbly accept that the impending future will require new outsets and new paradigms. New ideas that will most likely arise from a common effort of multiple, shared and applied expertise. Public spaces, as spaces that particularly favour interdisciplinary convergence, may serve to promote and explore technological reinventions or innovations. A continuing learning process that, in face of climate change, searches for new design solutions that increase adaptability and reduce vulnerability.

Figure 3.22 - Olympic Park, London. Image credits: © sbally1, 2012.

Public spaces of multiple purposes

The resulting combination of an interdisciplinary design that integrates flood adaptation functions with public space design, generally offers many side purposes among other sectorial needs such as recreation, microclimatic melioration or energy use and efficiency. Likely, the more interdisciplinary the design is, the more adjacent functions the resulting public space will comprise.

Traditional drainage infrastructure for instance, such as large scale underground retention chambers disconnected from public space, is only useful in certain ocassional times during the year, namely during heavy rainfall. In contrast, other source control measures, such as green walls, bioretention basins or rain gardens, when applied within public spaces, may not only serve its prime infrastructural function, but may also serve to improve local environment and quality of life as well as vulnerability reduction and local awareness. The side benefits that result from reconfiguring drainage infrastructure within public space design thus generally gathers recurring advantages all year long.

“The Circle”, in Roundabout at Uptown Normal, Illinois (#26) is an example that may evidence this argument. It is a green water square in a roundabout that collects, stores and purifies stormwater runoff from the nearby streets. Besides the aesthetical and leisure characteristics, the water feature serves to mask surrounding traffic noise, while purified water is used to spray nearby streets and thus lessen heat stress (Pötz and Bleuzé 2012). The square further serves as a meeting place situated near a multimodal transportation centre and a children’s museum (Figure 3.23).

Figure 3.23 - Detail of ‘the Circle’: a Roundabout at Uptown Normal, Illinois. Image credits: © Hoerr Schaudt.

The ‘Queen Elizabeth Olympic Park’ in London as previously mentioned, is one other example of an interdisciplinary design that consequently embraced multiple purposes. That is namely the case of the included treatment process that turn Londoner's wastewater from an outfall sewer into water suitable for irrigation, flushing toilets and as a coolant in the Park's energy centre (EEA 2012).

Community engagement

Community engagement is a particularly important factor in the success of adaptation endeavours, namely when acknowledging that adaptation is a learning process of continued assessment. Moreover, it is here argued that community engagement may be reached through community involvement, emotional connection and a design that makes visible the invisible. When adaptation actions are applied within a public space, where design can make visible certain intangibles, endeavours are no longer an abstract phenomenon for people and communities. Community engagement practices in public space design and management gain, therefore, a new dimension.

Considering flood events, which are expected to increase in light of future climatic extremes, the roughly intangible water cycle can be made visible through design. Particularly through the design of public spaces that, in light of their inherent values, provide the opportunity to approximate and connect people with water and thus potentially raise awareness and overall engagement.

The Benthemplein square (#18) and Tanner Springs Park (#19) may serve as examples that corroborate the argument that public spaces are rarely "mute" and may serve to connect people with water. Both cases encompass the concept of a "water plaza" that intentionally unveils part of the urban water cycle dynamics for the citizens that use that public space. As mentioned in the Rotterdam Climate Proof report "Water disarms and binds people. In adaptation projects in the city, citizens and different cultures come together. This can reinforce social ties and the sense of safety" (2009, p.7).

Specifically in regards to the case of Tanner Springs Park in Portland, its design comprised the restoration of a wetland into the setting of an urban context (Figure 3.24). Inspired by the area's original natural state, the park is composed of a pond at its lowest point, to which rainwater from the surroundings is conveyed. The design therefore combined several objectives among the fields of ecology, water management, art and participation. Some of its main characteristics include reintroduced groundwater, water features, appropriate vegetation and site-specific artwork that evidences the biological beings from the former wetland.

Figure 3.24 - Tanner Springs Park. Image credits: © Graham Ballantyne, 2011.

In order to promote community engagement it is further important to highlight the need to create places that people can value and connect emotionally too. Likewise, the success of community engagement processes is strongly related with the development and value of local identity. In this sense, the presence of water in urban design, and more specifically in the design of public spaces, has particular symbolic dimensions (emotional, aesthetic, and cultural) that should not be overlooked.

One of the oldest representations of water is Genesis' description of the Garden of Eden and its four structuring rivers that give life to this mythical space (Bíblia Sagrada 1991, Gn 2:10–14). Yet, as we are all aware of, water is not only the source of life but it is also a permanent treat. And so the fear of water is also tattooed in our civilizations worldwide. Genesis's flood narrative in the Bible is one of many flood myths found in our cultures.

Water's symbolic dimensions should therefore be enhanced in a public space design that aims to connect people with water. This exercise is particularly evident in the works of Atelier Dreiseitl, here represented by the examples #19, #22, #49, #61, #64, #73 and #76 of Table 3.1. Atelier Dreiseitl is an office that refuses to use water for pure decoration. Through its designs, it rather advocates for water to be integrated with other systems and other functions, always bearing in mind the final purpose of aesthetic appreciation and public perception of the value of water as a resource.

Another way to promote community engagement on the urging need to adapt our urban spaces in the face of climate change is through direct community involvement and interaction. Specifically because adaptation is not one in a lifetime project. On the contrary, adaptation processes and projects require ongoing collaborations and organization between and among government, institutions and its citizens.

Greenfield Elementary in Philadelphia (#54) is a good example of the fruitful results that may arise from collaborative design among stakeholders. More specifically, parents, teachers, students, school administrators, designers from Community Design Collaborative and the Philadelphia School District. More importantly, the all planning stages of the project until its end result worked as a living laboratory that teaches anyone who passes by about overall features of environmental processes (Figure 3.25). The plan aimed to convert the school yard, used previously as a parking lot, into a green space with sustainable concerns. The improvements included the installation of a flood management system with indigenous vegetation, the removal of impervious pavement, a permeable recycled play surface, an agriculture zone as well as solar shading. A stormwater bioretention area with a rain garden was also installed.

Communal management also occurred in New Orleans after the destruction and desolation of Hurricane Katrina. More precisely, an "extraordinary new level of civic and community engagement" (ISC 2010, p.61) helped the city towards recovery and rebuilding, through a process that retained a strong connection to the cities' history while also looking forward in addressing future challenges such as climate change.

In accordance with the report developed by the Institute for Sustainable Communities (ISC) in partnership with the Center for Clean Air Policy, the community embraced the idea that the best approach to endure future climatic extremes is to become a greener city that, consequently, promotes safety and enriches attractiveness for business and residents (ISC 2010). One of the implemented projects aimed to transform the constraint of having more than 60.000 vacant lost lots in the city, transforming some of them into a network of urban farms and public gardens (Figure 3.26).

It is further important to evidence that in New Orleans' recovery, governments' investments alone would have had a reduced impact. The city was able to recover, and it's able to take forward its strategic plans, because of a creative and energized community, because of public and private partnerships and because of a comprehensive cooperation among national and international experts (Dutch Dialogues 2011).

Figure 3.25 - Students learning about green infrastructure and flood management at Greenfield Elementary in Philadelphia. Image credits: © Water Blues Green Solutions, 2013.

Figure 3.26 - Community Orchard Project. Source: NOLA Tree project.

Public space as an extensive physical structure

Reflecting upon the perception of public space as a structuring element of the urban form (Martin 2007, Portas 2003), additional reasons promptly lead to further conclude that these are particularly favourable places for the implementation of flood adaptation measures.

Public spaces have a fundamental role in city life as they enable formal and environmental continuity, accessibility and legibility, contributing to the reinforcement of social and economic centralities (Pinto 2015). In the series of lectures "O Urbano e a Urbanística ou os tempos das formas"[45], Nuno Portas highlighted, that in the history of cities, public spaces are more durable than buildings; that buildings are stable elements, but not durable elements; and that after public spaces, the most durable elements are the buildings that are transformed into monuments, i.e., transformed into public spaces. Indeed, public spaces are determinant elements in the form and identity of a city.

According to Borja "The fact that public space is the determining element of the urban form is enough to attribute it the role of structurer of urbanism and, firstly, its urban fabric"[46] (Borja 2003, p.137, author's translation). One can thus claim that public spaces are not only the means of social, economic and cultural dynamics, but are also a physical structuring element of the urban fabric. A structuring network that is able to construct a "recognizable and lasting image of an individual unity, which arises from a system of complementary parts, as various and as unorganized as they may be"[47] (Portas 2003, p.17, author's translation).

By conforming a structural network based on the local scale, public space offers a decentralized and expansive means to tackle flood management. An approach that strongly contrasts with the traditional method that tends to be linear and centralized. A distinction that is here considered as a benefit and that will be particularly emphasized in the final chapter of this dissertation.

---

[45] By Nuno Portas with illustrations from Nuno Travasso; 2013, days 7, 14, 21, 28 of January, Culturgest – Fundação Caixa Geral de Depósitos. More information at: http://www.culturgest.pt/actual/01/01-nunoportas.html

[46] Original text: "El hecho de que el espacio publico sea el elemento determinante de la forma de la ciudad ya es razón suficiente para atribuirle el rol ordenador del urbanismo y en primer lugar de la trama urbana".

[47] Original text: "(o papel que o espaço colectivo é chamado a desempenhar ai bivel simbólico consiste (como sempre) em) tornar reconhecível uma imagem duradoura de unidade, de identidade do todo, a partir de um sistemas de partes complementares, por mais diversificadas e menos organizadas que estas se encontrem".

Moreover, public spaces offer a network that not only supports the urban fabric, but also connects its different urban spaces, from buildings and infrastructures to natural structures such as the ecological network. For Portas, this communicating network of public spaces "cannot be reduced to a simplistic addition of segments, unconnected streets, detached to the territories they cross, more or less urbanized"[48] (Portas 2003, p.17, author's translation). In other words, public spaces must not be understood by its individual elements, but rather as a "coherent structure that encompasses different territorial scales (from the neighbourhood to the metropolitan city)" (Pinto et al. 2011, p.1). Exactly the same can be said about hydrographic basins. As highlighted in chapter two, one of the main causes of urban floods is related to the manipulation of natural watersheds through forced interruptions or divisions into smaller parts. These approaches do not take into account the fact that their effective functioning is highly dependable on a system that is comprehensive by nature.

It is therefore equitable to conceive water systems equally converged within the network of public spaces. One can easily identify episodes were water systems networks have met with public spaces. However, most of the time, it is an event that is neither planned nor wanted. Considering, for instance, drainage overflows resulting from heavy rainfall. In this situation, stormwater generally flows along the next available spaces, generally "open" spaces and mostly public spaces. If this "encounter" could be looked upon through a different perspective, one that would capitalize from the inherent values of public space, the excess of water could be integrated within designs as an opportunity to potentiate a comprehensive adaptation in an extensive and decentralized network.

A representative undergoing example that taking advantage of the benefits offered by the extensive physical structure of public spaces, is probably New York's Green Infrastructure plan launched in 2010. In brief, this plan aimed to offer a more sustainable alternative to the conventional "grey" infrastructure by proposing integrated structure that combined solutions such as: rooftop detention, green roofs, subsurface detention and infiltration, swales; street trees, permeable pavement, rain gardens, engineered wetlands, among others.

While New York's particular programme is illustrated by the example of Elmhurst parking lot (#34), many other examples fit within its overall

---

[48] Original text: *"(o (re)desenho e construção das redes)… não poderá reduzir-se à simplista adição de troços, de estradas desligadas, indiferentes aos territórios que atravessam, mais ou menos urbanizados".*

approach. More specifically, examples such as the bioretention planters on Ribblesdale Road in Nottingham, United Kingdom (#39), the open drainage system in Trabrennbahn Farmsen residential area in Hamburg (#33), Germany or the drainage systems of the Ecocity Augustenborg in Malmö, Sweden (#35).

The bioretention planters of Ribblesdale Road in Nottingham were a pilot retrofit project of sustainable urban drainage. They were therefore created for its design and construction to be documented and evaluated in order to assess its comprehensive application. A total of 148 m2 of bioretention planters were implemented within an existing urban road setting (Figure 3.27). Among the main objectives of this intervention it is worth mentioning the following: 1) Maximise surface water interception, attenuation and infiltration; 2) Encourage participation from local residents in the design and future management of the rain gardens; AND 3) Evaluate the effectiveness of the scheme as an engagement tool around the sources of urban diffuse pollution and flood risk (Susdrain 2012).

Trabrennbahn Farmsen is an example of a newly built residential area that comprised the application of a particularly interesting open drainage system. Because its implementation area has little infiltration capacity, designers chose to implement an open water system that would retain and convey rainwater. In accordance, stormwater is collected from surrounding streets as well as from the building's roofs. Overall the system is composed of grassed swales, stormwater channels and two retention ponds (Howe et al. 2011). The greatest highlight of this example is the autonomy of this natural system to manage all stormwater from the Trabrennbahn Farmsen residential area on-site, evidencing a reduced importance of underground sewers for rainwater (Figure 3.28).

Figure 3.27 - Bioretention planters at Ribblesdale Road in Nottingham. Image credits: © CIRIA / Simon Bunn.

Figure 3.28 - Detail of Trabrennbahn Farmsen residential area. Image credits: © Michael Pasdzior.

Expose and share value through public space

By integrating infrastructure in the design of a public space, instead of camouflaging it underground or in an isolated impenetrable area, a public investment is exposed and shared with a community. A shared value that may instigate further opportunities such as amenity or environmental quality. As the example in Figure 3.29 illustrates, similar investments on drainage infrastructure, expose and share their value differently. While in the common mainstream approach on the left, investments are camouflaged underground and encompass a sole function and use for stormwater alone; in the second approach on the right, which integrates infrastructure within the public space itself, value is not only exposed to all, but also shared among everyone using that space.

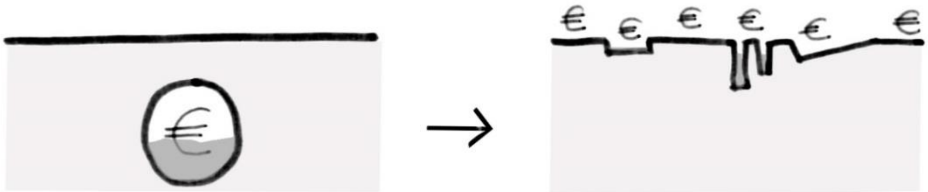


Figure 3.29 - Public spaces expose value. Adapted from (Papacharalambous et al. 2013, p.21).

Through dispersed, yet extensive, small scaled investments within public space design, urban amenities are further created while taking advantage of ecological and economic opportunities along the way. For example, buried culverts may sometimes be a missed opportunity for the enhancement of the quality of public space. Obsolete and no longer necessary flood walls may likewise hide valuable water assets (Papacharalambous et al. 2013).

Indeed, there are many opportunities for infrastructure renovation and necessary landscape improvements throughout urban areas: from the need to provide alternatives to reduce the load of obsolete drainage infrastructure to vacant lots that can be used to store water. Bearing in mind the ever exceeding costs of traditional infrastructure repair and expected climate change extreme events, a wide range of literature argues that established methods are no longer affordable or sustainable (such as White and Howe 2004, Hartmann and Driessen 2013, Lennon et al. 2014). As such, new alternatives, which rather support an integrated water management, should be considered not only as a necessary immediate investment, but more importantly, as an investment in our future.

Uncovering small scaled stormwater drainage systems, such as in Banyoles, Girona (#70) or in the 13th century Freiburg Bächle (#71), is one way of exposing and sharing the expressed value of water in an urban environment.

In brief, the regeneration of the old city centre of Banyoles, designed by Miàs Arquitectes, envisaged two main purposes: 1) to repave the town centre and define a new pedestrian area and 2) to reclaim the irrigation canals that used to feed medieval private gardens. These waterways used to run in open channels from the lake and throughout the town. With the loss of these gardens, the canals were progressively covered and water quality worsened. The resulting public space offers a new main square and adjoining streets composed by linear travertine paving stones that are "cut-off" by open channels, which undercover the presence of the water (Figure 3.30).

Figure 3.30 - Main square of the old city centre of Banyoles, Girona. Image credits: Adrià Goula.

Projects that "bring into light" buried pre-existing water lines are another example of an adaptation measures that aims to expose and share value. That is the case of Westersingel channel (#66) and the Soestbach River neat Soest (#69), besides the representative example of the Cheonggyecheon river (#68) previously analysed.

Rotterdam's Westersingel channel, which had been previously sunken, was redesigned by Dirk van Peijpe from the DE URBANISTEN office. The resulting promenade almost disguises its capacity to sustain and retain excesses of water when needed (Figure 3.31). It's "sinlgel's" banks are mostly made of brick as well as grass and trees. All materials, including urban equipment such as benches and lamps, are designed to endure occasional overloads of the canal. Currently this public space is enriched with sculptures by well-known artists such as Rodin, Carel Visser, Joel Shapiro and Umberto Mastroianni.

Figure 3.31 - Rotterdam's Westersingel channel. Image credits: Maria Matos Silva, 2010.

Public spaces as a means to diversify and monitor flood risk

According to the IPCC, "The main challenge for local adaptation to climate extremes, is to apply a balanced portfolio of approaches as a one-size-fits-all strategy may prove limiting for some places and stakeholders" (IPCC 2012, p.291). In other words, in light of climate change, it is not recommended the sole investment in one isolated infrastructure, built to fulfil only its particular purpose. If plan A fails, risk will be great and generalized. But if investments are diversified, risk is dissipated through the reliance on parallel plans.

In addition, when massive infrastructures are kept out of site, people do not remember their existence and thus will not expect their failure. This unpreparedness, led by a false sense of safety that is usually termed "levee-effect", may further exacerbate vulnerability and increment potential impacts. Contrastingly, if approaches are implemented within public spaces, some risks are more closely acknowledged and thus less unexpected.

Regardless, research aimed at analysing the social construction of risk or social risk perception is rather complex. As evidenced by Sergi Valera (2001) social theories of risk namely suggest that the causes and consequences of risk are mediated by the subjective criteria of individual processes (or psychological), social (psychosocial) behaviours and culture. The same way the design of a public space may reduce or exacerbate a risk through "rational and scientific" processes, it may also reduce or exacerbate the perception of that risk through "subjective-social" processes. It is further important to note that the social construction of a risk may influence the degree of the risk itself, minimizing or maximizing it. Risk perception is thus a very important factor that must be taken into consideration, namely in the design process of a public space with flood adaptation purposes, so that the resulting outcome does not contradict the initial purpose.

Through the diversification of risk, by investing in more than one great mono-functional strategy, the communal management among government, institutions, communities and private companies is also promoted; unlike traditional management that is essentially based on government's actions on behalf of communities. As a result of communal management, risk is further shared and communities are more likely involved in the management and monitoring of implemented infrastructures. In addition, local knowhow is explored, citizens are empowered to act before the need for safety and the identity of vulnerable places is reinforced.

In similarity with the representative example of Blackpool seafront, Scheveningen's waterfront boulevard (#105) also illustrates the different between its previous coastal defensive approach and the outcomes of the new implemented solutions. Designed by Manuel de Solà-Morales, this project demonstrates how a large scaled storm surge defence infrastructure, such as a "super levee", may be integrated within the design of a multifunctional public space (Figure 3.32).

Figure 3.32 - Scheveningen's waterfront boulevard. Image credits: Gerard Stolk, 2014.

Through this project people are more connected to the intense coastal water dynamics and thus more aware of its nature. By sharing the value of the infrastructure through its common use as a public space, not only is the awareness of the power of nature promoted but also a certain sense of responsibility and appropriation is reinforced. While the first aspect may lead to the respect and willingness to adapt, the second aspect may lead to active management and monitoring of the infrastructure itself.

Comprised by three levels of parallel and undulating waterfront boulevard, this space offers more than its functional requirement to protect The Hauge from coastal floods. More specifically, it articulates other programmes such as coastal life and recreation (bars and restaurants), public and private circulation (bicycles and cars) and connections with the urban fabric (Solà-Morales 2012).

3.4. Discussion

Within the multi-scaled scope of adaptation action, local scale, from the "bottom-up", adaptation is particularly relevant, not only because it very likely influences global climate, but also because it entails immediate repercussions on the reduction of society's vulnerability. Not only are hazards more acutely felt at the local level but it is also within local communities that lies most know-how and experience to promptly deal with existing vulnerabilities. As highlighted in this chapter, competent and politically autonomous municipalities that are close with its citizens, are therefore more likely to conduct effective adaptation action with wide ranging positive repercussions.

Moreover, namely as evidenced by the Barcelona model, local initiatives, such as specific public space interventions, rise the standard for good quality cities. Likewise, and as argued by several authors, also the quality of cities can be measured by the quality of its public spaces (Borja 2003, Brandão 2011a, among others). In this line of reasoning, and bearing in mind the particular advantages of local scale adaptation, it is argued that the quality of our future cities will be influenced by the quality of future adaptation measures applied in public spaces.

Public space enables and promotes community life. It further potentially offers wide-ranging benefits such as place-making, sense of place or local identity. As a civic common space, a collective entity of shared concerns, a new variety of insurgent citizenship is arising within public spaces as the urgent matter of climate change adaptation is recognized among our societies. Furthermore, as previously emphasised, social, cultural and emotional factors can be more valued and respected within a community than the need of physical safety or ecological services.

Through public spaces and public space design, local climate change can be made visible and consequently meaningful for citizens and their livelihoods. Public spaces additionally provide a different source of knowledge and information, besides the mainstreamed sources of science and media, which may be apprehended an autonomous and independent process. Accordingly, public spaces provide extended opportunities for experiential learning inherent to adaptation processes.

In this line of reasoning, the design of public space sees itself enhanced in the face of impending weather events, being considered as a key factor in the adaptation of urban territories when facing climate change, and flood events in particular.

Through the conducted empirical analysis, which evidenced and briefly characterized 112 examples of public spaces with flood adaptation features, it was possible to propose an initial conceptual organization in sixteen different categories of flood adaptation measures, namely: A. Urban greenery; B. Urban furniture; C. Rooftop detention; D. Reservoirs; E. Bioretention; F. Permeable paving; G. Infiltration techniques; H. Stream recovery; I. Open drainage systems; J. Floating structures; K. Wet-proof; L. Raised structures; M. Coastal defences; N. Floodwalls; O. Barriers and P. Levees. Following to the methodology presented in the introduction, next chapter will confront these categories through a literature review, which is expected to deepen the conceptual analysis and thus enable the construction of the Conceptual Framework.

The examples evidenced in this chapter further enabled the reasoning that, besides providing the means to include flood adaptation features, public spaces *per se* entail further specific connotations that are advantageous in adaptation endeavours. As evidenced by the analysed examples, potential benefits may specifically arise from the characteristics of public space to:

1. Favour interdisciplinary design – in places founded through interdisciplinary means, innovative thinking more easily emerges;
2. Embrace multiple purposes – by combining flood adaptation measures with public space design, adjacent purposes arise among other sectorial needs such as water depuration, recreation or microclimatic melioration;
3. Promote community engagement – by engaging the community in the design and use of a public space, not only awareness about climate change may be promoted but also the self-determining willingness for adaptation action is enhanced.
4. Be supported by an extensive physical structure and system – by conforming a communicating structural network based on the local scale, public space offers the advantage of a decentralized and expansive means to tackle flood management;
5. Expose and share value – by integrating flood management infrastructure in the design of a public space, instead of camouflaging it underground or in an isolated impenetrable area, a public investment is exposed and shared among all to which belongs. A shared value that may instigate further opportunities such as amenity or environmental improvements.
6. Promote risk diversification and communal monitoring – by investing in flood adaption measures applied in public space in addition to the conventional approaches, risk is dissipated and diversified and thus reduced. Moreover, through the diversification of risk, communal management among varied stakeholders is promoted. This way, communities are more involved and the sense of responsibility and appropriation is

> stimulated, thus potentially leading to autonomous management and monitoring of shared implemented infrastructures.

It is important to bear in mind that, in light of an unprecedented area of action, concepts, paradigms or structures are expected to change overtime, as are the functions, appearance and complexities of public spaces with flood adaptation measures. The design of these spaces must therefore encompass an ongoing process that is fundamentally grounded on the need to learn, reflecting upon mistakes and generating experience while dealing with change (Berkes et al. 2003). In the words of Jordi Borja, today we must "Accept the challenges with the intent to provide answers and with the modesty of providing them with uncertainty, with the audacity to experiment and with the humility to admit mistakes"[49] (2003, p.140).

It is furthermore essential to highlight that while the analysed initiatives have counterbalanced the inevitable uncertainties of global models and the generalized "top-down" policies, local action must be connected to the global scientific findings and its encompassing strategies. Otherwise applied adaptation measures may get lost in scale, lose its value, and thus fail its purpose. While local scale action is presently acknowledged as a fundamental element for effective urban climate change adaptation, its greater challenge therefore relies on finding the balance and explore the benefits from the arising synergies between local collective actions and national and international strategies. The same way local adaptation strategies must not be dissociated from global adaptation strategies, so too do the processes of public space design which must follow objectives and strategies of regional and national levels, otherwise "…actions will not contribute, in an effective way, to the achievement of community expectations in the safeguard public interests and collective resources"[50] (Brandão(Coord.) et al. 2002, p.19, author's translation).

Through the inclusion of flood adaptation measures within public space design, new challenges arise before contemporary urbanism and urban design practices. Likewise, although this research is specifically focused upon adaptation measures applied in public spaces, there are several other areas of opportunity that may additionally provide significant contributions in the development of flood adapted cities. More specifically, disciplines such as building design, governance or landscape architecture have been extending their literature regarding this specific

---

[49] Original text: *"Asumir los desafíos con intención de dar respuestas y con la modestia de darlas con incertidumbre, con audacia para experimentar y con humildad para admitir los errores".*

[50] Original text: *"(das acções) não contribuírem, de uma forma efectiva, para a concretização das expectativas da comunidade, para a salvaguarda dos interesses públicos e dos recursos colectivos".*

subject matter, suggesting further developments namely on floating buildings, transdisciplinary and transboundary consortiums or in blue and green corridors.

Overall, this discussion, essentially sustained by an empirical analysis based on concrete examples, has served to 1) provide an initial conceptual organization in categories of flood adaptation measures applied in public spaces and 2) to emphasize the particular advantages offered by public space itself as a means where food adaptation measures can be implemented. Yet, it is important to note that the presented findings are unintended to serve as restrictive boundaries. At the same time that a new category of flood adaptation measure might come to discussion, also an apparently established category might prove not to be significant. Likewise, it is not here advocated that flood adaptation endeavours can only be considered as such if comprising all the mentioned potential advantages offered by public space, nor that they are only successful if comprising all these mentioned advantages. What is argued is that the above mentioned characteristics are only potential and are considered as an additional asset either alone or combined.

Ultimately, it is reasoned that public space is an ideal interface for adaptation action. Consequently, it is further questioned whether the evaluation of adaptation initiatives should consider: 1) if the design of a public space comprises adaptation measures and, on a reverse perspective, 2) if the application of adaptation measures comprises the design of a public space.

Nuno Portas (in Brandão and Remesar 2003) reflected about two different phases of urban projects which have led to different ways on how public spaces were produced. In the described first phase most interventions were held in heritage areas, entailing projects such as the pedestrianisation of historic centres or creation of public spaces as a replacement of old industrial uses. The second phase entailed urban projects that were induced by events such as the Olympic Games, Capital of Culture or International Exhibitions. These projects had in common the aim to generate new facilities suited for leisure, culture or sports. Proposing a further prospective discussion, a final question arises: are we at the fringe of a third phase, in which, in a changing climate, urban projects will also aim to produce public spaces that are prepared to adapt to future impending weather events?

Chapter 4

Conceptual Framework of flood adaptation measures applicable in the design of public spaces

---

Parts of this chapter were disseminated in the following publications:

Matos Silva, M. and Costa, J. 2016. Flood Adaptation Measures Applicable in the Design of Urban Public Spaces: Proposal for a Conceptual Framework. *Water,* 8(7), 284. [Journal Article]

Matos Silva, M., 2014. Urban adaptation through flood risk management infrastructure and public space design. *In:* Silva, I. M. d., Marques, T. P. and Andrade, G. eds. *Landscape: A Place of Cultivation.* Porto, Portugal: School of Sciences, University of Porto, 292 - 296. [Conference Proceedings]

Matos Silva, M. and Costa, J. P., Flood adaptation measures applicable in the design of public spaces: identification and characterization. Joanaz de Melo et al. eds. *Rethinking Sustainability Models and Practices: Challenges for the New and Old World Contexts. 22nd Annual International Sustainable Development Research Society Conference (ISDRS)*, 13-15 July 2016 Lisbon, Portugal, Universidade Nova de Lisboa, 713-731. [Conference Proceedings]

In light of the previously developed empirical analysis (which has provided an initial organization in sixteen different categories of flood adaptation measures applicable in the design of public spaces), and together with a specifically directed literature review, chapter four identifies different types of adaptation measures within the previously identified categories. Chapter four additionally defines, classifies and organizes the different identified categories and types of adaptation measures in a Conceptual Framework based on the main highlighted infrastructural strategies. A framework that enables the possibility to easily grasp an overview of the existing range of options by their infrastructural function, and therefore facilitating and accelerating the initial stages of a public space design process with flood adaptation purposes.

The Conceptual Framework that will be hereby proposed, offers a different approach to tackle the well-known problem of urban flooding. Through a different perspective, one that highlights the importance of public space design in adaptation endeavours, the Conceptual Framework offers a specific group of measures that confront traditional flood risk management practices.

4.1 Learning from external research findings

In order to reinforce and develop the empirical analysis previously advanced in chapter three, this section focuses upon external research findings, which have directly, or indirectly worked with the subject of flood adaptation measures. More specifically, next paragraphs will aim to identify and analyse previously-developed research endeavours that proposed comprehensive frameworks, which included, or could be related to climate change adaptation measures, which in turn are particularly related to urban flooding; i.e. flood risk management measures[52] viewed through the lens of climate change projections.

Twenty one references were analysed, namely four from "research programmes", ten "R&D projects", and seven "books and report". These analysed references generally comprise vast and multidisciplinary teams and often involve international collaborations (besides which, entail "online sharing platforms" where knowledge in the form of case studies, reports and theses can be consulted or added to by anyone with Internet access). Furthermore, the particular area of climate change adaptation is quite vast and contains continuing developments and findings. It is

[52] According to the European Union's communication on "Flood Risk Management; Flood prevention, protection and mitigation", flood risk management aims to reduce the likelihood and/or the impact of floods. It further ascertains that flood risk management essentially comprises the strategies of "prevention", "protection", "preparedness", "emergency response" and "recovery and lessons learned" European Commission, 2004. *Flood risk management; Flood prevention, protection and mitigation.* Brussels, Belgium: Commission of the European Communities. 11 pp. . In accordance, besides the non-structural measures, such as land use planning or evacuation planning, most of the identified comprehensive frameworks encompassed structural strategies and concomitant measures, which were not only related to urban stormwater systems (or urban drainage systems), such as sustainable drainage systems (SUDS), low impact development (LID), best management practices (BMPs), water sensitive urban design (WSUD) Fletcher, T. D., et al. 2015. SUDS, LID, BMPs, WSUD and more - The evolution and application of terminology surrounding urban drainage. Urban Water Journal, 12(7), 525-542., but also those related to building design, flood defences and embankment systems, among others.

therefore acknowledged that adaptation to urban flooding will continue to promote the development of new and relevant studies.

4.1.1 Research programmes

Among the analysed research programmes are: 1) "Adaptation Planning, Research and Practice" (WeAdapt) from the Stockholm Environment Institute (SEI), 2) "United Kingdom's Climate Impacts Programme" (UKCIP) from the Environmental Change Institute (ECI) at the University of Oxford, 3) "Climate Adaptation Knowledge Exchange" (CAKE) created by the American NGO EcoAdapt and Island Press, and 4) the "European Climate Adaptation Platform" (Climate-ADAPT) from the European Commission and European Environmental Agency (EEA).

All these mentioned investigation programmes have a common "general" scope of adaptation, that is, they cover a variety of topics pertaining to climate adaptation and not solely flood adaptation, namely health, finance or biodiversity. As such, only some deliverables from each of the identified research studies were analysed. They further entail the constituent goal to provide and share information through online databases of case studies, reports or articles. Another common characteristic is their aim to promote the exchange of experiences, between practitioners, researchers and decision makers from all evolved disciplines, through online sharing platforms.

1. WeADAPT is an online webpage dedicated to facilitate "learning, exchange, collaboration and knowledge integration" (weADAPT 2011) or a professional community of practice on adaptation issues. It's a collaborative and distributed network of many contributing organisations and individuals, but its technological development is led by the Oxford Office of the Stockholm Environment Institute with input on strategic direction provided by all partners. WeADAPT began originally as wikiADAPT in 2005. Their outputs, which can be specifically related to the identification of adaptation measures to urban flooding, include articles, case studies and the Google Earth "Adaptation Layer" interface.
2. UKCIP research essentially provides tools and information to help organisations to consider climate risks and to plan to adapt. In their own words, the programme "coordinates and influences research into adapting to climate change, and shares the outputs in ways that are useful to stakeholders" (UKCIP 2012). In the scope of this research, the most relevant deliverables from this

programme includes the "adaptation case studies database" and the AdOpt report (Identifying adaptation options).

3. CAKE is an online sharing platform and database focused on the management of natural and built systems in the face of climate change. It further aims to build a community of innovative practice (CAKE 2010). Amongst others, it provides a series of case studies and a virtual library.

4. Climate-ADAPT is a European Commission initiative that helps decision makers to access and share information on: expected climate change in Europe, current and future vulnerability of regions and sectors, national and transnational adaptation strategies, adaptation case studies and potential adaptation options, and tools that support adaptation planning (Climate-ADAPT 2012). The unlimited information provided in the online sharing platform is expected to be periodically updated through the years. Among the knowledge generated, compiled and shared through this programme, the most significant ones relating to the conducted research are the "Adaptation options database" and the "Case study search tool".

4.1.2 R&D projects

The studied R&D projects can be divided into groups which approached adaptation measures generally, i.e. covering more than just flood adaptation, from those that are specifically focused on water management and those specifically focused on flood management.

The analysed R&D projects which encompassed a general scope are: 5) the Dutch national project "Climate 'changes' Spatial Planning programme" / "Klimaat voor Ruimte" (CcSP/KvR); 6) the European project "Adaptation and Mitigation - an Integrated Climate Policy Approach" (AMICA); 7) the European programme "ADaptation And Mitigation Strategies: supporting European climate policy" (ADAM); 8) the European project "Green and Blue Space Adaptation for Urban Areas and Eco Towns" (GRaBS); 9) and the German national project "The Climate Impacts: Global and Regional Adaptation Support Platform" (ci:grasp).

The studied R&D projects which specifically covered water management adaptation measures are: 10) the European project "European Spatial Planning: Adapting to Climate Events" (ESPACE); 11) the Belgian project "Towards an integrated decision tool for adaptation measures. Case study: floods" (ADAPT); 12) the European programme "Managing Water for the City of the Future" (SWITCH); and 13) the European project

"Climate Adaptation – modelling water scenarios and sectoral impacts" (ClimWatAdapt). Finally, the scrutinized R&D project that is particularly focused on flood adaptation is the 14) "Foresight Project on Flood and Coastal Defence" (Foresight projects), managed by the United Kingdom.

5. The Dutch national project "Climate 'changes' Spatial Planning programme" had as its primary goal, the introduction of climate change and climate variability as one of the guiding principles for spatial planning in the Netherlands. Furthermore, it anticipated the generation of international alliances that would provide a competitive knowledge base that would support practice in the face of climate change (CcSP 2004). Their agenda was specifically centred in five main themes (climate scenarios, mitigation, adaptation, integration and communication) and in a wide range of sectorial areas, namely coastal areas and water. Among the used deliverables from this project are: Final report COM11: "Deltas on the move" and Report A11 – "Routeplanner 2010 – 2050".
6. The AMICA project is a European project that aims to help local and regional entities to adopt a comprehensive approach to climate change. It is their objective to motivate local governments to include climate protection and adaptation in their planning practices. In order to fulfil their objectives, AMICA developed three central online tools: the adaptation tool, the mitigation tool and the integration tool. In the scope of this research, the adaptation tool is the most relevant. Its main components correspond to a matrix of adaptation measures and a list of evaluated practice examples. The matrix of adaptation measures explore various possibilities of adapting to climate variability and climate change on the local and provincial scales. The matrix has more than 40 adaptation measures, organized in four impact types and nine categories of measure (AMICA 2006). A detailed description of the measure is also available in this online tool.
7. ADAM programme essentially aims at a better understanding of the synergies, trade-offs and conflicts that exist between adaptation and mitigation policies at multiple scales. Amongst the project's objectives is the goal to create a "Digital Compendium" that can contribute to the emerging knowledge on adaptation. This virtual manual organizes results from four types of analysis: Workshops and interviews; meta-analysis of climate change impact, vulnerability and adaptation case studies, adaptation catalogue and risk analysis (ADAM 2009). Focusing on the

"adaptation catalogue" output, an examination of adaptation measures across the European Union (EU) was undertaken, paying particular attention to pioneering measures and institutions that either manage, reduce, or transfer the risks associated with extreme events. In summary, the catalogue acts as an inventory of options, differentiating between alternatives according to the form of adaptation (institutional structures and processes, planning and management practice, financial / legal, or technological), hazard, landscape type (urban, rural, coastal), economic sector, geographical region, responsible actor (highlighting whether public or private), and the scale of implementation (e.g. adapting to heat waves can involve action at the city, neighbourhood or individual building level; flood risk management can operate from the level of the catchment down to individual responses). A brief characterization is further provided for each measure, namely by comprising the answers to the questions of "what", "why", "how and who", "implications" and "resources".

8. GRaBS project encompasses a consortium of 14 project partners, drawn from 8 EU Member States and is specifically targeted at the adaptation to climate change through the use of green and blue infrastructure. Among others, results are presented in the form of an online database and in the form of an adaptation action planning toolkit (GRaBS 2008).

9. Ci:grasp project consists of a climate information service that aims to provide state of the art knowledge on projected climate stimuli, climate impacts and adaptation options. Research is targeted at national, sub-national and regional scales. The particular goal to supply information on adaptation options is based on the analysis of adaptation projects, targeted at specific impacts (Ci:Grasp 2008).

10. The main goal of the ESPACE project consisted on influencing the "philosophy and practice of spatial planning by recommending how adaptation to climate change can be incorporated into spatial planning policies, processes and practices" (ESPACE 2007). Amongst their research findings, the most relevant in the scope of this research, i.e. the most relevant for the identification of different types of flood adaptation measures, is the "SERRA toolkit". One of its purposes is to serve as a guidance document on delivering climate change adapted development through planning at the local level. It was designed for planning professionals and developers, assisting them in the integration of

water management and climate change adaptation issues into all stages of the planning and development processes. It further adds information on ten "Good Practice Case Studies" on water management adaptation options.

11. The ADAPT project is composed of two parts. The first part consists of a general introduction about research on available knowledge on climate change, whilst the second part discusses the determining and assessment of possible adaptation measures (ADAPT 2005). Among used deliverables from this research project is the final report from phase 1: (Hecq(coord.) et al. 2008).
12. SWITCH research project essentially aims to change the paradigm of urban water management "from existing ad hoc solutions to a more coherent and integrated approach" (SWITCH 2006). Two particularly interesting deliverables of SWITCH are: 1) the manual "Water Sensitive Urban Design. Principles and Inspiration for Sustainable Stormwater Management in the City of the Future" (Jacqueline Hoyer et al. 2011) and the handbook "Adapting Urban Water Systems to Climate Change" (Loftus 2011). Both research outputs explore possible innovations on sustainable stormwater management, elucidating how they can be applied in cities while at the same time taking advantage of the opportunities on how they can be used for the improvement of the cities' urban experience. Examples of specific measures are further contrasted with the analysis of corresponding case studies.
13. Outputs from the ClimWatAdapt research project include tools which can help improve the knowledge base on adaptation measures, facilitating the exchange of adaptation best practice between countries and regions (ClimWatAdapt 2010), namely the "inventory of measures" database which is particularly relevant in this conducted analysis. In this database, measures are inventoried through four groups of attributes: 1) "Basic attributes" that includes name and description, 2) "Descriptive attributes" that comprise: the "category of measure" (Technical measures, Measures related to "green" infrastructure, Measures changing management or practices, Risk prevention measures, among others), the "character of measures" (Preventive, Preparatory, Reactive, Recovery), the "objective of measures" (reduce exposure and sensitivity, increase adaptive capacity, to exploit benefits), "climate events" (not enough water, too much water, impaired water quality, snow related events), and "sector affected" (Water management, Agriculture, Energy, Industry, among others); 3) "Assessment attributes" that include

effectiveness, economic effects (cost), side effects, flexibility, and acceptance (implementation and time to implement); and (4) "Additional information" that includes references and comments.

14. UK's Government Office for Science has been developing "foresight projects", which consist on in-depth studies that look at major issues for 20-80 years in the future. They are based on the latest scientific evidence and futures analysis in order to tackle complex issues and to provide strategic options for policy (Neue Ufer 2013). The particular foresight project on Flood and Coastal Defence produced two reports: "Future Flooding volume 1" and "Future Flooding volume 2". While the first was focused on the elaboration of scenarios regarding the risk and extent of fluvial and coastal flooding over the next 30-100 years, the second report assessed the techniques or responses that are available to meet the flooding risk, and the key issues associated with their use. In this latter report, researchers developed literature reviews, interviews and workshops in order to gather information on scientific developments and international best practice in flood and coastal defence. They started by looking at the measures which are currently in use, considering the extent to which they are adaptable to future flood risk. Later on, new tools and techniques were evaluated in order to identify which measures should be further included and analysed in the concerning study.

4.1.3 Books and reports

Among the books and reports analysed within this literature review, which included important information for the identification and organization of different types of flood adaptation measures applicable in the design of public spaces, are:

15. Three technical reports from the European Environmental Agency (EEA), namely report No 2/2012 – "Urban Adaptation to Climate Change in Europe" (EEA 2012b) of general nature; report No 18/2011 – "Green Infrastructure and Territorial Cohesion" (EEA 2011) also of general nature; and report No EEA/ADS/06/001 – "Report on good practice measures for climate change adaptation in river basin management plans" (EEA 2009) that is specifically focused on water management.
16. UK's Town and Country Planning Association (TCPA) guide on "Climate Change Adaptation by Design" with a general scale extent (TCPA 2001);

17. "Adaptation Inspiration Book" developed by the R&D project CIRCLE-2, compiling a series of case studies and corresponding brief analysis (CIRCLE-2 2013);
18. "Toolbox Adaptive Measures" policopied document, developed by the Dutch company Doepel Strijkers Architects, which is an unpublished work shared at the "Water & City" "working conference"[53]. It is a document that graphically organizes different types of flood adaptation measures (such as "Constructing and furnishing of watersides", "Temporary adaptations on a building", "Floating or amphibious platforms", "escape ways", among others) in a number of strategies (such as "embanking", "elevating", "wet-proofing", "temporary adaptation") and on different scales (from the building scale to the district or city scale) (Strijkers 2011).
19. The book "River.Space.Design: Planning Strategies, Methods and Projects for Urban Rivers", edited by Martin Prominski, Antje Stokman, Susanne Zeller, Daniel Stimberg and Voermanek (Prominski et al. 2012). Although this book is particularly focused on urban river landscapes, and thus has no direct relation to climate change adaptation measures, it provides useful assessments on additional case studies as well as catalogued and categorised information that contributes to the conceptual organization adaptation measures envisioned in this research.
20. The report entitled "Adaptation Strategies for European Cities", which is part of the European R&D project with the same title, compiled by Ricardo-AEA for the European Commission Directorate General Climate Action (2013). This report presents a literary review of the impacts and vulnerabilities within the European context, as well as the ongoing adaptation strategies and adaptation options that are being taken in several European cities. It also presents a review of the tools and guidelines for adaptation action, as well as the details on how to educate and train for adaptation. Twenty one European cities participated in this research.
21. And, finally, the "Green Streets Design Manual" from the City of Philadelphia, more specifically from the Mayor's Office of Transportation and Utilities (2014). In this manual, targeted at building green stormwater infrastructure within urban areas, one

[53] International Scientific Conference, June 13-15, 2012. TUDelft University of Technology, Netherlands.

may find particularly innovative concepts such as the Green Gutter, which is currently being piloted.

Lastly, it is important to restate that the presented literature review offers an overview of the comprehensive frameworks that encompass different types of urban flood adaptation measures applied in the design of public spaces, and that, most likely, there are many other references that would fit the purpose.

Table 4.1 summarizes some characteristics of the analysed frameworks, such as the names of the deliverables used in this research or the dates in which there were developed[54].

Table 4.1 – Comprehensive frameworks that encompass adaptation measures related to flood risk management, an overview.

	Name (Acronym)	Start–End Year	Used Deliverable(s)	
			Name of Deliverable	**Main Characteristics**
Research centres				
1	Adaptation Planning, Research and Practice (WeAdapt)	2005	Articles, Case studies and "Adaptation Layer"	Online database and sharing platform
2	UK Climate Impacts Programme (UKCIP)	2007	Adaptation case studies, AdOpt	Online database, sharing platform and report (34 pp.)
3	Climate Adaptation Knowledge Exchange (CAKE)	2010	Case Studies Database	Online database and sharing platform
4	European Climate Adaptation Platform (Climate-ADAPT)	2012	Adaptation support tool:database	Online database and sharing platform
R&D projects				
5	European Spatial Planning: Adapting to Climate Events (ESPACE)	2003–2007	SEERA toolkit (2005)	Report (68 pp.)
6	Climate 'changes' Spatial Planning/Klimaat voor Ruimte (CcSP/KvR)	2004–2011	Final report COM11: Deltas on the move	Report (97 pp.)
			Report A11, Routeplanner 2010–2050	Report (145 pp.)
7	Foresight project on Flood and Coastal Defence (Foresight projects)	2004	Future Flooding, Volume 2 (2007)	Report (405 pp.)

[54] A more complete version of this table, including further information such as the targeted scope or scale extent of the developed works, or the corresponding coordinating or funding country / region, may be consulted in Annex III "Comprehensive frameworks that encompass adaptation measures related to flood risk management – Table 4.1 extended".

8	Adaptation and Mitigation - an Integrated Climate Policy Approach (AMICA)	2005–2007	Adaptation Tool	Online database
9	ADaptation And Mitigation Strategies: supporting European climate policy (ADAM)	2006–2009	Adam Digital Compendium, Adaptation Catalogue	Online database
10	Towards an integrated decision tool for adaptation measures. Case study: floods (ADAPT)	2006–2008	Final report (Phase I)	Report (129 pp.)
11	Managing Water for the City of the Future (SWITCH)	2006–2011	Deliverable 5.1.5	Report (115 pp.)
			Handbook Adapting urban water systems to climate change	Report (53 pp.)
12	Green and Blue Space Adaptation for Urban Areas and Eco Towns (GRaBS)	2008–2011	Adaptation Action Planning Toolkit	Online database
13	The Climate Impacts: Global and Regional Adaptation Support Platform (ci:grasp)	2008–2012	Adaptation project database	Online database and sharing platform
14	Climate Adaptation – modelling water scenarios and sectoral impacts (ClimWatAdapt)	2010–2011	Inventory of adaptation measures	Database
Books and report				
15	European Environmental Agency (EEA)	1993	Technical No. 2/2012	Report (143 pp.)
			Technical No. 18/2011	Report (138 pp.)
			EEA/ADS/06/001	Report (116 pp.)
16	Climate Change adaptation by design – a guide for sustainable communities (TCPA Guide)	2007	–	Report (49 pp.)
17	Climate Impact Research & Response Coordination for a Larger Europe (CIRCLE-2)	2010-2014	–	Book (162 pp.)
18	Toolbox Adaptive Measures by Doepel Strijkers Architects (Toolbox)	2011	–	Policopied document
19	Planning Strategies, Methods and Projects for Urban Rivers (River.Space.Design)	2012	–	Book (295 pp.)
20	Adaptation Strategies for European Cities	2013	Ricardo-AEA/R/ED57248 Final Report	Report (148 pp.)
21	Green Streets Design Manual (City of Philadelphia)	2014	–	Design Manual (95 pp.)

Research findings from the previously highlighted references, in the form of types of adaptation measures that could be applicable in the design of public spaces, were specifically highlighted and simplified, compared and organized with the help of multiple spreadsheets.

Besides the requirements to identify (1) flood-related climate change adaptation measures that are (2) applicable to the design of public spaces, the selection process from the findings of previously-developed frameworks followed the additional criteria (3) to be relevant to urban contexts and (4) include solely structural operational measures, i.e. those which include technical design[55]. Envisioning the best possible result, significant contributions, such as further empirical observations and research findings, were also used in the Conceptual Framework's construction. Examples of these relevant inputs namely include past know-how, such as the Greek and Arab cisterns or the street channels of Freiburg Bächle.

For exemplification purposes, seventeen measures from ESPACE research project were highlighted together with fifty seven measures from the Foresight project, twenty measures from the AMICA project, nineteen measures from ADAM project, thirty eight measures from ClimWatAdapt project, and so on. Measures that did not fit the above-mentioned criteria were excluded such as "Information folder" (AMICA), "Flood-risk mapping" (Foresight project), "Flood insurance" (ADAM), "Buffer strips between water bodies and agricultural fields and within fields" (ClimWatAdapt) or the often repeated measure of "off-shore barrier".

In this undertaken systematization process, common perspectives and redundancies were identified, namely in the given nomenclature[56]. In order to choose the most appropriate vocabulary for the scope of this

[55] This last criteria specifically aims to distinguish approaches that use design as a basic tool to face potential vulnerabilities, such as the ones associated with the projected increase of flood hazards. As a result, this separates the aforementioned criteria from those that are non-structural and more strategic, institutional, regulatory or political, such as forecasting, warning, information, evacuation, aid services, building codes or shared risk and compensations.

[56] Mentioning just a few: a) AMICA project and EEA reports mentioned "Green roofs"; b) River.Space.Design book mentioned "Floating jetties" and "Floating islands" while the Toolbox work mentioned "Floating platform or building block"; c) the Foresight project included the measure of "Permeable land cover" and the ESPACE project the measure of "permeable and porous paving surfaces"; d) while ADAM project included the measure of "Enhancing storage for water", AMICA project included the measure of "Water Storage"; d) "Dams" were suggested by the Foresight project, ADAM and the Toolbox work; e) "Reservoirs" were mentioned in the research projects ClimWatAdapt and ADAM; f) "Floodwalls" were included in the research projects ESPACE, AMICA, ADAM and in the book River.space.design and Toolbox work; g) although latter substituted by their synonym "Levee", "Dikes"were mentioned in ADAM research project, Foresight project and Toolbox work.

research, a semantics analysis was also conducted. This analysis permitted further conceptual clarifications[57].

Ultimately, and as expected, information regarding the types of flood adaptation measures applied in the design of public spaces, gathered through the analysis of external research findings, started to provide repetitious results, thus confirming to be unnecessary the scrutiny of more sources.

[57] More specifically, it was not only important to choose between nomenclatures, namely between "Floating jetties", "Floating platform" or a new terminology, but also to clarify conceptual divergences, such as between "underground storage" and "reservoirs". Regarding the latter, underground storage was considered too general as it could entail measures such as aquifer recharge and would therefore surpass the scope of the proposed framework. Reservoirs, on the other hand, have a more confined definition. They comprise a physical structure, above or below ground, which reserves water for a certain period of time. Contrastingly, a more general terminology of "wet bioretention basin" will serve to substitute the "wetlands" measure identified in three analysed external research (EEA, ESPACE and Foresight project). This resolution is primarily related to the need to distinguish and include both wetlands ("land that has a wet and spongy soil, as a marsh, swamp or bog", Oxford dictionary) and floodplains ("a nearly flat plain along the course of a stream or river that is naturally subject to flooding" Oxford dictionary). Both measures which can serve as a wet bioretention basin, i.e. a generally water-filled basin that can retain more water that is then progressively dissipated through infiltration or evapotranspiration processes.

Other relevant semantic resolutions helped elucidate the difference between "retention" and "detention". In brief, in retention systems water is generally harvested and reused, it stays on site and infiltrates into the soil. In detention systems, water is intended to slowly drain off site through streams or drain pipes. Retention systems are more adequate when subsoil percolation is reliable whereas detention systems are more adequate when subsoil percolation is not reliable (Urban, J., 2008. *Up By Roots.* Champaign, Illinois: International Society of Arboriculture. 479 pp. ISBN: 9781881956655.). Potential ambiguities, namely in the identified measures "Detention ponds" (Future flooding), "Catchment basins" (AMICA), "Retention basins" (River space design) and "Detention basins" (ESPACE) which seemed to be referencing similar concepts, where therefore clarified.

In regards to the "Stream recovery" category of measures, further semantic undertakings clarified the difference between "Restoration", here interpreted as the change from an artificial stream to "near natural" stream, and "Rehabilitation", here interpreted as the partial improvement of a severely disturbed stream.

4.2 Types and categories of flood adaptation measures applicable in the design of public spaces

The abovementioned systematization process based on external research findings, together with the portfolio screening developed in chapter three, enabled the convergence of the fundamental data that will allow the construction of the envisioned Conceptual Framework. Indeed, both these tasks, conceptual and empirical, endorse and validate each other, allowing the identification and organization of sixteen categories of flood adaptation measures, further divided in forty types of measures.

From past know-how to contemporary innovations, examples applied in different contexts and with different purposes reinforce the conceptual analysis and support the framework's construction. As evidenced in Table 4.2, there is at least one example for each type of identified measure, some types of measures have up to six associated examples. It is nonetheless important to highlight that this process is open ended and built on the premise to be continuously revisited in light of new findings.

Table 4.2 - Identified flood adaptation categories and measures applicable to the design of public spaces, matched with existing examples.

Flood adaptation measures applicable in the design of public spaces				Examples	
Category		Type: Label	Type: Name	Project name	Location (City)
A	Urban greenery	1	Green walls	Caixa Forum plaza	Madrid
				Westblaak' car park silo	Rotterdam
B	Urban furniture	2	Inverted umbrellas	Woolworths playgr.	Walkerville
				North Road	Preston
				Expo Boulevard	Shanghai
		3	Art installations	Jawaharlal Planetarium Park	Karnataka
				Water Table / Glass	Washington
				Whole Flow	California
C	Rooftop detention	4	Green roofs	Dakpark	Rotterdam
				Promenade Plantée	Paris
				European Patent Office	Rijswijk
				Womans University	Seoul
				High Line Park	New York
		5	Blue roofs	Waltebos Complex	Apeldoorn
				Stephen Epler Hall	Portland
D	Reservoirs	6	Artificial detention basins	Parc de Diagonal Mar	Barcelona
				Parc del Poblenou	Barcelona
		7	Water plazas	Benthemplein square	Rotterdam
				Tanner Springs Park	Portland

		8	Underground reservoirs	Parc de Joan Miró	Barcelona
				Escola Industrial	Barcelona
				Potsdamer Platz	Berlin
				Museumpark car park	Rotterdam
				Place Flagey	Brussels
		9	Cisterns	Stata Center	Massachusetts
				The Circle	Illinois
				Georgia Street	Indianapolis
E	Bioretention	10	Wet bioretention basins	Parque Oeste	Lisbon
				Qunli park	Haerbin
				Emerald Necklace	Boston
		11	Dry bioretention basins	Quinta da Granja	Lisbon
				Parque da Cidade	Porto
		12	Bioswales	Trabrennbahn Farmsen	Hamburg
				Elmhurst parking lot	New York
				Ecocity Augustenborg	Malmö
				Museum of Science	Portland
				High Point 30th Ave	Seattle
				Moor Park	Blackpool
		13	Bioretention planters	Ribblesdale Road	Nottingham
				South Australian Museum	Adelaide
				Columbus Square	Philadelphia
				Derbyshire Street	London
				Onondaga County	New York
		14	Rain gardens	Edinburgh Gardens	Melbourne
				Taasinge Square	Copenhagen
				Australia Road	London
				East Liberty Town Square	Pittsburgh
F	Permeable paving	15	Open cell pavers	Can Caralleu	Barcelona
				Zollhallen Plaza	Freiburg
		16	Interlocking pavers	Green park of Mondego	Coimbra
				Bakery Square 2.0	Pittsburgh
		17	Porous paving	Praça do Comércio	Lisbon
				Percy Street	Philadelphia
				Greenfield Elementary	Philadelphia
G	Infiltration techniques	18	Infiltration trenches	Etna Butler Street	Pittsburgh
				Community College	Philadelphia
				Elmer Avenue	Los Angeles
		19	Green gutter	Green streets design manual	Philadelphia
H	Stream recovery	20	Stream rehabilitation	Ribeira das Jardas	Sintra
				Ahna	Kassel
				River Volme	Hagen
				Promenada	Velenje
				Catharina Amalia Park	Apeldoorn

		21	Stream restoration	Kallang River	Bishan Park
				Alb	Karlsruhe
		22	Daylighting streams	Westersingel	Rotterdam
				Thornton Creek	Seattle
				Cheonggyecheon River	Seoul
				Soestbach	Soest
I	Open drainage systems	23	Street channels	Banyoles	Girona
				Freiburg Bächle	Freiburg
				Roombeek	Enschede
				Solar City streets	Linz
		24	Extended chann.	Pier Head	Liverpool
		25	Enlarged canals	Olympic park	London
		26	Check dams	Kronsberg	Hannover
				Renaissance Park	Tennessee
				21st Street	Paso Robles
J	Floating structures	27	Floating pathway	West India Quay	London
				Ravelijn Bridge	Bergen op Zoom
		28	Floating platform	Yongning River Park	Taizhou
				Landungsbrücken pier	Hamburg
		29	Floating islands	Spree Bathing Ship	Berlin
				Leine Suite	Hannover
K	Wet-proof	30	Submergible parks	Rhone River Banks	Lyon
				Parque fluvial del Gallego	Zuera
				Rio Besòs River Park	Barcelona
				Buffalo Bayou Park	Houston
				Parc de la Seille	Metz
				Park Van Luna	Heerhugowaard
		31	Submergible pathways	Passeio Atlântico	Porto
				Quai des Gondoles	Choisy-le-Roi
L	Raised structures	32	Cantilevered pathways	Elster Millraces	Leipzig
				Terreiro do Rato	Covilhã
		33	Elevated promenades	Waterfront promenade	Bilbao
				Tagus Linear Park	Póvoa de Sta. Iria
M	Coastal defences	34	Multifunctional defences	Elbe promenade	Hamburg
				Dike of “Boompjes”	Rotterdam
		35	Breakwaters	Zona de Banys del Fòrum	Barcelona
				Molhe da Barra do Douro	Porto
				Jack Evans Harbour	Tweed Heads
		36	Embankments	Schevenigen	The Hauge
				Sea organ	Zadar
N	Floodwalls	37	Sculptured walls	Main riverside	Miltenberg
				Blackpool Seafront	Blackpool
		38	Glass walls	Westhoven	Cologne
O	Barriers	39		Waalkade promenade	Zaltbommel

			Demountable barriers	Kampen waterfront	Kampen
				Landungsbrücken build.	Hamburg
P	Levees	40	Gentle slope levees	Corktown Common	Toronto
				Westzeedijk	Rotterdam
				Anf. Colina de Camões	Coimbra

4.2.1 Overall characterization of the proposed types and categories of measures

Numerous references have already described the types flood adaptation measures identified in Table 4.2. References which may be found not only from the analysed literature review but also from other occasional investigations. In most cases, the exposed definitions among these studies entail specific purposes or approaches such as the execution technics, materials, costs or the assessment of infrastructural efficiency. In similarity and yet with a distinct purpose, the following text will aim to specifically characterize the identified measures in regards to their applicability in the design of public spaces.

As such, and based on a scientific, grey and technical literature review, as well as on data collection, networking, site visits and empirical observations, a synthetized characterization of each category and type of measure is next proposed. Drawn schemes of each type of measure were further developed, namely as tool which helped the reasoning process behind the proposed typification and conceptualization (Cabezas 2001, Matos Silva 2008). In the end of this characterization section, all the sketched typologies are presented in one single matrix.

The coming characterizations will dwell upon the practical and operational considerations. Whenever appropriate, particular attention is given namely to: their primary and secondary infrastructural function, the materials that can be used in their implementation, the type of flood to which they are more appropriate to, the scale and extent of their benefits or maintenance requirements, among others. Overall, descriptions are supported by the literature from the previously highlighted state of the art overview, namely Philip (2011) and Prominski et al. (2012), together with other consulted references such as Novotny et al. (2010) and LNEC (1983).

A. Urban greenery

Every living plant can be considered as part of the urban greenery of a city. From the smallest *Bryophyta* (Moss) to the biggest tree, all living vegetation contributes to the "harvest" and "detention" of rainwater, thus contributing to the adaptation of floods specifically associated with rainstorms (pluvial floods). Measures within this category further include adjacent benefits such as carbon capture, microclimatic balance or biodiversity enrichment both flora and fauna wise.

Although tree alignments or vegetated balconies form part of the category of 'Urban greenery', '**Green walls**' is the only highlighted measure essentially because of its increasing use as an adaptation measure with significant aesthetical and infrastructural contributions.

1. Green walls

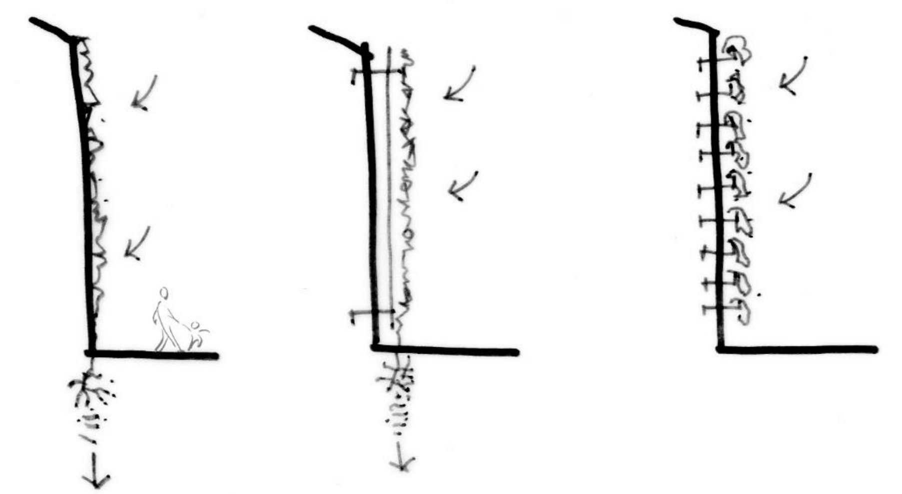


Figure 4.1 - Green walls. From left to right: 1) routed in ground, directly over a wall; 2) routed in ground, with supporting structure; 3) with growing medium. Source: author's sketch.

Green walls are widely known for their functional qualities of thermal regulation, biodiversity and rainwater harvesting. Green walls can also be known as vertical gardens or living walls. They are seen in both public and private properties. Most examples are an integral part of or influence its encompassing public spaces.

There is no minimum space required to install a green wall. They are usually installed in blind facades although they can be applied in almost any type of wall, namely walls with different materials or with varied available space. In order to maintain the high performance of green walls, maintenance is required, particularly in irrigation and drainage systems. Plants also need continued check-ups for pruning, deadheading and weeding.

Green walls are usually built over panels that sustain a growing medium. Among the different types of support media are: loose media, generally consisting of “soil-on-a-shelf” or “soil-in-a-bag”; mat media that can be of either coir fibre or felt mats; sheet media, usually of polyurethane and structural media that combines loose or mat medium in a structural block that can be designed with various forms. In other situations, vegetation emerges from ground planters, namely when using climbing species. In this former situation, green walls can be built directly over a wall or in a supporting structure (Figure 4.1). When green walls are built directly over walls a particular attention must be given to avoid moisture problems by contact or condensation.

There are many iconic examples of green walls in most major world-wide capitals. The green wall of Westblaak' car park silo in Rotterdam exemplifies the impact that this measure can have when extensively applied in an urban element such as an urban block. Although it is still far from reaching this goal (Figure 4.2), it aims to fulfil the 5.000m2 façade surface, equalling 200 mature trees. Rainwater is collected by the green structure and is used to irrigate its own plants and thus relieving overburdened sewer systems. It will further enriches the surrounding urban environment, both aesthetically and ecologically through the enhancement of the city centre's biodiversity.

Another example is the green wall at the Caixa Forum Plaza in Madrid. This particular green wall is not built directly over the building’s wall but rather in a supporting structure in order to avoid moisture problems. This structure, albeit attached to the building, is distanced enough so that it is possible to walk through its interior for monitoring of the irrigation and fertilization system. The vegetation that forms part of this green wall includes species such as *Arenaria montana*, *Bergenia cordifolia*, *Cornus sanguinea*, *Lonicera pileata*, *Sedum alpestre*, *Campanula takesimana*, *Garrya elliptica*, and different Begonias.

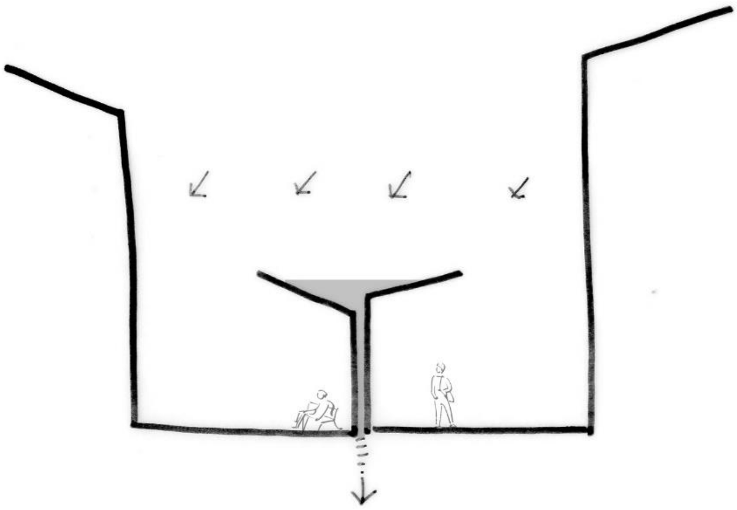
Figure 4.2 - Left: Intended end result. Simulation of Westblaak' car park silo. Source: Rotterdam Climate Initiative, 2009. Right: Westblaak' car park silo in 2010. Image credits: Maria Matos Silva, 2010.

B. Urban furniture

Urban furniture as a contributing element to flood adaptation started to encompass innovative ideas, particularly when facing the challenges presented by climate change. Among the materialized ideas are the '**Inverted umbrellas**' and '**Art installations**' of specific purposes.

2. Inverted umbrellas

Figure 4.3 - Type of adaptation measure: 2. Inverted umbrellas. Source: author's sketch.



As the name indicates, inverted umbrellas resemble upside-down traditional umbrellas and may have various shapes and sizes (Figure 4.3). With inverted umbrellas, incoming water flows inwards into the central column which may then lead it to a storage tank or into the drainage system for effective reuse or distribution of rainwater. Besides taking advantage of rainwater as a precious resource through harvest and storing functions, this measure may also serve as a shadowing structure, thus further contributing to microclimatic melioration through albedo reduction. This measure is particularly adequate for the adaptation to pluvial floods. Examples of interved umbrellas include the Mega-water-collecting-structure at the boulevard of Expo Shangha or the small inverted umbrella applied in a playground at Woolworths Shopping in Walkerville, Australia.

Figure 4.4 - Left: Mega-water-collecting-structure at the boulevard of Expo Shanghai. Image credits: © Tonylaw, 2010. Right: Inverted umbrella applied in a small playground at Woolworths Shopping in Walkerville, Australia. Image credits: © Universal Magazines Pty Ltd., 2013.

3. Art installations

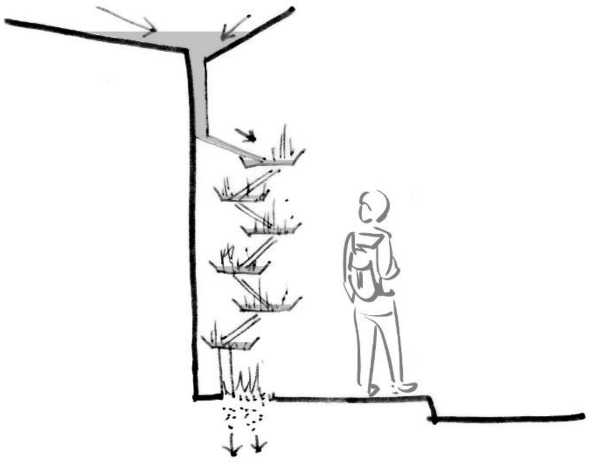


Figure 4.5 - Type of adaptation measure: 3. Art installations. Source: author's sketch.

Most art installations, namely the ones associated to flood adaptation purposes, have as its primary motive, the communication of information, namely of a problem or concern, and thus are more likely be related to strategic measures such as warning and escape information instead of operational measures[58]. Although only in some cases, art installations may also involve operational measures. That is namely the case of the art installation at Jawaharlal Planetarium Park in India previously highlighted in chapter three, or the art installations of Buster Simpson such as the Water Table / Water Glass and the Whole Flow (Figure 4.5 and Figure 4.6).

The Water Table / Water Glass intervention, located at Ellington Condominiums plaza in Seattle, Washington, represents a metaphor composed by two elements, "glass" and "table", which are both fountains. Both fountains are fed by the rainwater collected in the ten-story towers' roof: the "glass" is filled by the south tower while the fountain embedded within the "table" is fed by the north tower. The 2.4 meter high tapered "vessel-glass" is also a container that serves as a detention tank. Collected rainwater is expected to be of use for irrigation purposes (Buster Simpson 2015).

[58] Recalling the used criteria for the identification of flood adaptation measures applied in the design of public spaces, only operational measures were highlighted, leaving measures that are more strategic for other research endeavours. Operational measures are here understood as measures that, through technical design, face the potential vulnerabilities associated to flood threats. On the other hand, strategic measures are generally related to institutional, regulatory or political undertakings such as forecasting, warning, information, evacuation, aid services, building codes or shared risk and compensations.

The Whole Flow intervention briefly explained, is an artistic solution for a downspout. The designed structure recovers rainwater from the roof, aerates this collected rainwater through a number of flowing plates, and then finally directs the (now recycled) water into a plant sand (Buster Simpson 2015). The process of water descending through the bowls and cleansing its way onto being useful for irritation may be seen and heard by whomever crosses by the Whole Foods Store in Pasadena, California.

Figure 4.6 - Water harvesting art installations designed by Buster Simpson. Left: Water Table / Water Glass (2001) located at Ellington Condominiums plaza in Seattle, Washington. Right: Whole Flow next to Whole Foods Store in Pasadena, California. Source: (Buster Simpson 2015).

C. *Rooftop detention*

Roofs are a privileged area among urban territories as they comprise an elevated impermeable area from which the supply of good quality water can be easily collected for later use. Rooftop detention systems mostly comprise a multi-layered structure that is designed in accordance to the function and size of the roof system. This measure can be applied in small or large scale areas, from singular buildings to housing developments, from elevated obsolete train-lines to industrial estates. Public spaces may exist among any of these areas.

Besides the fact that capturing and reusing rainfall from roof surfaces can attenuate overall urban runoff, rooftop detention further contributes as a reliable source of water for irrigation and other non-potable uses on-site, such as toilet flushing, heating systems, direct groundwater recharge, among others. Commonly, the category of 'Rooftop detention' is associated or integrated to other identified categories and their respective types of measures, such as 'Reservoirs', 'Bioretention' or 'Permeable paving'.

The identified measures encompassed within the category of rooftop detention are '**Green roofs**' and '**Blue roofs**'. Both of which are particularly adequate for the adaptation to pluvial floods.

4. *Green roofs*

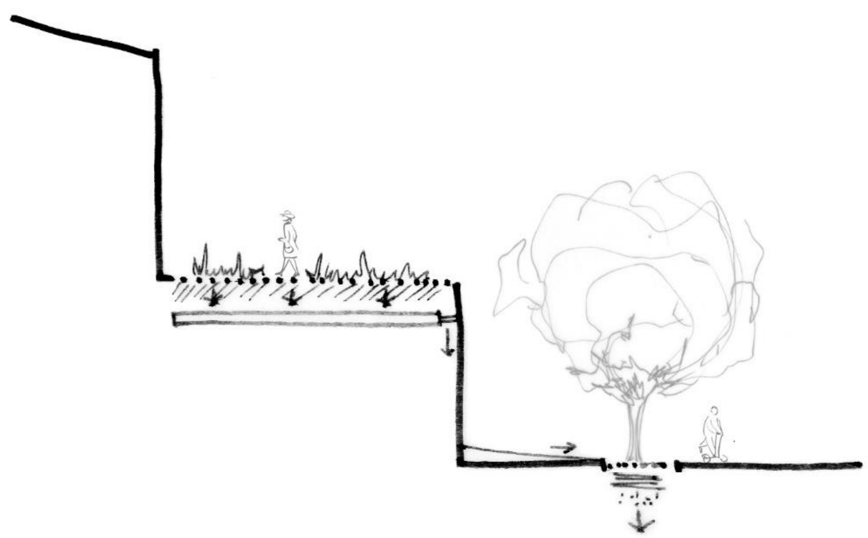


Figure 4.7 - Type of adaptation measure: 4. Green roofs. Source: author's sketch.

As the name suggests, green roofs are generally characterized by roofs covered with vegetation (Figure 4.7). Green roofs are usually divided by their range of vegetation "intensity". This characterizing range of intensity goes from green roofs of intensive use to green roofs of extensive use. Extensive green roofs have thin substratums and have few succulent plants. Intensive green roofs include a thick soil medium in order to sustain deep-rooted vegetation. They can be applied in both plain and sloping surfaces although particular attention must be given to the details of its design so that the roof remains water-hermetic.

Rainwater that is harvested by green roofs is purified by its composing vegetation and can later be let into other storage devices such as tanks or cisterns in order to be re-used. Besides contributing for the reduction of overall urban runoff, green roofs further improve thermal and acoustic insulation of buildings, promoting the reduction of energy consumption for heating and cooling. In the winter, green roofs contribute to stabilize the temperature of the living space serving as an additional heat insulating layer. During the summer, evaporated soil moisture resulting from the incidence of solar radiation provides a cooling effect which benefits all adjoining areas.

There are many examples of public space green roofs. Among the analysed cases in the scope of this research are Ewha Woman's University in Seoul, South Korea (Figure 4.8). Contrasting with other examples that retrofit pre-existing covering structures for the implementation of this type of measure such as the "Promenade Plantée" in Paris, France or the "High line park" in New York, US, the Ewha Woman's University project emphasizes how a green roof can be specifically designed to sustain a public space.

Figure 4.8 - Ewha Womans University in Seoul, South Korea, design by the office Dominique Perrault Architecture. Credit: © André Morin, 2008.

5. *Blue roofs*

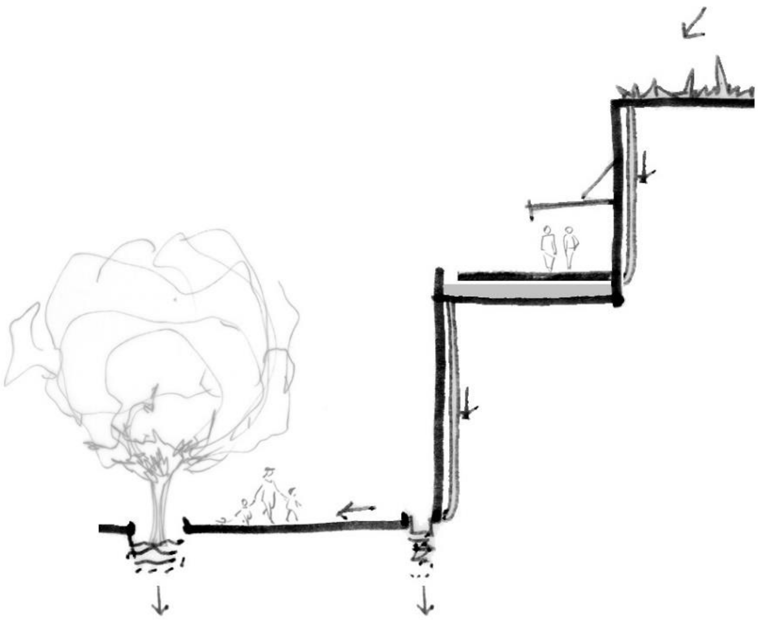


Figure 4.9 - Type of adaptation measure: 5. Blue roofs. Source: author's sketch.

Blue roofs, also known as water roofs, are similar to green roofs only they use various types of flow controls to regulate, block or store water instead of vegetation (Figure 4.9). More specifically, blue roofs commonly use downspout valves, gutter storage systems and cisterns (CCAP 2011).

Esplanades, for example, can be built over blue roofs, through a floating or elevated structure, or even placed over a permeable pavement connected to a cistern. Blue roofs may further serve as a water feature to be appreciated by its surrounding public spaces as may be evidenced by the case of Walterbos Complex at Apeldoorn (Figure 4.10).

Once rainwater is harvested by blue roofs it may be diverted onto adjacent public spaces and different types of adaptation measures. This complementary situation between blue roofs and other measures can be namely illustrated by the Stephen Epler Hall case at Portland State University.

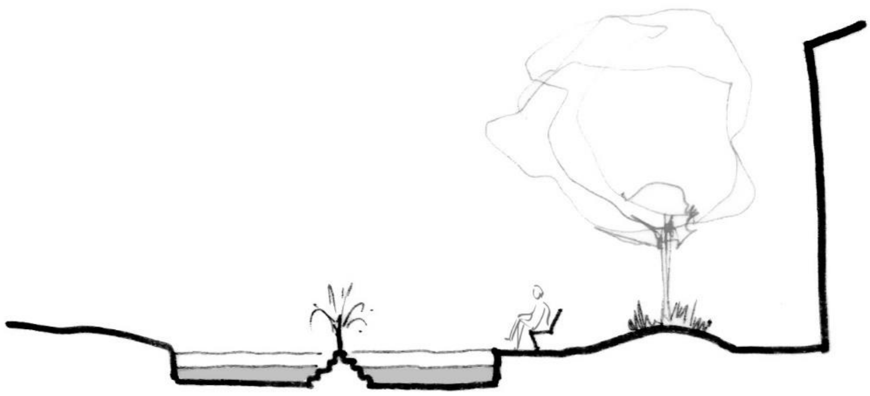
Figure 4.10 - Left: Blue roof at Walterbos Complex in Apeldoorn, Netherlands. Image credits: © Bart van Damme, 2010. Right: Blue roof implemented in a building at Trancas Canyon Malibu, US. Source: Douglas Bush Design, 2006.

D. Reservoirs

In the scope of this research, the category of Reservoirs groups measures that store water either from traditional "grey" sewage drainage systems or from other measures such as bioswales, blue roofs or green walls. Their main common purpose is not to lessen the volume of urban stormwater through natural infiltration or evapotranspiration, but to provide temporary storage during heavy rainfall and thus attenuate intensity peak flows through the posterior gradual release of runoff. Accordingly, they are rarely stand-alone solutions, requiring supporting infrastructure both up and downstream of its implementation site. Among the measures related to this category are '**Artificial detention basins**', '**Water plazas**', '**Underground reservoirs**' and '**Cisterns**'.

6. Artificial detention basins

Figure 4.11 - Type of adaptation measure: 6. Artificial detention basins. Source: author's sketch.



Artificial detention basins are above-ground reservoirs, usually located in downstream areas of low topographical elevation. They are commonly the receptors for rainwater from distanced watersheds that has been conveyed through separate drainage systems.

Artificial detention basins resemble sealed impermeable lakes with a permanent, albeit variable, water level. Usually these systems entail separate storage tanks in order to facilitate the control of water retention and subsequent continuing slow evacuation. Stagnant water can be very dangerous to public health, therefore this measure usually encompasses water features, such as fountains or cascades, which promote water dynamics and consequent oxygenation (Figure 4.11).

This type of measure can be built in various shapes and sizes, from a simple rectangle, as illustrated by the example of Poblenou park, to an undefined polygonal form as illustrated by Diagonal Mar park (Figure 4.12). Both examples are from the city of Barcelona. Considering the former example, it is possible to identify both the compartmentation of the lake in two different storage tanks, as well as the introduction of several water features including water and vapour sprays springing out of a tubular sculpture. This example further includes some vegetation surrounding the lake, which facilitates water oxygenation and promotes biodiversity.

Figure 4.12 - Left: Water feature within empty artificial detention basin at Poblenou park, Barcelona. Right: Tank compartmentation detail of the artificial detention basinsat Diagonal Mar park, Barcelona. Images credit: Maria Matos Silva, 2010.

7. Water plazas

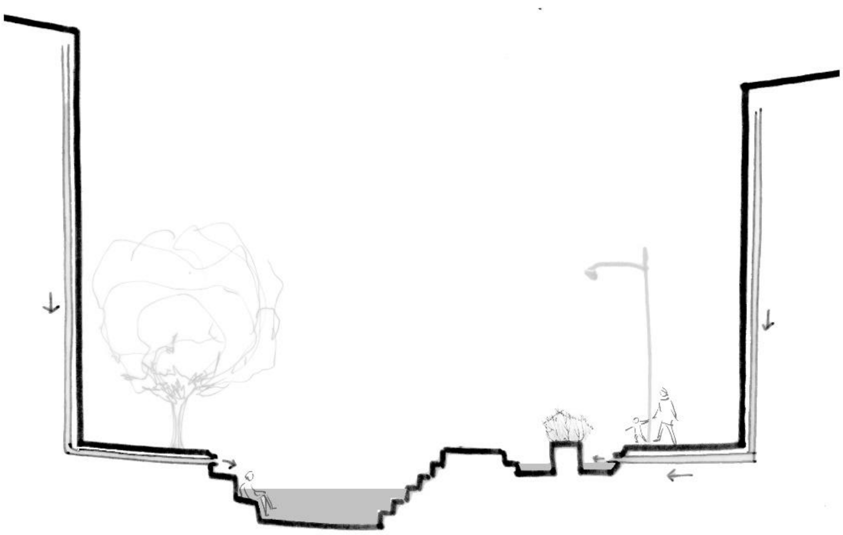


Figure 4.13 - Type of adaptation measure: 7. Water plazas. Source: author's sketch.

The water plaza or water square can be generally characterized by being a low-lying urban area, such as a square, which is submerged only during storm events (Figure 4.13). It is a measure that fits particularly well in densely built-up urban areas, and not only in downstream areas or areas with low topographical elevation. It is designed to harvest rainwater from the nearby surrounding area, arising from rainwater drainage systems as well as other types of measures such as green and blue roofs, green walls, bioswales, among others. Harvested rainwater in then directed to its sunken square, which stores the water and tolerates its temporary presence.

According to Rotterdam's second "Waterplan", water plazas can be divided into the following dissimilar subtypes: "the water balloon", "the deep square", "the shallow square", "the dam", "the recessed square" and the "smart street profile" (Sliedrecht et al. 2007, p.98). All of which have the distinguishable characteristic of being a particularly adequate adaptation measure to be applied in inner-city areas, especially where outflows are hindered, such as in situations when high ground water levels impede infiltration. Another feature particular to water plazas is that their design is inherently associated to the design of urban public spaces. Resulting implementations therefore entail variable dimensions and thus different water retention capacities. In addition, among the analysed examples, their design can either have vegetation or solely inert materials.

Designed as an urban public space, this measure must encompass one or multiple urban functions. In addition, it can be designed so that some areas are deeper than others and thus the flooding can be processed in stages. In the case of Benthemplein square, for example, the borderline and smaller basins fill up first (Figure 4.14) before the larger and deeper sports field (Figure 4.16). While the plaza will remain dry for most of the year, if there is a heavy rainfall, water will be temporarily stored within these interstitial spaces. In this implemented example one can further note the attention given to the integration of the infrastructural requirements, such as the open drainage canals or the inflow channels, with the design of the public space (Figure 4.15).

This type of measure has been considered as an efficient solution for compact urban areas where water does not flow away easily (Boer et al. 2010). In addition, by making water visible, a closer social approach with regard to the water cycle and flood dynamics is instigated. In other words, by encouraging people to become closer to natural changes and the flood management process, they are more likely to expect and monitor them, with the possibility and likelihood to also accept them.

Lastly, it is important to bear in mind the maintenance required for this type of measure after its implementation. Once the water that reaches the square is unlikely to have been previously purified, it carries with it some pollutants and solid materials such as mud, litter, leaves and branches. This waste remains on the square after water volumes have been redirected. As such, these solid materials need to be removed when the square becomes dry after a storm so that the designed urban area can maintain its attractiveness as a public space.

Figure 4.14 - Left: Dry borderline basin at the Benthemplein square in Rotterdam, Netherlands. Image credits: Maria Matos Silva, 2014. Right: Flooded borderline basin at the Benthemplein square in Rotterdam, Netherlands. Image credits: © Johannes Odé.

Figure 4.15 - Right: Dry open drainage canals at the Benthemplein square in Rotterdam, Netherlands. Image credits: Maria Matos Silva, 2014. Left: Stormwater conveyed by the open drainage canals at the Benthemplein square in Rotterdam, Netherlands. Image credits: © Jurgen Bals.

Figure 4.16 - Above: Dry central basin that is also a sports field. Benthemplein square in Rotterdam, Netherlands. Image credits: Maria Matos Silva, 2014 Below: Inflow channel in central basin that also works as a water feature. Benthemplein square in Rotterdam, Netherlands. Image credits: © Jurgen Bals, 2014.

8. Underground reservoirs

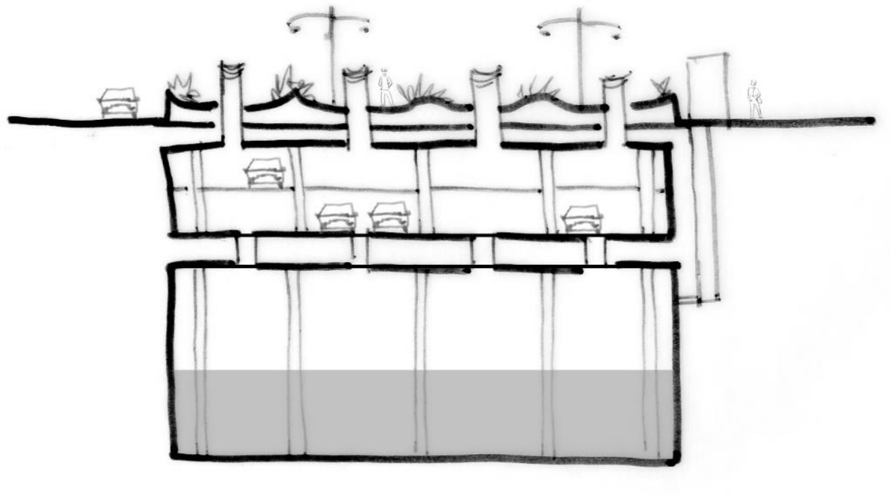


Figure 4.17 - Type of adaptation measure: 8. Underground reservoirs. Source: author's sketch.

Underground reservoirs, also known as regulation reservoirs, are a highly specialized drainage infrastructure measure. They are generally large in scale and therefore difficult to implement in compact urban areas.

At first, it can be difficult to conceive how this measure relates to public space. However, as the city of Barcelona has taught us, with more than eleven implemented reservoirs, it is possible to have this large-scale infrastructure integrated with the design of bellow an above-ground public space (Figure 4.17). Albeit with some limitations and requirements, Barcelona's public spaces, which exist above underground regulation reservoirs, range from parks to sport fields, from plazas to streets.

Off all the types of measures comprised within the category of reservoirs, underground regulation reservoirs is the only measure that may receive more than just rainwater. More specifically, this type of measure is usually integrated within pre-existing combined sewerage systems that mix both sewerage and stormwater. One of the main goals of this measure is therefore to avoid Combined Sewage Overflows (CSO's). Once stored, the stormwater volumes combined with sewerage flows can be gradually sent to the Wastewater Treatment Plant (WWTP).

Underground regulation reservoirs are capable of storing very significant volumes of water. Barcelona's reservoir at Zona Universitària, for instance, can store up to 105.000 cubic meters of water, equivalent to about 42 Olympic swimming pools. Bearing in mind its size and necessary structuring system as well as the deep excavation requirements, the cost associated to implement this measure is also considerable.

As highlighted in Matos Silva (2011), among the mandatory equipment that has a direct interference in the design of public spaces are: ventilation systems with a minimum height of 2m, expansion joints, hydrants, emergency exits and technical galleries. In addition, plantations are limited to the capacity of the reservoir's cover slab. Trees, for instance, are generally installed over the reservoir's pillars. Bearing in mind these prerequisites "it's up to the designer to choose whether to use them in a discreet or manifest way" (Matos Silva 2011, p.39).

The case of Joan Mirò park is an example of how the aforementioned requirements can be harmonized in the design of a public space (Figure 4.18). One of the highlighting characteristics of this design is an extended soil bed, raised 0.3 to 0.8m from the ground level, which forms vegetated land ramps of slight inclination. In this case it was further possible to combine a multi-storey subterranean car park in-between the reservoir and the public space, which has likely diminished the costs of such great infrastructural investment.

Figure 4.18 - Vegetated public space above underground regulation reservoir at Joan Mirò park, Barcelona. Notice the presence of the mandatory ventilation systems. Image credit: Maria Matos Silva, 2010.

9. Cisterns

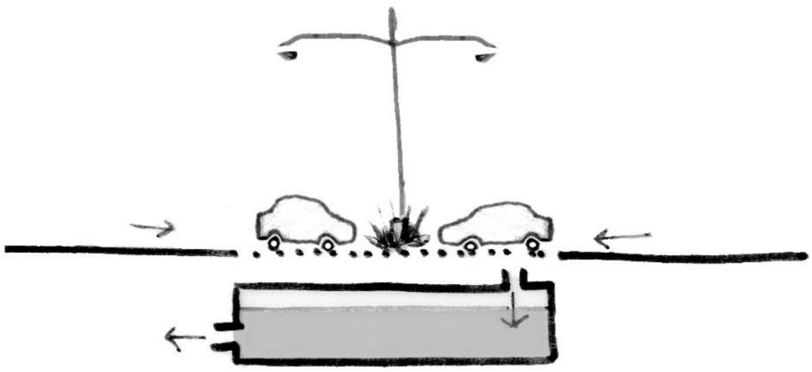


Figure 4.19 - Type of adaptation measure: 9. Cisterns. Source: author's sketch.

Cisterns are an ancient concept consisting essentially on an impermeable container for storing liquids, generally harvested rainwater that can serve for later use (Figure 4.19). They can be built either below or above ground, or even on a roof. Today, some ancient cisterns have turned into public monuments. That is the case of the Basicila Cistern (Yerebatan Saray) in Istanbul, Turkey, or the cistern below Principe Real Garden in Lisbon, Portugal. However, in the scope of this research, cisterns are understood as reservoirs of small dimensions, which store rainwater runoff from near-by areas. These storage chambers can be built with various materials in accordance with their specific implementation contexts, from concrete to plastic. They can be distinguished from underground regulation reservoirs for their dimensions and water basin coverage, as well as their specification to only receive rainwater. More specifically, while detention basins and underground reservoirs are usually constructed to collect runoff from a wide area such as a housing estate or industrial area, in the scope of this research, cisterns are reservoirs that collect runoff from adjacent streets, buildings or through pavements. This last approach is often mentioned in literature as a separate measure named "reservoir pavements".

The landscape architecture project (by Olin Partnership) of the Ray and Maria Stata Center at the MIT in Massachusetts, is a good example of an autonomous water management system integrated in the design of a public space (Figure 4.20-left). Within this system, composed of several measures, is a cistern below a constructed wetland. This cistern is composed of stacked, injection-moulded plastic panels and in between the cistern and the wetland there is an isolating Geosynthetic Clay Liner (Zheng 2007, p.47). The cistern collects and stores rainwater that is previously filtered by passing through soil and hydrophilic plantings. Collected water in the cistern is used for irrigation of the gardens and toilet flushing.

For an example of a reservoir pavement, or of a cistern right below a pavement structure, one can consider the case of Georgia Street in Indianapolis, also in the US (Figure 4.20-right). In a subtle yet significant design, this street collects rainwater runoff into its central permeable boardwalk, below which there is a water management system that alleviates the city's overloaded combined sewers. Collected rainwater from the street is firstly directed to a stormwater forebay that serves for irrigation. When forebay troughs below the permeable pavement are full, overflows runoff into an infiltration basin composed by a sandy subsoil, which will further filter water before recharging the ground water aquifer. According to RATIO Architects, this system will reduce Georgia Street's runoff by more than 50 percent during a 10-year rain event and 40 percent during a 100-year storm.

Figure 4.20 – Left: Detail of the wetland over the cistern at the Stata Center exterior spaces, MIT, Cambridge. Image credits: Jay R. Hood, 2014. Right: Detail of Georgia Street in Indianapolis, US. Image credits: © RATIO Architects, 2012.

E. Bioretention

Bioretention measures can be generally characterized by their capacity to simultaneously include the processes of detention, infiltration and evapotranspiration. They consist on excavated landscaped areas in which runoff is collected and infiltrated through the soil below and, if necessary, into an underdrain connected to the main drainage system. Measures included in this category generally entail a broken stone bottom layer and engineered soil in order to offer high infiltration rates and efficient pollutant removal as well as fertile growing conditions for vegetation. Planted vegetation may vary from herbaceous species to woody bushes and even trees. In addition, an overflow mechanism is occasionally included when surface storage is exceeded and overspills to adjacent areas are unwanted.

Through the implementation of these measures it is possible not to increase the risk of floods in new housing developments, its associated roads, pavements and parking lots. When encompassing vegetation, these measures additionally provide amenity value for urban environments. The visual impact of spaces comprising these measures is improved together with biodiversity and the quality of water and air.

Among the measures encompassed in this category are '**Wet bioretention basins**', '**Dry bioretention basins**', '**Bioswales**', '**Bioretention planters**' and '**Rain gardens**'.

Some important implementation and maintenance specificities are common to all the aforementioned measures. Among them are the requirements of any landscape design, namely the short-term maintenance in the first and second year's. Other maintenance needs include the removal of trash and debris, the monitoring of clogging and the removal or trimming of undesired plants.

10. Wet bioretention basins

Wet or Dry Bioretention basins aim to reduce overall pluvial runoff, minimize the outflow volumes during extreme events and alleviate the pressure upon existing combined drainage systems. These measures additionaly promote the infiltration of retained water volumes through a built bottom substratum and surrounding slopes, favouring aquifer recharge. These basins can be either "wet" or "dry", meaning that they can either have a permanent water level or only temporarily hold stormwater during extreme events.

Adjacently, these measures are mostly compatible with recreation activities as they enclose a generally large, vegetated area, which contributes towards environmental comfort and ecological quality. Both wet and dry bioretention basins can be designed in a way that promotes public use, contrasting with conventional engineered retention basins that often comprise lined rectangular basins with informative signage to keep the public away. Collected and stored runoff within these measures may additionally serve as water supply for irrigation and firefighting purposes.

Specific maintenance procedures associated to these measures include: water quality control of the stormwater inflow; water quality control of stored water; removal of floating elements; cleaning of drainage devices, such as storm outlets or grid chambers; and protection, treatment and cleaning of the bottom and edges of the basin (LNEC 1983, p.256).

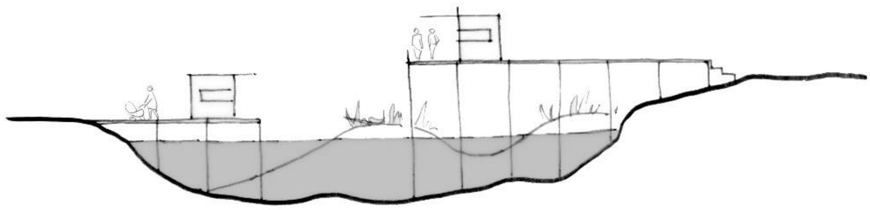


Figure 4.21 - Type of adaptation measure: 10. Wet bioretention basins. Source: author’s sketch.

Particularly in the case of wet bioretention basins, additional stormwater volumes are stored above the permanent water level (Figure 4.21). The depth of the pond should range from 1 to 3 meters, and it is additionally important for the marginal slope to be gentle in its gradient so that the risk of drowning is minimized (Novotny et al. 2010. p.205).

Among the many examples of wet bioretantion basins is the Qunli Stormwater Wetland Park designed by Turenscape. In this notable case, together with an ecological restauration of a pre-existing wetland, a new public park was designed. Among other features, this park offers an intricate network of paths, some at a groundwater and others at an elevated level, from which the ecological processes of the natural landscape can be appreciated (Figure 4.22).

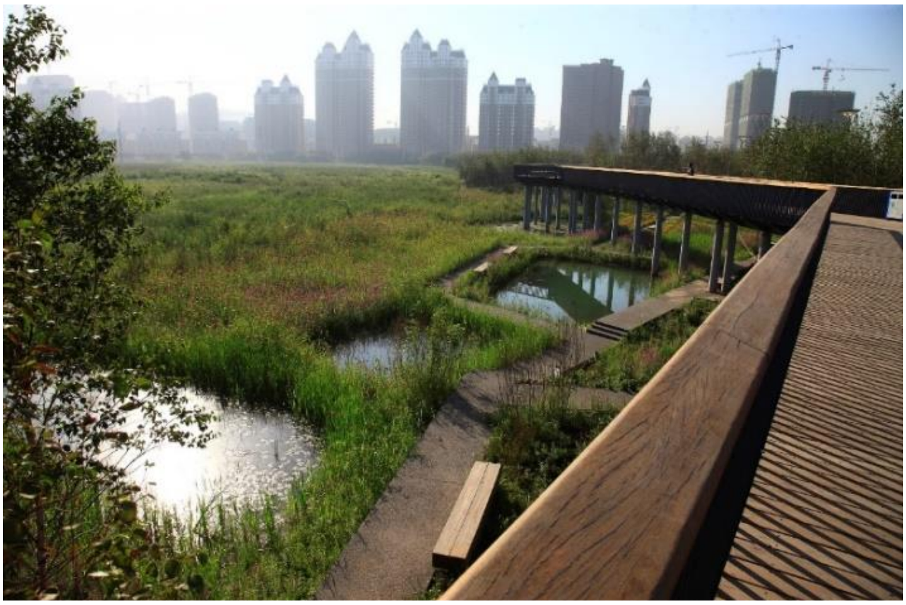


Figure 4.22 - Detail of Qunli Stormwater Wetland Park. Elevated and groundwater level path system. Image credits: Courtesy of Kongjian Yu/Turenscape.

11. Dry bioretention basins

Figure 4.23 - Type of adaptation measure: 11. Dry bioretention basins. Source: author's sketch.

Dry bioretention basins are also very common in mainstreamed drainage endeavours. During dry weather, and when designed on a bigger scale, they may welcome other uses such as temporary markets or football fields. When designed on a smaller scale, they may include complementary benches or facilities for art installations (Figure 4.23). They are generally different from the 'Submergible park' measure because of the limited excavated and concave form, and because they are not so commonly applied in downstream areas. They might also resemble raingardens when designed on smaller scales yet they do not comprise dense plantations. Dry bioretention basins rather include a highly porous substratum particularly targeted for stormwater to be filtrated and infiltrate.

Dry bioretention basins must not be implemented in areas with high groundwater levels as it may lead to prolonged standing water and consequent intrusion of untreated contaminants into the soil as well as mosquito breeding. In the same line of reasoning it is a measure unadvised for the adaptation to groundwater floods.

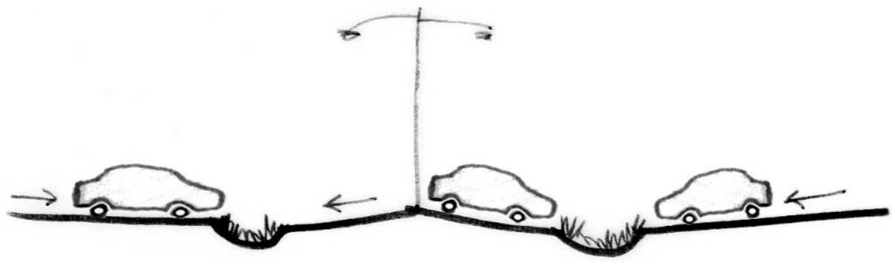
One can consider Parque da Cidade at Porto as an example where this measure is applied in various forms, on a small scale (Figure 4.24).

Figure 4.24 - One of many dry bioretention basins at Parque da Cidade, Porto, Portugal. Image credits: Maria Matos Silva, 2016.

12. Bioswales

Bioswales, bioretention planters and rain gardens entail further common characterizing aspects. In similarity with dry bioretention basins, these measures must avoid high groundwater levels. There should be a considerable depth between the ground floor of these measures and their bottom layers in order to properly treat stormwater. They are also particularly inappropriate for areas with highly contaminated runoff given their limited purification capability. They are also not adequate for drainage areas with great storm volumes and velocities due to the consequences of erosion, which may significantly reduce their infrastructural capacity to store runoff and thus attenuate peak flows. Both bioswales, bioretention planters and rain gardens have been used to provide traffic calming and delineate parking bays. It is however important to note that these three measures should be located some meters away from buildings in order to prevent foundations from being damaged by moist. Lastly, as measures of a relatively small scale, they may further endorse community involvement. In some implemented examples, residents have a shared responsibility to maintain these bioretention areas. In other situations, these measures are applied in private property, albeit benefiting all public surrounding areas, both as a drainage infrastructure as well as an environmental amenity.

Figure 4.25 - Type of adaptation measure: 12. Bioswales. Source: author's sketch.



Specifically regarding the bioswales measure, they can be generally characterized as a linear vegetated ground channel designed to collect, treat, infiltrate and, in particular, convey runoff. Bioswales are generally shallow, have a variable section and are commonly covered by grass and/or small bushes. This measure therefore also reduces runoff and is capable of naturally filtering some pollutants by the vegetation and underlying soil. Bioswales may be easily retrofitted into existing urban areas, namely along streets or integrated in the design of parking lots and other open space areas of public usage. Besides their infrastructural value, bioswales can additionally contribute as physical boundaries or simply for the encompassing aesthetic comfort value.

Among the several existing examples of implemented bioswales, the case of the High Point Redevelopment in Seattle illustrates how this measure can be integrated in the design of its public spaces (Figure 4.26).

Figure 4.26 - Left: Bioswale at High Point Redevelopment natural drainage, 30th Ave SW South of Graham, Seatle, Washington. Image credits: © SvR Design Company, 2006. Right: High Point Neighborhood mentioned in Ped Shed Post. Image credits: sitephocus.com

13. Bioretention planters

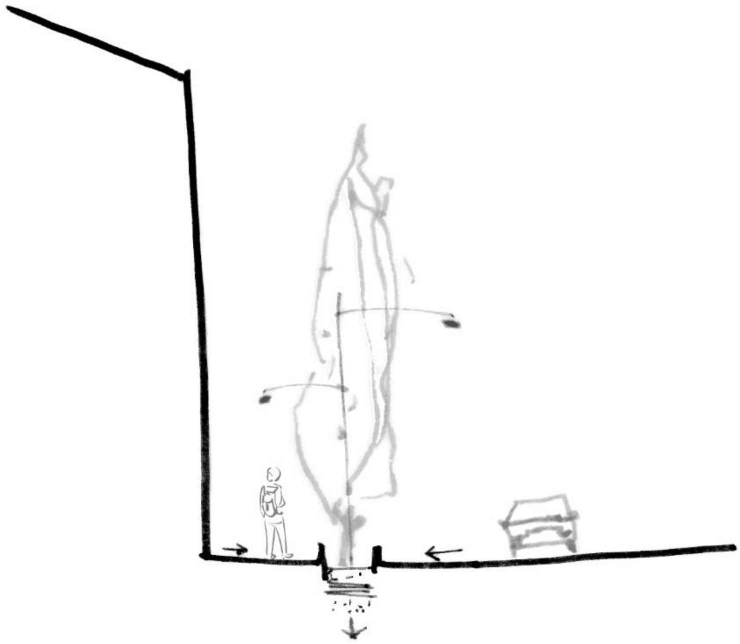


Figure 4.27 - Type of adaptation measure: 13. Bioretention planters. Source: author's sketch.

Bioretention planters can be generally characterized by being vegetated depressed planters, sequentially implemented along a road, commonly composed of various scrub and small tree species bounded by a kerb (Figure 4.27). In some examples, bioretention planters are also fenced along their limits. These particular planters are filled with a gravel and rock medium that filters collected stormwater and promotes its infiltration into the soil. Unlike the bioswales more targeted at the transport and depuration of stormwater, bioretention planters are mainly aimed to store water within each "planter" and to gradually promote its infiltration. This measure is therefore most efficient when associated with other measures that capture and convey stormwater such as green roofs or bioswales.

These specialized landscaped planters may be designed to fit within sidewalks, road separators or park boundaries. Although their design may vary in shape, they are usually rectangular with vertical edges on all four sides. These edges may further contribute to the surrounding public space design as they could have other functions such as a seat wall, an artistic fence, amongst others. This measure is commonly built between existing surface features such as driveways, signs, street furnishings and street trees. In some cases it serves to separate pedestrians from the moving traffic. In this latter situations, an adequate sidewalk that accommodates both the bioretention planter and pedestrian circulation is required.

In order to better exploit the capabilities of this measure, the existing soil should not be too porous as it may reduce the treatment capacity and increase the risk of groundwater contamination. Likewise, reduced permeability may lead to the clogging of the system. In keeping with this method, it is advisable the use of sedimentary traps. For an illustrative example of a bioretention planter, one may consider the project at Bakery Square in Pittsburgh, US (Figure 4.28).

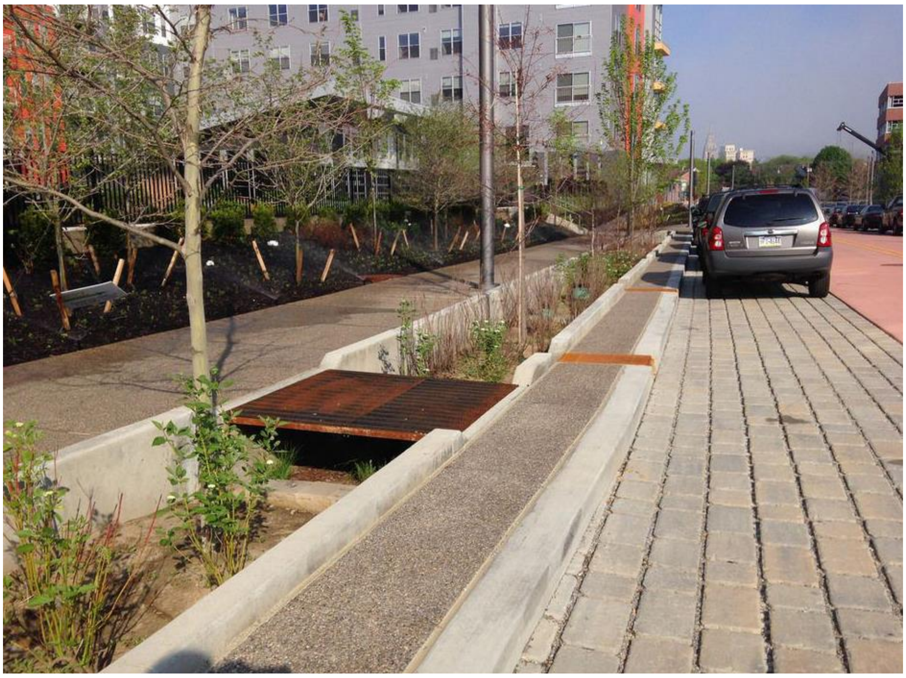


Figure 4.28 - Bioretention planter and semi-permeable interlocking paver at Bakery Square in Pittsburgh, US. Image credits: © Pittsburgh Green, 2015.

14. Rain gardens

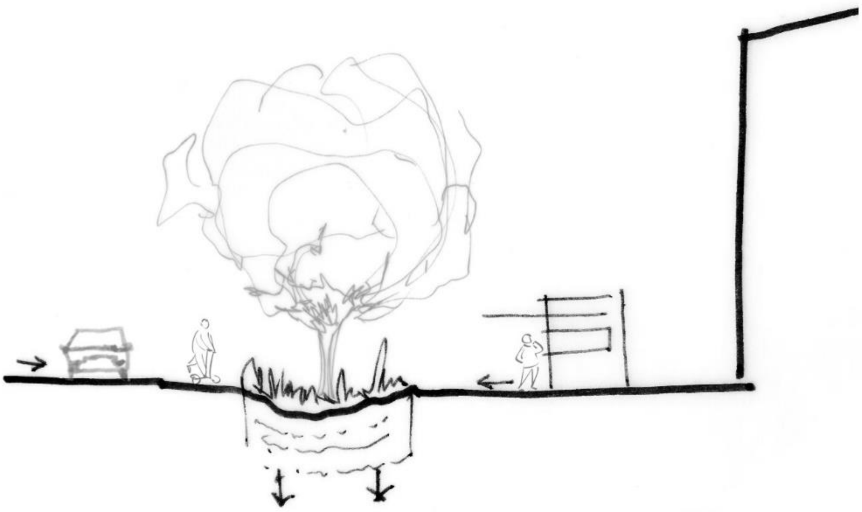


Figure 4.29 - Type of adaptation measure: 14. Rain gardens. Source: author's sketch.

Raingardens, still within the category of Bioretention, are particularly envisioned to imitate the natural rainwater absorption of a forest or meadow. They consist of depressed areas, planted with a variety deep-rooted filtrating shrubs, perennials and trees that receive and infiltrate rainwater (Figure 4.29). The commonly varied use of vegetation species further promotes a rich localized biodiversity.

The design of raingardens is very diverse, albeit most are irregular in form. They are usually bigger than bioretention planters and smaller than retention and infiltration basins. Rain gardens can be incorporated within most outdoor urban landscapes, although they are more commonly found in residential yards and parks.

Taasinge Square in Copenhagen, Denmark, integrated in the municipal Climate Adaptation Plan, is one example of a rain garden among many others, usually of smaller scale, implemented within urban developments (Figure 4.30).

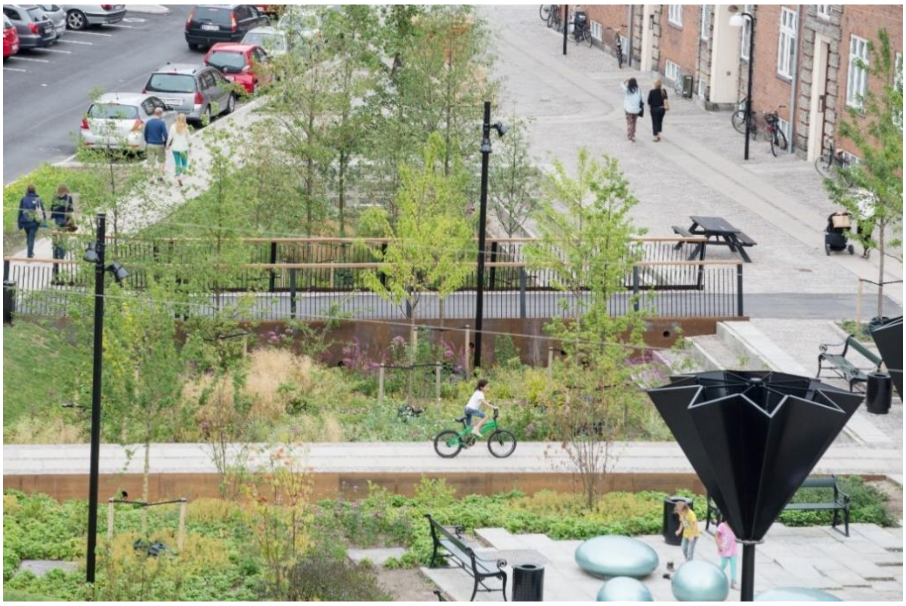


Figure 4.30 - Rain garden at Taasinge Square, Copenhagen, Denmark Image credits: © David Buchmann.

F. Permeable paving

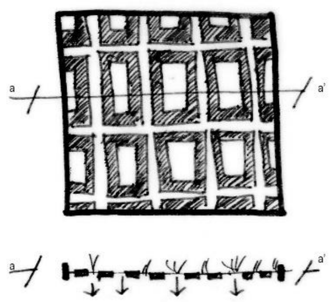
Permeable paving or pavement is a pervious surface that allows rainwater to infiltrate through its surface and into an underlying storage layer. From this storage layer, water can infiltrate into the ground, and can be reused or conveyed into other measures such as a raingarden for instance. Permeable pavements can therefore attenuate runoff and can remove common street pollutants such as hydrocarbons and metals through absorption and filtration processes occurring in their pervious surface as well as their hidden sublayers.

Measures associated to this category are commonly used for source control purposes as they manage rainfall that directly lands on its surface. They are generally able to cope with severe storms and are thus beneficial for the adaptation to pluvial, fluvial and coastal floods. However, some potential constrains are important to bear in mind: "soils with low infiltration rates may not be suitable for porous paving; drainage through paving will not be able to infiltrate soils that are saturated due to a high water table; porous paving needs to be strong enough to withstand the weight and volume of traffic that uses the road; the construction of the porous paving needs to be appropriate for the volume and intensity of rainfall" (Philip 2011, p.35), amid others.

Among the highlighted measures within this category are: '**Open cell pavers**', '**Interlocking pavers**' and '**Porous paving**'. While open cell pavers allow water to enter through the gaps between the pavers, porous paving is made of aggregate materials with some porosity that allow water to pass through their surface. All of which can be designed for car or pedestrian traffic and can be implemented in almost any urban area. Presently, there is a wide variety of pavement designs and materials, which can further add to the aesthetic quality of a space. Their texture can also serve to distinguish areas or to slow or quiet traffic.

15. Open cell pavers

Figure 4.31 - Type of adaptation measure: 15. Open cell pavers. Source: author's sketch.



Simply put, open cell pavers pave surfaces with gaps (Figure 4.31). The individual units of pavers can have inherent holes or the pavement openings are set by the way the pavers are installed. The paver's materials can range from concrete to plastic (Figure 4.32).

Figure 4.32 - Left: Open cell pavers at Park Ave, Swissvale in Pittsburgh, US. Image credits: © Pittsburgh Green, 2015. Right: Open cell pavers applied for a parking lot. Image credits: Tim De Winne and Karolien Keppens.

16. Interlocking pavers

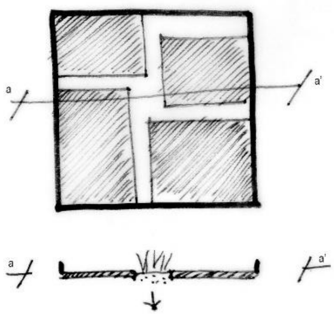


Figure 4.33 - Type of adaptation measure: 16. Interlocking pavers. Source: author's sketch.

Interlocking pavers are here seen as a pavement of interlocking blocks (Figure 4.33 and Figure 4.34). These blocks can be of regular or irregular stone or concrete. The distance applied between blocks may vary, regardless of this, it must not be too long so that they are no longer considered a pavement nor too short so that they are no longer permeable.

Another factor that can make this type of permeable or semi-permeable paving into an impermeable pavement is the level of compression. In situations where the paved surface reaches its maximum load capacity, for being frequently used and/or by sustaining heavy weights, its structuring layers are so compressed that no water infiltrates. This phenomenon is frequently observed in densely populated compact urban areas where the typical Portuguese pavement "Calçada Lisboeta" is applied. Albeit being a pavement that is generally characterized by being semi-permeable, in most situations, namely in Lisbon's centre, this pavement is entirely impermeable.

Figure 4.34 - Left: Interlocking pavers at Mondego Park in Coimbra, Portugal. Landscape Architecture project by PROAP. Image credits: Vitor Oliveira, 2008. Right: Interlocking pavers at Phipps Conservatory Green Roof in Pittsburgh, US. Image credits: © Pittsburgh Green, 2015.

17. Porous paving

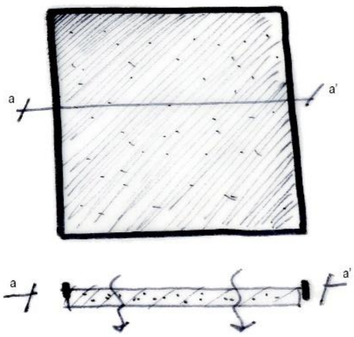


Figure 4.35 - Type of adaptation measure: 17. Porous paving. Source: author's sketch.

Albeit having substantially different environmental effects, porous paving is visually similar to nonporous materials (Figure 4.35). Pervious materials for the above layer of porous pavings can range from pervious concrete to porous asphalt or a simple aggregate of grit or broken stone[59]. As illustrated in Figure 4.36, the works at Percy Street in Philadelphia, US, can serve as an example of porous asphalt applied in a small urban street.

Figure 4.36 - Construction and final result of the implementation of a porous asphalt at Percy Street in Philadelphia, US. Image credits: Left: © Seravalli Inc, 2014; Right: © Philadelphia Water Department, 2013.

[59] As technology evolves, porous paving's increase their absorbing capacity. In recent years, Lafarge Tarmac, a British building materials company, has come up with a new type of concrete that has the capacity to absorb 4,000 litres of water in around a minute.

G. Infiltration techniques

In the scope of this analysis, the types of measures associated to this category are primarily targeted at fulfilling the purpose of infiltration or, in other words, the rapid infiltration of stormwater. This approach does not neglect the fact that other types of measures, integrated within other categories, might also encompass the same infrastructural function as a secondary purpose.

Among the measures specifically targeted to infiltrate stormwater, one may consider: infiltration trenches, leaky wells, geocellular systems and green gutters. Regardless, only '**Infiltration trenches**' and '**Green gutters**' were substantiated with implemented examples by the portfolio screening developed in this research.

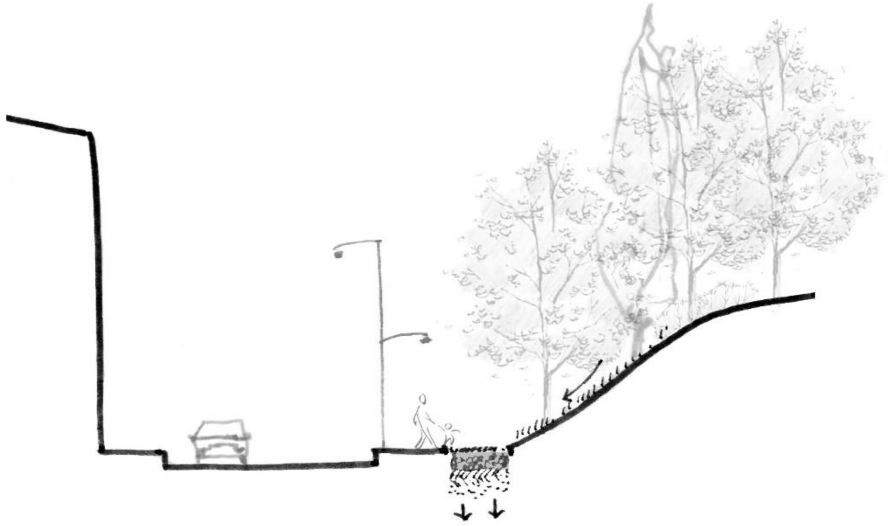
The types of measures within this specific category feature underground layers that may be composed of gravel, sand, or broken stones. The design criteria, such as the materials to use in the sections of each underground layer is highly dependable on rainwater intensities and the conditions of local soil and available space. They can be implemented in various urban settings from public gardens to roadside alignments, from parking lots to roundabouts.

Measures within this category are not adequate for areas with high water levels, or for areas that receive runoff with high pollution levels. They are also particularly inappropriate when subsurface soil is not sufficiently permeable.

For prevention purposes, raised drains should be provided when implementing measures within this category. If the infiltration systems, trenches or green gutters, reach their retention capacity after an intense storm, stormwater should be redirected to where it is most convenient. This same concern is applied to the types of measures within the category of Bioretention.

18. Infiltration trenches

Figure 4.37 - Type of adaptation measure: 18. Infiltration trenches. Source: author's sketch.



Infiltration trenches collect and retain stormwater until it infiltrates into the subsoil or evaporates into the atmosphere (Figure 4.37). This type of measure not only reduces peak volumes to downstream basins, but also improves the quality of stormwater discharges to the receiving environment through its porous and filtrating layers.

Infiltration trenches can be generally characterized by having a relatively shallow depth (no more than one meter), a gentle concave depression and a longitudinal development. They are relatively easy to implement and are not very costly (LNEC 1983). Constituent layers of this type of measures generally include a gravel layer, where sediment, leaves and debris are trapped, surrounded by a geotextile fabric.

Figure 4.38 - Ornamented infiltration trench at Etna Butler Street in Pittsburgh, US. Image credits: © BH Buchart Horn Engineers Architects Planners, 2014.

19. Green gutter

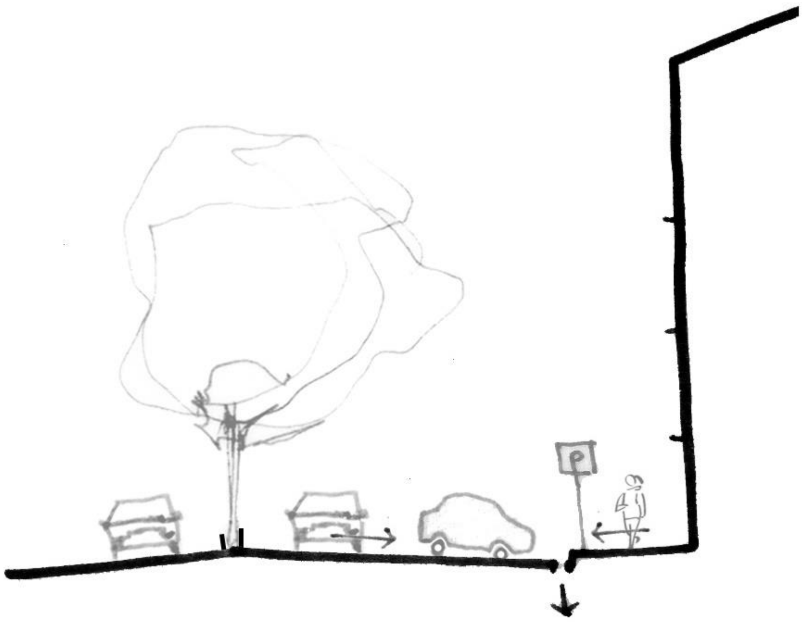


Figure 4.39 - Type of adaptation measure: 19. Green gutter. Source: author's sketch.

A green gutter is a thin and shallow landscaped strip, which can be located namely between a road and its sidewalk. In similarity with infiltration trenches, this type of measure is developed longitudinally, it is also designed to manage stormwater runoff mostly through the process of infiltration yet with inferior volume capacity. In accordance, this measure is commonly placed below the street's gutter and requires a reduced area for implementation. Other benefits include the improvement of the overall amenity of the streetscape and the provision of a physical separation between pedestrians and the traffic lane. The design of its edges should bear in mind the inhibition of pedestrians, cyclists or cars from falling into the green gutter. It is therefore a measure that may not be considered adequate for areas of intensive pedestrian use, such as exterior markets, children's playgrounds or parks. Its management requires the conventional maintenance of green areas (Figure 4.39 and Figure 4.40).

Figure 4.40 - Green gutter example. Image source: (City of Philadelphia 2014).

H. Stream recovery

Stream recovery, here only focused upon urban territories, essentially involves the processes of improving or recuperating, totally or partially, the natural ecosystem of a watercourse. This process may be accomplished in a small section of the stream or in its total length. It is however important to note that stream recovery is only possible when major pollution sources have been eliminated, namely CSO's and SSO's (Combined Sewage Overflow and Sanitary Sewage Overflow).

In dense urban settings, the ecological potential of a stream recovery adaptation project can rarely be comparable to that achieved in a less urban setting. Regardless, recovered streams must be ecologically viable and sound as they will technically become part of the surface drainage system.

Other benefits are more likely enhanced in urban settings, namely the ones that respond more directly to human needs and uses. Accordingly, besides the possible ecological improvement in urban territories, stream recoveries must also encompass the goals to please the public with adequate opportunities for recreation and enjoyment.

Public spaces generated out of stream recovery projects are common nowadays. Considering the extended literature on the subject of urban rivers and its recovery, namely research works from Graça Saraiva or Mathias Kondolf or feasibly studies applied to particular contexts (such as Lehrer et al. 2010), a significant number of examples can be considered as exemplary in the improvement of a communities' quality of life. Most examples are also exemplary as flood adaptation undertakings applied for most types of floods. Measures within this category also contribute to the increase of flow capacity of the river system during flood events and can reduce the velocity of water flows. By improving the riparian habitat of streams, these measures also harvest stormwater and promote groundwater recharge.

Among the highlighted processes of stream recovery are: '**Stream rehabilitation**', '**Stream restoration**', and the process of '**Daylighting streams**' that were formerly concealed**.**

20. Stream rehabilitation

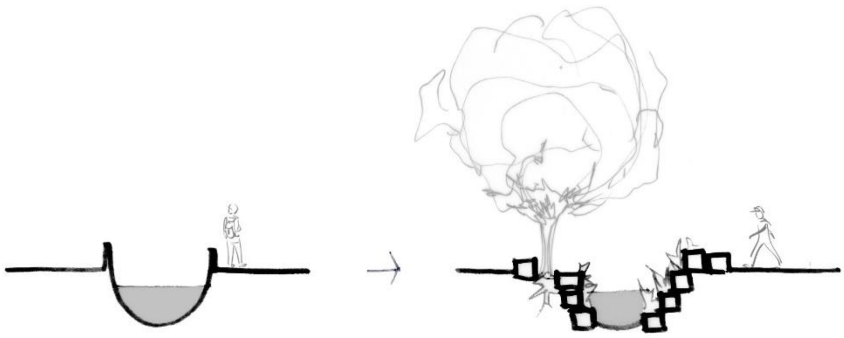


Figure 4.41 - Type of adaptation measure: 20. Stream rehabilitation. Source: author's sketch.

In the scope of this research, stream rehabilitation is understood as a partial improvement of a severely disturbed open stream. A severely disturbed open stream is here considered, for instance, a natural stream that has been channelled by a half-piped concrete conduit. Stream rehabilitation is therefore essentially targeted at resurrecting the stream back into a good or sufficiently good working order. By applying this adaptation measure, the benefits will invariably improve the visual aspect of that particular artificialized stream and partially improve its ecological status, although not completely. (Figure 4.41).

An example here considered as stream rehabilitation is the intervention made in Ribeira das Jardas at Agualva-Cacém, Sintra financed by the Polis Program[60] (2001-2008) and designed by NPK-landscape architects. This project gave rise to a new urban park by a watercourse that was previously bounded by a limited concrete wall (Figure 4.42).

Figure 4.42 -Ribeira das Jardas at Agualva-Cacém, Sintra. Design by NPK-landscape architects under the Polis Program (2001-2008). Image credits: Rouxinol de Pomares, 2012.

[60] POLIS programme is a Portuguese programme on urban environment, specifically designed for integrating urban requalification and the improvement of the urban environment in cities.

21. Stream restoration

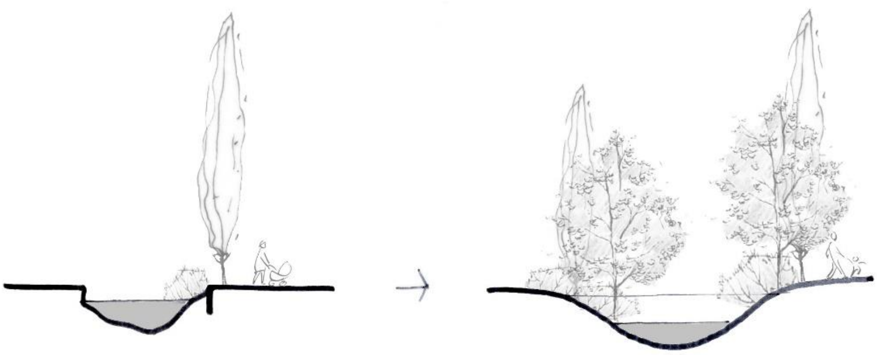


Figure 4.43- Type of adaptation measure: 21. Stream restoration. Source: author's sketch.

Stream restoration is here interpreted as the change from an artificial stream to a "near natural" stream. It can be very difficult to recreate the watercourse ecosystem exactly like it was before its disturbance period, simply because of the required change of its surrounding situation including all contemporary urban stresses such as pollution or closing of ventilation corridors. Regardless, in a stream restoration process, the structure, function and self-sustaining dynamics of its riparian habitat is re-established (Figure 4.43).

Among the existing examples of stream restoration is the intervention made at Kallang River in Singapore, which gave rise to the urban river Bishan Park. In this project, designed by Atelier Dreiseitl, a 2.7 km long straight concrete drainage channel was replaced by a meandering natural river with 3 km of length. Alongside the stream, sixty-two hectares of park area were designed to accommodate the dynamic process of the restored river system as well as to provide recreation and amenity value (Figure 4.44).

Figure 4.44 - Restored Kallang River at Bishan Park in Singapore. Image credits: © Atelier Dreiseitl, 2012.

22. Daylighting streams

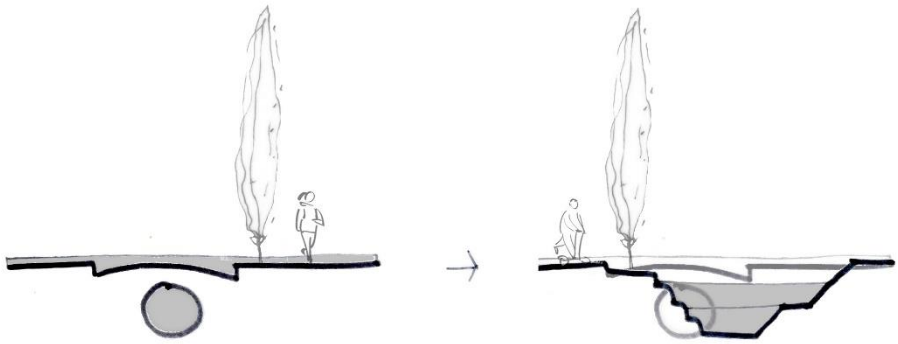


Figure 4.45 - Type of adaptation measure: 22. Daylighting streams. Source: author's sketch.

The type of adaptation measure here named 'Daylighting streams' essentially involves the process of bringing a buried stream to the surface. This measure re-establishes a watercourse to its former channel wherever feasible, or in a new channel that can be built between buildings, streets, parking lots or playing fields (Figure 4.45).

The number of examples that illustrate how this measure may be implemented increase every year. Amongst them, one particular example is the daylighting of Thornton creek in Seattle, US. This project, designed and engineered by SvR Design Company, turned an abandoned parking lot into water treatment facility that is also an open public space to be enjoyed by the local community (Figure 4.46).

Figure 4.46 - Stream daylighting project at Thornton creek in Seattle, US. Design and image credits: © SvR Design Company, 2009.

I. Open drainage systems

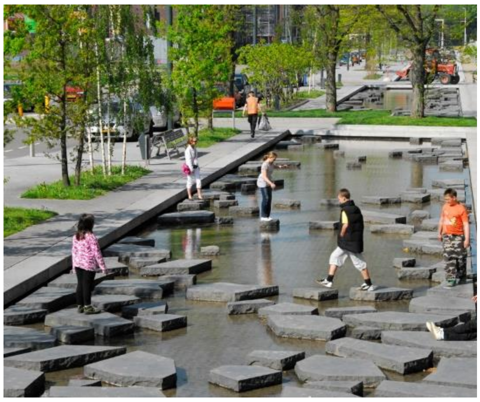
Open drainage systems are uncovered water channels that are complementary or alternative to underground drainage systems. These open channels should only receive water that has been previously treated or is already free from pollutants. Whilst measures within this category include improvements made in pre-existing watercourses, others serve to convey cleaned stormwater arising from other types of measures, such as rooftops or bioswales, leading it into the underground sewage system, or to a receiving water body or to other types of adaptation measures such as rain gardens or bioretention basins.

Among the measures presented within this category are: '**Street channels**', '**Extended channels**', '**Enlarged canals**' and '**Check dams**'. All of which can be designed in various dimensions and forms and all of which can be particularly effective when tackling pluvial and fluvial floods.

In resemblance to other measures that instigate the communities' approximation to the processes of natural water systems, the aforementioned measures can also greatly change the perception of an urban space and its social appropriation. By exposing a fragment of the water cycle and by inviting users to be a part of it, whereby education and awareness is promoted.

This goal in bringing people closer to these exposed stormwater conveyance systems can be approached in many ways, from the inclusion of bridges to the use of stepping stones. This latter concept, which was earlier on used by the Romans in the crossings of their streets which served as stormwater runoff channels, is now often used in contemporary designs such as in the case of the Roombeek Street water channel (Figure 4.47). Open drainage systems can be designed to also include filters, cascades, pools and many other water features that promote different possible interactions between rainwater, community and space planning.

Figure 4.47 - Left: Stepping stones street crossing in the ancient city of Pompeii. Image credits: © Rebecca Bugge, 2007. Right: Water channel at Roombeek commercial street. Image credits: © Buro Sant en Co Landscape Architecture, 2005.



23. Street channels

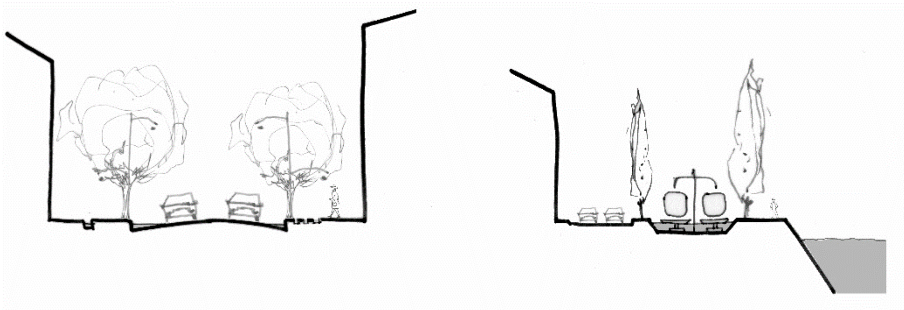


Figure 4.48 - Type of adaptation measure: 23. Street channels. Left: Smart street profile. Right: Canal below train line Source: author's sketch.

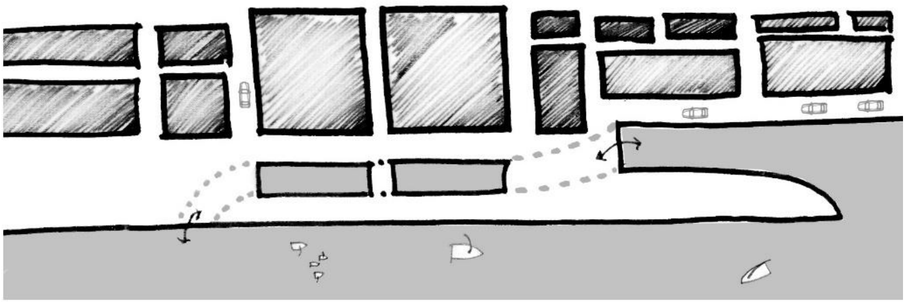
As the name indicates and as illustrated by the example of Roombeek Commercial Street (Figure 4.47-right), street channels are a means through which cleansed water is transported from one point to another. These water channels can have various dimensions and their design can have many different forms, from straight canals of 0.15x0.15 sections to light street adaptations commonly called "smart street profile". Among the other different possible applications is the idea to convert train or tram tracks into street channels (Figure 4.48). Of all design possibilities, it is important to bear in mind the requirement for the channel to have a minimum sloping gradient in order to avoid stagnant water.

This particular measure can be applied in dispersed urban areas as well as in compacted urban centres or coastal areas. As illustrated by the medieval example of central Freiburg Bächle (Figure 4.49), and also by the recent interventions at the old city centre of Banyoles highlighted in the previously chapter, this measure can be further compatible within a core historical centre.

Figure 4.49 - 13th century street channels of Freiburg Bächle, Germany. Image credits: © Steven Glassman, 2013.

24. Extended channels

Figure 4.50 - Type of adaptation measure: 24. Extended channels. Source: author's sketch.



Extended channels are here considered as the artificialized water curses that have been, occasionally or as a whole, extended in their length, namely through meandering processes (Figure 4.50). By extending pre-existing water channels through new water courses, wider stormwater volumes can be managed, thus alleviating stormflow velocities and overall flood risk.

In order to illustrate an example of an extended channel measure applied in the design of a public space, one may consider the intervention made in Pier Head in the City of Liverpool, UK, as previously highlighted in chapter three. The goal of this project was to create a canal extension - linking the Leeds and Liverpool Canal to the north with the dockland water basins adjacent to King's Waterfront to the south - and a public plaza worthy of such a high-profile site as the surroundings of Three Graces waterfront buildings (Figure 4.51).

Figure 4.51 - Pier Head, Liverpool, UK during a cultural event. Image credits: © Mark Holt, 2014.

25. *Enlarged canals*

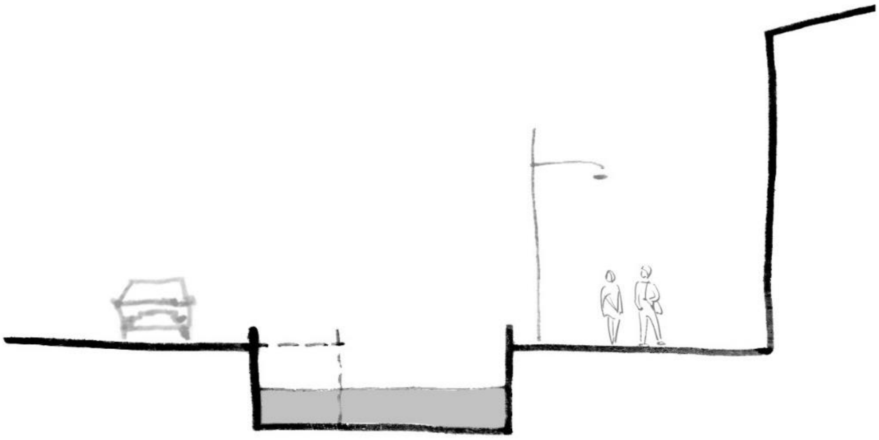


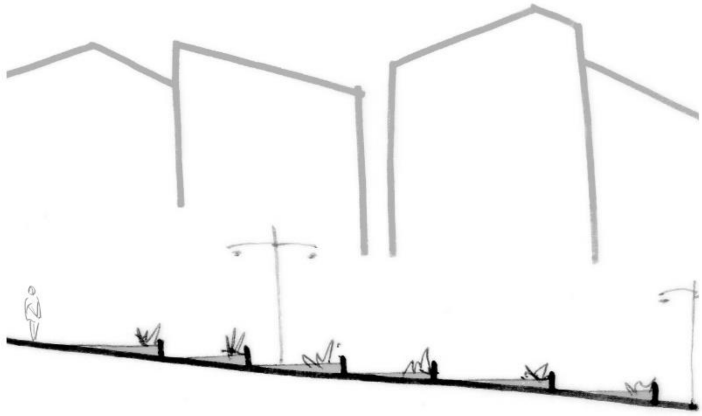
Figure 4.52 - Type of adaptation measure: 25. Enlarged canals. Source: author's sketch

The type of adaptation measure here named as 'Enlarged canals' encompasses the process of broadening the basin of an artificial or natural water course (Figure 4.52). Among the many existing examples, it is possible to highlight the case of London 2012 Olympic Park. In this case, the channel of River Lea was widened specifically for the implementation of generous area for wetlands (Figure 4.53).

Figure 4.53 - Detail of the wetland at London 2012 Olympic Park. River Lea enlarged part of its canal through this intervention. Image credits: © Salix Solutions, 2012.

26. Check dams

Figure 4.54 - Type of adaptation measure: 26. Check dams. Source: author's sketch.



The adaptation measure identified here as check dams, can be generally characterized by the implementation of permanent or temporary barriers along a water course in order to promote localized water accumulation and overall attenuation of runoff velocity (Figure 4.54). These barriers can be built from various materials, such as wood or stone, plastic or concrete, and from steel or plexiglass. This type of measure is usually associated with other types of measures that include the infrastructural strategy of Convey, that is, which include the process of transporting stormwater through channels.

This particular measure also reduces erosion and promotes sedimentation. After stormflows, water is retained behind the small dams and it may seep slowly to lower soil layers as well as infiltrate or evaporate. In order to promote water purification and avoid mosquito breeding, the implementation of this measure should be accompanied by the plantation of appropriate vegetation. Moreover, this measure requires periodic maintenance and sediment collection in the upstream area of dams, preferably after each storm.

One illustrative example of applied check dams is the slightly sloping bioswale at Kronsberg hill residential area (Figure 4.55).

Figure 4.55 - Check dams throughout a bioswale at Kronsberg, Hannover, Germany. Design and image credits: © Atelier Dreiseit, 2000.

J. Floating structures

Floating structures are an old concept and practice[61] that have been revisited in recent years, likely as a result of climate change threats. Newly incorporated designs and experimental approaches have recently been exploring the potential of floating structures as the ultimate flood resilient measure, one that tolerates and adapts to any type of flood, being it pluvial, fluvial, groundwater, artificial drainage or coastal flood.

Floating structures can range from floating mega structures such as oil sea platforms, to floating buildings and floating urban developments such as the ones in Ohe en Laak, Limburg, in the Netherlands, designed by Dura Vermeer. Likewise, floating structures can also be built to support public spaces. Designs can have as many dimensions and forms as the advances in technology permits. Among the types of floating structures that can be specifically associated to public space design, the following were highlighted: '**Floating pathway**', '**Floating platform**' and '**Floating islands**'.

27. Floating pathway

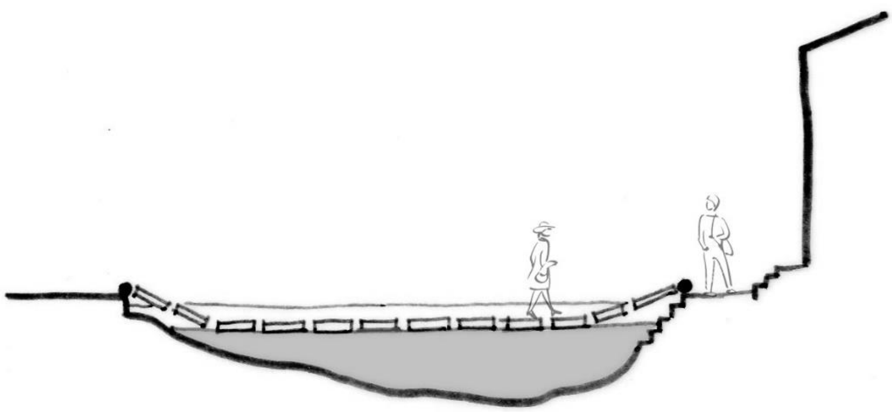


Figure 4.56 - Type of adaptation measure: 27. Floating pathway. Source: author's sketch.

A floating pathway or a floating bridge is a flexible structure that connects one place to another through water. In similarity to other floating structures, a floating pathway adapts to different water levels without compromising its public space character, namely the function of being a passage (Figure 4.56).

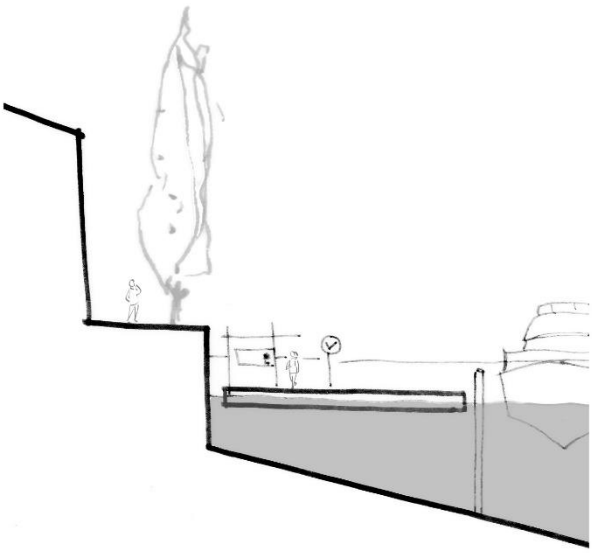
[61] One can mention, among several other examples: 1) the biblical reference to the Noah's Arch; 2) the Ingenious Floating Gardens of the Ancient Aztecs; 3) the floating islands of a local tribe by the Uros in Peru and Bolivia, built with native vegetation; or 3) the Teatro del Mondo architectonic gesture, by Aldo Rosi, a floating building designed for the 1979 Venice Biennale.

Among the existing illustrative examples of a floating pathway, one may distinguish the design of the Ravelijn Floating Bridge for its simple lines and aesthetic appeal. This pedestrian bridge had two primary goals, the first was to connect a city fortress to its city centre and the second was to provide an escape route from the fortress in case of emergencies. The shape of the budge pathway is convex, therefore it blends with the water and its surroundings, inhibiting a mirrored effect. As illustrated in Figure 4.57, the stairs that connect to the small pier in the fortress entry are designed to move up and down with the water level. In order to allow the bridge to float, air-filled polyethylene pipes are located underneath its timber surface.

Figure 4.57 - Connection detail of the floating bridge to the Ravelijn "Op den Zoom" fortress entry. Image credits: © Erik Stekelenburg.

28. Floating platform

Figure 4.58 - Type of adaptation measure: 28. Floating platform. Source: author’s sketch.



The Floating platform as a type of adaption measure is here interpreted as an extensive structure contiguous to a non-floating structure that offers a public space of multiple uses (Figure 4.58).

Floating platforms can be used for the design of floating gardens, such as the case of the Yongning River Park described in chapter three. They can also be used for the design of floating waterfronts, as is the case of the floating piers of the Landungsbrücken by the Elba River in Hamburg. Deprived from the load of architectonical reference, this former example offers a 700 m long public space that supports a diverse and varied use, from commercial to cultural, whilst at the same time providing a close relation with the Elbe River (Figure 4.59).

Figure 4.59 - Floating piers of the Landungsbrücken. Image credits: ® Sugin Ong, 2007.

29. Floating island

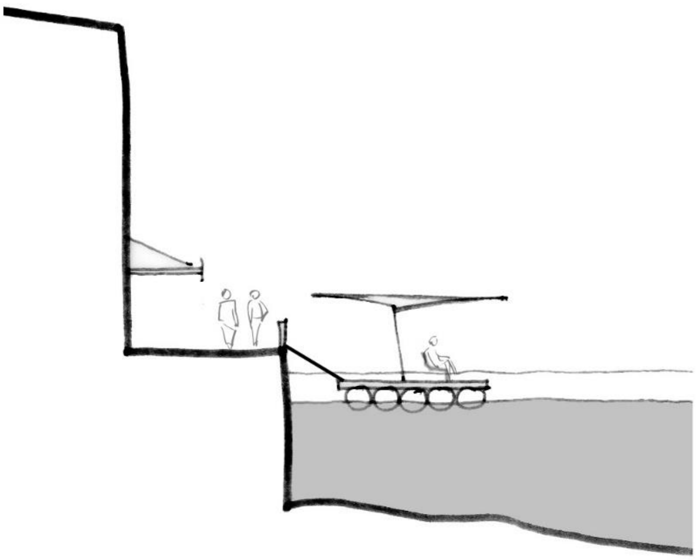


Figure 4.60 - Type of adaptation measure: 29. Floating island. Source: author's sketch.

The adaptation measure here named as floating island, is different to the other identified floating measures as it refers to an occasional floating structure and not a linear path or extensive area. It can comprise an esplanade, a sports field, stage or an audience structure for cultural events (Figure 4.60).

Floating islands can be constructed through the use of various materials. In some cases obsolete ships are reconfigured from its transport function onto another function such as a public space. That is namely the case of the Bathing Ship (Badeschiff) at the Spree in Berlin. In this example, an old barge was adapted into a pool. Its superstructures where removed allowing for its hull to be flexibly moored in a jetty. With a depth of around 2 m and a length pf 32 m a floating pool by the Spree can today be enjoyed (Figure 4.61). The same ship could have been adapted to other types of public uses.

Figure 4.61 - Bathing Ship (Badeschiff) at the Spree in Berlin, Germany. Image credits: © Felipe Artengo Rufino, 2004.

K. Wet-proof

The types of adaptation measures within the identified wet-proof category include different types of public spaces that are resistant to the periodic and temporary submersion by floods. Among the alternatives, '**Submergible parks**' and '**Submergible pathways**' were singled out. In most situations these measures are applied in flood prone areas, which can exist in interior lowlands or in areas adjacent to natural water streams. Wet-proof measures are particularly suitable in the adaptation to pluvial, fluvial and coastal floods.

Urban elements used in the design of these measures, such as pavement or urban furniture, must be particularly resistant in order to assumedly sustain the impacts of recurrent flood events. More specifically they must be made out of robust materials and a particular attention must be given to their constituent foundations. In the same line of reasoning, the vegetation used in these elements must also be suitable. Species originating from the habitat of riparian woodlands can tolerate the oscillations between flood and drought. Once the risk of flooding is high in these areas, their design must also encompass clear and visible information signage and escape routes.

30. Submergible parks

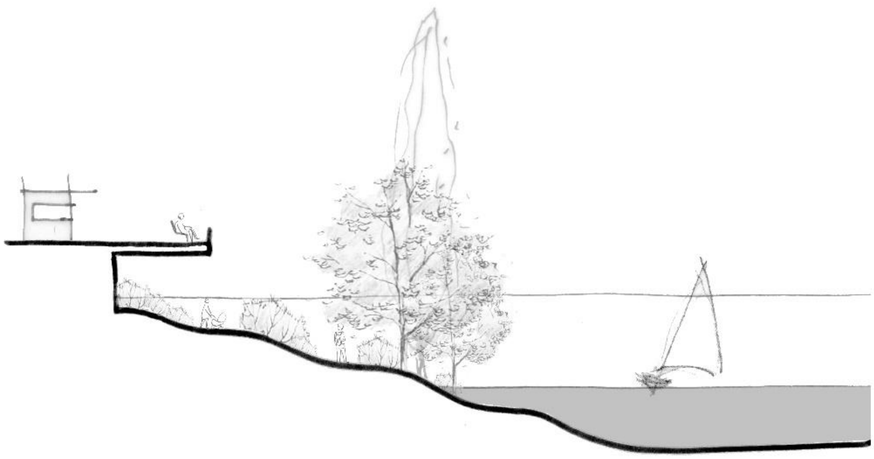


Figure 4.62 - Type of adaptation measure: 30. Submergible parks. Source: author's sketch.

Submergible parks as an adaptation measure is generally associated to other measures, such as the ones within the category of stream recovery. The resulting public spaces are however more extensive, generally configured as parks. These parks can then serve a wide range of purposes such as playgrounds or sports facilities, although only during dry weather (Figure 4.62).

Among the various existing examples where this adaptation measure has been applied, the case of Buffalo Bayou Park in Houston, Texas in the US, is here highlighted (Figure 4.63). Designed by SWA Group, this project turned a flood prone green field, with a poorly managed stream, into an open public space that is also a stormwater management facility. Among others, stream restoration processes included the redesign of the stream's profile and the plantation of riparian species. As a result, when the periodic floods occur, the park is able to sustain the impact without considerable risk. Among other examples of submergible parks are the French Rhone River Banks in Lyon and the Parc de la Seille in Metz.

Figure 4.63 - Left: Detail of a flood prone area at Buffalo Bayou Park. Image credits: © Tom Fox, SWA Group, 2006. Right: Jacob Lopez captured this image from his balcony overlooking Buffalo Bayou Park in Houston, on May 26, 2015. Image credits: Jacob Lopez, 2015.

31. Submergible pathways

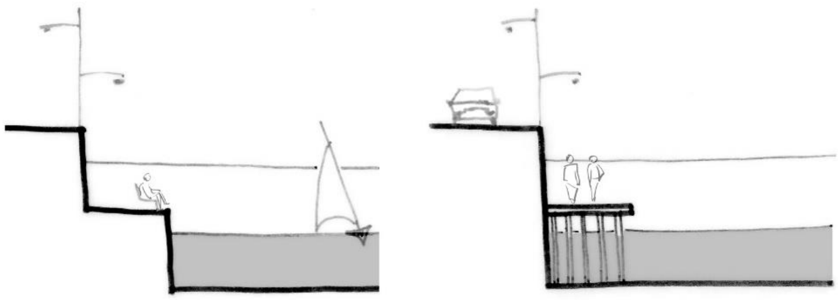


Figure 4.64 - Type of adaptation measure: 31. Submergible pathways. Source: author's sketch.

Submergible pathways are a particular type of wet-proof structure that during dry-weather can increase the available space for connection or leisure purposes (Figure 4.64). Such measure was applied in Quai des Gondoles at Choisy-le-Roi by the River Seine in France (Figure 4.65-left). Implemented using a robust flood resistant steel structure that is fixed underground, this 4m wide boardwalk extends over 500m. When floods are anticipated, the entrances to this submergible boardwalk are closed with mobile elements (Prominski et al. 2012, p.164). One other illustrative example is Passeio Atlântico at Porto designed by Manuel de Solà-Morales and others (Figure 4.65-rigth). This submergible pathway, which develops between Montevideu Avenue and the Atlantic coast, encompasses both submergible boardwalks as well as submergible concrete pathways.

Figure 4.65 - Left: Submergible boardwalk at the Quai des Gondoles in Choisy-le-Roi. Image credits: © SLG PAYSAGE, 2009. Right: Submergible concrete pathway at the Passeio Atlântico in Porto, Portugal. Image credits: Maria Matos Silva, 2007.

L. *Raised structures*

Raised structures as an adaptation category are here interpreted as the public space structures that are elevated or suspended over the maximum levels of a watercourse in order to be unaffected by flood events.

The concept to elevate a structure in order to protect against flooding is long-established. One might recall, for instance, the prehistoric stilt-houses settlements in Lake Zurich in Switzerland (namely, Lacustrine Village). It is also a model that is still very much used in present days. For instance, recently after the destruction by Hurricane Sandy in 2012, where thousands of homeowners from the most affected areas in the state of New York have applied for specific funding that would help them elevate their homes. Entire houses are therefore still being raised up through pillars, at levels 1.5 to 3 meters higher than they were before in order not to be affected by future floods.

Expectedly, this concept is also often applied in the design of public spaces, namely in promenades, passageways, stages, esplanades, plazas, gardens, among others. This approach is generally used in waterfront margins, although it is also possible to implement into interior flood prone areas. In waterfronts, measures within this category are commonly used in densely urbanized areas where the availability of space is limited. Through overhanging balconies or elevated platforms, space is extended over the water as part of the waterfront structure.

The implementation of these measures do not affect the watercourse profile or the flood basin and their stormwater volume capacities. The resulting public spaces are therefore unlikely affected by flood waters of any source as they are placed over the levels of projected flood dynamics. They can be used all year round and their design generally fits with the surrounding open spaces. The designs of raised structures that protrude out off a waterbody, further offer inhabitants the possibility to more closely engage with the water dynamics happening around and/or underneath. However, for safety reasons, these measures must encompass a proper fencing and this enclosing barrier might strongly influence the visual connexion with water (Prominski et al. 2012).

Construction techniques used in the implementation of these measures include the use of stilts (pillars, pilotis) or cantilevered structures. Among the different possible types of 'Raised structures' adaptation measures, the following were identified in the scope of this research: '**Cantilevered pathways**' and '**Elevated promenades**'.

32. *Cantilevered pathways*

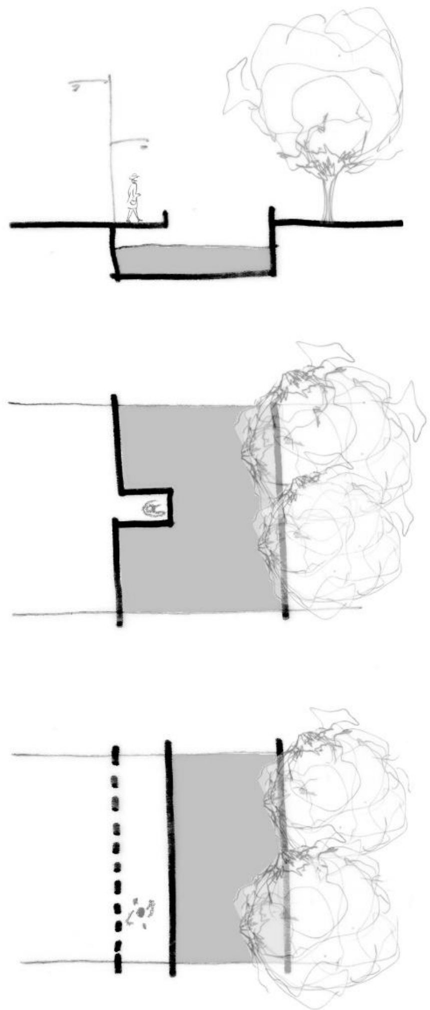


Figure 4.66 - Type of adaptation measure: 32. Cantilevered pathways. Source: author's sketch.

Figure 4.67 - Man fishing in a suspended balcony at the Green Park of Mondego in Coimbra, Portugal. Image credits: © PROAP.

Figure 4.68 - Detail of Ester millrace daylighting project: the pedestrian path alongside the street is suspended over the watercourse. Image credits: © Ulf Jenninger, 2013.

Cantilevered pathways are shown here as structures that are raised over the water without including pillars in their structure, i.e. they comprise areas suspended by a cantilevered system. Furthermore, they are also generally characterized as narrow pathways. These structures are therefore mostly used by pedestrians and/or cyclists. They can be designed in various shapes and they can be built by different construction techniques.

Cantilevered pathways can be generally divided into two distinguishable types: 1) in an overhang, which is a suspended pathway that goes along, or is mostly parallel to, the margin of a watercourse and 2) in a balcony, which is a suspended punctual terrace that is mostly configured perpendicularly to the watercourse (Figure 4.66). For example, in the daylighting of Ester millrace watercourse in Leipzig (Germany), it was necessary to substitute a former street with a suspended pathway or overhang (Figure 4.68).

At the Green Park of Mondego in Coimbra (Portugal), several balconies were designed so that users could enjoy privileged viewpoints of wider perspectives (or to practice fishing. Figure 4.67).

33. Elevated promenade

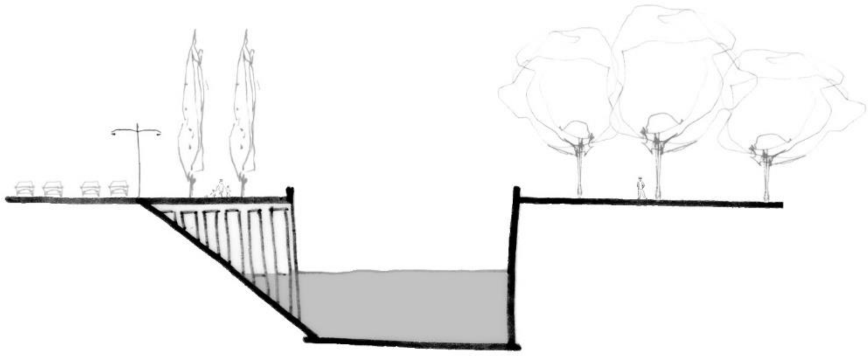


Figure 4.69 - Type of adaptation measure: 33. Elevated promenade. Source: authors' sketch.

Elevated promenade is here interpreted as a raised public space of larger scale. These spaces entail more extensive areas and therefore require a stronger supporting structure such as reinforced concrete pillars. These areas may be built for pedestrian circulation as well as for automobile or public transport traffic. They might also include plantations of large shrubs or small trees (Figure 4.69).

For an illustrative example one may consider Bilbao's waterfront, more or less from the Areatzako Zubia Bridge to de Laa Slave Bridge (Figure 4.70). With an average width of 18 meters, this elevated promenade evolves along the Nervión river. Its public space is composed by periodic and regularly placed small and medium-sized trees as well as urban furniture such as benches and lamps. Occasionally it supports light building structures such as kiosks or removable tents.

Figure 4.70 - Detail of Bilbao's waterfront. Image credits: Maria Matos Silva, 2015.

M. Coastal defences

In the scope of this research, the category of coastal defences specifically includes the types of measures encompassed within coastal management, which aim to adapt urban territories to the impacts of storm events that lead to flood occurrences, namely the impacts from fluvial floods as well as storm surges and a rise in sea level.

In this category of measures, the change of paradigm evidenced in chapter two, regarding flood risk management approaches, is particularly evidenced. More specifically by the recognized and proclaimed change to adapt waterfronts so that they could combine both the requirement to defend land from floods and the promotion of a closer and more intimate relation between local inhabitants and the Sea. In situations previously tackled through robust flood protection engineering, approaches included major seawalls or other impenetrable types of infrastructure that would generally cut and divide the city from its waterfront.

In this new Era, various examples have shown that it is possible to maintain the high standards of hard engineering flood defence whilst also benefiting from the opportunities provided by interdisciplinary and multifunctional spaces of public utility. Along these opportunities is the potential available space for public encounter. As argued in chapter three, through public spaces the engagement in climate adaptation action can be enhanced, namely when the impacts of extreme weathers can be made tangible. In carefully designed coastal defences that also encompass public spaces, the power of water dynamics becomes meaningful for citizens and their livelihoods.

Measures highlighted in this category of coastal defence are: '**Multifunctional defences**', '**Breakwaters**' and '**Embankments**'.

34. Multifunctional defences

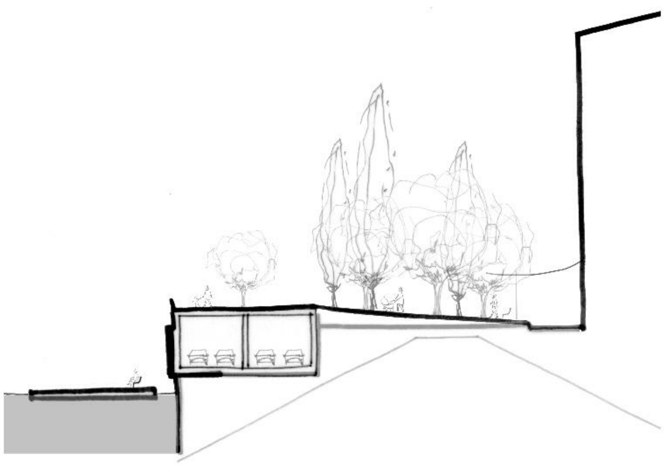


Figure 4.71 - Type of adaptation measure: 34. Multifunctional defences. Source: author's sketch adapted from De Urbanisten office design.

As the name reveals, multifunctional defences are coastal defences that are able to encompass multiple functions. They are commonly applied in urban waterfronts where space is limited and flood protection is indispensable. Often, they are built within or over pre-existing dikes or other types of coastal defences. The Netherlands for example, frequently applies this measure in its urban coastlines as can be verified in the proposal by the De Urbanisten office regarding the improvement in the "Dike of 'Boompjes'" illustrated in Figure 4.71.

The design of multifunctional defences can be very diverse, yet it must contemplate intricate pre-existing situations as well as the infrastructural requirements of contemporary flood defence. The possible multiple configurations of multifunctional defences in light of different supporting contexts have been exhaustively studied in literature. Dutch research institute Deltares for example, under FloodProBe research project, has differentiated the following types of design concepts: coffer dam, step dike, l-wall, soil-retaining wall, oversized inner slope and oversized outer slope (Deltares 2013).

One example of a multifunctional flood defence is the Elbe promenade in Hamburg, designed by Zaha Hadid Architects. In this case, the previously existing coastal defence structure was outdated and with no added aesthetic value. Through this renovation project, a new and improved flood barrier was integrated with a 750 meter long promenade with large and all-encompassing steps towards the waterfront. In these steps and when possible, people can get closer to the river and enjoy the dynamics of its landscape (Figure 4.72).

Figure 4.72 - Detail of the Elbe promenade in Hamburg, Germany. Design by Zaha Hadid Architects. Image credits: © Arlene Nathania.

35. *Breakwaters*

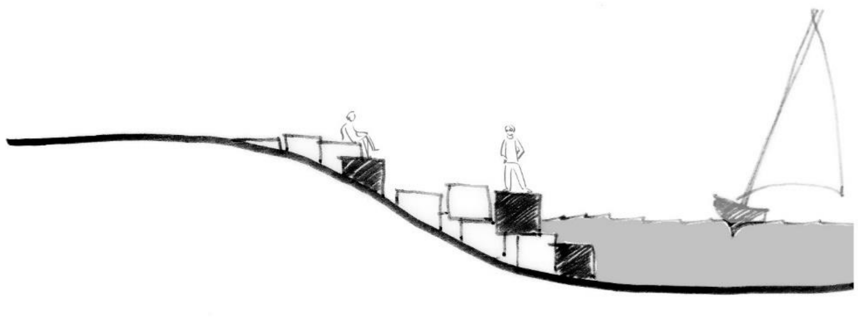


Figure 4.73 - Type of adaptation measure: 35.Breakwaters. Source: author's sketch.

Breakwaters or wave-breakers are structures constructed on coasts in order to block or attenuate the intensity of waves, currents or longshore drift. In most situations, these structures are used for their distinct infrastructural purpose and encompass no other function. Regardless, there are some examples that were designed with the additional goal to encompass a space for public use. When permitted by the weather and intensity of water dynamics, breakwaters can therefore also serve the as viewpoints, pathways or stopovers (Figure 4.73). This is the case of the Breakwaters smoothly designed for Jack Evans Boat Harbour in Australia by Aspect Studios (Figure 4.74). Other examples include the sculpturally treated breakwaters at Zona de Banys del Fòrum designed by BB+GG Arquitectes or the Douro pier designed by Carlos Prata Arquitecto and previously explored in chapter three.

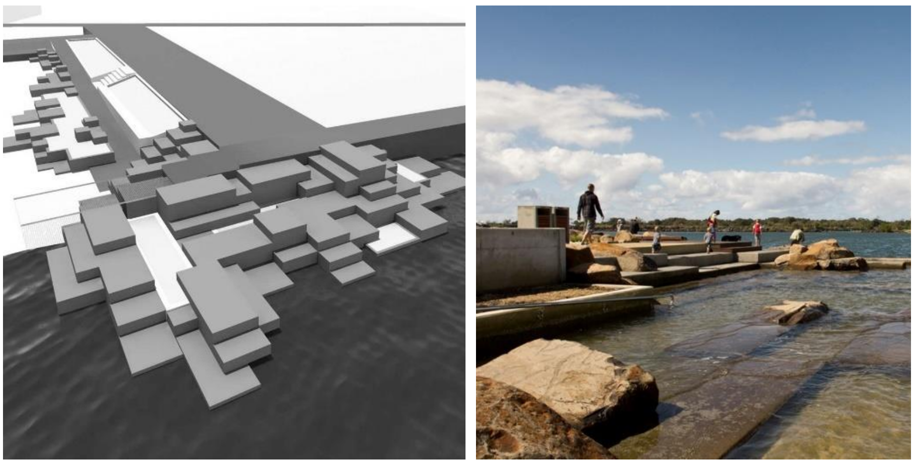
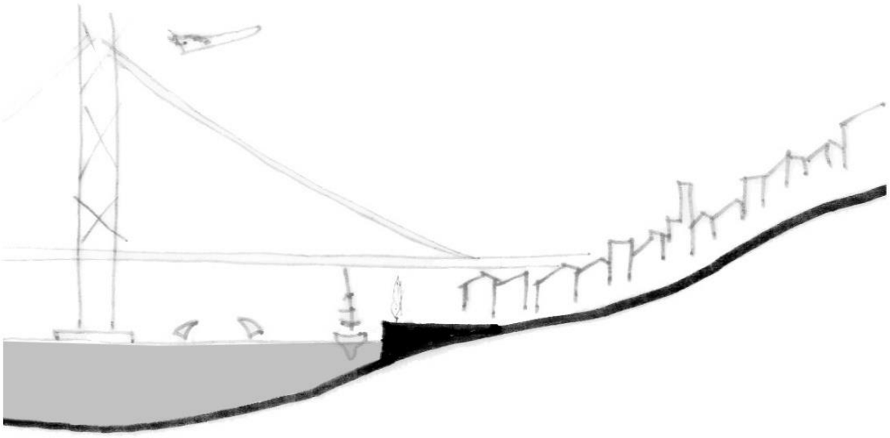


Figure 4.74 - Left: Rendering of the wavebreakers. Image credits: © Aspect Studios. Right: Detail of the wavebreakers in Jack Evans Boat Harbour at Tweed Heads in Australia. Image credits: © Simon Wood.

36. Embankments

Figure 4.75 - Type of adaptation measure: 36.Embankments. Source: author's sketch.

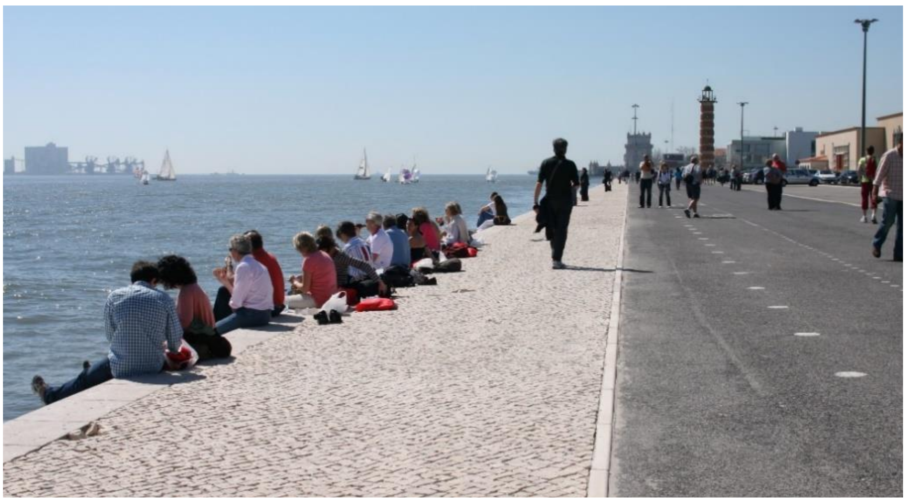


Embankments can be described as land reclamation constructions along a river bank. They are mostly present in cities whose morphology is naturally elevated and thus protected against floods (Figure 4.74). Unlike dikes or levees that are occasionally built in inner-land, embankments are considered here as exclusive to waterfronts.

Most embankments were built during the industrial era. In similarity with the measures identified in the category of 'Raised structures', embankments allow a growth of marginal land in the city.

Embankments are very common in contemporary urban territories and, depending on the context, their "reclaimed" areas offer new land that is managed by municipal interests. Among the potential benefits of "extra" land is the construction of public spaces, as it happens in part of Lisbon's riverfront (Figure 4.76).

Figure 4.76 - Riverside embankment at Belém, Lisbon, Portugal. Image credits: Maria Matos Silva, 2011.



N. Floodwalls

Floodwalls can be characterized by being artificial flood, generally consisting of extensive reinforced concrete vertical platforms perpendicular to the ground and alongside a watercourse. Their size and shape varies considerably depending on the projected flood characteristics. They are mostly applied with the goal to face fluvial and coastal floods.

They are mostly used in dense urban settings where available space is very limited. In similarity to other measures that must comprise applied engineering techniques, floodwalls are not required to have an infrastructural flood defence purpose as a sole objective. Although in most situations they are implemented without aesthetic considerations, they do have the potential to be integrated as part of a public space design.

Today's knowhow allows for floodwalls to be artistic sculptural elements or didactic structures while maintaining their robustness and efficiency as a flood barrier. That is the case of the adaptation measures here highlighted, namely '**Sculptured walls**' and '**Glass walls**', respectively.

37. Sculptured walls

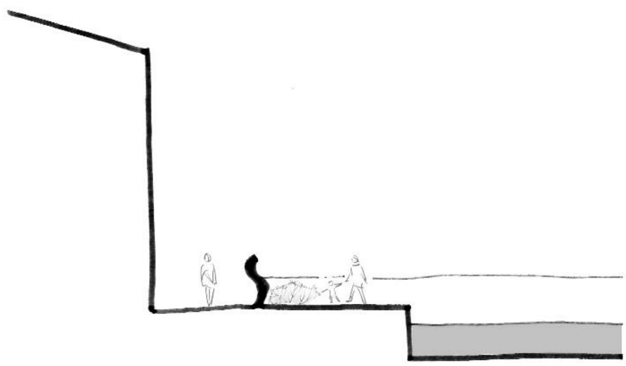
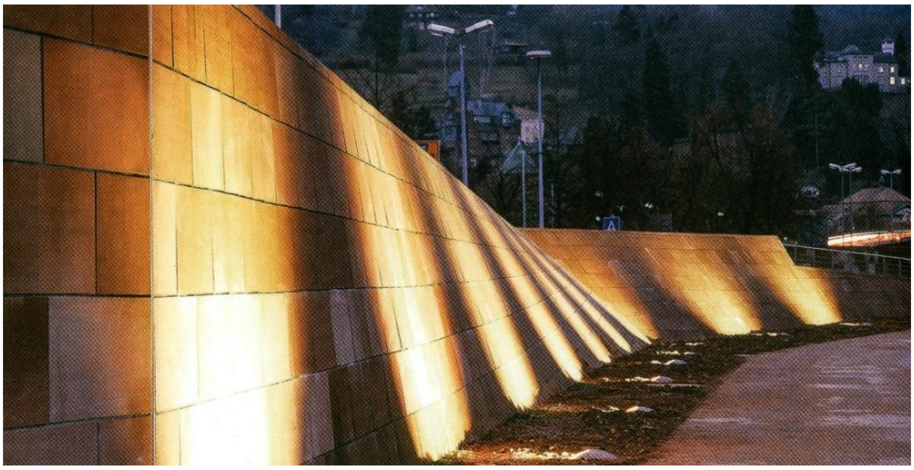


Figure 4.77 - Type of adaptation measure: 37.Sculptured walls. Source: author's sketch.

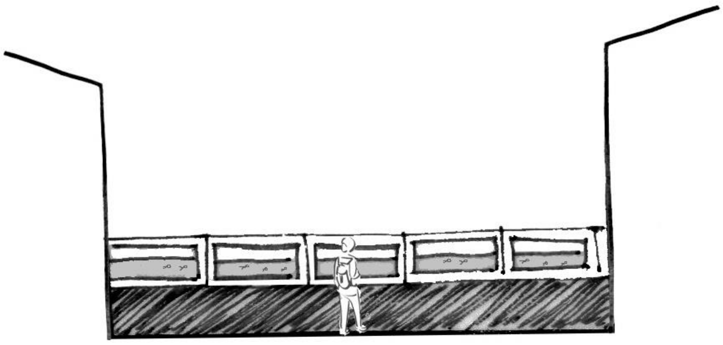
The case of Main's riverside in Miltenberg, Germany, is a good example of a sculpted floodwall integrated in the design of a public space. With changing slopes and a base of varied thickness, the wall enriches the surrounding public space as an individual sculptural element. Besides encompassing a car park, green open spaces and pedestrian and bicycle paths, the public space adjoining to this sculpted floodwall is also used as an event area, namely for the Michaelismesse fair. At night, its design is exacerbated by means of illumination (Figure 4.78). During extreme flooding the height of the wall can be further increased with additional automatic floodgates thus also protecting the area to the one-in-100-year flood events (Prominski et al. 2012).

Figure 4.78 - Detail of the sculpted flood wall at Main's riverside, Miltenberg, Germany. Source: (Prominski et al. 2012, p.178).



38. Glass walls

Figure 4.79 - Type of adaptation measure: 38.Glass walls. Source: author's sketch.



Glass walls have been applied for example at Westhoven, Cologne in Germany (Figure 4.80). They are able to provide both effective protection and unobstructed views between land and the watercourse (Figure 4.79). These flood protection means evidenced as highly robust, further offer interesting views of the water during flooding. This type of measure can be further used for educational purposes, namely when implemented by fish pass dams such as the case of "Passage309 Fish Ladder" at Gambsheim in Alsace, France.

Figure 4.80 - Detail of a glass floodwall implemented at Westhoven, Cologne in Germany. Image credits: © IBS Technics GmbH.

O. Barriers

This category of adaptation measure refers to the group of flood defences that are locally implemented either through temporary or permanent **demountable** mechanisms. They are mostly applied when facing fluvial and coastal floods.

Temporary barriers can be generally described as a provisional flood protection mechanism that is composed of detachable flood protection products that are exclusively installed during a flood event and are totally removed once flood levels are no longer a nuisance (EA 2011). This type of mechanism can be applied through the use of prefabricated or artisanal metal plaques, sandbags, inflatable devices or the combination of all the aforementioned. Prefabricated plaques are generally placed in linear series, sandbags are generally piled, and artisanal metal plaques are often seen in the doorways of the more often affected properties.

This type mechanism only exists during a flood event. Regardless, it is a frequently implemented measure and a constituent part of the urban environment. Its assemblage process and resulting configuration should therefore be thought of, together with urban design concerns. As evidenced in Figure 4.81 there is potential to integrate and accept temporary flood defences as established components of urban and public space design.

As the developed portfolio screening was unable to identify at least one existing example were the application of temporary barriers was integrated within the design of a public space, only the type of adaptation measure of permanent '**Demountable barrier**' is here considered.

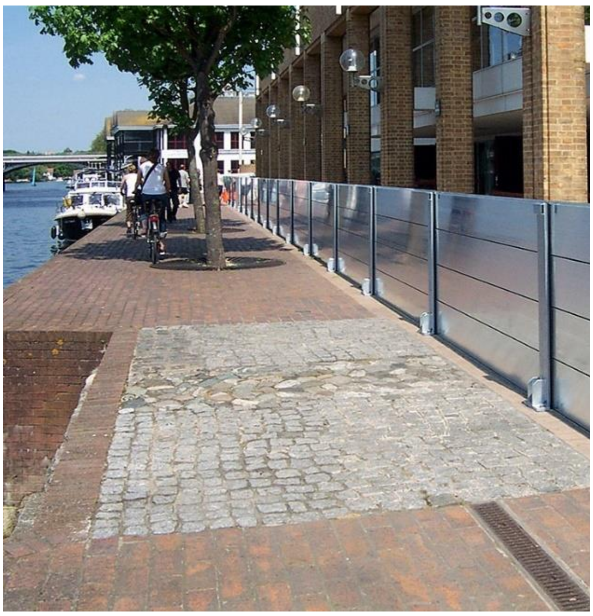
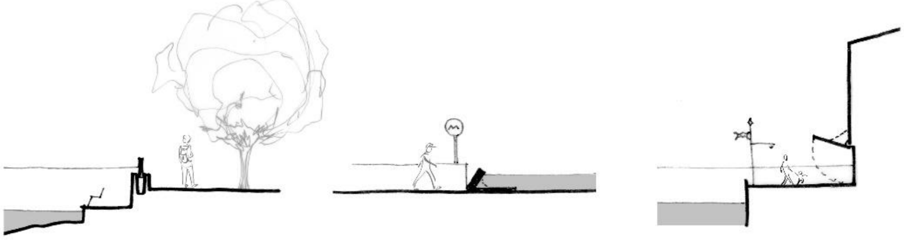


Figure 4.81 - Left: Most Venetian householders have temporary flood barriers at their doorways in order to deal with "Acqua alta". Image credits: © Nick Thompson, 2010. Right: Temporary flood barriers to stop flooding from the River Thames at John Lewis, Kingston. Image credits: © Flood Control International.

39. Demountable barrier

Figure 4.82 - Type of adaptation measure: 39.Demountable barrier. From left to right: vertical wall, frame wall and flood gate. Source: author's sketch.



A demountable barrier is here understood as a permanent flood protection, albeit movable, that has been pre-installed and requires operation during a flood event; or a structure that is partially installed in pre-implemented guides in a pre-constructed foundation (EA 2011).

Demountable barriers can include various types of mechanisms, i.e. variants, from sectional barriers, such as an elevated vertical wall, flood gates in the shape of a frame wall or a flood door (Figure 4.82). Several examples may serve to illustrate how this measure may be applied in practice. One of which is the Waalkade promenade at Zaltbommel, in the Netherlands. In this particular case, the height of the flood protecting wall can be raised by 50 cm with the use of mobile elements. This system is embedded into the wall as can be noted in Figure 4.83-left. A flood taskforce can raise this demountable barrier in five hours (Prominski et al. 2012).

Other examples include the sectional barrier at Main's riverside sculpted wall in Miltenberg, Germany; or the flood gates in the Landungsbrücken building, 1910 Hamburg's fluvial station adapted to protect from the Elbe floods (Figure 4.83-right).

Figure 4.83 - Left: Demountable sectional barrier, embedded at the Waalkade promenade flood wall in Zaltbommel, Netherlands. Image credits: © Joroen Miltenburg. Right: Demountable floodgate in the Landungsbrücken building at Hamburg, Germany. Image credits: © Jan-Moritz Müller, 2010.

P. Levees

Levees are an old category of flood defence infrastructure. They can also be called levée, dyke, embankment, floodbank or stopbank[62]. This category can be generally characterized by encompassing natural or artificial slopes that regulate water levels. These slopes are usually made out of earth, although they can be reinforced by strengthening their inner core with other types of materials such as steel, or by improving the characteristics of its surface in order to contribute to the overall stability of the levee structure. Levees can also be re-enforced by heightening or broadening their scale. They are often implemented parallel to the path of a watercourse either in urban or agricultural lands.

In most situations, levees are unrecognized by being designed together with the design of parks or other types of public spaces. In these cases, the type of adaptation measure of '**Gentle slope levees**' is identified. Within this type of measure one may further distinguish two variants: the urban-levee and the green-levee (Figure 4.84). Arguably, the 'Super-levees' could be another type of measure within the category of 'Levees'. Yet 'Super-levees' were not considered in the scope of this research as their scale, with heights over 10 meters and extensions of kilometres, overcomes the scale of public space.

40. Gentle slope levees

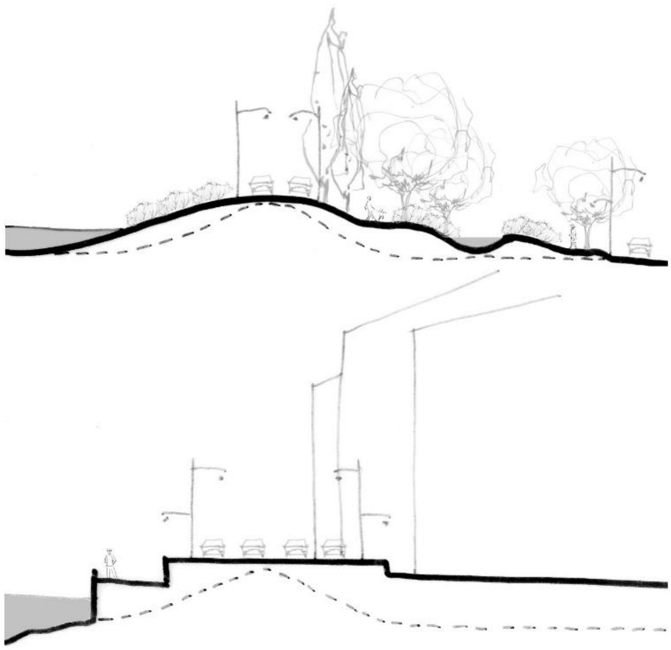
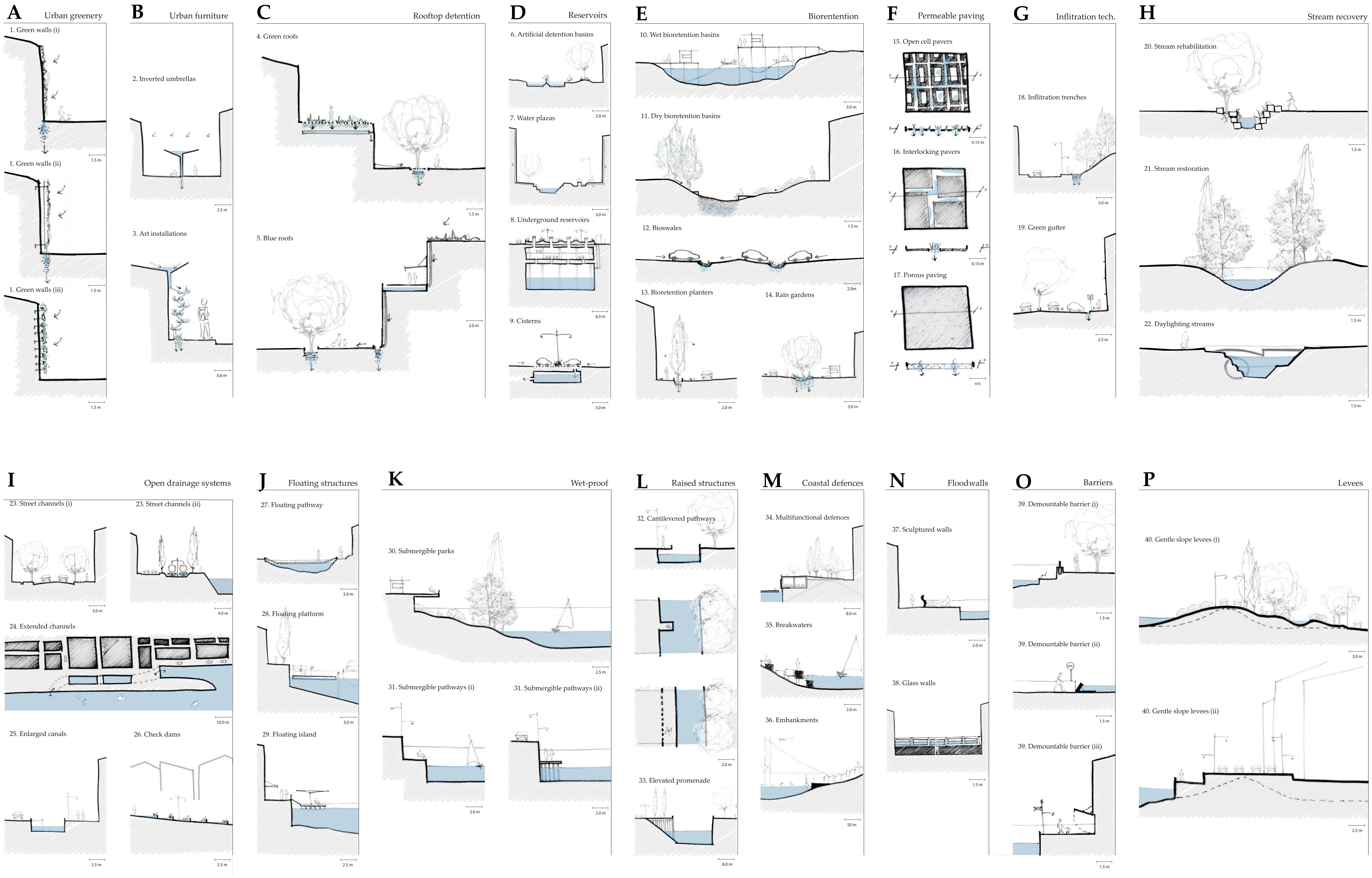


Figure 4.84 - Type of adaptation measure: 40.Gentle slope levees. Above: green-levee. Below: urban-levee. Source: author's sketch.

[62] The word "levee" comes from the French word "levée" (meaning "to raise"), while the modern word "dike" likely comes from the Dutch word "dijk", similar to the English word "dig", and referring to both the trench as the bank of this flood protection and drainage infrastructure.

The Netherlands has a great network of levees, all of which are a constituent part of spatial planning and urban design. Most of their levees have roads or their upper level, therefore serving also as transport facilities. In addition, most Dutch cities are comprised by several consecutive levels of dikes. In some situations, these dikes are so old and so strongly incorporated within the urban fabric that can easily become unnoticed. In these cases, multiple public spaces may arise over then. That is namely the case of the "Hilledijk" in Rotterdam (Figure 4.85). In other situations their form can be more simply acknowledged, namely when landscaped. An example of a green-levee is, for instance, the case of Corktown Common Park in Toronto, Canada, designed by Michael van Valkenburgh Associates partnered with Arup.

Figure 4.85 - Part of the Hilledijk in Rotterdam, Netherlands. Image credits: © Luc Vermeijden, 2009.



Flood adaptation categories and types of measures applicable to the design of public spaces

Diagram of the sketched typologies

4.3 Proposed Conceptual Framework

In light of the constructed database of categories and types of flood adaptation measures applicable to public space design as presented in Table 4.2, various frameworks can be proposed. In other words, the identified categories and types of measures can be differently organized in accordance with diverse and particular purposes or contexts. The range of possible organizations is as wide as the potentially numerous analysis of the identified types of measures and its corresponding examples.

Among the possible analysis are the resulting classifications in light of the following questions: for which type of flood is the measure most appropriate (pluvial, fluvial, groundwater, artificial drainage, coastal)? To which infrastructural strategy does the measure primarily relate to (Harvest, Store, Infiltrate, Convey, Tolerate and Avoid)? In what areas of the watershed are the measures applicable? What is the physical extent of the benefits provided by each measure (on-site; downstream, upstream, off-stream)? What is the estimated scale of the investments (building, neighbourhood, small town, urban regional)? What are the estimated costs associated with each measure? In what type of public space can each measure be applied (layout spaces, landscape spaces, itinerating spaces, memory spaces, commerce spaces, generated spaces); or even in circumstances that call for a comparative analysis between different measures, such as the contrast between "artificial", "hard" engineering measures and "soft", "natural" measures? Other analysis can dwell, among others, upon the infrastructural efficiency of each measure, namely regarding water accumulation (large, small, how much) or into further distinctions among "win-win", "no-regrets", "low-regrets" (or limited-regrets) or "flexible adaptation" strategies.

Each classification is to be primarily based on the analysis of the gathered existing examples. As illustrated in the hypothetical Table 4.3, examples may be analysed regarding diverse aspects. For instance, in Measure 2, Examples 1 and 2 are solely related to Flood Type 2. As a result, it is concluded that Measure 2 is mostly related to a specific type of flood, i.e., Type 2. Following this line of reasoning a little further, all three examples of Measure 1 do not encompass Infrastructural Strategy 3. As such, Measure 1 entails Infrastructural Strategies 1, 2 and 4 and not 3. The classifications are made through empirical observations and a literature review related to each specific example, both underpinned by the state of the art review regarding the subject of analysis (type of flood, infrastructural strategy, physical extent of benefits, scale of investment, area of the watershed, among others).

Table 4.3 - Illustrative diagram of the classification process carried out for each analysed subject (type of flood, infrastructural strategy, physical extent of benefits, among others).

Category	Measure	Example	Type of Flood					Physical Extent of Benefits				...*
			1	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**...**
Category 1	Measure 1	e.g., 1	X	–	–	X	–	–	–	X	–	...
		e.g., 2	–	X	X	X	–	X	–	X	–	...
		e.g., 3	–	X	X	–	–	–	X	–	–	...
	Measure 2	e.g., 1	–	X	X	–	–	X	–	–	–	...
		e.g., 2	–	X	X	–	X	X	–	–	–	...

* Each example may be analysed regarding several further aspects.

Results must be revisited in light of new examples or new information about each concrete situation. Furthermore, most analyses lead to multiple classifications. For example, among the identified types of measures, some may be particularly associated with one specific infrastructural strategy, while others may relate to more than one strategy. More specifically, for instance, in addition to storing water, 'Bioretention basins' potentially contribute to the strategies of harvest, infiltrate, convey and tolerate. Contrastingly, 'Underground regulation reservoirs' potentially serve the infrastructural Store, Harvest, Convey and Tolerate strategies.

Contributing to the complexity of the disclosed assessment, all of the proposed questions and provided classifications are intimately interlinked. One can namely highlight how the type of flood generally dictates the most commonly chosen infrastructural strategy. More distinctly, pluvial floods are generally tackled with the infrastructural strategies of Harvest, Store, Infiltrate and Convey; fluvial floods are generally approached with strategies of Convey, Tolerate and Avoid; coastal floods are usually tackled with the strategies of Tolerate and Avoid; groundwater floods are mostly tackled with the strategies of Convey and Tolerate; and artificial drainage flooding is commonly tackled with the strategies of Store, Convey and Tolerate. Yet one must bear in mind that, although some measures may be particularly adequate to face a certain type of flood, they may also provide complementary benefits for the adaptation to other types of floods by comparison. For instance, the benefits provided by green roofs (which can be particularly useful in the adaptation to groundwater floods, once they can Harvest water before it reaches the ground) are wide-ranging and can also be considered as beneficial to the reduction of both the frequency and intensity of pluvial floods.

The associated implementation costs also naturally influence the process of choosing the adequate measure or range of measures. While some measures may be significantly more costly than others, they may prove to be more efficient in light of a particular infrastructural strategy. ‘Multifunctional defences’, for example, regardless of their high costs, may be considered as particularly adequate for an area that has already been severely affected by intense storm surges and advocates the Avoid strategy. For the same situation, yet in light of other infrastructural strategies, other measures may be applied, such as ‘Wet-proof parks’ or ‘Floating structures’ related to the Tolerate approach. Although they are less efficient in comparison to the strategy of Avoid, these measures that are particularly targeted at tolerating stormwater, comprise additional parallel benefits that should not be underestimated, including a better adaptive capacity for a much wider timeframe. A similar association can be made when generally comparing “artificial” and “hard” engineering measures with more “soft”, “natural” measures. Whereas the first may be particularly efficient in solving intense flood hazards in a relatively short period of time, natural solutions require extensive implementations and longer timeframes. On the other hand, these solutions have the added value of contributing significantly to the overall quality of water bodies and of the urban environment (Jacqueline Hoyer et al. 2011). When a measure is characterized by not being very costly, and by not worsening the initial situation even when it does not work as expected, it can be identified as a “safe-to-fail” measure (Ahern 2011). This is can be seen in the case of the previously mentioned type of measure ‘Green roofs’. They are fairly inexpensive measures that even if not fulfilling the flood risk management purpose of water harvesting, they may fulfil other purposes, such as improving microclimatic conditions by permitting increased albedo levels or encouraging evapotranspiration. These types of measures are particularly interesting in the context of learning and exploring adaptation processes, since they are not hindered by the need to succeed and consequently endorse continual improvement (Howe et al. 2011). Contrastingly, the malfunctioning of an underground regulation reservoir, even when disregarding the costs associated with its construction, may lead to increased flood occurrences and the aggravation of the initial situation, namely by being an added obstruction to the flow of underground water.

4.3.1 Assessment by Flood Adaptation Infrastructural Strategies

Amongst the above-mentioned alternatives to assess the identified types of measures, it was chosen to deepen the Conceptual Framework’s construction and to organize its structure in light of flood adaptation infrastructural strategies. Each measure was therefore associated with one main and/or one or more secondary infrastructural purpose. Several concepts describe various possible infrastructural strategies, yet the following comprehensive group is here proposed: **Harvest**, **Store**, **Infiltrate**, **Convey**, **Tolerate** and **Avoid**. Each highlighted infrastructural strategy will be concisely described in the subsequent Table 4.4. In order to provide a quantitative sense of scale, brief numerical results regarding particular exemplified cases are further included.

The option to emphasize the measure's infrastructural capacities is essentially related to the conducted methodological approach that primarily envisioned the proposition of a Conceptual Framework of prompt utility. By organizing measures by their infrastructural strategies, the framework's practical use is directly evidenced. Another motive is related to the needed and fundamental integration with the few established leading disciplines in solving the problems associated with urban flooding. By approaching the matter with commonly-used vocabulary and similar technical notions, the communication and exchange of know-how are facilitated.

Regardless of not being included in the proposed encompassing set of infrastructural strategies, it is important to highlight that source control is one other commonly-used concept, which entails a particular infrastructural approach. As the name indicates, this infrastructural strategy aims to tackle floods at their source, namely through harvest, store and infiltration measures.

Table 4.4 - Proposed range of flood adaptation infrastructural strategies, each with a summarized description.

Harvest 	Measures that relate to the infrastructural strategy of Harvest can be generally characterized by their capacity to catch and collect rainwater before contributing to stormwater runoff. Collected rainwater can replace or supplement treated water of drinkable quality, thus contributing to the reduction of a city's demand for water supply. It can further extend supplies from regional reservoirs and restore environmental flows in rivers used for water supply (Coombes and Barry 2007). It is therefore a particularly interesting infrastructural strategy to be applied in urban situations where water is scarce. It is also an especially attractive infrastructural strategy to face groundwater floods, since rainwater harvesting in upstream catchments can decrease stormwater-driven peak flows and overloads in drainage infrastructure (Coombes and Barry 2015). Harvesting measures can range noticeably in scale and complexity from a single urban fixture to a green wall, such as inverted umbrellas or a community system of green roofs. For example, at Potsdamer Platz in Berlin, a total of 32.000 m^2 of roof collects 21 inches (around 0.5 m) of annual rainfall and stores it in a 3.500 m^3 tank (UNEP 2011 in EEA 2012a).

Store

Measures that entail the infrastructural capacity to Store water also contribute to the minimization of overall urban runoff and pressure alleviation upon existing infrastructural systems. This type of measure can be designed to store water either above or belowground. When comprised with appropriate vegetation and depending on the design detention time, stored water can be additionally filtered and purified, thus potentially providing water with improved quality. It has been further evidenced that rainwater collected from roofs improves its quality by storage in tanks (Coombes et al. 1999).

Measures with the capacity to store water also vary in scale and complexity. Raingardens or bioswales are relatively small and straightforwardly implemented when compared to wet bioretention basins or regulation reservoirs. Although compact urban territories are unlikely to have the available space for the implementation of larger-scale measures, alternatives exist in order to store water in densely-urbanized areas. An exemplary case regarding the formerly mentioned situation is the water plaza at Rotterdam in the Netherlands, designed by the De Urbanisten office. The total surface area encompassed within this project is 9.500 m^2, including street and parking. The actual water square has an area of 5.500 m^2 and offers 1.800 m^3 of temporal water storage (De Urbanisten 2013).

Infiltrate

Measures that encompass the flood adaptation infrastructural strategy to Infiltrate stormwater include trenches, basins or permeable pavements that enhance the intrusion of water into subsoil layers or into other types of storage or conveyancing measures. The porous paving implemented in Praça do Comercio in Lisbon (Portugal) is, for example, composed of limestone gravel and stone dust compressed with a colorless synthetic binder, draining stormwater into the underneath drainage system.

Measures primarily targeted at the infrastructural strategy to Infiltrate generally entail filtration mediums, such as gravel and rock, which treat stormwater and lead it into substratal soils. Yet, the particular function to infiltrate into subsoil layers is more effective when measures are combined with other measures specifically related to the functions of harvest or store in order to effectively pre-treat stormwater (Philip 2011). Through correctly implemented infiltration processes, it is therefore not only possible to remove a great range of pollutants, such as suspended solids or heavy metals, but also to promote the recharge of groundwater aquifers and, thus, support water supply sources (Woods-Ballard et al. 2007).

In similarity to storage measures, infiltration measures may therefore also substantially reduce runoff volumes. For example, the infiltration trench implemented below Elmer Avenue is capable of capturing 750,000 gallons of runoff (Robinson and Hopton 2011).

Convey

The infrastructural strategy of Convey is related to the process of transporting stormwater through channels. These channels may vary in size and nature, such as from large and environmentally-sound rivers to small artificial street channels. In the scope of this research, measures that include fast conveyance systems, such as traditional underground drainage infrastructure whose primary objective is to drain water as quickly as possible, are not included, as they do not entail any relation with public space design. When comprising appropriate vegetation, measures entailed within this strategy may additionally offer the complementary benefits of water depuration and amenity value (Jacqueline Hoyer et al. 2011).

Measures that encompass this infrastructural strategy include, among others, the daylighting of streams, such as the case of Westersingel channel at Rotterdam, in the Netherlands, or the Cheonggyecheon river. In the latter, resulting benefits encompass the capacity to sustain a flow rate of 118 mm/h and flood protection for up to a 200-year flood event (Kwon 2007).

Tolerate

Measures that entail the infrastructural capacity to Tolerate are generally characterized by their ability to occasionally endure water excess from periodic flood events. These measures include both old know-how, such as the construction of elevated structures, as well as innovative designs, such as floating systems. The Yongning River Park, for example, designed to sustain up to a 50 year flood event, encompasses a floating platform for public use above the seasonally-flooded natural wetland (Turenscape). Through this platform, people can more closely enjoy and learn from natural processes even during a flood event.

The employment of measures capable of tolerating flood water excesses can be less welcomed for cultural reasons, and this fact must be taken into consideration within the design process (Valera 2001). Moreover, the application of measures with this particular purpose must bear in mind the perquisite of using strong and resistant materials in order to maintain its utility during and after storm events. In the case of submergible parks or pathways, urban fixtures, such as benches or lamps, should be effectively attached to the ground as in the case of Passeio Atlântico at Porto in Portugal.

Avoid

As the name indicates, measures that encompass the infrastructural strategy to Avoid aim to impede or prevent the presence of stormwater. These measures therefore serve the exact opposite purpose from the previous Tolerate strategy. They can have small dimensions, such as automatic floodgates applied in building doorways, or they can have very large dimensions, such as a city's waterfront embankment. They can be of a temporary nature, namely by using removable metal plaques, or of long-lasting value, namely through the use of breakwaters.

Measures targeted at avoiding the intrusion of stormwater can conciliate hard protective infrastructure with public spaces that promote local awareness and community involvement. Such an approach can be exemplified by the case of glass flood walls, which are capable of withstanding flood heights up to a typical standard of 1.8 m (Flood Control International). This type of measure is of particular interest when enduring flood protection is required in an area where the visual stimulus of a traditional flood wall is undesired.

Although large-scale traditional flood defence infrastructures, such as storm surge barriers, may integrate complementary public uses, such as transport facilities or art installations, bearing in mind the scope of this research, these are not here considered. New flood risk management paradigms present additional possibilities that are integrated with the design of public spaces. That is namely the case of urban multifunctional defenses, such as Zaha Hadid's design for the Hamburg river promenade, which integrates road infrastructure and promenade parking lots, restaurants and kiosks. One can also refer to the example of "Molhe da Barra do Douro", a robust pier that combines aboveground benches and an interior area below for inside facilities.

In line with the descriptions presented in the Table 4.4 above, which are underpinned by the previously mentioned and analysed frameworks presented in Table 4.1, the proposed analysis was specifically made considering each identified example. Each classification is based on empirical observations, as well as bibliographical information regarding each specific public space project. As displayed in Table 4.5, each exemplar is associated with a primary infrastructural strategy (identified with a bold **X**) and, if recognized, one or more secondary infrastructural strategies (identified with a plain X). For example, the wet bioretention basin of Parque Oeste in Lisbon (Categoty: E.Bioretention; Type: 10.Wet bioretention basins) encompasses all of the infrastructural strategies, except Avoid, while the Escola Industrial sports field (Category: D.Reservoirs; Type: 8.Underground reservoirs), comprising an underground reservoir, solely includes the infrastructural strategies of Store and Tolerate.

As a result of the overall analysis of the classifications made for each example, it is possible to inaugurate some conclusions regarding the primary and secondary infrastructural strategies related to each type of measure. For instance, in light of three analysed projects with different classifications ("Stata Center", "The Circle" and "Georgia Street"), Cisterns (Category: D.Reservoirs; Type: 9. Cisterns) have been classified with the infrastructural strategies of Harvest, Store, Convey and Infiltrate. It is however recognized that new or overlooked examples might potentially add further information. The same way that supplementary examples can add infrastructural qualifications for each type of measure, they can add new types of measures or categories alongside those that have not yet been addressed.

Table 4.5 - Classification of the primary and secondary infrastructural strategies encompassed in each presented example.

Examples	**Infrastructural strategy**					
Project name	**Harvest**	**Store**	**Infiltrate**	**Convey**	**Tolerate**	**Avoid**
Caixa Forum plaza	**X**	X	X			
Westblaak' car park silo	**X**	X				
Woolworths Shopping playgr.	**X**	X				
North Road	**X**	X				
Expo Boulevard	**X**	X				
Jawaharlal Planetarium Park	**X**	X				
Water Table / Water Glass	**X**	X				
Whole Flow	**X**	X				
Dakpark	**X**	X	X			
Promenade Plantée	**X**	X				
European Patent Office	**X**	X				
Womans University campus	**X**	X	X			
High Line Park	**X**	X	X			
Waltebos Complex	**X**	X				
Stephen Epler Hall	**X**	X				
Parc de Diagonal Mar		**X**			X	
Parc del Poblenou		**X**			X	
Benthemplein square	X	**X**			X	
Tanner Springs Park	X	**X**			X	
Parc de Joan Miró	X	**X**				
Escola Industrial		**X**			X	
Potsdamer Platz	X	**X**		X		
Museumpark car park		**X**			X	
Place Flagey		**X**			X	
Stata Center		**X**	X			
The Circle	X	**X**				
Georgia Street		**X**	X	X		
Parque Oeste	X	**X**	X	X	X	
Qunli park	X	**X**	X		X	
Emerald Necklace	X	**X**	X	X	X	
Quinta da Granja	X	**X**	X		X	
Parque da Cidade	X	**X**	X	X	X	
Trabrennbahn Farmsen	X	**X**	X	X		
Elmhurst parking lot	X	**X**	X	X		
Ecocity Augustenborg	X	**X**	X	X		
Museum of Science	X	**X**	X	X		
High Point 30th Ave	X	**X**	X	X		
Moor Park	X	**X**	X	X		

Ribblesdale Road	X	**X**	X	X	
South Australian Museum	X	**X**	X		
Columbus Square	X	**X**	X	X	
Derbyshire Street	X	**X**	X	X	
Onondaga County	X	**X**	X	X	
Edinburgh Gardens	X	**X**	X		X
Taasinge Square	X	**X**	X		X
Australia Road	X	**X**	X		X
East Liberty Town Square	X	**X**	X		
Can Caralleu	X	X	**X**		
Zollhallen Plaza	X	X	**X**		X
Green park of Mondego	X	X	**X**		X
Bakery Square 2.0	X	X	**X**	X	X
Praça do Comércio		X	**X**		X
Percy Street		X	**X**		X
Greenfield Elementary		X	**X**		X
Etna Butler Street		X	**X**		
Community College		X	**X**		
Elmer Avenue Neighbourhood		X	**X**	X	
Green streets design manual		X	**X**	X	
Ribeira das Jardas	X	X	X	**X**	X
Ahna	X	X		**X**	
River Volme		X		**X**	
Promenada				**X**	X
Catharina Amalia Park	X	X	X	**X**	X
Kallang River	X	X	X	**X**	X
Alb	X	X	X	**X**	X
Westersingel	X	X	X	**X**	X
Thornton Creek	X	X	X	**X**	X
Cheonggyecheon River	X	X	X	**X**	X
Soestbach		X		**X**	
Banyoles		X		**X**	X
Freiburg Bächle		X		**X**	X
Roombeek	X	X		**X**	
Solar City streets		X		**X**	
Pier Head		X		**X**	X
Olympic park	X	X	X	**X**	X
Kronsberg	X	X	X	**X**	X
Renaissance Park	X	X		**X**	X
21st Street	X	X	X	**X**	X
West India Quay					**X**
Ravelijn Bridge					**X**
Yongning River Park	X				**X**
Landungsbrücken pier					**X**

Spree Bathing Ship		X			**X**	
Leine Suite					**X**	
Rhone River Banks	X	X	X	X	**X**	
Parque fluvial del Gallego	X	X	X	X	**X**	
Rio Besòs River Park	X	X	X	X	**X**	
Buffalo Bayou Park	X	X	X	X	**X**	
Parc de la Seille	X	X	X	X	**X**	
Park Van Luna	X	X		X	**X**	
Passeio Atlântico					**X**	X
Quai des Gondoles	X				**X**	
Elster Millraces				X	**X**	
Terreiro do Rato				X	**X**	
Waterfront promenade	X			X	**X**	
Tagus Linear Park				X	**X**	
Elbe promenade					X	**X**
Dike of 'Boompjes'	X	X	X		X	**X**
Zona de Banys del Fòrum					X	**X**
Molhe da Barra do Douro					X	**X**
Jack Evans Harbour					X	**X**
Schevenigen					X	**X**
Sea organ					X	**X**
Main riverside					X	**X**
Blackpool Seafront					X	**X**
Westhoven					X	**X**
Waalkade promenade					X	**X**
Kampen waterfront						
Landungsbrücken building					X	**X**
Corktown Common	X		X		X	**X**
Westzeedijk						
Anfiteatro Colina de Camões	X	X	X		X	**X**

4.3.2 The Doughnut Diagram: Assimilating Comprehension, Simplicity and Flexibility

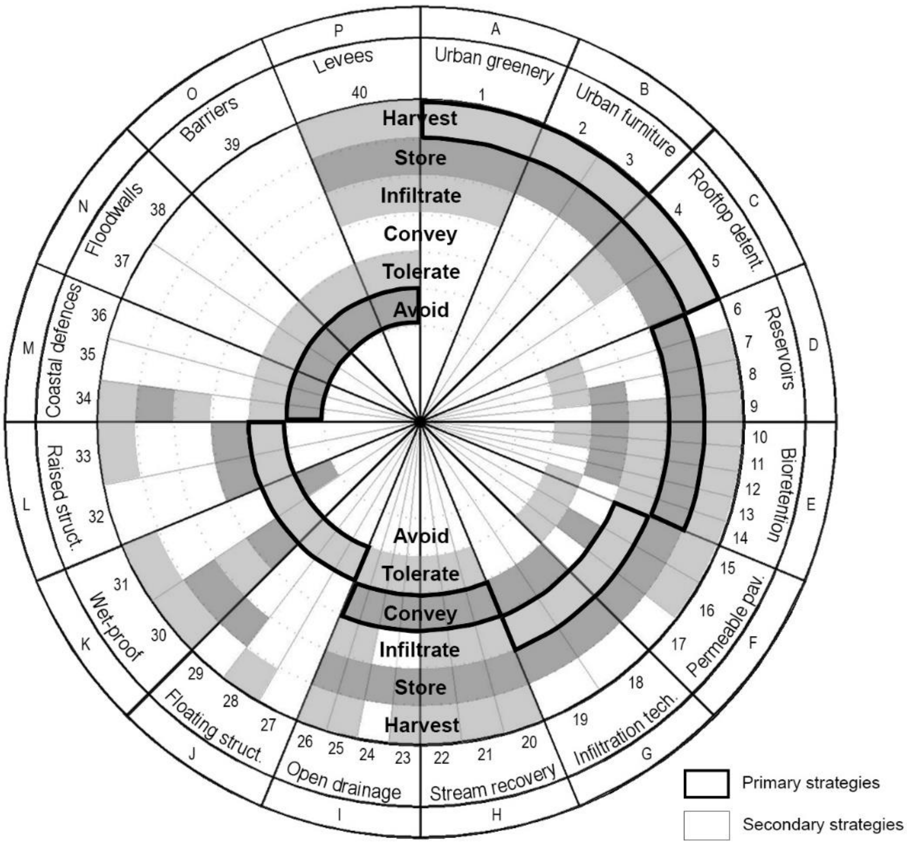
Recalling the methodological objectives, the Conceptual Framework's resulting output it is intended to be: (1) of a generic nature, yet capable of including an amplified range of alternatives; (2) simple in form and content, so that users find it easy to work and rationalize with; and (3) flexible to change in light of new arising information. As such, particular attention is given to its form and format.

Considering the previously highlighted complexity of the proposed Conceptual Framework, in which measures can be associated with more than one infrastructural strategy, the initial communicating output in the form of a tree diagram proved to be very limitative. Indeed, the search for an alternative type of diagram was a continuously evolving design process as can be confirmed by the proposed diagram published in the ECLAS conference proceedings[63], which is now outdated.

In light of this reasoning, a doughnut diagram is thus proposed, combining a radial "pie chart" with a potentially growing range of "classification rings". While the radial "pie chart" refers to the identified categories and types of measures, the classification rings refer to the chosen subject under analysis (type of flood, infrastructural strategy, physical extent of benefits, amongst others).

In the proposed Conceptual Framework, illustrated in Figure 4.86, the circular diagram is radially divided into 16 equal "slices of pie". Each "slice" represents a category that is further divided into as many slices as its respective number of types of measures. Each ring refers to the chosen approach to classify each category and type of measure by its infrastructural strategies of Harvest, Store, Infiltrate, Convey, Tolerate and Avoid.

Figure 4.86 - Flexible and comprehensive output of the proposed Conceptual Framework of categories and types of flood adaptation measures applicable to the design of public spaces. Source: designed by the author, 2016.



[63] Matos Silva, M., 2014. Urban adaptation through flood risk management infrastructure and public space design. *In:* Silva, I. M. d., Marques, T. P. and Andrade, G. eds. *Landscape: A Place of Cultivation.* Porto, Portugal: School of Sciences, University of Porto, 292 - 296.

The contents of the presented Conceptual Framework derives from the analysis of the classifications made for each example presented in Table 4.5. If one example is classified with a particular infrastructural strategy, then the type of measure associated with the analysed example also encompasses that particular infrastructural strategy. The outlined segments of each ring highlights which categories and measures are considered as primary for each related strategy. For instance, regarding the category of 'Bioretention', the measure b of 'Dry bioretention basin' encompasses the infrastructural strategies of Harvest, Store, Infiltrate, Convey and Tolerate, but not the infrastructural strategy of Avoid. The justification for this relates to the fact that, in light of the analysed examples, no exemplar was classified by encompassing the infrastructural strategy of Avoid. Conversely, the infrastructural strategy of Store was highlighted as being the primary strategy among all analysed examples.

Overall, through this proposed diagram, each category of measure, and its corresponding types, is associated with main and secondary infrastructural strategies. Moreover, and as previously mentioned, quality public spaces particularly favour interdisciplinary design and embrace multiple purposes. As such, when considering the measures associated with a particular infrastructural strategy, one should not only consider the ones that directly assist the respective strategy, but also the specific measures that indirectly support it. In other words, if one is to design a public space with flood adaptation aptitudes particularly directed towards the infrastructural strategy of Store, then, besides the measures within the categories primarily aimed at this strategy (such as 'Reservoirs' and 'Bioretention'), the measures within categories of 'Urban greenery', 'Urban furniture', 'Open drainage systems', 'Stream recovery' or 'Permeable paving' should also be considered (Figure 4.87). In the case of Qunli Park (Categoty: E.Bioretention; Type: 10.Wet bioretention basins), for example, the primary infrastructural purpose to Store stormwater and revitalize a dying wetland was complemented by the infrastructural strategies of Harvest, Infiltrate and Tolerate in the design by Turenscape. More specifically, through the inclusion of specific native greenery, the processes of stormwater collection, filtration and infiltration are facilitated. In addition, by the inclusion of elevated promenades, the recreational and aesthetic experiences are reinforced, allowing visitors to fully acknowledge the surrounding natural environment.

Considering another practical example, if one is to design a public space with flood adaptation capacities, that are predominantly directed towards the infrastructural strategy to Tolerate, then besides the measures within the categories primarily aimed at this strategy (such as

‘Floating structures’, ‘Wet-proof’ or ‘Raised structures’), the measures within categories of ‘Stream recovery’, ‘Open drainage systems’, ‘Coastal defences’, ‘Levees’ or ‘Permeable paving’ should also be considered (Figure 4.88). In the case of Park Van Luna (Category: K.Wet-proof; Type: 30.Submergible parks), for example, besides the primary purpose to Tolerate flood waters, it additionally encompassed the infrastructural strategies of Harvest, Store and Convey. Indeed, besides being implemented on a floodable polder landscape in the Netherlands, this park was further designed to store and conserve water during the dry months. The design also entails a pumping system that, through conveyance, prevents water in the lakes from becoming stagnant. Furthermore, albeit maintaining the “soil balance”, the design incorporates varied earthworks in the form of small levees.

The framework has the additional potential to be disseminated through an “open source” software medium where it is possible to add, remove or alter information within the supporting excel dataset through a simple Boolean logic of “true” or “false”. Examples, categories and types of measures can be added or removed, as can the classification made for each example also be reassessed. As a result, different layouts within the same diagram can be generated. The same software medium could further include cross references to the literature review regarding the contents of the proposed Conceptual Framework, from the conceptual definitions, to the information supporting the classification process of each example.

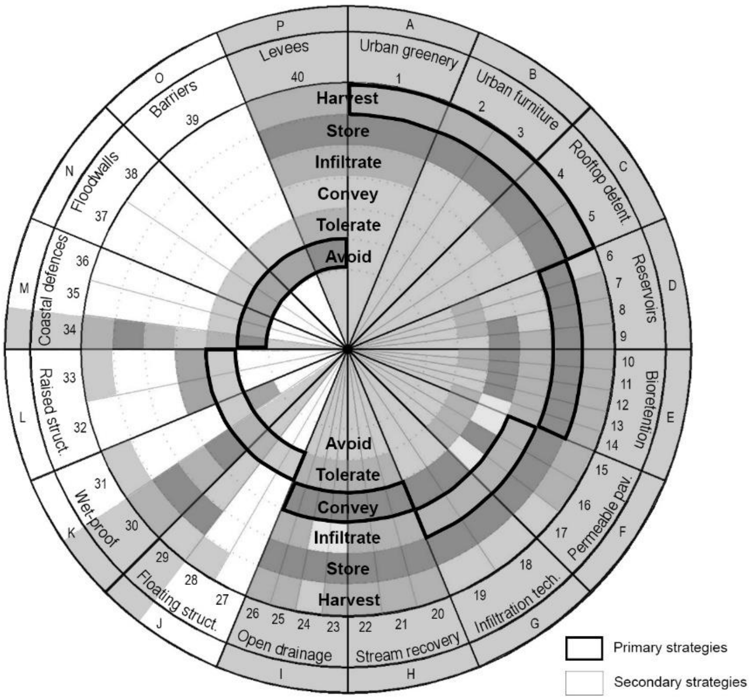


Figure 4.87 - Highlighted categories and types of measures, within the proposed Conceptual Framework, which encompass the infrastructural strategy to Store floodwaters. Source: designed by the author, 2016.

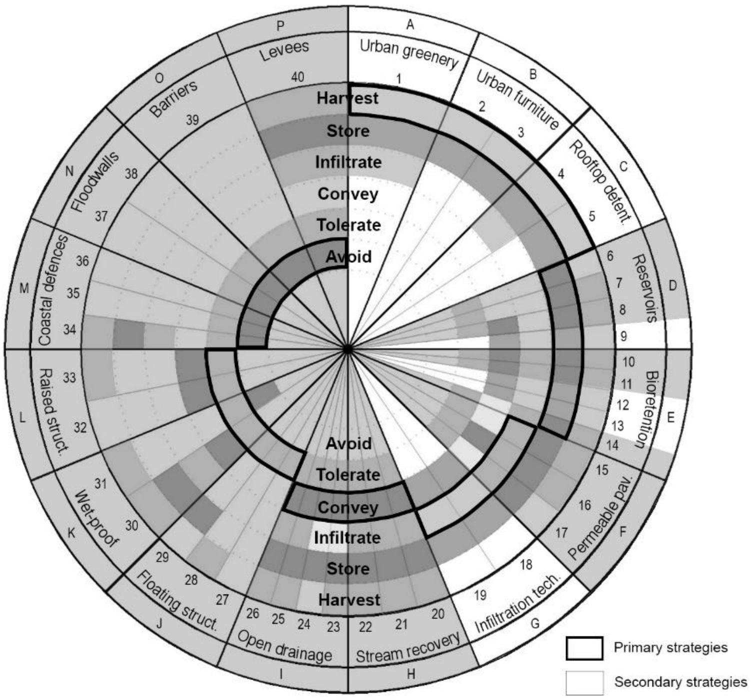


Figure 4.88 - Highlighted categories and types of measures, within the proposed Conceptual Framework, which encompass the infrastructural strategy to Tolerate floodwaters. Source: designed by the author, 2016.

4.4 Discussion

In light of the findings presented in chapter three, which highlighted how the quality of our future cities may be dependable on local adaptation measures applied in public spaces, this chapter specifically addresses the construction and design of a Conceptual Framework of flood adaptation measures, that is concretely applicable to the design of public spaces. Bearing in mind the fundamental requirement to be sufficiently elucidated with regard to existing knowledge/practice when approaching any public space design project with flood adaptation capacities, the identification, characterization and organization of a wide range of existing types of measures is particularly relevant for anyone involved in this type of practice. The proposed Conceptual Framework is therefore targeted at supporting the initial stages of a respective design process. The possibility to easily grasp an overview of the existing range of options regarding the different types of adaptation measures facilitates and accelerates the initial phase of a particularly targeted design process. In addition, the resulting overlay of information, enabled by the proposed diagram, supports the envisioned purpose to design multifunctional public spaces. Furthermore, this can be accomplished through an interdisciplinary implementation process capable of tacking numerous questions while exploiting its beneficial opportunities.

A state of the art review on previously-developed frameworks supported the initial identification of the existing types and categories of measures. A systematization process, as envisioned, provided results of a general nature based on a comprehensive research of contextualized examples worldwide. Adjacent to this systematization process, examples were gathered with the purpose of supporting the ongoing classifications with illustrations of concrete situations specifically applied to public spaces. Ultimately, two tasks supported one another, as the collected range of examples also provided the identification of both new categories and associated measures. Each measure is therefore potentially applied within any geographical context.

Combining the literature review with the analysis of examples (portfolio screening), it was possible to identify forty types of measures grouped within sixteen categories. These identified categories and types of measures can be differently organized in accordance with the diverse and particular purposes or contexts. The range of possible organizations is as wide as the various potential analysis of the identified types of measures and their corresponding examples. When opting to organize these categories and types of measures into a Conceptual Framework, to be particularly directed at featuring their infrastructural relevance, it was additionally possible to classify each type of measure, and more specifically its associated examples, in light of the six infrastructural strategies of: Harvest, Store, Infiltrate, Convey, Tolerate and Avoid. Through the classification analysis of each collected example, all measures were related to one main infrastructural strategy and/or one or more than one secondary infrastructural strategy. The more examples are classified, the more accurate is the assessment made for each measure. Ultimately, the Conceptual Framework is expected to converge in a stable layout that displays all of the possible and impossible synergies amongst the different infrastructural strategies encompassed within each type of flood adaptation measure applied to the design of a public space.

In light of the disclosed results, one may note a strong correlation with the principles established by urban drainage management systems, such as SUDS, LID, BMPs, WSUD and more (Fletcher et al. 2015). Yet, these differences essentially rely on the initial leading focus on adaptation to the risk of flooding; more specifically, on the aim to include structural measures that not only support strategies of "prevention", such as urban drainage management measures, but that also support "protection" strategies, such as flood defence measures (European Commission 2004). With regard to the presented Conceptual Framework, its distinctiveness can be found in the measures associated with the Avoid infrastructural strategy, such as 'Breakwaters', 'Sculptured walls', 'Glass walls' or 'Demountable barriers'. Other particularly targeted measures may be further identified in the remaining infrastructural strategies, namely 'Inverted umbrellas', 'Art installations', 'Underground reservoirs', 'Floating platforms', 'Elevated promenades', among others. A similar parallel can be made with encompassing concepts of Greenways or Green Infrastructure (Ribeiro and Barão 2006); measures included in the proposed Conceptual Framework can relate and sometimes be part of these notions yet they are not bounded by them.

The resulting circular diagram synthetizes the framework's contents in a manageable format that is intended to be easily comprehended and used by anyone involved in the initial phases of a public space design project with flood adaptation purposes. Since every situation is dependent on context specificities and any project may rapidly become an interdisciplinary challenge (Brandão 2008), whereby the Conceptual Framework is not intended to offer a final design solution. Instead, the proposed framework aids its users by presenting a wide range of options that are identified and characterized through a simple vocabulary and organized into a flexible and straightforward layout. Furthermore, through the use of the Conceptual Framework, options may be combined and creativity may be endorsed as each identified measure is associated with different potential and interrelating strategies.

Furthermore, it is important to enforce that, both in method and structure, the design of the proposed framework always acknowledged the advantageous possibility to add new knowledge as it becomes available. It is therefore an "open work" (Eco 1989), prepared to evolve and be restructured as new teachings, designs, concepts or approaches arise. While the measures here proposed can provide a very useful starting point, most likely, and most fortunately, they will also change and develop as new challenges arrive.

Prompted by the urging need to adapt our cities in the face of potential climate change, the Conceptual Framework here proposed offers a different approach to tackle the well-known problem of urban flooding. Through a different perspective, one that highlights the importance of public space design in adaptation endeavours, this framework offers a specific group of measures that confront traditional flood risk management practices. Through the design of public spaces with flood adaptation capabilities, our urban territories may become better adapted for the projected unprecedented impacts of climatic change.

How to use and apply the Conceptual Framework will expectedly vary across contexts. Each city needs to explore what measures are best suited for each particular situation. Recalling upon the precautious principles in line with adaptive planning, the search should not be focused on finding a single (optimal) solution or measure but rather a combination of measures that, in time, would contribute to reduce flood risk impacts.

Part III

Evaluation

The third and final part of the thesis is specifically targeted at assessing the relevance and applicability of the Conceptual Framework in a detailed context. The city of Lisbon, Portugal, is chosen for this purpose.

Chapter five aims to highlight the relevance of the Conceptual Framework by identifying Lisbon's present and projected vulnerabilities regarding flood events, as well as its municipal actions in light of past and present flood impacts. Chapter six is targeted at a practice-based analysis that tests the applicability of the Conceptual Framework in the Lisbon case. Facing the presently identified municipal endeavours particularly related to flood adaptation, different types of adaptation measures are here highlighted and discussed, prompting further questions regarding the future of municipal flood management undertakings.

Chapter 5

Flooding in Lisbon: municipal actions and projected climate change impacts

Parts of this chapter were disseminated in the following publications:

Matos Silva, M., Ochoa, R. and Nouri, A., 2014. Lisbon riverfront climate change impacts: local scale and public space management. *In:* Costa, J. P. and Sousa, J. F. d. eds. *Climate Change Adaptation in Urbanised Estuaries Contributes to the Lisbon Case*. Óbidos: Várzea da Rainha Impressores (in press), 214-229 ISBN: 978-989-98628-1-4. [Book Section]

Coelho, C. D., *et al.*, 2014. Thinking Lisbon for 2100 – "What if?" essays on the climate change adaptation agenda. *In:* Cavallo, R., *et al.* eds. *New Urban Configurations*. EAAE / ISUF International Conference, Delft: IOS Press, 981 - 987 ISBN: 978-1-61499-365-0. [Book Section]

Chapter five is particularly targeted at assessing the pertinence of the Conceptual Framework in the Lisbon case. In other words, this chapter will consider if the city evidences vulnerabilities related to the present day impacts of flood events, if these impacts are expected to increase when considering the projections emanated by climate research and, and if flood management practices still undergo the conventional mono-functional approach. Accordingly, it identifies the main characteristics and related climate change projections regarding Lisbon's floods. In addition, it advances a brief historical overview regarding the applied flood management practices in Lisbon and their relationship with public spaces.

In light of the undertaken bibliographical review, it is possible to confirm that floods are a recurrent phenomenon in the city of Lisbon. It is also verified that the projected climate-driven changes related to Lisbon's floods, albeit with interwoven uncertainty, indicate an increase in the frequency and intensity of events.

With particular regards to the analysis of contemporary practices, it is further evidenced how Lisbon is yet distant from the paradigm shift anticipated in chapter two, which basically endorses flood risk management as an integrated, comprehensive, interdisciplinary and multifunctional process. Lastly, the Conceptual Framework's contents, namely the identification and characterization of categories and types of adaptation measures, are reinforced when analysing the existing examples within the city of Lisbon, implemented throughout the years.

5.1 Flooding in Lisbon: main characteristics and related climate change projections

5.1.1. Brief overview of Lisbon's floods

…. torrential rains, …, that which drags everything in its way, destroying the very cultured land and harming villages. These are the very frequent torrents of Lisbon with strong northwest winds.

Xavier de Brito, M., 1954. O relevo da cidade de Lisboa e as enxurradas Revista Municipal nº62. Publicação Cultural da Câmara Municipal de Lisboa, 7: p.45. Author's translation[64].

In contrast to the characteristic river floods, which are created after several days or weeks as a result of prolonged rainfall, Lisbon floods are generally defined as urban floods, which can be created in just a few minutes[65]. These floods are typically associated with the phenomena of torrential precipitation accompanied by thunderstorms (Einfalt et al. 2009) falling over an urban fabric that is almost entirely impermeable and with its water courses channelized. Combined, these factors give rise to the term flash floods, which can be observed every year in the city of Lisbon.

[64] Original: "Sabe-se que a precipitação da água proveniente das nuvens segue três rumos: Uma parte evapora-se; outra penetra no terreno fertilizando-o e produzindo nascentes, parte benfazeja para o homem; finalmente, talvez mesmo a mais importante na ocasião de chuvas torrenciais, ou pelo menos copiosas, aquelas que tudo arrastam na sua frente, destruindo as próprias terras de cultura e prejudicando as povoações. São as enxurradas muito frequentes em Lisboa com vento forte de noroeste."

[65] The Portuguese language usually differentiates inundations (inundações) from floods (cheias), defining the first as the 'overflow of a water course' and the second as 'the flooding of an area that is usually emerged' Ramos, C. 2013. Perigos naturais devidos a causas meteorológicas: o caso das cheias e inundações. *e-LP Engineering and Technology Journal*, vol. 4, 11-16.

Beyond 1) torrential precipitation and 2) soil sealing characteristics of most contemporary urban fabrics, these floods may be aggravated by other factors. Specifically in the case for Lisbon, these include the particular characteristics of 3) land morphology, 4) the influence of the estuary dynamics, 5) the characteristics and condition of the drainage infrastructure and 6) future climate change impacts.

Torrential precipitation has been identified as one of the major causes of the most severe flood episodes in Lisbon (Oliveira 2003)[66]. Adjacently, Lisbon's existing urban matrix and its highly impermeable area[67], with various underground obstructions and buildings within flood prone areas, with landfills and walls continually built across water lines, also greatly contribute to the experienced flood hazards (Annex IV - Spatial data regarding the city of Lisbon – Map 1 – Lisbon's urban matrix over European Soil Sealing Raster data).

Besides exacerbating urban floods, urban imperviousness encompasses additional impacts, namely in the regulation of temperature and negative influence on the Urban Heat Island (UHI). Such impacts have long been stressed by both international and Portuguese experts. One of which is Gonçalo Ribeiro Telles, who invariably mentions the degree of urban sealing as one of the most significant conditioning factors of recurrent flash floods specifically in the Lisbon case[68].

The characteristic land morphology of Lisbon is one other aggravating factor of its floods. As Orlando Ribeiro eloquently states, "Lisbon is a city in a very unique site. Unlike Rome or Athens, with its famous hills that rise abruptly in the middle of flat land, our capital is itself largely a city of small hills, formed by a patchwork of plateaus which are cut and

[66] For instance, and like other floods in Lisbon, the main cause of the 1997 floods has been recognized as being the experienced heavy rains. As stated by Rebelo e Gancho "The cause of flooding was first of all the heavy rains of day 18. Between 12 am and 6 pm, 85 mm of rainfall were recorded, which are very close to the normal daily maximum for the period 1931-1960 (87.5 mm) and not far from the daily maximum recorded after 1960 in Lisbon/Airport (109.4 mm)" Rebelo, F. and Ganho, N. 1998. As inundações do Outono de 1997 no Sul de Portugal. *Territorium,* (5), 25-30.

[67] In 2006, the European Environment Agency (EEA) produced the first version of a high resolution soil sealing layer for all Europe, based on satellite pictures. In 2013 a second version was made available for the general public. Among thirty-eight capitals, Lisbon is the forth with higher mean of soil sealing per UMZ. With a rate of 60.66% of soil sealing, Lisbon is placed before Bucharest, Tirana and Warsaw. Comparatively, London has a rate of 42.51% and Stockholm, the best ranked capital, a rate of 22.90%.

[68] On this matter, one must highlight a television program presented by Luis Filipe Costa in 1973 that analysed the causes of the 1967 floods in the Lisbon region. This program, which is available in the online archives of RTP, had the important collaboration of Gonçalo Ribeiro Telles *As Cheias de 1967* [Video]. (1973). Costa, L. F. Available from: www.rtp.pt/arquivo/?article=732 [Accessed July 15th].

separated by a vigorous network of valleys" (Ribeiro 1994, p.65, author's translation) (Annex IV - Spatial data regarding the city of Lisbon – Map 2 – Delimitation of Lisbon's main underground drainage basins over the cities' land morphology). In objectified terms, the average land slope of Lisbon's municipality is 9%. Regardless, there are areas with slopes greater than 25%. About 17% of the municipal area has slopes below 2%, namely the low waterfront areas along the Tagus (ChiRoN et al. 2006a). This described groundscape, and the reduced drainage area of some of its watersheds, promotes the rapidity of flooding.

For a long time, flood prone areas have been identified in the city of Lisbon. At least since the fifties, "Flood sites are well known. They correspond to the landfills adjacent to existing valleys" (Xavier de Brito 1954, p.46, author's translation). Indeed, most floods occur in the humid water system, composed by water lines and its adjacent flat or concave areas, but they also happen frequently in the city's waterfront, which collect rainwater from upstream and also from the Tagus estuary.

The average altitude of the municipality is 76 m, ranging from 2 m at the waterfront, and 216 m in Monsanto. According to the analysis of Lisbon's land morphology data through the use of ArcGIS 10.2 software, about 6.1% of the Lisbon's area is below 5m, plus 2.4% between 5 and 10 m. These areas below the 5m quota are particularly vulnerable to Estuary dynamics and its influence on the flow capacity of the drainage system (Annex IV - Spatial data regarding the city of Lisbon – Map 3 – Area susceptible to direct tidal influence over Lisbon's urban matrix). Estuary dynamics are namely subject to the changing amplitudes of tides, storm surges, winds and undulation. The effects of high tide in particular, when added to the mentioned Lisbon characteristics of torrential rains, small basins, steep slopes and dense urban fabric strongly sealed, often result is considerable floods that can undermine the normal functioning of the city, namely by stopping traffic and metro lines for a considerable amount of time. Specifically, the level of the receiving waters in the Tagus estuary is mainly dependent on the ocean tide. If extreme precipitation occurs during high tide, the water body of the estuary will block the discharge of water. Additionally, estuary waters may enter the sewerage network, overloading the entire system along the riverfront. Due to the age of the historic city centre drains, a common problem occurs when the coincidence of high tide and heavy rainfall ruptures the sewerage collectors due to excessive water pressure.

Similar to the tidal effect, other factors, namely, winds and undulation, storm surges and the so-called progressive river flood of the Tagus may contribute, more or less, to the aforementioned buffer effect of the drainage system. Particularly, when considering the increase of urban population density and the escalating effects of climate change, this hazard becomes more prominent and important to resolve (Ahmad and Simonovic 2012).

Presently, the recurrent floods in Lisbon are mostly tackled through the cities' underground drainage infrastructure. This infrastructure is a particularly complex system. Most of the large sewers are combined, but they also include "separate and partially separated sewers, dendrite (tree-like) and looped or partially looped sewer networks…"; in addition it is a network composed of "infrastructures with very different ages and materials" (Matos et al. 2009, p.2). Most of the infrastructure is constituted of sewers built with modern materials such as concrete, stoneware or plastic pipes (e.g., PVC, PEAD e PP). The areas of "Avenidas Novas", "Campo de Ourique" and "Ajuda", built by Ressano Garcia in the end of the 19th century, are mostly composed of stone masonry sewers. Moreover, and with a significant presence, the historic centre of Lisbon still comprises of the so-called "saimeis", which are old Pombaline sewers built of stone, and the antecedent "cascões" or "rateiros" (ChiRoN et al. 2006a, p.16).

The city is therefore highly dependent on an artificial drainage system that has several deficiencies. Particularly, in the old sewerage network, which comprises sewers that are more than two hundred years old, the infrastructure does not have the hydraulic capacity to support contemporary outflows (Gaudio et al. 2015). The age of the infrastructure further contributes to structural fragilities such as cracks, fractures, residual water leaks into the ground and overall lack of septicity (Annex IV - Spatial data regarding the city of Lisbon – Map 4 – Lisbon's drainage network divided by classes of age).

Other structural fragilities that may occur in the overall network include; sewerage subsidence, improper or faulty connections, defective equipment, damaged surfaces, corrosion or collapse (Cardoso 2008). Hydraulic efficiency may be additionally disturbed by sediment accumulation, which may lead to sewerage obstruction, a situation frequently observed in the flat marginal areas of the city (ChiRoN et al. 2006a). Gutter obstructions, often mentioned in the media as the main source of the problem, have been seen to also partially contribute to the Lisbon floods.

Another distinctive factor of Lisbon drainage infrastructure, includes its reduced storage capacity. In addition to the previously mentioned groundscape and urban sealing characteristics, which promote rapid peak flows, the absence of upstream retention further contributes to a high concentration of water in the low areas and main water lines.

Furthermore, while separate sewerage systems exist, mostly all of these are connected to primary combined sewers, also contributing therefore, to the frequent overflow of the drainage system (Annex IV - Spatial data regarding the city of Lisbon – Map 5 – Identification of the existing combined and separate underground sewerage systems of Lisbon).

The occurrence of overloads in the combined sewerage collectors (Combined Sewage Overflows - CSO's) are therefore particularly frequent in these areas and are highly dependent on the speed of subsequent coastal discharge (Annex IV - Spatial data regarding the city of Lisbon – Map 6 – Evaluation of the drainage capacity of the existing sewerage system in the event of a stormwater flow with a return period of 50 years). Bearing in mind climate change projections explored in previous subchapters, namely 1) variations in atmospheric pressure, and the consequent increase of storm surge magnitudes, 2) the increase of the average sea level, and 3) the extreme event precipitation changes, Lisbon floods are likely to increase in frequency and intensity (Figure 5.1).

Figure 5.1 - Floods of 1945-11-18 in Lisbon. The good humour patent in some of the photographic records of this day, are unlikely common in present days, as floods have already become more frequent and intense nuisance. Image credits: Benoliel, Judah, 1945. Source: Arquivo Municipal de Lisboa – Fotográfico. PT / AMLSB / JBN / 003559, 003560, 003565.

Considering that the existing drainage system is already undersized to most registered precipitation events and whose efficacy is additionally worsened when there is a coincidence with the high tide, one can directly conclude that the simultaneous occurrence of projected sea level rise (SLR) and intense rainfall episodes will significantly contribute to an increased amount of impacts that already cyclically disturb Lisbon.

If nothing is done, Lisbon's drainage system will therefore progressively become even more undersized. As a consequence, impacts of increased urban flooding will additionally cause overall urban deterioration and progressive infrastructural malfunction. As stated by Fadigas, "most likely degradation will increase and infrastructures will function progressively worse" (2014, p.241). Likewise are the consequent maintenance and construction costs of infrastructure, which will also increase as long as strategies opt for "business as usual".

Lastly, regarding Lisbon's flood characteristics, it is further important to highlight that by being located in a region of high seismic hazard, Lisbon is forever at the mercy of another type of hydrological disaster: a tsunami. This phenomenon, unrelated to the more common flood events abovementioned, essentiality consists of a series of very powerful waves caused by the displacement of a large volume of water from the ocean. Among others, tsunamis may be generated by earthquakes.

In 1755, followed by an earthquake with its epicentre in the ocean, a tsunami submerged Lisbon's harbour and downtown area. Following the earthquake and tsunami, another great catastrophe left the city in flames for five consecutive days. A disaster impregnated in the memory of the Lisbon people, which further had strong consequences on the Enlightenment culture of Eighteenth-century Europe. Among others, while Voltaire argued that "Evil is on the Earth", Jean-Jaques Rousseau disagreed, claiming that Human-made errors are the ultimate responsible for the corruption of the harmony of creation (Fonseca 2005). Overall, these reflections regarding pain and the Human condition prompt the emergence of new mentalities. More specifically, as a result of an unprecedented natural hazard, the enlightenment optimism started to give up from trying to replace itself to God and Nature.

Flood events in the city of Lisbon, some examples

The study developed by Oliveira and Ramos, which covered the period between 1918/19 and 1994/95, where it was concluded that since the 70's, the number of flood events have declined in Lisbon. Among the mentioned possible causes are the gradual improvements of the drainage system and the "decreasing waste, earth and debris to clog drains and sewers" (Oliveira and Ramos 2002, p.39). Yet, still within this period in time, there were two devastating episodes that marked the city of Lisbon: the floods of 1967 November 25th and of 1983 November 19th, which respectively affected the areas of Loures-Lisbon and Cascais-Lisbon. These floods resulted in the loss of life along fringe areas, namely as a consequence of illegal construction in low-lying, flood prone areas.

On the 25th of November 1967 the recorded precipitation from 10 a.m. of the 25th until 10 a.m. of the 26th was of 109.4 mm, 158.7 mm and 131.9 mm in the stations of Lisbon (Airport), Monte Estoril and S. Julião do Tojal - Loures respectively (Amaral 1968). It was therefore considered as a "flash flood" and its consequences were desolating (Figure 5.2). This flood led to the death of around 700 people, of which only 4 died inside the city of Lisbon (Oliveira and Ramos 2002).

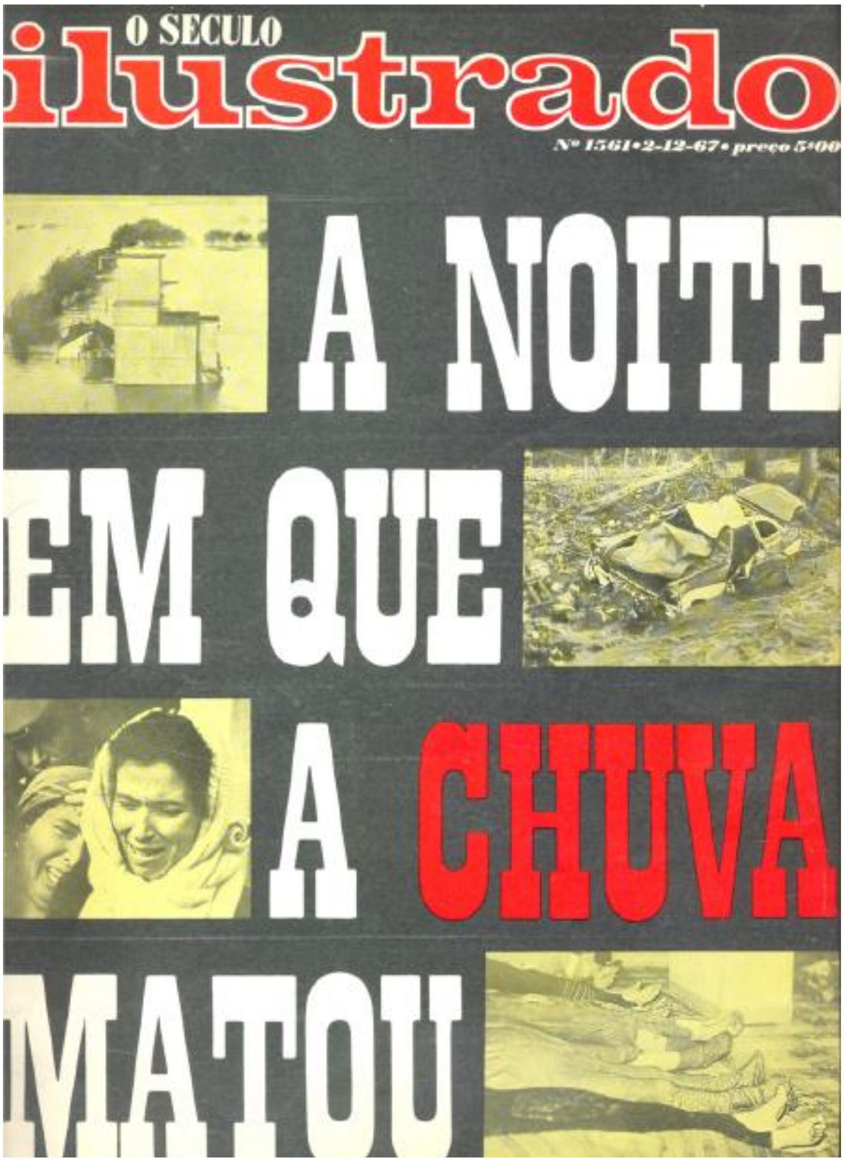


Figure 5.2 - The dramatic cover of the newspaper "O Século Ilustrado" highlighting the flood event of 25th of November of 1967.

On November 19th of 1983, 126.6mm was the recorded daily precipitation at the Instituto Geofísico Station (Rebelo 2008). This was second highest record of this station, which was only surpassed in 2008 (Moreira(Coord.) et al. 2008). According to Rebelo, as in the floods of 1967, the ground was already soaked with water (2008). However, the scale of the consequent impacts of this flash flood was very different in terms of human victims, which comprised a total of ten according to Ramos and Reis (2001).

In the last decade, among the main pluvial events registered in the city of Lisbon, the events of 18/2/2008 and 30/10/2010 are considered as exceptional. It was verified that the registered precipitations in these events were above the expected levels for a 50 year return period. Specifically, Instituto Geofísico station registered 118mm of daily rainfall for the event of 18/2/2008 (Moreira(Coord.) et al. 2008) and 79.4mm for the event of 30/10/2010 (IM 2010).

The intensity of the rainfall event of 18/2/2008 caused flooding in several parts of the city, namey at Praça de Espanha, Campo Grande, Martim Moniz and Alcântara. In this situation, estuarine dynamics did not contribute as an aggravating factor once there was the coincidence of low tide levels. This fact prompts to the conclusion that even without costal obstruction, the drainage system is undersized for an episode of this magnitude. Besides the aboveground damages as illustrated in Figure 5.3, underground conduits were also damaged, which may be the result of a combination of great stormflow pressures with obsolete infrastructure.

Figure 5.3 – Lisbon's Floods on the 18 of February of 2008. Major damages in Alcântara, Praça de Espanha, Campo Grande and Martim Moniz. Image credits: Inácio Rosa and Mário Cruz, 2008, LUSA Agência de Notícias de Portugal S.A.

In the event of 30/10/2010, the high tides strongly contributed for the extension of its impacts. In addition, a pipe rupture at Martim Moniz which further hindered the efficiency of stormwater outflow. Impacts were felt all over the city. In low-lying areas, water reached levels above one meter. Among the most affected areas were Downtown, Rossio, Restauradores, Av. da Liberdade and Alcântara (Figure 5.4).

Figure 5.4 - The floods on the 28th of October 2010 affected several low-lying areas in the city of Lisbon. Streets and Metro stations closed. Damages were additionally felt in several economic activities such as restaurants and museums. Image credits: Jornal O Público / LUSA.

More recently the media and social networks widely reported the events of 22/09/2014 and 13/10/2014. As can be seen in Figure 5.5, these specific events flooded Alcântara as well as several other areas of the city such as, Downtown, Benfica, Avenidas Novas, among others. In contrast, the registered precipitation levels of the 22/09/2014 event is clearly below the expected levels for a return period of 5 years (Hidra et al. 2015). Considering the experienced impacts of this flood, it has been argued that this event might have resulted from very localized extreme precipitation or that the monitoring equipment, within the areas affected by more intense rainfall, failed to register the occurrence (Hidra et al. 2015).

Also, the values recorded in the event of 13/10/2014 were similar to the expected values for a return period of 20 years. According to this data, this flood was theoretically less intense than the floods of 2008 and 2010. Yet different records indicate a peak of precipitation intensity that led to an outflow increase in all monitoring stations of SIMTEJO (Concessionary Company of the integrated sanitation of the municipalities of the Tagus and Trancão rivers), namely the monitoring station near Alcântara Wastewater Treatment Plant (WWTP) registered flow rates above 110 m3/s, exceeding the measuring limits of the speed sensors (Hidra et al. 2015).

Figure 5.5 - Floods of 13th of October 2014. Most affected areas included the usual Downtown area, Alcântara, Avenidas Novas, among others. Source: Jornal O Público / LUSA.

As corroborated in the study developed by Pedro Elias Oliveira (2003), which identified and located the total number of floods, with more than two episodes, between the periods of 1918/19 and 1997/98 (Annex IV - Spatial data regarding the city of Lisbon – Map 7 – Total number of floods, with more than two episodes, by location in Lisbon, between 1918/19 and 1997/98), the most affected areas of the aforementioned floods, generally corresponded to the areas identified as "very high" within the Flood Vulnerability Map of Lisbon's Municipal Master Plan (PDM Lisboa) in effect (Annex IV - Spatial data regarding the city of Lisbon – Map 8 – Lisbon's Flood Vulnerability Map over the cities' urban matrix).

5.1.2. Projected climate-driven changes in Lisbon's flood events

Among the most important climate-driven projections related to the particular matter of flooding in Lisbon, the following must be taken into consideration: 1) variations in atmospheric pressure, and the consequent increase of storm surge magnitudes, 2) the increase of the average sea level, and 3) the extreme event precipitation changes.

According to Santos et al., it is estimated for Portugal to have a greater frequency of low-pressure systems, which will lead to an increase in storm surges (Santos et al. 2002). While it has been further concluded that there is a low probability of simultaneous occurrence of extreme storm surges and high tide conditions (Santos et al. 2006), the possible combination of these events should not be ignored.

Although changes in the intensity and direction of wind patterns may increase wave heights, winds and undulation are considered to be minor threats (Dias and Santos 2014, Oliveira and Ramos 2002). Regardless, their combined occurrence, with the likely storm surges and less likely progressive river flood of the Tagus (which, as previously outlined, results from rainfall throughout consecutive days) may also lead to significant risks.

Although protected from the oceanic dynamics, it is very likely for Lisbon to be affected by the impacts of projected storm surges and SLR. As argued by Guerreiro et al., the projected rise in sea level will increase tide amplitude and therefore exacerbate marginal flooding (2013).

Specifically in regards to sea level rise projections, data series within the Tagus estuary are insufficient or not long enough to define a statistically significant SLR tendency (Dias et al., 1988 in Dias and Santos 2014). Most studies therefore use the Cascais (oceanic) tide gauge, which, in operation since 1882, offers one of the longest time series in the world (Antunes and Taborda 2009) and thus constituting, a reliable source of scientific data. Empirical observation throughout the years concluded a constant sea level rate increase (from 1.3 mm/year the since 1880 till 1990, to a 2.1 mm/year in the 90`s, and 2.5 mm/year on the last decade), supporting the idea of an expected mean SLR between 0.60 and 1.00 meter for 2100 (PECAC 2010). Results that are consistent with IPCC projections (IPCC 2007) and other sources (Schaeffer et al. 2012, Rahmstorf 2010, Antunes 2010).

Still regarding the impact of SLR and storm surges upon Lisbon's waterfront, the research project "Urbanised Estuaries and Deltas. In search for a comprehensive planning and governance. The Lisbon case" developed the so called "what if" research approach, gathering and combining "worse case scenarios" from research findings related to: 1) SLR, 2) storm surges, 3) the effect of progressive floods in the Tagus, 4) flash floods in streams and watercourses in the urban context, 5) the effect of tides, 6) waves and 7) topographic correction of cartography (Costa et al. 2013). Table 5.1 and Table 5.2 synthetize its corresponding main findings.

Table 5.1 - Used variables for the calculation of flooding elevation lines for the Lisbon case. Source: FCT R&D project, Urbanized Estuaries and Deltas, FA/ULisbon and FCSH/UNL, 2012.

<table>
<tr><th>Scenarios for 2100</th><th>Increase in sea level</th><th>Cartographic correction [1]</th><th>Increase in Tide [2] (corrected)</th><th>Waves [3]</th><th>Increase through flooding</th><th>Storm surge [4]</th></tr>
<tr><td>IPCC (2007) A1 scenario
Rahmstorf (2007) B1 scenario
CCIAM - Portugal (2010) B1 scenario</td><td>+ 0.60 m</td><td rowspan="7">+ 0,16m</td><td rowspan="7">+ 1,92m (62 events in 2011)

+ 2,12m (21 events in 2011)

+ 2,22m (4 events in 2011)</td><td rowspan="7">+ 0,20m (frequent wave size)

+ 0,40m (extreme events)</td><td rowspan="7">+ 0,15m (progressive floods of the Tagus) [5]

+ 0,45m (flash flood of urban streams) [6]</td><td rowspan="7">+ 0,40m (1 event in 5 years)

+ 0,50m (1 event in 25 years)

+ 0,58m (1 event in 100 years)</td></tr>
<tr><td>Rahmstorf (2007)
CCIAM - Portugal (2010) A1 scenario
North Carolina AR (2010) recommended</td><td>+ 1.00 m</td></tr>
<tr><td>Vellinga et al (2009)
Defra (2006) recommended scenario
Climate Rotterdam (2010) worse scenario</td><td>+ 1.20 m</td></tr>
<tr><td>Delta Rotterdam (2008) worse scenario</td><td>+ 1.30 m</td></tr>
<tr><td>Rahmstorf (2010)
California CATR (2009) A1f1
North Carolina AR (2010) worse scenario
CCIAM - Portugal (2011)</td><td>+ 1.40 m</td></tr>
<tr><td>Defra (2006) worse scenario
New York CPCC (2009) worse scenario</td><td>+ 1.60 m</td></tr>
<tr><td>Hansen (2007)
Pfeffer et al (2008) extreme scenario
Thames Estuary (2009) extreme scenario
Defra, London (2010) extreme scenario
UKCIP09 extreme scenario</td><td>+ 2.00 m</td></tr>
</table>

[1] According to the Hydrographic Institute, given that the Mean Sea Level was established in relation to average levels adopted in 1938, there is currently a systematic difference of circa +0,10m between the various water heights observed and the expected height of the tide. The same correction should be applied to land cartography that establishes altitude based on Mean Sea Level. More recent data, points towards the need to ensure a correction of +0,159m (Antunes 2010).

[2] According to data calculated by the Prediction Model of Astronomic Tides of the University of Lisbon's Faculty of Science, the range of the highest tides for Lisbon at high tide for the reference period of 2000-2010, varies between 4.26 m and 4.50m. The Administação do Porto de Lisboa (APL) Tides Table for 2011 registers maximum events of 4.30m, with 62 tide events occurring with high tides at 4.0m. The water height indicated

in the tide tables refer to the Mean Sea Level of the APL, located at 2,08m below the average sea level in Cascais (APL 2011). As this is used as the reference point to determine the 0,00m level of land cartography to be used in simulations, this correction needs to be made.

[3] The estimate of wave size on the northern bank of the Tagus is the most inconsistent element of the projection data; based on the data available 0,40m is taken as the value for a frequent wave, with extreme values reaching 0,80m. For the purpose of SLR, only the increase of the wave in half of these values, should be considered.

[4] The maximum storm surge registered in the Cascais tide gauge in the period between 2000 and 2010, was 0,42m (PECAC 2010). Previously, values estimated for the recurring periods of 5, 10, 25, 50 and 100 years were 0,40m, 0,44m, 0,50m, 0,54m and 0,58m (ARH-Tejo 2009a, p.4) Records from 1978 and 1981 point towards events of 0,42m and 0,52m, respectively (Santos et al. 2006). For the purposes of analysis on riverfront land use, ARH-Tejo has used the 0,59m as the reference value for the 100 years recurring period (ARH-Tejo 2009b, p.3).

[5] For the purposes of accounting for the effect of progressive flooding today, in the Tagus, River LNEC's determination of the reference values of 0,15m for the Rio Trancão areas, has been adopted by the ARH-Tejo (2009a, p.4).

[6] To reflect on the effects of flash floods on the riverfront, historical data can be used as a reference for the 2008 and 2010 Lisbon floods, though this also requires approximate measurement of levels in several points, as well as information made available by the National Civil Protection Authority. There are several simulation models being developed for flow and flooding of water courses in Lisbon, such as SIMTEJO or the University of Lisbon's Faculty of Science.

Further note: To simplify the processes, the simulations do not consider the specifications of the drainage infrastructure of the city, which is expected to become congested in the analysed scenarios, an exacerbating factor in flooding situations.

Table 5.2 - Simulation of 4.50 elevation "what if?" scenario for Lisbon in 2100. Source: FCT R&D project, Urbanized Estuaries and Deltas, FA/ULisbon and FCSH/UNL, 2012.

Scenarios for 4.50 elevation (approximately)	**Increase in sea level**	**Cartographic correction**	**Increase in Tide**	**Waves**	**Increase through flooding**	**Storm surge**
Best scenario SLR, time tide 21 events/year	+ 1.00 m	+ 0.16 m	+ 2.12 m	+ 0,40 m	+ 0,40 m	+ 0,42m
Best scenario SLR, time tide 4 events/year			+ 2.22 m	+ 0,40 m	+ 0,40 m	+ 0,32m
Intermediate scenario SLR, time tide 21 events/year	+ 1.20 m		+ 2.12 m	+ 0,40 m	+ 0,30 m	+ 0,32m
Intermediate scenario SR, waves tide 4 events/year	+ 1.40 m		+ 2.22 m	+ 0,40 m	+ 0,10 m	+ 0,22m
Intermediate scenario SLR, time tide 62 events/year			+ 1.92 m	+ 0,40 m	+ 0,30 m	+ 0,32m
Extreme scenario, normal wave size tide 21 events/year	+ 2.00 m		+ 2.12 m	+ 0,28 m	-	-

In the development of the "what if" simulations, the elevation point was established at 4.50m. "Considering the general acceptance of the international scientific community on SLR scenarios of between 1,20m to 1,40m (Rahmstorf, 2010), considering the known evolution dynamics of greenhouse gas emission levels with the greenhouse effect, and considering the precautionary principle, it is reasonable to use the 4.50 m point of land cartography as the reference tipping point to be used for urban planning work in Lisbon, till 2100" (Costa et al. 2014, p.184). This research, which aimed to contribute to the inclusion of the climate change adaptation issue into the agenda of urbanised estuaries and deltas, further highlighted that this "what if" benchmark can be reached namely 1) on a day with strong wave activity, for a tide with 4 events/year, or 2) on a stormy day, with a tide of 62/events/year (Table 5.2). Both situations that can be easily recognised as possible and, as such, may further promote the effective adoption of adaptation measures. Moreover, as can be verified in Map 9 (Annex IV - Spatial data regarding the city of Lisbon – Map 9 – Lisbon's different profiles throughout the years, together with the highlighted area below the 4.50m quota), the consequences of occasionally reaching the 4.50m "what if" scenario broadly imply the retreat of Lisbon's waterfronts and the retrocession of the city's profile to what it was before the industrial Era. In other words, around 1.052 million square meters of waterfront area, which is particularly vital for the proper functioning of the city of Lisbon, is affected in light of the aforementioned "worst case", yet existing, projections (Figueira de Sousa et al. 2014).

Although there is wide confidence among the scientific community about SLR, where opinions generally diverge on how much it will rise and not on "if" it will rise, uncertainty generally overcomes scientific confidence when considering storms and precipitation extremes. Yet the most current and comprehensive analysis that help to comprehend Lisbon's situation regarding future precipitation extremes, namely "Cartas de Inundações e de Risco em Cenários de Alterações Climáticas" (CIRAC) and "Plano Estratégico de Cascais face às Alterações Climáticas" (PECAC) reports (Figure 5.8), point towards a high degree of confidence that flooding will increase and bring stronger impacts and more severe damages.

Specifically regarding precipitation regimes, climate projections indicate a substantial decrease in the amount of annual precipitation in Portugal at the end of the century, with reductions of about 20 to 40% as previously mentioned. According to the research report developed for Cascais, cumulative monthly precipitation is expected to reduce except for one of the four emissions scenarios (B2)[69] (Aguiar 2010). Since present emission rates are closer to the worst-case scenarios than to the best-case-scenarios, the strong decrease of precipitation can be considered the most likely for the Lisbon case. However, while a decrease in precipitation involves a

[69] Information about the Emission Scenarios in IPCC, 2000. *Special Report on Emissions Scenarios (SRES) - Summary for Policymakers.* Intergovernmental Panel on Climate Change. 27 pp. ISBN: 92-9169-113-5.

smaller number of consecutive days with rain, it could also imply an increase in the intensity of the precipitation event, and a decrease in the return period of the extreme event in every projected scenario (PECAC 2010, IPCC 2012, EEA 2012). Findings from the CIRAC research project indicate that extreme rainfall events will be more frequent, with increased precipitation in relatively short time intervals, consequently leading to an increased risk of flooding (CCIAM 2014).

Under the European research project ENSEMBLES, Mendes and Oliveira (2012) have also concluded that most projections for the end of the century indicate an increase in maximum daily rainfall, notably in Central and South of Portugal. In regards to the Lisbon case, although variable, the projections for maximum daily precipitation suggest an increase in the maximum annual daily rainfall, which may or may not be reflected in increased precipitation in shorter time intervals (Hidra et al. 2015).

More recently, in his doctoral studies, Luis Dias concluded that there will be an increase of precipitation in the city of Lisbon in light of the return periods considered in his research (Dias 2016).

Invariably, future precipitation regimes are the subject in which most uncertainty exists. Considering the overall characteristics of models and their limitations in particular, climate models are unable to fully grasp the complexity of the water cycle. As a consequence, one may often find contradictory studies, which vary in accordance with the used models, indexes or datasets.

What is particularly important to note, is that while the increase of extreme precipitation will imply bigger flow rates in shorter concentration times, mostly affecting adjacent areas of water lines, storm surges and SLR will hinder coastal runoff. Specifically in the Lisbon case, by hindering the coastal outflow, the duration of flooding will increase together with the amount of water accumulated in low-lying areas. As previously highlighted, considering that current water levels in Lisbon during high tides already reach the riverfront quota in some places (Figure 5.6), the slightest rise in sea levels will significantly contribute to the buffering effect of the existing drainage system if no additional measures are undertaken.

Regardless of the uncertainty, all variables must be framed and taken into consideration, in order to establish this subject in contemporary urban dialogues. In addition, when opting to tackle climate change matters in light of the advocated precautionary approach, “worst case scenarios” must be analysed and looked upon as opportunities rather than barriers.

Figure 5.6 - Lisbon's waterfront during the highest tides of 2011 (in September). Above: Terreiro do Paço. Below: Cais do Sodré. Image credits: Maria Matos Silva, 2011.

Flood vulnerability and risk assessments for the city of Lisbon

Severe floods within urban territories are generally associated to various impacts such disruption in the transport systems, commercial activities, services, together with overall damages within residential areas. Some cities, which are particularly vulnerable to floods, entail greater risks such as the loss of property and even life. In the Lisbon case, floods do not usually lead to mortal victims. According to Oliveira and Ramos "…in the worst floods to ravage Lisbon region in the twentieth century (November 1967), of the approximately 700 recorded deaths only 4 died inside the city" (2002, p.35, author's translation).

In 2006, one of the guidelines of the National Program of Regional Planning Policy (Programa Nacional de Política de Ordenamento do Território, PNPOT) comprised the introduction of a preventive risk assessment agenda. This agenda was established as an essential priority within spatial planning policy and was further considered as mandatory in land management proceedings. As a result, subsequent revision proposals incorporated within the regional land management plan for the metropolitan area of Lisbon (PROT-AML), and its Municipal Master Plan (PDM) started to include flood risk management cartography.

As previously highlighted, Lisbon's Municipal Master Plan in effect comprises a flood vulnerability assessment within its map of "Natural and Anthropogenic Risks I". This flood vulnerability map, enriched by previous analysis (CML 2008), identifies the geographical boundaries of the areas that could be affected by flooding in accordance with several parameters, namely: 1) registered extreme precipitation, 2) historic records of flood occurrences, such as previously studied by Oliveira (2003), 3) land morphology gradient, 4) level of permeability, 5) direct tidal influence, 6) presence of watercourses, 7) presence of road infrastructures and sanitation facilities, among others (CML 2010, p.24). Findings were aggregated in three qualitative levels: moderate, high and very high; corresponding to the areas: 2.939.676, 18.049.997 and 3.474.061 m2 respectively (Annex IV - Spatial data regarding the city of Lisbon – Map 8 – Lisbon's Flood Vulnerability Map over the cities' urban matrix). In total, flood vulnerable areas in the city of Lisbon sum 24.463.634 m2. As may be noted, the areas considered as vulnerable to floods are mostly located along waterlines and corresponding lowlands and along the riverfront.

It is however important to note that the abovementioned vulnerability assessment presented by the PROT-AML, and applied namely in Lisbon's PDM, is only focused towards the impacts affecting present day and the near future as it does not consider any climate change scenarios and their consequential territorial impacts. Indeed, as may be consulted in the main reports presented in Figure 5.8, climate change was preferably tackled through the mitigation perspective, leaving the adaptation agenda for other endeavours.

Following instructions from the EU Floods Directive (2007/60/CE), Member States had to start preliminary assessments by 2011 in order to identify the river basins and associated coastal areas at risk of flooding. For such zones, flood risk maps were required by 2013 together with flood risk management plans by 2015, which focused on prevention, protection and preparedness (2007/60/EC 2007). As requested by the EU directive, these flood risk maps, had to specifically consider future projected changes regarding the risk of flooding as a result of climate change, as well as comprise an analysis on the exposed elements, such as buildings, heritage and agricultural fields.

According to the Portuguese Decree-Law 115/2010, which transposed the mentioned directive into national legal systems, flood risk maps should express the potential adverse consequences, both present and future, through the indication of the number of affected inhabitants and/or economic activities in areas potentially affected, the identification of sensitive buildings, the identification of installations that may cause pollution in case of flooding, among others (DL 115/2010).

Although the vulnerability map presented by Lisbon's PDM does not correspond to the risk map requested by the EU directive, the "Flood Risk Mapping Methodological Guide", published under CIRAC research project, argues that the requested elements only provide parameters of vulnerability "being required a further analysis to obtain flood risk cartography" (Dias et al. 2014, p.24). In light of their own critique, CIRAC research project developed a particularly targeted flood risk cartography which included their added considerations. More specifically, for the involved researches, flood risk maps are "a geographic representation of the flood characteristics, the exposed elements and the result of the risk assessment of those elements"(Dias et al. 2014, p.23). They should associate information regarding the type of flooding, the flood extent, depth, the speed and / or direction of flow (De Moel et al., 2009 in Dias et al. 2014).

One of the goals of CIRAC project was to provide the first systematic study of flood risk cartography for Portugal. Its analysis was particularly focused within four urban downtowns: Lisbon, Porto, Coimbra and Algés. Particularly regarding the case of downtown Lisbon, the flood risk map was created through the combination of: 1) flood maps, which include water height for different return periods and 2) damage maps at the building scale, calculated by probability-damage curve that relate water height with the average potential damage (CCIAM 2014). Furthermore, this assessment was made for current climate as well as for two global climate scenarios, regionalized from HadCm3 regional model.

Although flood risk maps can be a very useful management and planning tool for climate change adaptation, namely as they provide a differentiated analysis of higher or lower risks according to the element under study - which can be either cultural heritage, infrastructure, goods, agricultural fields or people (Merz et al., 2007 in CCIAM 2014) - one must bear in mind that this particular study was requested and financed by APS (Portuguese Association of Insurers) and consequently buildings and their associated damage costs are at the centre of the overall analysis. "Exposed" elements as well as its associated "value" and "cost", were therefore strictly directed to building data.

CIRAC further developed their own flood vulnerability maps in climate change scenarios for mainland Portugal. "Zooming in" in their analysis one may get a glimpse of what could be considered as the first Climate Change Flood Vulnerability Map for the city of Lisbon (Annex IV - Spatial data regarding the city of Lisbon – Map 10 – Detail, encompassing the city of Lisbon, of the Portuguese Flood Vulnerability maps in climate change scenarios developed by CIRAC over the cities' urban matrix). Their presented cartography was essentially based on the equation presented by Balica S-F (2012) (Equation 1, Figure 5.7) yet with added considerations (Equation 2, Figure 5.7). More specifically, resilience was approached as an equivalent to "social susceptibility" which includes a socio-economical characterization of the population in regards to factors such as age, income and education. In addition, in order to include the precipitation component, as required by the promoting entity APS, the geographical distribution of annual rainfall was added to the equation[70].

Figure 5.7 - Vulnerability equations used by the CIRAC project.

(1) Vulnerability = exposure + physical susceptibility – resilience [1]

(2) Vulnerability = exposure + physical susceptibility + precipitation – social susceptibility

[1] 1) Exposure, as the values which are present at the location when flood occur; 2) Physical Susceptibility, as the physical characteristics of an area given by its natural terrain configuration and occupation and 3) Resilience, considered as "the ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions" (UNISDR, 2009 in CCIAM 2014, p.30).

A different research project, "Urbanized Estuaries and Deltas", also developed a particular vulnerability research by analysing the possible impacts in light of the "what if" scenario of 4.50 m of sea level elevation. This scenario was spatially considered with 3D simulations and the impacts among different sectors was quantified, namely the built environment, urban functions, the economic value of buildings, networks and urban systems, the transport system, infrastructures and road traffic,

[70] It is important to note that the precipitation component was based on average rainfall dada between the years 1961 and 1990. Although it is mentioned that this data set is used as an international standard and reference for climatic change, its representativeness is specific to this period and does not take into account future projected trends and changes. The resulting vulnerability map therefore represents current vulnerabilities in a precedent "worst case scenario" and therefore does not represent the projected future vulnerabilities. Regardless, this type of assessment is here considered as an important starting point for any critical analysis regarding upcoming impacts and risks.

passenger public transport, river transport of passengers, the Lisbon Port and freight transport, and the Lisbon riverfront imaginary (monuments and public art).

Among other findings, it was concluded that 1.225 buildings would be affected in a total area of 1.052 million square meters. The construction typology may influence the strength of a particular building. The main construction typology in this area is brickwork (61,6%) and less than a third had a reinforced concrete structure (29,4%). Buildings in brick are found mostly in the Alcântara, Santos-o-Velho and Marvila, corresponding to the older parishes of the city. In regards to the building's dominant functions, housing takes the lead with 35.0% and in second offices/services with 21, 8%. Another significant finding is that 12,0% of the buildings are empty. When considering the function of the ground floor 23,5% of all the buildings are occupied with offices/services, 21,3% with commerce and only 15,3% with housing (Costa et al. 2013). One third therefore corresponds to housing on the ground floor, comprising circa 420 homes. A number of vulnerable buildings that should be subject to particular attention in future urban development commitments.

Within Lisbon's waterfront, other important functions coexist, namely transport infrastructures such as roads, rails, port or the river, which serve not only passengers' mobility, but also serve the necessary transport of goods. Additionally, it comprises of a network with associated services and equipment that are crucial for the connection with other parts of the city, be it between eastern and western parts of the city's urban front, the neighbouring municipalities, the inland areas where the city has expanded to, or the two banks of the estuary (Figueira de Sousa et al. 2014). The coexistence of fundamental functions within Lisbon's waterfront therefore entails an importance that goes beyond the local scale.

Impacts from flooding which results from projected SLR can be directly measured, as this type of flooding corresponds to a progressive phenomenon, albeit non-reversible. Impacts from flooding which results from extreme precipitation or storm surges are as unpredictable as the severity and intensity of events and therefore more complex to measure and assess.

Overall, it is widely accepted that areas which are particularly vulnerable to flooding should be specifically managed in light of potential constraints to economic activities, public funds, transport or underground infrastructure, housing, services and overall everyday life. In accordance, further research on risk assessment and specific adaptation action is expected to be developed in the near future. That is namely the case of the recently launched (2015) European R&D project "Bringing INovation to onGOing Water Management – A better control of our future under climate change (BINGO) led by the Portuguese Civil Engineering National Laboratory (Figure 5.8).

Assuming uncertainty as part of the equation, available information is more than sufficient to state that one cannot merely glance at climate change adaptation. Before our territories are hit by the urgency projected by climate change scenarios, adaptation must be considered as the next urban prerogative.

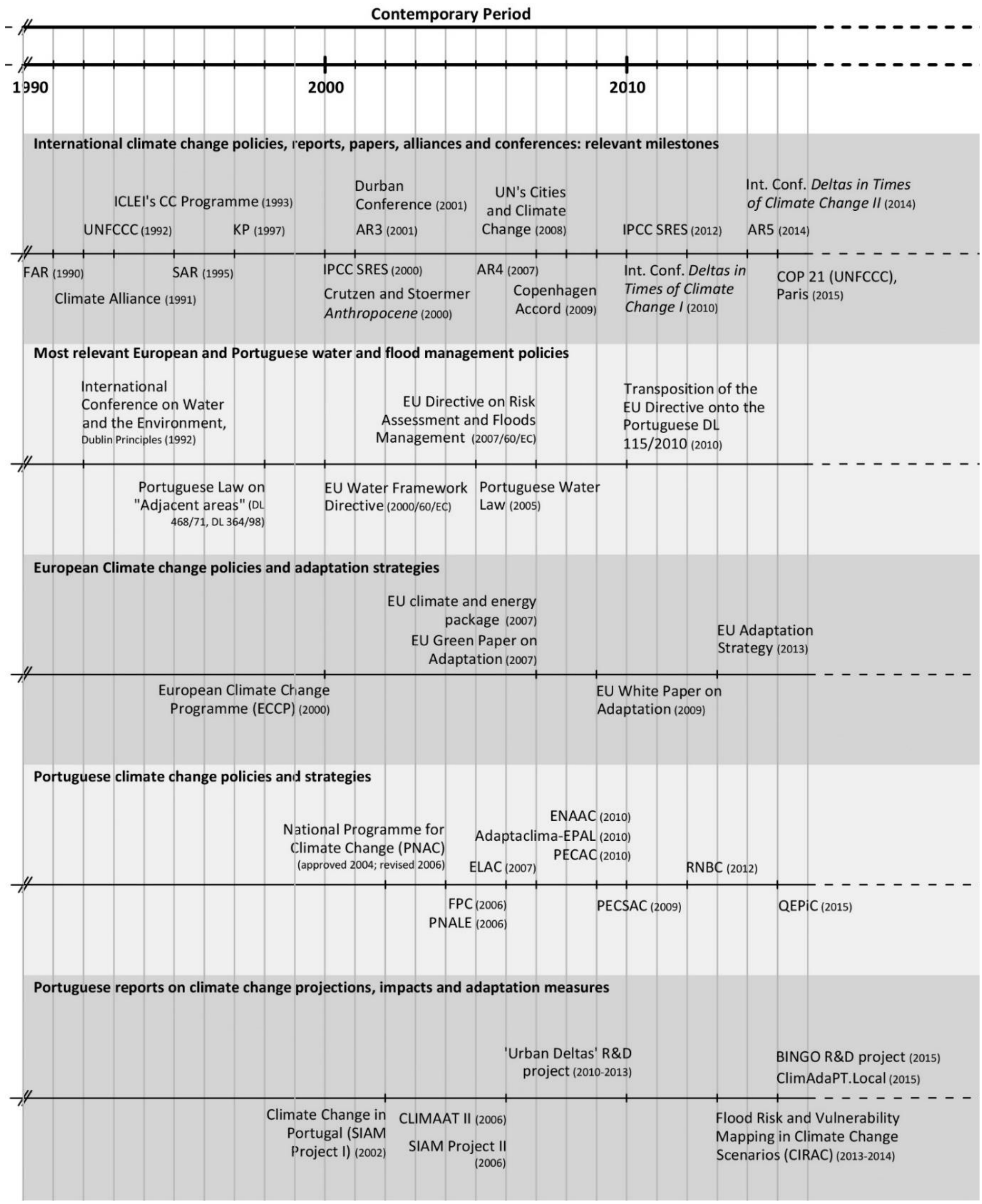


Figure 5.8 - Major references on International, European and Portuguese, climate change adaptation policies and strategies and European and Portuguese water and flood management policies visually compiled in a timeline. Source: developed by the author.

5.2 An overview of applied flood management practices in Lisbon and their relation with public spaces

5.1.3. Brief historical overview

In Lisbon, during the Roman Era and Arab occupation, extreme precipitation events were not considered as a nuisance. Conjointly with its steep topography, which effortlessly drained rainwater into the Tagus, rainwater excesses from downpours was managed as major asset in similarity with such places of Mediterranean climate that are generally characterized by encompassing a long dry summer, during which precipitation is scarce. The quantity and quality of rainwater was therefore acknowledged as an asset that should be directed onto vital areas in order to recharge aquifers that would feed the springs of mineral and thermal waters, namely of Alfama (Quintino 2011). An asset that should be collected and stored for future use, to be used for consumption, irrigation or cooling. Strategies that were applied through the use of the elaborate technical knowledge of hydraulic infrastructure of this time, such as systems of gutters throughout the streets, small aqueducts, cisterns, among others.

During the Middle Ages and later with the era of the Portuguese Discoveries, the city and its population grew significantly. As a result, uncovered drainage channels began to be increasingly polluted and dangerous to public health, leading the successive closure of the existing hydraulic infrastructures. By this time in the city of Lisbon, good quality water became an increasingly scarce and controlled resource.

Not directly related to floods but with the need to improve overall salubrity within the city, the first records of underground drainage and sewage infrastructure date back to the royal charters of D.João II (Matos 2003). More specifically, as a consequence of pest epidemics, the king emanated several orders of urban cleaning, particularly the cleaning of its aboveground drainage channels. In this regard, the indicated measures within the royal charter of 1486 are of significant importance, namely the particular recommendations for 1) parishes, supported by its residents, to pay for man to clean its streets "averem dallimpar a cidade" and 2) that "big pipes" should be constructed along main streets together with smaller pipes along smaller streets, to which every house should dump its dirty waters[71]. In Lisbon, drainage and sanitation developments have therefore been intimately connected since their origin.

[71] "Que sse deue fazer por alguas Ruas prinçipaaes canos mui grandes, e por as outras ruas outros mais pequenos, que vaão teer a elles; e de cada casa cano q vaa teer aos ssobre ditos, por onde possam deytar suas agoas çujas e vir a eles" Carta régia de 22 de Março

These sanitation and drainage improvements had direct repercussions on the quality of the urban environment. As it became clear that a proper sanitation and drainage system significantly contributed to reduce the spreading of mortifying epidemics, the role of this type of infrastructure within the city grew in importance and became a constant concern among its decision makers. As a result, the drainage network, for both domestic waste and stormwater, was gradually improved and extended. According to Barros "Some of the drainage channels used natural water lines that flowed in the Tagus river, …, taking advantage of the natural land slope to facilitate the flow." (2014, p.89). By the end of the XVII century, the existing drainage infrastructure corresponded approximately to that illustrated in Figure 5.9.

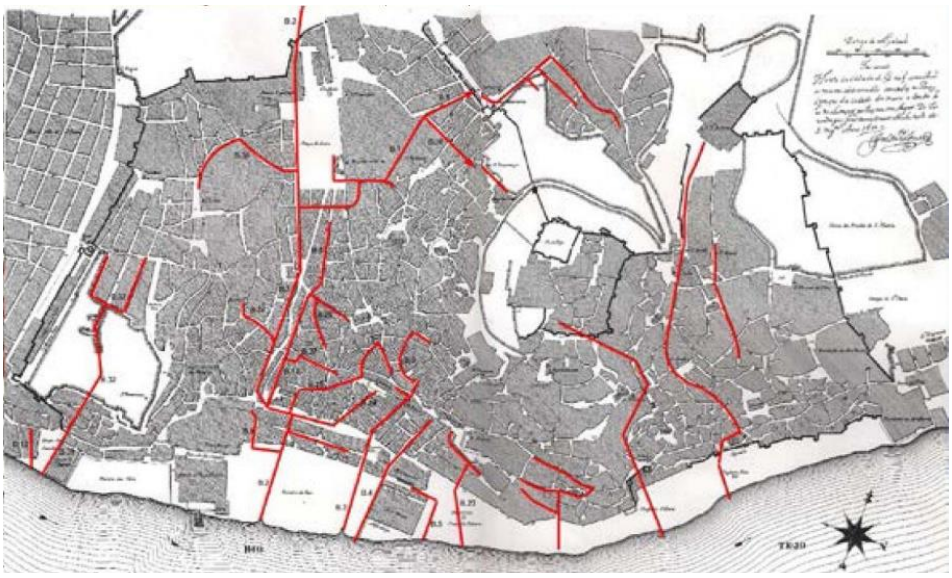


Figure 5.9 - Approximate layout of Lisbon's drainage network over João Nunes Tinoco cartography, based on a compendium of existing drainage channels carried out in 1685 (AML, "Livro dos canos antigos da cidade", f. 12-17 v). Source: (Barros 2014, p.103).

In representations of the old Lisbon neighbourhoods in the post-Pombaline period, with yet strong reminiscences of picturesque medieval times, it is possible to notice how the street profiles were designed in order to convey rainwater, either away to the Tagus, to the occasional underground channels, into cisterns or into wells (Figure 5.10). Particularly the book "Lisboa Velha", an illustrated compendium of urban forms and livelihoods specifically from Lisbon's oldest neighbourhood of Alfama, was considered by its author as a glance of an Era that was doomed to be lost under the steam of "progress" (Gameiro 1925). Indeed, the time where the fountains and waterspouts, once fed by rainwater or natural springs, were still meeting and mingling places, are long lost from our current urban character, even on the oldest areas of

de 1486. A.N.T.T. Chancelaria de D. João II, livro II, fs. 71 in Oliveira, E. F., 1885. *Elementos para a história do município de Lisboa.* Lisboa: Typographia Universal. tomo I, p.463.660 pp.

Lisbon. However, in most situations, the characteristic pavement design remains the same.

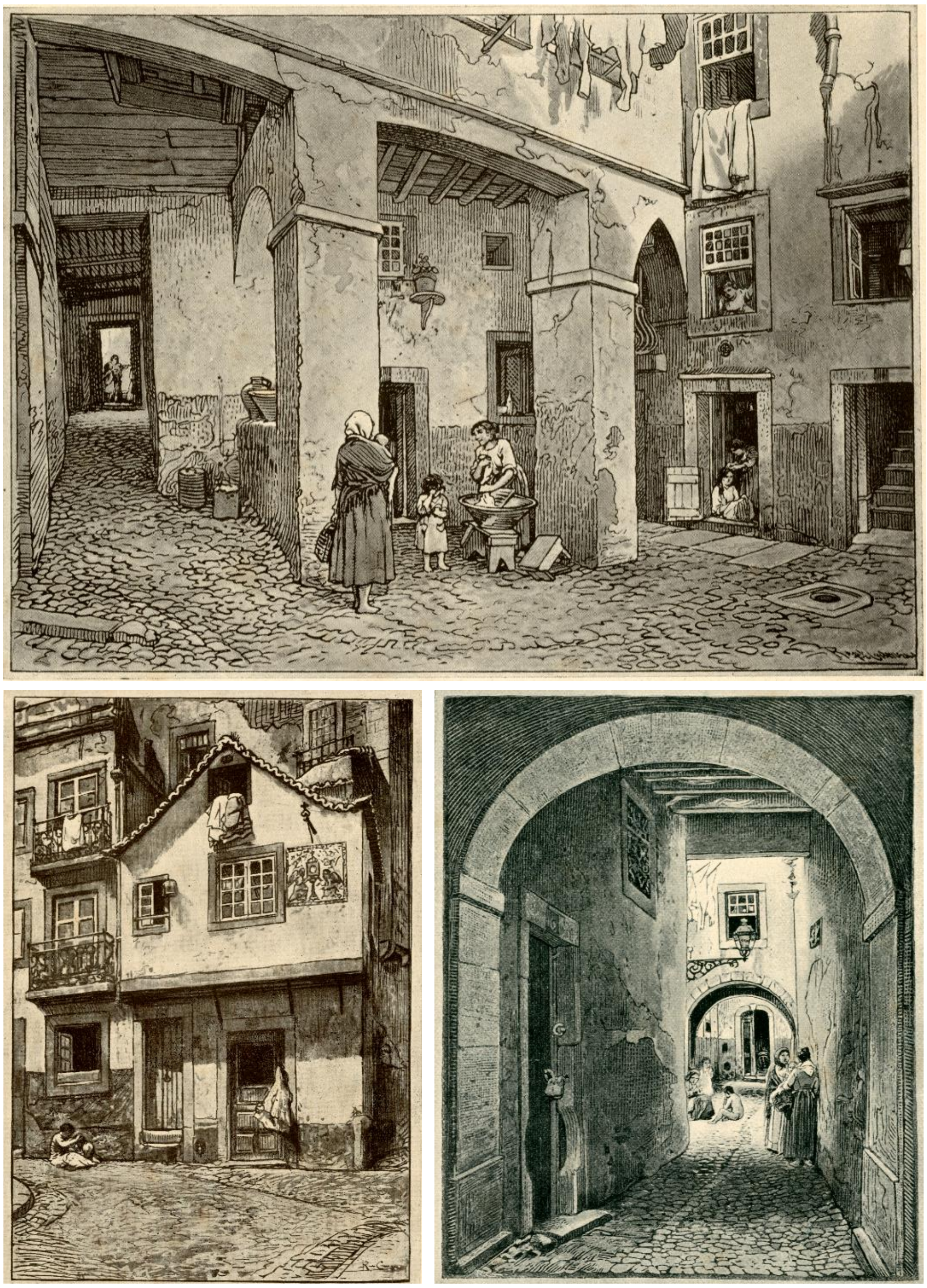


Figure 5.10 - "Lisboa Velha" illustrations from Roque Gameiro. In these drawings one can note how paving stones were deliberately placed in order to promote a certain form of drainage. Above: Est.68 "Páteo do Peneireiro" – pavement design leads rainwater into a well or cistern; Below left: Est 44 "Casa Quinhentista da rua dos cegos" – rainwater channels located in the edges of streets. Below right: Est. 92 "Beco dos cortumes (visto de fora)" – small rainwater channel placed in the middle of the street, longitudinally formed by paving stones in line. Source: (Gameiro 1925).

Until the great earthquake of 1755, Lisbon's drainage system therefore comprised both open and closed channels. The first, embedded within the street profile, had various forms and configurations. The latest, named "cascões" or "rateiros" as mentioned earlier, with a rectangular stone section, were not so common and were implemented with some reluctance, as they often propitiated the access and proliferation of unwanted rats (Matos 2003).

Beyond the notable “Pombaline” plan and architecture, Lisbon’s reconstruction after the earthquake and tsunami, also comprised significant improvements in the city’s drainage system. In accordance with Man’s advances in the theoretical knowledge of fluid mechanics, sewer systems started to be developed based on rational considerations. The principle of "methodical channelling" therefore marked this and the forthcoming Era, essentially corresponding to combined collectors arranged in a grid, which were connected to the Tagus estuary (ChiRoN et al. 2006a).

Through Figure 5.11 one may further note how the designed public space of the main streets encompassed a small gradient, symmetric to its profile centre, which promotes rainwater to drain into the underground sewers[72]. Dirty water from the building’s interior courtyards are also directed into these stone collectors, named “saimeis”. Besides the gradient that is visible in the street’s profile, the main streets of the Pombaline design, which are perpendicular to the Tagus (Rua Aurea, Rua Augusta e Rua da Prata), were also built along a subtle longitudinal gradient.

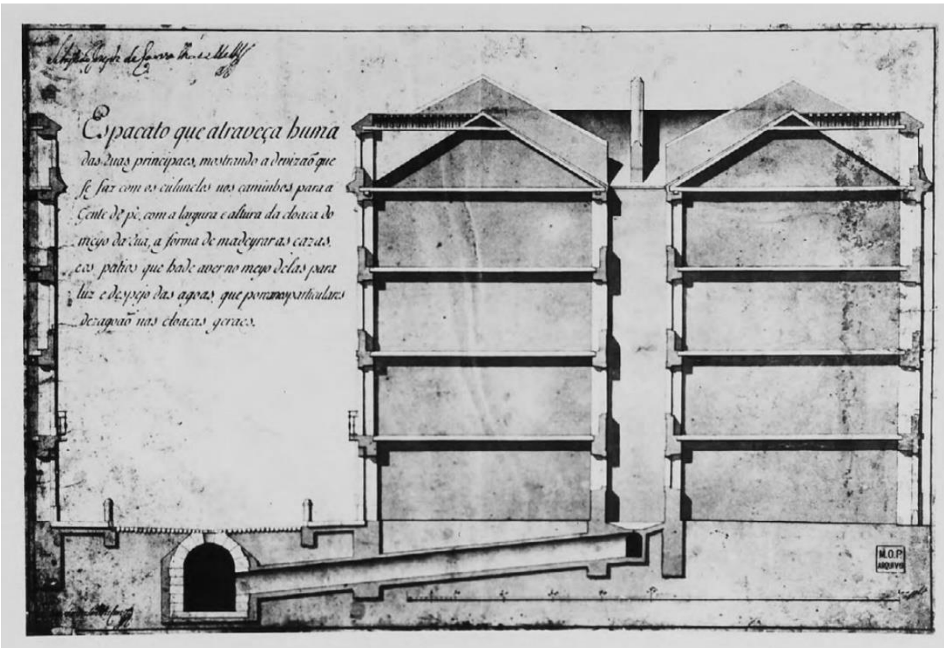


Figure 5.11 - Cross-section of the “Pombaline” building and public space, evidencing the designed drainage and sewage system. Source: Eugénio dos Santos e Carvalho, c. 1758, in (Leal 2013, p.15).

In the nineteenth century, as a counterpoint to the ever-increasing industry and population growth, the hygienist principles grew in

[72] “Espacato que atraveca huma das ruas principaes, mostrando a devizao que se faz com os colunclos nos caminhos para a gente de pe com a largura e altura da cloaca do meyo da rua, a forma de madeyrar as cazas e os pateos que hade aver no meyo delas para luz e despejo das agoas, que por canos particulares dezagoao nas cloacas geraes” Eugénio dos Santos e Carvalho, c. 1758, in Leal, J. C., 2013. Sobre a Paisagem da Baixa. *Rossio - Estudos de Lisboa.* Lisboa, Portugal: Gabinete de Estudos Olisiponenses, 12-21.

importance. In line with these advocated salubrity principles, besides the construction of various refined gardens, such as the gardens of Estrela, S. Pedro de Alcântara, Principe Real or the "Public Promenade" garden along the present Av. da Liberdade, the particular concern about natural urban streams and rivers emerged.

By this time urban streams and rivers started to be used as a means to discharge growing amounts of wastewater. These dirty waters came not only from domestic use but also from industrial facilities, which in terms of quantity and toxicity implied even greater impacts. The overall urban environment therefore became progressively deteriorated. As a result, and further considering the fragile conditions of the sewerage networks, the risks of waterborne diseases were particularly exacerbated.

After the Cholera and Yellow fever outbreak in Lisbon in the years 1856 and 1857, respectively, it was clearly recognized that the city faced a serious problem of urban health. In accordance, several Portuguese and foreign engineers drafted proposals with different measures targeted at solving this particular problem, namely the reports by João Fagundo da Silva, "Ante-projecto do saneamento de Lisboa" of 1874, the 1877 drainage master plan of Gotto & Beesley (namely mentioned in the minutes of the municipal works committee of 28 June 1887) and the chained proposals on the "Assainissement de la ville de Lisbonne"[73].

Yet every presented solution requiered the existance of a generous amount of clear water. A fundamental element that, by this time, was very scarce in Lisbon. As a consequence, concrete applications aimed to improve sanitation quality, had to be delayed until the problem of Lisbon's intrinsic lack of water was resolved. Only in 1880, with the construction of Alviela channel, was the water supply for the city of Lisbon sufficient enough for new sewerage systems to start being implemented[74].

---

[73] Overall, according to Maria Helena Lisboa, proposals were divided in two types: 1) those proposed debris removal via septic tanks, which, through container vehicles, was transported into reservoirs in order to be latter used for agricultural fertilization; and 2) those who, questioning the economic viability of the debris usage, rather opted to convey sewage into the river, although at a sufficient distance so as to avoid their accumulation along the shore Lisboa, M. H., 2002. *Os engenheiros em Lisboa: urbanismo e arquitectura (1850-1930).* Livros Horizonte. 293 pp. ISBN: 9789722412148.

[74] Alongside the improvement of the water supply system through the new Alviela channel, great underground reservoirs were constructed. Among them is the Campo de Ourique reservoir, with a total capacity of 120.000m3, planned to be built in 1880 to strengthen the water supply in the summer months or in the event of disruptions on Alviela channel (SIPA, "Reservatório de Água de Campo de Ourique"). In 1833, Principe Real reservoir also started to be supplied by the Alviela channel and the size of its gigantic structure started to be useful [Recalling the failed expectations that the "Águas Livres"

The then needed expansion of the city led to the development of an encompassing municipal improvement plan – "Plano Geral de Melhoramentos da Capital" – which was only formally approved in 1904. Greatly influenced by Frederico Ressano Garcia's ideals and pragmatism, who formed part of the plan's working committee from 1876 to 1881, the plan ended up being particularly targeted at providing new broad and decongested public spaces, designed along a structure that connects old urban arteries with new ones, and extends the city towards the North. (Figure 5.12).

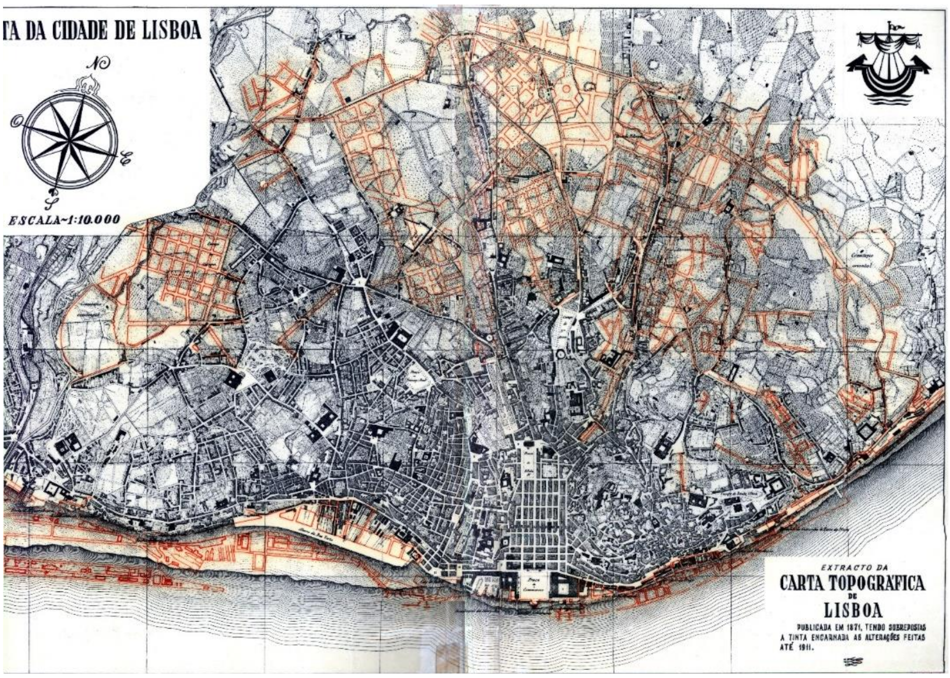


Figure 5.12 - Lisbon map by Augusto Vieira da Silva: Extract of Lisbon's topographic map published in 1871, with changes made until 1911 identified with overlapping red ink. Published by Lisbon's Municipality in 1950. Source: Gabinete de Estudos Olisiponenses (GEO) (Silva 1950).

Among the most important municipal works directly coordinated by Ressano Garcia who is the "Plano de Esgotos da Capital", Lisbon's first drainage master plan. Even though the proposal of Lisbon's drainage master plan was presented in 1884, "one would have to wait until 1897 for the general plan, drawn since 1888, to be approved" (França 2009[2008], p.543, author's translation). According to Matos et. al, this plan was "largely influenced by the work and studies of Gotto & Beesley of 1877" (2009, p.1) and by the hygienist concerns led by Edwin Chadwick (Matos 2003, p.18), who contributed immensely to improve sanitary

aqueduct (1713-1748) would bring plenty of water to the capital, José Augusto Franca characterized Principe Real reservoir, as having been, in its origin, a "remarkable but useless underground construction" França, J.-A., 2009[2008]. Lisboa, História Física e Moral. Livros Horizonte 872 pp. ISBN: 978-972-24-1612-2. p.543]. Although Principe Real reservoir is presently a monument and, as such, a public space, the reservoir at Campo de Ourique is not only an unused infrastructure but its aboveground grassed area is an inaccessible space bounded by a metallic net over a brick wall. It is presently a hidden example of industrial architecture built on a noble area with great potential for public use.

conditions and public health (see timeline presented in the end of this section – Figure 5.30). This plan introduced several technological progresses such as the change from stone or brick masonry sewers with plane bottoms into ovoid stone masonry collectors, as illustrated in Figure 5.13.

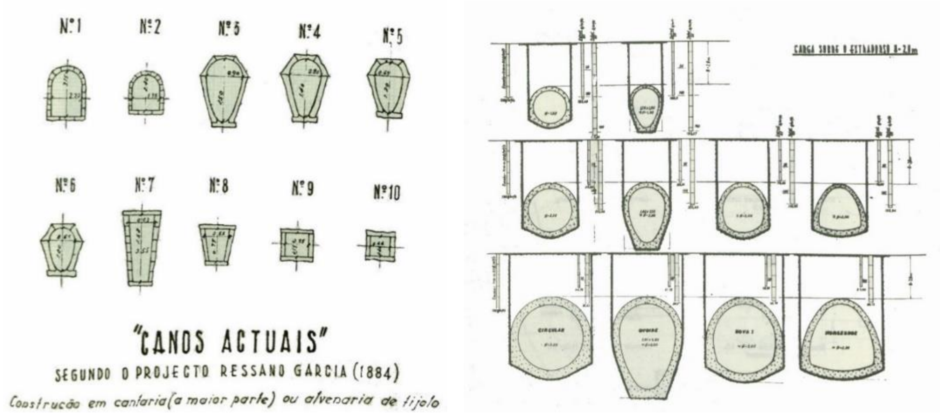


Figure 5.13 - Left: Sections of "Existing drainage pipes" according to Ressano Garcia's project (1884). Right: Proposed drainage pipes according to Ressano Garcia's project (1884), Source: (LNEC 1983, p.331 and p.320).

Breakthroughs were additionally felt in regards to the treatment of effluents as expressed within some of the minutes of the "Lisbon sewage" committee appointed on the 4th of August of 1880[75]. The particular solution proposed by Ressano Garcia comprised "a long gravity interceptor under pressure partly as a tunnel, discharging by a sea outfall 15 km far from Lisbon city, close to what is actually called the Carcavelos beach" (Matos et al. 2009, p.1). This channel was further envisioned as a combined collector that would transport both wastewater and stormwater.

Even though this tunnel was never constructed, the works carried out by Ressano Garcia in the planning and design of the expansion of the city comprised his advocated guidelines and technical sewerage infrastructure improvements. More specifically, the new neighbourhoods of "Avenidas Novas", "Campo de Ourique", "Novo Bairro de Stº Amaro", "Avenida dos Anjos e ruas adjacentes", "Bairro do Operário, among others (drawn in orange in Figure 5.12), alongside most of the drainage network built from the late nineteenth century, encompassed the improved types of drains illustrated in Figure 5.13-right.

[75] This committee, composed Lourenço António de Carvalho, Ressano Garcia and the hygienists Joaquim Eleuterio Gaspar Gomes, Manuel Bento de Sousa, Silva Amado, João Ignacio Ferreira Lapa e Agostinho Vicente Lourenço, published its overall findings in the following year together with minutes of the held meetings. Regarding the treatment of effluents, discussions generally focused on two options: 1) to convey previously depurated sewage into the river or 2) to directly convey sewerage into the sea without any precedent treatment.

One other discarded plan of Ressano Garcia is his proposed park for Campo Grande (Figure 5.14). Specifically regarding the current need for stormwater source control measures in the corresponding area of the planned intervention, which is currently considered with "very high" vulnerability index (Annex IV - Spatial data regarding the city of Lisbon – Map 8 – Lisbon's Flood Vulnerability Map over the cities' urban matrix), it would be interesting to assess the potential impact that this parkland would have on flood management. One could additionally compare the qualities, regarding both the infrastructure and the resulting public space, between the proposed park and the flood management measures that have been more recently proposed for the same surrounding area, namely an underground reservoir.

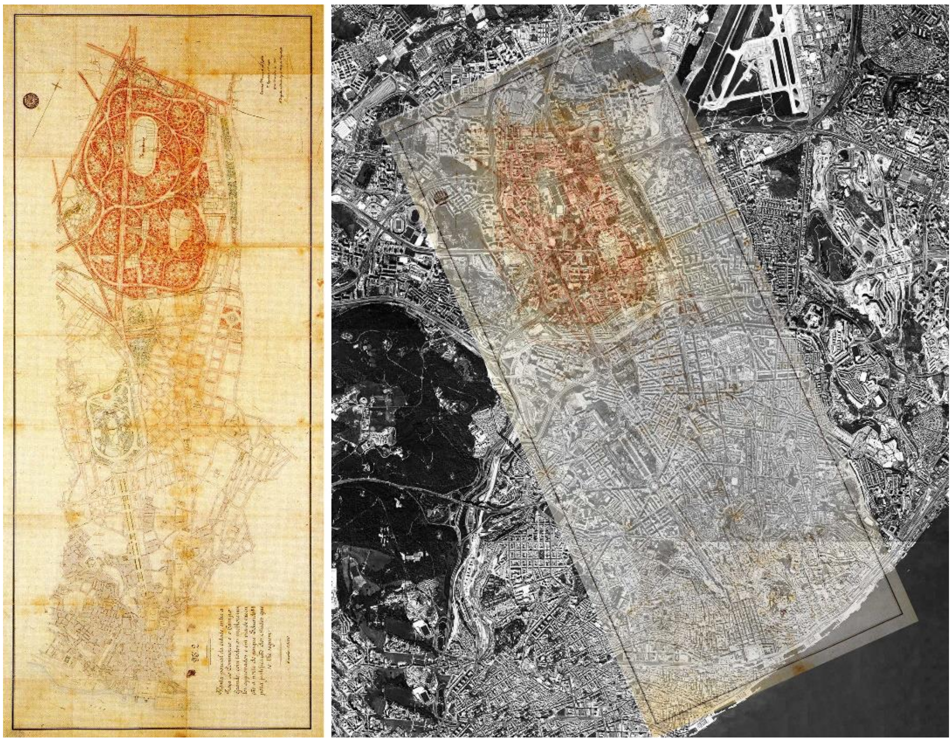


Figure 5.14 - Campo Grande Park proposed by Ressano Garcia (1903) overlapped on an aerial image. Source: Combined information from (Silva 1989) and google earth.

In line with what was happening in most European and North American cities, combined sewerage, or the so-called "tout-à-l'égout" approach, was the generally chosen option in the city of Lisbon in this time of great expansions in underground drainage infrastructure. As mentioned in chapter two, the debate regarding combined versus separate sewerage systems only started in the second half of the 19th century, being particularly instigated by English engineers[76].

[76] The first separate sewerage system to be implemented in Portugal was in Porto city in 1897, a project designed by the English company "Hughes & Lancaster". Brandão, P. A. and Piqueiro, F., Interceptor Douro. Sistema centenário de saneamento da cidade do

As a result of an increasing use of sewerage systems, and particularly as a consequence of the combined sewerage approach as followed in Lisbon, existing watercourses were transformed into open sewerage streams. That was namely the case of the Alcântara valley that, by the middle 20th century, was an exposed deposit of all kinds of debris that came from almost half of the city. Curiously, in the words of Raúl Ressano Garcia (Frederico Ressano Garcia's son) when commenting on the repercussions of combined underground sewerage, stated that "a problem was avoided by creating another one" (Garcia 1933, p.88, author's translation).

Ten kilometres of the Alcântara stream were therefore channelized between 1943 and 1967, in light of its increasing pollution condition. With the exception of necessary repairs over the years, until today, the physical characteristics of the infrastructure remain the same. In an article of the Muncipal Magazine nº27 of 1945, entitled "Grandes problemas de Lisboa: caneiro de Alcântara" ("Big problems of Lisbon: the Alcantara stream") in respect of this great public construction, it is said "Another major problem in Lisbon is solved in perfect harmony in this "Era of exaltation" that the country is experiencing. When this endeavour of exceptional form is completed, other grand works of fundamental importance to the urbanization of the west zone will start to be implemented in the same place: in the Alcântara valley, crossing under the arch of the most magnificent Duarte Pacheco viaduct, Ceuta avenue will be extended, one of the most important arteries of this City that is transformed and will now decisively reach every dimension of its true character as a European capital." (CML 1945, p.46, author's translation)[77] (Figure 5.15 and Figure 5.16).

Similarly, with the comments expressed by Raúl Ressano Garcia, many are those who today consider this measure as counterproductive in the sense that, "hiding" a problem does not solve it (Saraiva 1999, Stokman 2008, Kondolf 2009) and can rather create new problems. Indeed, namely the final section of the Alcântara stream, channelized in the late

---

Porto. ed. *6.as Jornadas de Hidráulica, Recursos Hídricos e Ambiente*, 2011 Faculdade de Engenharia da Universidade do Porto, Portugal, 56-81.

[77] Original: "Mais um dos grandes problemas de Lisboa se resolve em perfeita integração na 'era de engrandecimento' que o País atravessa. E concluída esta empreitada de excepcional vulto começarão, no mesmo sítio, outros grandiosos trabalhos, estes de importância fundamental para a urbanização da zona de oeste: no vale de Alcântara, passado sob o arco maior do magnífico viaduto "Duarte Pacheco", estender-se-á a avenida de Ceuta, uma das mais importantes artérias desta cidade que se transforma e com a decisão vai atingindo, agora, todas as dimensões da sua verdadeira categoria de capital europeia."

nineteenth century due to the improvement works of Lisbon's port, was affected in its early stages by floods (ChiRoN et al. 2006a).

Figure 5.15 - Alcântara valley, view taken from Duare Pacheco viaduct. Channelization works of the Alcântara stream in 1947. Image credits: Portugal, Eduardo, 1947. Source: Arquivo Municipal de Lisboa – Fotográfico. PT / AMLSB /E DP / S00349.

Figure 5.16 - Ceuta Avenue built over Alcântara underground drainage channel. Image credits:: Portugal, Eduardo, 1950. Source: Arquivo Municipal de Lisboa – Fotográfico. PT / AMLSB / EDP / 000983.

While the Alcântara stream was being channelized, Francisco Keil do Amaral begins the design of the reforestation of Monsanto by order of Duarte Pacheco. In 1929 the first commission for the Monsanto Forest Park was put together, and in 1938 expropriations of existing agricultural areas (almost deprived from trees) were initiated (Soares and Castel-Branco 2007). Although the idea came originally from 1868 and was based on the intention to provide the city with sufficient firewood and timber, other objectives were considered at the time of its implementation. In continuity with Lisbon's General Plan of Urbanisation and Expansion of 1948 by Etienne de Groer (Plano Geral de Urbanização e Expansão de Lisboa, PGUEL), the forest park of Monsanto was considered a key element for the envisioned new image of a greener city. Besides being considered as a "green lung" of great importance to public health this reforestation project was further recognized as paramount in the improvement of the urban microclimate. Its contribution to the reduction of flood events is also significant, particularly with regard to its capacity as an urban forest to harvest and retain rainwater. If there was no Monsanto forest park, Lisbon would surely face more severe episodes of flooding from greater volumes of urban runoff, namely at Alcântara valley. Currently, through its increasingly popular pedestrian paths, one can appreciate the water streams that are formed on a rainy day (Figure 5.17).

Figure 5.17 - Path at Monsanto forest park over crossed by a stormwater drainage streamlet. At the centre of the image is a vent from the "Águas Livres" aqueduct. Source: CML Ambiente e Espaços Verdes, 2008.

In 1941, Eduardo de Arantes e Oliveira published a detailed report on Lisbon's sewerage entitled "Esgotos de Lisboa – Estudos de Anteprojecto" which, in brief, consisted in a "... prior review and discussion of the solution or general solutions for the problem, outlined in a preliminary proposal." (Oliveira 2004[1941], epilogue, author's translation). Its content and findings are strongly motivated and grounded on the previous studies and discussions held in the late 19th century, namely the discussions of the 1880 Lisbon sewerage committee. According to Arantes e Oliveira "Numerous are the projects, opinions, suggestions and critiques which have been established about one century ago, with the participation of our best technicians and renowned foreign experts in the matter." … "Those who wish to re-analyse and try to solve this problem, can use these elements as a basis for further studies which may likely guarantee a deeper clarification of the factors involved in the problem and fundamentally condition the proposed solution" (Oliveira 2004[1941], epilogue, author's translation).

The study from Arantes e Oliveira is divided in the following main sections: 1) Studies on the volume and composition Lisbon's sewerage; 2) Studies related to Lisbon's precipitation regimes; 3) Hydrographic studies on the Tagus estuary; 4) Studies related to pollution and natural purification of the Tagus estuary and 5) Treatment and disposal of Lisbon's sewage. Particularly within section five, different operations and processes for sewerage treatment are suggested together with the implementation of two wastewater treatment plants, one in to the West and another to the East of Lisbon.

As illustrated in Figure 5.18, this study further divided Lisbon in seven main drainage basins (A to G), expecting, for the project horizon of 1965, a population of 1.104.900 inhabitants and that 4791 ha would be served by a sanitation and drainage system[78].

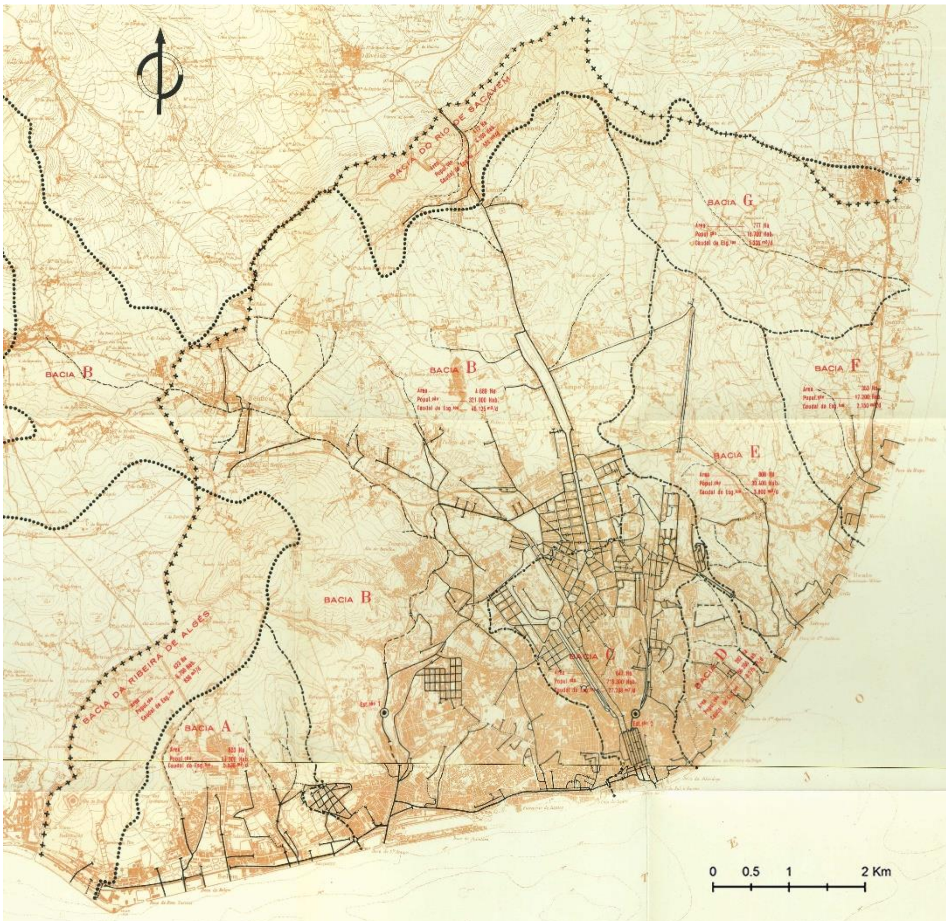


Figure 5.18 - Present conditions of Lisbon's sewerage by Eduardo Arantes e Oliveira: Area, population and sewerage flow rates for each drainage basin of Lisbon's Municipality. Source: (Oliveira 2004[1941]), Arquivo Histórico do Ministério das Obras Publicas, Transportes e Comunicações (BAHOP), Quota 013957.

5.1.4. Contemporary flood management strategies

Following the studies from Arantes e Oliveira, Celestino da Costa further developed Lisbon's drainage master plan in 1955. In this project, combined sewer systems continued to be advocated within dense and

[78] Lisbon's inhabitants never reached the projected number. According to the latest records of 2011 census, Lisbon has a population of 547 733, which is more or less half of what was projected by Arantes e Oliveira.

older urban areas, while in low marginal areas such as Algés or Belém or in new areas such as Olivais and Benfica separate sewerage systems started to be implemented (Matos 2003).

Later, in Lisbon's Urbanization Master Plan (Plano Director de Urbanização de Lisboa, PDUL)[79] concluded in 1959, a concern on the need to preserve the environmental quality of pre-existing watercourses is expressed, namely in the landscape recognition and analysis made for Benfica, Carnide and Lumiar, particularly stating that "It is also envisioned the identification of the waterways that still maintained its natural features…. The inconveniences, which are today universally accepted, regarding the pollution of water lines with sewage must be highlighted. The fact that some of these water lines have a torrential character, or at least are dry for a few summer months, does not imply that they need to be deprived from specific vegetation and characteristic animal life that can support walking paths through green areas" (PDUL-GEU in Reis 1989, p.51, author's translation) (Figure 5.30). This subject of maintaining the natural state of a stream, instead of channelizing it, is particularly relevant when discussing flood management strategies. As previously exploited in chapter four, among other benefits of a natural water stream, restored or rehabilitated, is the potential to reduce stormflow velocities. By improving the riparian habitat of streams, rainwaters may be additionally harvested and recharged into subsoil layers.

Wastewater treatment plant of Alcântara (WWTP) started working in 1989 carrying out primary treatments and disinfection with chlorine. Since 2009, after expansion and improvement works, this WWTP started to operate with biological treatment and disinfection by ultraviolet radiation. Only recently did it start to receive wastewater from the riverside area of Lisbon. Today, there are two more WWTPs in Lisbon, WWTP of Chelas and WWTP of Beirolas. There is also one Fito-WWTP in Monsanto (similar to a treatment wetland, which uses the depuration capacities of specific vegetation), which is much smaller when compared with the previous.

All mentioned WWTPs are of restricted use and, from the outset, are unsuitable with the integration of a public space. Yet the construction of a 8.4 ha green roof over Alcântara WWTP in its recent renovation

[79] In 1954, the Municipality of Lisbon created the Gabinete de Estudos de Urbanização (GEU) with the purpose to revise and update Lisbon's General Plan of Urbanisation and Expansion of 1948 by Etienne de Groer (Plano Geral de Urbanização e Expansão de Lisboa, PGUEL). The resulting document, consisted on Lisbon's Urbanization Master Plan (Plano Director de Urbanização de Lisboa, PDUL), which was concluded in 1959.

finalized in 2011, turned this infrastructure into a space not only more ecologically integrated in the Alcântara valley, but also an area whose landscape, widely visible by those who pass over Duarte Pacheco viaduct and the Fertagus railway line, and partially visible to viewers from Av. de Ceuta, has become more appreciated by all (Figure 5.19). In addition, bearing in mind the characteristic of a green roof as previously highlighted in chapter four, it is a privileged area among the urban territory from which rainwater can be easily collected for later use, therefore also promoting the attenuation overall urban runoff and associated flooding events.

Figure 5.19 - View of the green roof constructed over Alcântara WWTP. Design by PROAP, Aires Mateus, Frederico Valssasina. Image credits: PROAP.

In the early 90s, Gonçalo Ribeiro Telles and Manuela Raposo Magalhãoes together with the support of a small research office, strengthened concepts and offered contemporary solutions regarding a natural systems structure specific for the Lisbon case. This study, developed from 1991 to 1994, was named "Plano Verde de Lisboa" (PV) and became an important milestone on the regulation and defence of the fundamental natural landscape systems which characterize the city. One of its main policy instruments is based on the "Municipal Ecological Structure" that was later contemplated within Portuguese legislation by the decree-law nº380/99.

According to PV, the system of valleys, as a constituent element of the "Municipal Ecological Structure", "…is specifically associated with protection and recreational functions, a fact that is particularly related with the need to ensure the protection of these lines of air and water drainage" (Telles 1997, p.89, author's translation). These appreciations, among other teachings from PV, have been successively exploited in municipal studies, reports and master plan revisions, namely in intervention proposals such as the construction of network of green roofs, the recovering of permeable interior courtyards or the implementation of retention and infiltration basins. Currently, Lisbon's Municipal Master Plan in effect encompasses a very detailed Municipal Ecological Structure (Annex IV - Spatial data regarding the city of Lisbon – Map 11 – Lisbon's Municipal Ecological Structure).

As a commemoration of the 500 years of the "Great Portuguese Discoveries", Lisbon held the World Exposition Fair in 1998. Expo '98, also projected in light of a future area for urban expansion, encompassed as one of its main goals the restoration of the overall environmental quality of the area. Indeed, particularly the area that today encompasses Tejo and Trancão Park was one of the most polluted zones of the city. The winning team for the design of this park, Hargreaves Associates and Proap, had to specifically provide solutions for a sanitary landfill, for a new WWTP, for a solid waste station and for the polluted river mouth Trancão (Soares and Castel-Branco 2007).

Due mainly to the construction of the Frielas WWTP, it was possible to drastically reduce the pollution rates of the Trancão river. The implemented landscape architecture design further enabled the appropriation by its users of an urban area formerly neglected. Today, whoever passes by Tejo and Trancão Park and its series of wooden piers, can be in close contact not only with the rich biological life of a wetland (serving as a tertiary purification system), but also with the natural water dynamics of a Mediterranean stream that can have greatly reduced flows in the dry seasons and very high flows in the winter seasons (Figure 5.20).

Throughout Expo'98, now Parque das Nações, there are various examples on how the water element can be used as a key feature in the design of a public space (Figure 5.21). Indeed, water was an important element among the main theme regarding Portuguese nautical explorations. From these examples, it is possible to assess numerous potential reconfigurations that specifically use collected excesses of stormwater rather than "company water", integrating it as part of the space design for public indulgence.

Figure 5.20 - Detail of a wooden pier at Tejo and Trancão park overviewing Trancão river. Image credits: Maria Matos Silva, 2016.

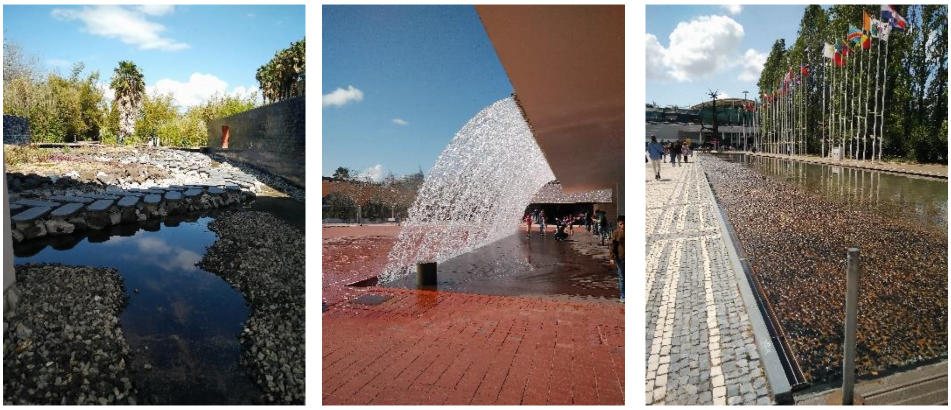


Figure 5.21 - Some examples of the water features in public spaces at Parque das Nações. Image credits: Maria Matos Silva, 2016.

By 1999, DRENA – Estudos e Projectos de Saneamento, Lda., founded by Celestino da Costa, developed the "Revision of the General Drainage Master Plan of Lisbon", which basically consisted on an actualization of the 1955 drainage project. Yet according to a mono-disciplinary approach, among other findings, this updated master plan recognized the difficulty in the implementation of separate sewerage systems in low marginal areas. As such, the strategy to maintain a combined sewerage system was the one recommended, intercepting domestic sewers through spillways and providing tidal valves in the discharge connections to the river (ChiRoN et al. 2006a).

In 2006, a subsequent drainage master plan was developed for the city of Lisbon ("Plano Geral de Drenagem de Lisboa" (PGDL) 2006-2008) by a consortium between the companies ChiRoN, Engidro, Hidra and EMARLIS led by José Saldanha Matos. Its main objective relied on the proposition of a reliable and efficient plan that could provide the municipality with an integrated strategy to tackle flooding. In brief, the proposed solutions were based on the following key strategies: 1) the strengthening of the transport capacity of the drainage network; 2) a mixed intervention (that increases the storing capacity and reinforces the drainage network) favouring the construction of separate sewerage systems; and 3) an intervention that increases the storage capacity of the system, namely through underground reservoirs or other source control measures, such as aboveground retention basins[80], in order to attenuate peak flows (ChiRoN et al. 2006b, p.46).

This plan further advocates an extensive implementation of source control measures, whenever possible. It also highlights that, in order for these measures to be successfully implemented, there must be a particularly strong political will, and that they must be determined in the early stages of urban planning processes, mediated by interdisciplinary efforts between engineers, architects and landscape architects (ChiRoN et al. 2006b). Regardless, when considering the specific situation of Lisbon, and particularly its dense urban territory, the report contrastingly mentioned that source control measures "… are not, per se, sufficiently effective in the control rainfalls with high return periods, namely when it is required to attenuate flows of several dozen m3/s" (ChiRoN et al. 2006b, p.117, author's translation). Nonetheless, the particular relevance of source control measures in the Lisbon case will be further discussed in the next chapter.

In brief, and as illustrated in Figure 5.22, PGDL 2006-2008 specifically suggested the construction of five underground reservoirs, two retention and infiltration basins and one infiltration trench. More specifically: one infiltration trench at Rua Alto do Duque that is said to reduce 30% of the stormwater flow from Monsanto; one retention basin at Ameixoeira, whose primarily function is to retain stones, sand and other debris, preventing their entry and deposition in the downstream pipeline section; one retention and infiltration basin near the University centre of Ajuda, with a proposed capacity of 1200 m3; and five underground reservoirs namely at Rua Eduardo Bairrada (capacity of 9,400 m3); Campolide-Benfica (38,100 m3); Avenidas Novas (13,400m3); Olaias (45,000m3) and Avenida de Berlim (20,100m3). Although recommended

[80] It should be highlighted that by 1991, the time when PV was being developed, Ribeiro Telles had already suggested retention and infiltration basins as one possible solution to mitigate flood events in the Lisbon case, particularly during peak flows: "In an hydrographic basin integrated within a dense urban area, natural streams may be used as a privileged object for recreation and, simultaneously, for flood mitigation, promoting rainwater infiltration and the reduction of peak storm flows through the creation of small retention basins" Telles, G. R., 1997. *Plano Verde de Lisboa.* Lisboa: Edições Colibri. 200 pp. ISBN: 9789728288747.

throughout the entire report, specific locations for other source control measures, such as porous pavements or infiltration devices, were not indicated.

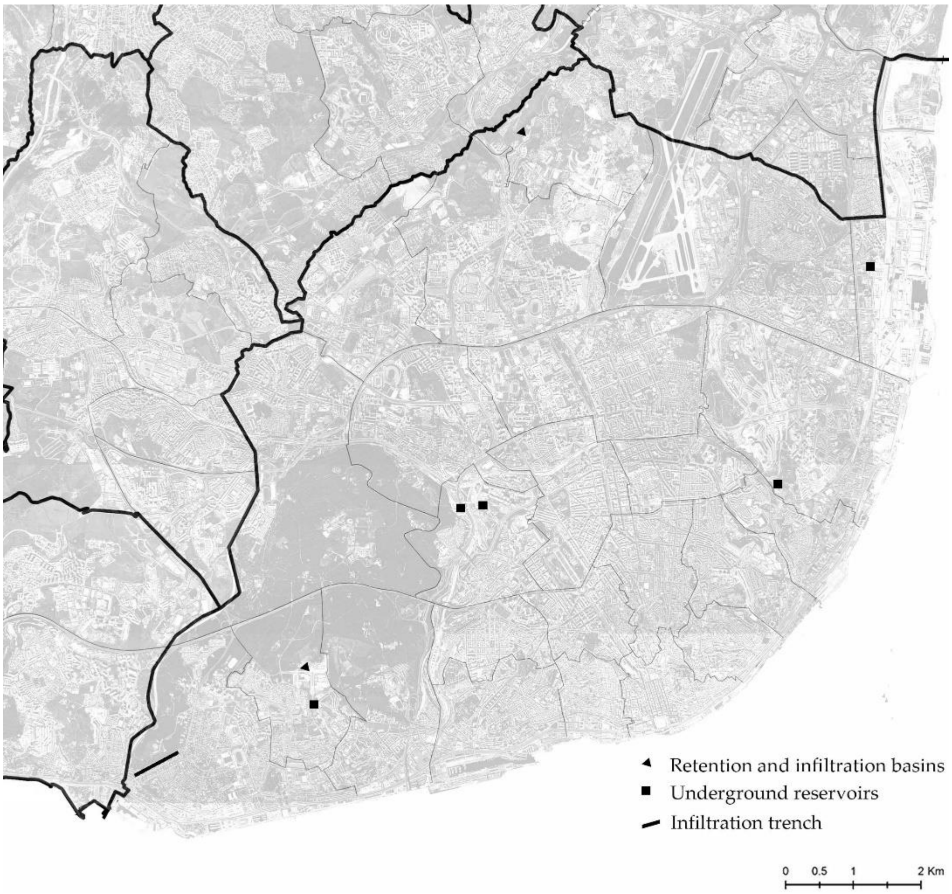


Figure 5.22 - Location of the recommended interventions of Lisbon's General Drainage Master Plan 2006-2008: five underground reservoirs (Rua Eduardo Bairrada, branch of Campolide-Benfica and branch of Avenidas Novas, Olaias, Avenida de Berlim); one retention and infiltration basins (University centre of Ajuda); one retention basin (Ameixoira); and one infiltration trench (Rua Alto do Duque). Source: Adapted from PGDL 2006.

With regard to the environmental concerns associated with the operation of drainage infrastructure, it is important to note that only recently did Lisbon's domestic sewage stop being directly discharged into the Tagus Estuary. This source of pollution was only fully eliminated in 2011 by the Municipality of Lisbon, in collaboration with SIMTEJO and other institutions and with the support of the European Union Cohesion Fund. In fact, it was only during the 60s and 70s that environmental awareness arose regarding receiving-water-quality-degradation (Burian et al. 1999). Concerning the Lisbon case, this matter was originally raised as early as 1971, when Paul de Falco, an American engineer, shared the knowledge and experience of his country in a small report entitled "Estuary, the septic tank of the megalopolis" (Júnior 1971, author's translation), aiming to show and condemn the adverse effects of the direct discharge of urban sewerage into the estuary. In 1990, Marcelo Rebelo de Sousa, currently the President of the Portuguese Republic, also aimed to raise awareness on this concern by elaborating a media event of him jumping into the visibly polluted Tagus River.

Between 2009 and 2011, during the rehabilitation works at Terreiro do Paço led by Frente Tejo and subsequently by Lisbon's Municipality, a major investment (5.4 million euros) was made in the construction of two wastewater-regulating chambers combined with tide gates. These structures, designed by SIMTEJO intercepted the ancient Pombaline sewers, including the combined drains of Rua Augusta, Rua da Prata and Rua do Ouro, and their respective outflows into the Tagus. However, floods persist in the downtown area, leading to questions regarding whether this costly and highly engineered system was working properly, and if the investment on this type of solution was the most appropriate. Still concerning the requalification project of Terreiro do Paço, the renewed design of the central square further encompassed a porous pavement as its primary materiality in order to quickly drain excess water from eventful flood events.

Under the same municipal endeavour to rehabilitate key public spaces of Lisbon's riverfront, Ribeira das Naus was also subject of intervention. In this project, designed by PROAP and Global[81], the space is redefined in line with the uncovering and integration of partially buried elements, such as docks or shipyard ramps, acknowledged as determinant for the identity of this place. In this line of reasoning, the project further proposed to re-align the bank of the river, by "trimming" the coastline of the Arsenal Dock tangential do the Torreão Poente, and by reconfiguring the marginal alignment up to Cais do Sodré with a great ramped stairway 250 meters wide. This way, the Tagus River and its dynamic tides are not only welcomed, but also interwoven in the design and uses of the public space itself (Figure 5.23).

Figure 5.23 - The proposed ramped and wide stairway resulted as a new popular icon of Lisbon's riverfront. Image credits: Maria Matos Silva, 2014.

[81] Project Consortium: Global Arquitectura Paisagista Lda + PROAP Estudos e projectos de Arquitectura paisagista Lda. Authors: João Gomes da Silva, João Ferreira Nunes and Carlos Ribas.

In 2012 Lisbon's current Municipal Master Plan (PDM) came into effect. As it will be later scrutinized, the Lisbon's 2012 PDM took into account findings from previously established strategies, reports and plans, such as the mentioned "Plano Verde de Lisboa" (1997), the revisions of the "Municipal Ecological Structure" and PGDL (2006-2008). In this report, although the adaptation agenda is addressed only superficially as climate change it is preferably tackled through the mitigation perspective, the integration of five reservoirs, one infiltration trench and forty two retention and infiltration basins are explicitly planned (Figure 5.24).

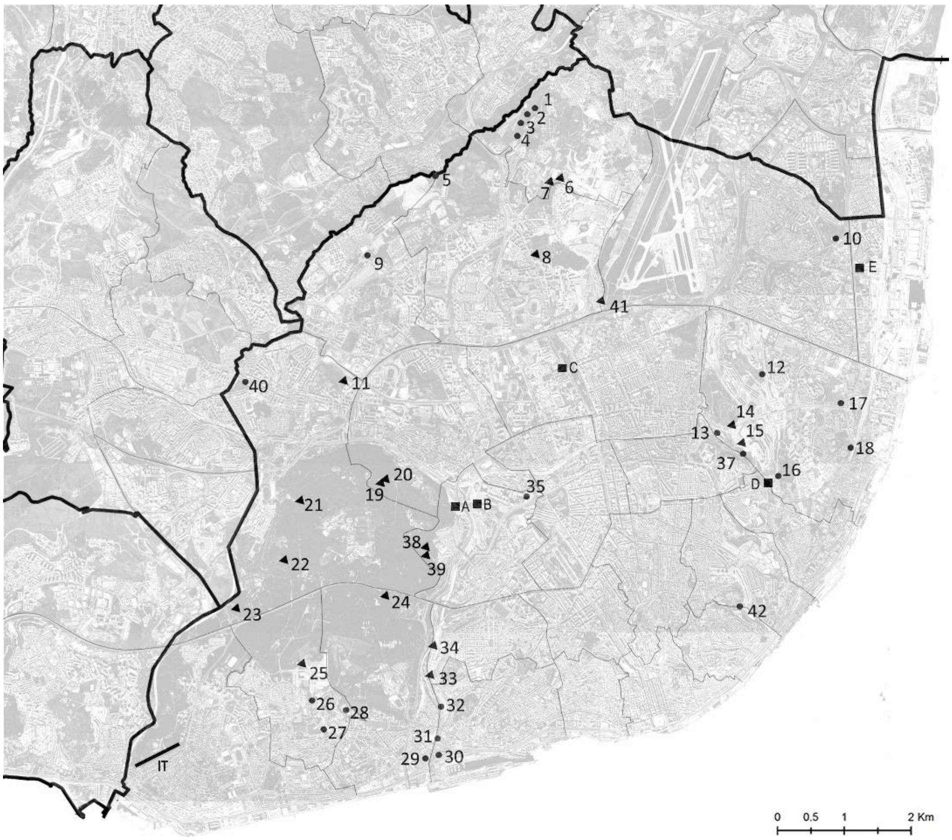


Figure 5.24 - Spatial distribution of planned interventions for the improvement of the drainage system within Lisbon's Municipal Master Plan in effect: five reservoirs (A, B, C, D), one infiltration trench (IT) and forty tow retention and infiltration basins (1-41). Source: Adapted from (PDML 2012).

Retention and infiltration basins	"Qualificação do Espaço Urbano" Lisbon PDM 2012
1-5, 9-10, 12-13, 17, 26-27, 29-30, 36-37, 42	Espaços Verdes de Recreio e Produção a consolidar
6-8, 11, 14, 15, 19, 20, 23, 25, 38, 39	Espaços Verdes de Recreio e Produção consolidados
21, 22, 24	Espaços Verdes de Proteção e Conservação consolidados
28	Espaços Verdes de Proteção e Conservação / Espaço de Uso Especial de Equipamentos a consolidar
16, 18, 40	Espaços Verdes de Recreio e Produção a consolidar / Espaços de Uso Especial de Equipamentos consolidado
31	Espaços Verdes de Recreio e Produção a consolidar / Espaços Centrais e Residenciais (traçado urbano A) consolidados
32	Espaços Verdes de Recreio e Produção a consolidar / Espaços Centrais e Residenciais POLU a consolidar
35	Espaços Verdes de Recreio e Produção a consolidar / Espaços Centrais e Residenciais (traçado urbano C) consolidados
33, 34	Espaços Verdes de Enquadramento de Infraestruturas consolidados / Espaços Centrais e Residenciais (traçado urbano C) consolidados
41	Espaços Verdes de Enquadramento de Infraestruturas consolidados

When correlating the indicated location of these retention and infiltration basins with the "Urban Space Qualification Spatial Plan" (author's translation for "Qualificação do Espaço Urbano"), eighteen are in consolidated urban spaces, as opposed to the remaining twenty-four, which are in the process of consolidation (entirely or partially). Bearing in mind that consolidated urban space refers to an "urbanized area that is stabilized in terms of urban morphology and infra-structuring" (9/2009), it is assumed that, presently, there are eighteen operational retention and infiltration basins in the city of Lisbon. Among these eighteen functional basins, three are in "protection and conservation landscapes", another three are in "infrastructural framing landscapes" and the remaining twelve are in "recreation and production landscapes" (author's translation for "Espaços Verdes de Protecção e Conservação", "Espaços Verdes de Enquadramento de Infra-estruturas" and "Espaços Verdes de Recreio e Produção", respectively).

While some retention and infiltration basins are yet to be designed and implemented, others are already well-established. Among the implemented examples are the wet retention and infiltration basins at Oeste Park – Alta de Lisboa, Quinta das Conchas park and the south area of Bela Vista Park; and the dry retention and infiltration basins at Quinta da Granja park (Figure 5.25)[82].

Figure 5.25 - Wet retention and infiltration basins in Lisbon. Above-left: Oeste Park, Alta de Lisboa. Image credits: Maria Matos Silva, 2014. Above-rigth: Quinta das Conchas Park, Alameda. Image credits: Catarina Alves de Sousa, 2015. Below-left: South area of Bela Vista Park, Marvila. Image credits: Vitor Oliveira, 2007. Quinta da Granja park, Benfica. Image credits: MariaPiaFerreira, 2012.

Contrastingly, no references where found on the construction of the specified reservoirs. Likewise, despite the seemingly simple construction process, the proposal to implement an infiltration trench is also still just an idea "in paper".

Analysing the spatial distribution of the mentioned measures within Lisbon's consolidated urban spaces, one may conclude that they are mainly bound by the crown of the city, as opposed to the more compact centre (Figure 5.26). This observation is very likely dictated by two factors. Firstly, these measures were envisaged as source control measures and thus preferably located upstream with the goal to prevent

[82] Oeste Park in Alta de Lisboa, is a 70ha public urban park that is privately managed. Besides its drainage infrastructural function, it further includes facilities such as a maintenance circuit, a kiosk and a stage for holding spectacles. Quinta das Conchas Park in Alameda is a 24ha urban public park, encompassing the restauration facilities, playgrounds, toilets, stage for spectacles, building with reception and exhibition area, among others. Quinta da Granja Park in Benfica, is an agricultural park of public management. It has an area of 3.3ha and comprises additional facilities such as a kiosk with terrace, a playground and fitness equipment. The south area of Bela Vista Park in Marvila, is an 85ha park, which further entails a restauration area with esplanades, fitness equipment, among others.

or mitigate downstream impacts. Secondly, the significantly large required area for a justifiable application of these measures further limited their implementation to the available lands for construction.

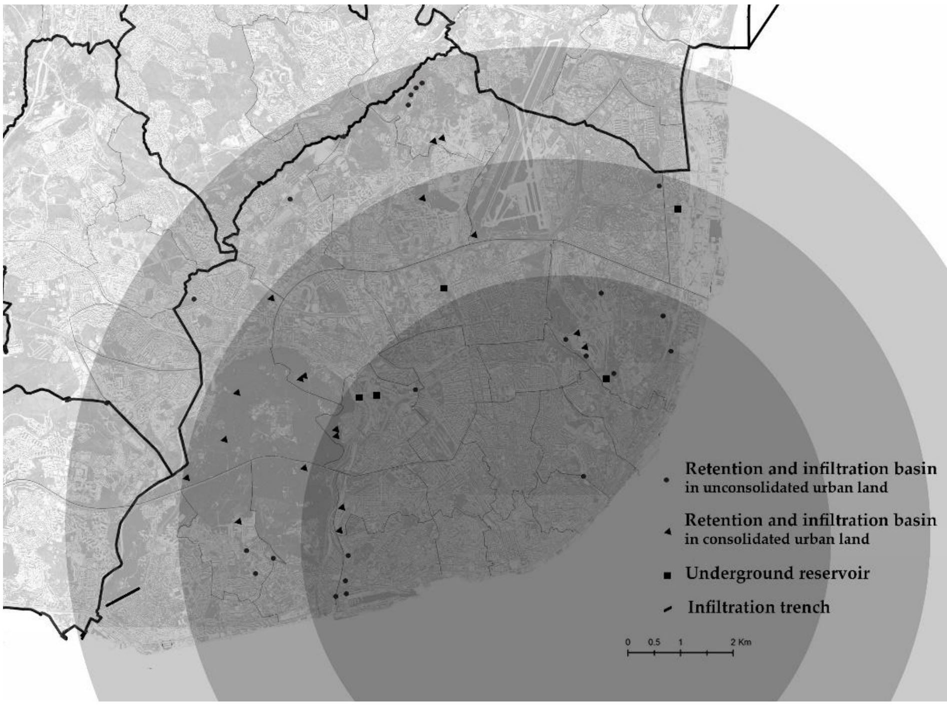


Figure 5.26 - Spatial distribution analysis of planned interventions for the improvement of the drainage system within Lisbon's Municipal Master Plan in effect. Source: author's diagram.

In 2015 the Municipality of Lisbon requested a revision of the PGDL 2006-2008 to the consortium Hidra / Engidro / Bluefocus. Under this revision, three main strategies were analysed and compared: 1) the attenuation and disconnection of stormflows, which essentially consisted on solutions presented in the former PGDL; 2) the attenuation and diversion of stormflows and 3) the diversion of stormflows. In light of the findings set out in this report, the third strategy was the most recommended, specifically comprising of tunnels and storage wells as its structuring solution.

All the reservoirs advocated in the PGDL 2006-2008 and later in Lisbon's 2012 PDM were therefore substituted by the recommendation of the alternatively analysed deviation tunnels. Through a comparative analysis, the latter is considered as a better option as it is more efficient in regards to the main purpose of this General Plan, to diminish Lisbon's flood events, being able to control stormflows for return periods superior to 20 years, while considering the estimated effects of climate change such as projected extreme weather occurrences and rising sea level. It is also considered as a better option when considering the extent of aboveground interference during construction, the costs of operation and maintenance, amongst others (Hidra et al. 2015). Another distinguishable aspect of this project, when compared with its precedent, is the effort of articulation with other municipal strategies and ongoing programs such as "Uma Praça em cada Bairro"[83] or "Pavimentar Lisboa"[84].

Overall the biggest budgetary proposals associated to the advocated strategy within this plan consist on the implementation of two major tunnels: Monsanto – Sta. Marta – Sta. Apolónia[85] (Figure 5.31) and Chelas – Beato[86], with an estimated investment of fifty-nine million, and eleven

---

[83] The program "Uma praça em cada bairro"/"A square in every neighbourhood" (author's translation) provides a set of interventions in Lisbon's public space. Specifically, interventions are planned for 30 "squares". The aim is to replicate the success achieved in the improvement works carried out at Duque d'Avila Avenue, which resulted in the promotion of this urban artery as a meeting point for the local community (CML, 2015c. *Urbanismo - Uma Praça em Cada Bairro-Intervenções em Espaço Público* [online]. Available from: http://www.cm-lisboa.pt/viver/urbanismo [Accessed 16th August 2015].)

[84] "Pavimentar Lisboa 2015-2020" is a municipal plan that aims to repave and repair streets for major and minor nuisances such as holes, unappropriated type of pavement, etc. It is projected to intervene in more than 150 streets, identified as priority areas, until 2017. 17 roads have already been rehabilitated (CML, 2015b. *Pavimentar Lisboa 2015-2020* [online]. Available from: http://www.cm-lisboa.pt/pavimentar-lisboa [Accessed 16th August 2015].)

[85] The first mentioned tunnel has an extension of five kilometres and a Nominal Pipe Size (NPS) 5500. As illustrated in Figure 5.27, its course develops from Monsanto (more specifically from Quinta José Pinto) to Cais do Sodré (Santa Apolonia) where the intercepted stormflows are discharged into the Tagus River. It will be mostly executed by an underground tunnelling machine with the exception of the final section, from the military museum until the Tagus River, which is foreseen to be constructed in open ditch. This great linear infrastructure is expected to divert stormwater from Alcântara upper basin as well as intercept and divert stormwater from the watersheds of Avenida da Liberdade, Duque de Loulé e Almirante Reis. It also comprises the implementation of five flow control or deviation well/chambers: one in the beginning of the tunnel, by Campolide train station; other two by Avenida da Liberdade and Rua de Santa Marta; and the last two by Av. Almirante Reis/Intendente área. According to the report's estimated analysis, this tunnel will have the ability to drain stormflows above 160 m3/s. This currently proposed solution, which is said to "ensure good performance levels for rainfall return periods of 100 years" (Hidra, Engidro and Bluefocus, 2015. Plano Geral de Drenagem de Lisboa 2016-2030. Monteiro, A., et al. eds.: Câmara Municipal de Lisboa. 345 pp.) will specifically substitute the previously advocated strategy to attenuate stormflows in reservoirs, namely the proposal within PGDL 2006-2008 consisting on two reservoirs (Campolide-Benfica and Avenidas Novas/Quinta José Pinto) which together would store 51.500 m3 (38.100 and 13.400, respectively). The upgraded version of these reservoirs, presented in this latest drainage plan specifically comprises five reservoirs (expanded reservoirs of Campolide-Benfica and Quinta José Pinto in order to retain 65.000 and 30.000 m3, respectively; and added reservoirs of Quinta da Alfarrobeira, Sete Rios, Praça de Espanha) which all together would store 171.000 m3 (ibid.)

[86] The secondly mentioned tunnel is to be developed from Estrada de Chelas/Calçada da Picheleira to Rua dos Amigos de Lisboa. It has an approximate extension of one thousand meters and also a NPS 5500 as updated in the final version of the plan, after its public discussion (ibid.). In similarity with the previously described tunnel, it will mostly constructed through the use of an underground tunnelling machine with exceptions in its initial and final sections which are projected to be constructed through open ditch (ibid.). In Figure 5.31, one may perceive the scale of the proposed NPS 5500 tunnels when

million euros respectively (Figure 5.27). Among other advocated solutions are the following: 1) the reinforcement and rehabilitation of the secondary drainage network, such as construction of a reinforced collector with NPS 2500 which goes along Av. Recíproca and Av. do Indico until the Tagus River; 2) the separation and control of rainwater and wastewater flows; 3) the minimization of local energy losses, such as the proposed rehabilitation of the final stretch of the Alcântara underground channel; 4) update of records (cadastre) and system checkup; 5) the development of a monitoring and warning system; 6) implementation of preventive maintenance procedures; as well as the previously[87] proposed; 7) implementation of retention and infiltration basins such as the one proposed for Polo Universitário do Alto da Ajuda and another for Qta das Lavadeiras (Ameixoeira waterline); 8) source control solutions, such as the proposed infiltration trench at Rua do Alto do Duque; amongst others (Hidra et al. 2015).

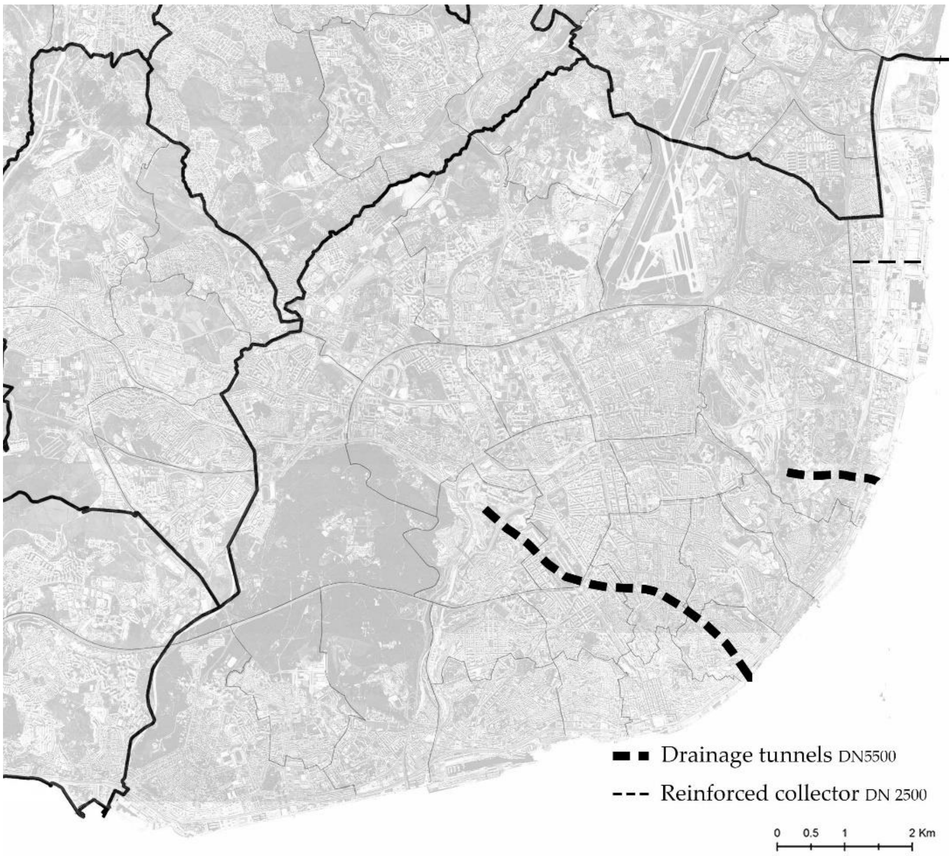


Figure 5.27 - Spatial visualization of the structural measures recommended in the updated General Drainage Master Plan 2016-2030: From bottom-up and left to right: 1) Monsanto – Sta. Marta – Sta. Apolónia tunnel and 2) Chelas – Beato tunnel, and 3) the strengthening of the collector at Av. Berlim. Author's elaboration from (Hidra et al. 2015).

compared with the full diameter of the existing metro tunnels, namely at the crossing points with: Rua Braacamp, Av. Liberdade, Av. Almirante Reis and Santa Apolónia.

[87] ChiRoN, *et al.*, 2006b. *Plano Geral de Drenagem de Lisboa. Fase C: Desenvolvimento do Plano Geral de Drenagem.* Matos, J. S., *et al.* eds. Miraflores. 270 pp.

It is estimated a total investment of one hundred and seventy-eight million euros for the implementation of this updated PGDL. Of which, one hundred and fourteen million are to be will be allocated in the first five years (Hidra et al. 2015). In the plan´s public presentation, Fernando Medina as the Mayor of Lisbon, proudly stated that "This is the most important and more structuring project of the last decades for the future of Lisbon" (CML 2015a, author's translation). Indeed, this is the first municipal drainage plan to include climate change projections in its calculations, and it's interesting to note that, the first version of the plan prior to its public discussion, considered an SLR of 30cm and that the last final version of the plan rather considered an SLR of 70cm.

Combining the advocated strategies within the 2012 Municipal Master Plan in effect with the strategies advocated in the recent revision of the Drainage Master Plan (2015), one may argue that there are currently two major flood management strategies developed and envisioned for the city of Lisbon, namely: 1) a source control strategy, advocating the implementation of retention and infiltration basins, permeable pavements, green roofs, among others; and 2) a conveyance strategy, materialized in underground tunnels that transport excesses of stormwater from highly urbanized upper basins into the receiving water body of the Tagus River.

Yet disconnected to any wider structural strategy, strolling through Lisbon one may further find, here and there, some flood adaptation measures applied in the design of public spaces or with direct implications on the public space design. That is namely the case of the check dams at Quinta das Conchas (Figure 5.28-left), the bioswale at Instituto Geografico Português (Figure 5.28-midle) or the green wall at Travessa do Patrocinio (Figure 5.28-rigth), amongst others.

In days of extreme precipitation or after a flood event, one may further glace at the latent opportunities for stormwater management provided by a different configurations of the public space. Possibilities are almost as numerous as the categories ad types of measures previously presented in the Conceptual Framework of flood adaptation measures applicable in the design of public spaces. For example, Figure 5.29-left, which pictures a great volume of rain draining down the stairways at Miradouro S.Pedro de Alcantara, recalls the Minoan stairway canals (see chapter two, Figure 2.4) and how these waters could be directed onto measures with the infrastructural capacity to Store, Infiltrate or Tolerate. In the same line of reasoning, flooded Praça do Rossio, illustrated in Figure 5.29-midle, may guide conjectures on whether cisterns, street channels or a variant of a water plazas could be implemented. Or even the remaining rainwater in-between the very common rails in Lisbon, as can be seen in Figure 5.29-

right, may further direct the thought on the possibility to encompass stormwater channels along or in-between tram or train lines.

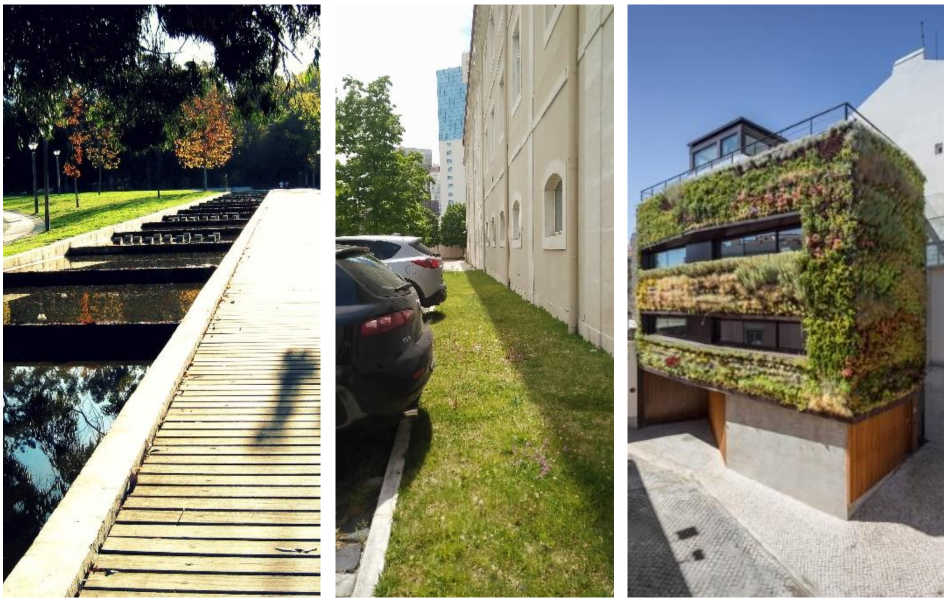


Figure 5.28 - Left: Check dams at Quinta das Conchas. Image credits: ® Meeg-el, 2008. Middle: Attempted bioswale at Instituto Geografico Português. Image credits: Maria Matos Silva, 2016. Right: Green wall in house at Travessa do Patrocinio. Project by Luis RA and Tiago RA. Image credits: © rebelodeandrade .com

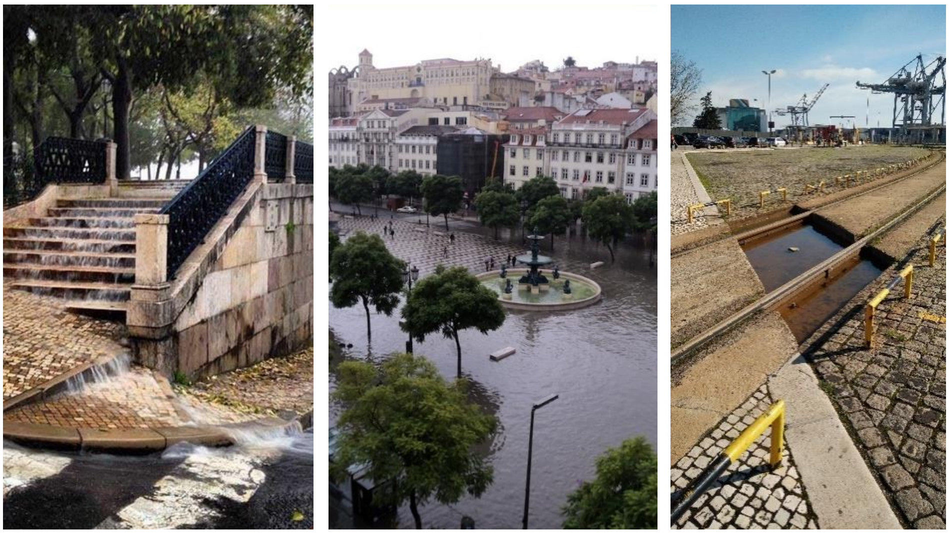


Figure 5.29 - Left: Rain draining down the stairways at Miradouro S.Pedro de Alcantara. Image credits: © lisboalive, 2014. Milde: Flooded Praça do Rossio. Image credits: © Teresa Lousada, 2010. Right: Rainwater retained in-between tramlines at Porto de Lisboa. Image credits: Maria Matos Silva, 2016.

As discussed in chapter two how our cities have been dealing with floods throughout the years is intimately related with the perception of water as a resource, which is also naturally influenced by the intricacies of history and urban planning paradigms. As previously argued, urban territories are in the verge of a new relationship with water, one that embraces it as an opportunity rather than as a hindering threat: an environmental opportunity to preserve an endangered resource, the opportunity to learn how to live in constant change and uncertainty, the opportunity to connect people with change, the opportunity to improve urban territories throughout change, amongst others. In continuity with this argument a concluding question is proposed: where does Lisbon stand in this tendency towards a shift of paradigm?

As highlighted in chapter two, in the "urban water transitions framework" proposed by Brown et al. (2008) six different stages regarding how our cities managed water were introduced. Transposing this analysis into the specific case of Lisbon, it is possible to identify five of the outlined stages, namely "Water Supply City", "Sewered City", "Drained City", "Waterways City" and "Water Cycle City". This analysis can be accompanied by Figure 5.30.

"Water Supply City" corresponds to the times when concerns where essentially focused on providing good quality and quantity of water for a growing number of urban population. In Lisbon, these times can be generally associated with the stage from the construction of "Águas Livres" Aqueduct in 1732-1784 until the date of conclusion of the Alviela channel in 1880 as it was only from this date on that water was effectively supplied for all Lisbon's population. In this period, fountains and waterspouts fed by rainwater and/or natural springs were a major meeting and mingling public space. Urban floods were yet no major concern. Stormwater was either collected in cisterns or wells or drained away to the Tagus through small conveyance trenches embedded in the pavement morphology or through the still emergent underground drainage network.

Lisbon's outbreaks of Cholera and Yellow fever instigated the urgent need to provide the city with a proper and effective drainage and sewage system, and started to point towards the upcoming stage of the "Sewered City". This specific stage had its apotheosis with Ressano Gracia's drainage master plan, which was influenced by the previous studies of Gotto & Beesley as well as by the hygienist concerns of Edwin Chadwick. "Plano de Esgotos da Capital", Lisbon's first drainage master plan, together with Ressano Gracia's aims of providing new broad and decongested public spaces, improved Lisbon's salubrity and overall quality of life. Notably, one of Ressano Gracia's plans that was latter discarded, was a 200 hectare park at Campo Grande. Most likely, great benefits related to stormwater management, as well to other extensive urban concerns (such as air quality, microclimatic melioration, amongst others) could have been gained if this project was to be carried out. As the so called "tout-à-l'égout" approach was extensively implemented, increased amounts of grey water were drained into natural water courses, namely the Alcântara stream, which was gradually transformed into an open sewerage ditch. In order to work around this matter, the Alcântara stream was channelized in 1942, marking the beginning of the "Drained City" stage.

Facing the need to expand the city, the "Drained City" is particularly characterized by having roughly channelized waterlines and drained floodplains. An era were stormwater was considered as a nuisance that should be rapidly conveyed out of the city and preferably through an imperceptible way with no relation with people and their communal spaces. This era further encompassed the international dissemination of the new discipline of Urban Hydrology, acknowledged in Celestino da Costa's drainage master plan for Lisbon in 1955. Curiously, Lisbon's Urbanization Master Plan of 1959 signalled a glimpse of the looming stage as it specifically expressed concerns regarding the need to preserve the environmental quality of pre-existing water courses also for leisure purposes, namely in the landscape analysis made for Benfica, Carnide and Lumiar.

Indeed, throughout the period associated to the "Waterways City", the importance of unpolluted waterways started to be recognized not only for environmental reasons but also for the visual and recreational delight of communities (Júnior 1971). In accordance, wastewater discharges started to be regulated in treatment plants. Although Arantes e Oliveira had planned the construction of two waste-water treatment plants for the region of Lisbon in 1941, the first treatment plant was only constructed in 1989 at Alcântara. Also in the early 90s, innovative strategies and techniques were developed in the "Plano Verde" report, comprising contemporary concepts such as the "ecological structure" as well as alternative bio-filtration infrastructures such as retention and infiltration basins. This knowledge, which has been consecutively transposed into municipal reports and master plan's revisions, started to recognize the relevance of interdisciplinary design processes, giving rise to multifunctional public spaces such as the "Corredor Verde de Monsanto" (only officially opened in 2012). Specifically related to urban floods, retention and infiltration basins as measures implemented in public spaces not only contribute with their infrastructural capacity to store and infiltrate stormwater but also promote a closer relationship between water dynamics and its users. Undertakings from Expo'98 further encompassed a particularly successful stream rehabilitation project as well as the implementation a number of public spaces where water is used as a key element of the design. This highlighted presence of water in the design of public spaces can be particularly significant in light of a subtle approximation to the anticipated contemporary shift of paradigm into flood adapted cities.

The "Water Cycle City" is a period characterized by a generalized understanding that the natural resources are limited and that the urban water cycle must be managed in transdisciplinary means involving technicians, government and communities. Conceivably, Lisbon's Drainage Master Plan 2006-2008, marks the entrance in this stage as it clearly recognizes the need for varied and complementary strategies that range from “hard” to “soft” engineering systems such as underground reservoirs and infiltration trenches, respectively. The updated version of this master plan (2016-2030) entailed further efforts towards a shared management of the water cycle among the public and the private sector as well as among the government and community. Particularly, its current initial phase widely benefited from a developed workshop involving various stakeholders, from institutions to professional associations, such as SIMTEJO, APL, EPAL, Lisbon’s Metro and municipality technicians, which assessed and supported the plan’s decisions. Furthermore, a wide and effective public participation is clearly advocated throughout the report, not only for information purposes, but also for its contributions for alternative flood mitigation solutions, as well as for overall citizen engagement in the water management of the city (Hidra et al. 2015). For the Municipality, this latest proposal overcomes the problem of floods “in a sustainable way, with minimal social, environmental and economic costs” (CML 2015a, author’s translation), yet the stated sustainability attribute is rather questionable, namely when considering its impacts on subsoil drainage and the misuse of the pluvial resource. Indeed, the challenges that need to be faced in order to reach a comprehensive water cycle resolution within cities, are so complex that there are significant barriers in its achievement. Although some of our present public spaces do offer a closer relationship with water and flood management processes, the “Water Cycle City” stage in Lisbon is still in its infancy. In order to effectively move beyond the “Waterways City” stage and overcome the established academic and policy rhetoric it is necessary to deliver an encompassing strategy that would gather and make sense out of the existing dispersed interventions such as green roofs (e.g. WWTP de Alcântara), green walls (e.g. house at travessa do patrocinio), bioswales (e.g. Instituto geografico Portugues), check dams (e.g. Quinta das Conchas), retention and infiltration basins (e.g. Oeste Park, Alta de Lisboa), embankments (e.g. Ribeira das Naus), elevated promenades (e.g. Parque Tejo e Trancão), amongst others.

As a result, Lisbon is quite distant from the “Water Sensitive City” stage, considered by Brown et al. as the most “adapted” stage, as it still strongly relies on the strategy of optimization and enlargement of singular mono-functional infrastructures instead of effectively change traditional mainstreamed approaches towards a multifunctional and integrated water management practice. A strategy that specifically argues on its advantage to resolve an urgent situation in a relatively short period of time[88]. Indeed, the PGDL 2015-2030 envisioned communal risk management, which comprises complementary and alternative "soft" solutions (such as infiltration trenches or "swales"), yet this discourse is still largely only present in narrative with little considerations regarding effective plans and designed measures.

[88] The main structural interventions are expected to be implemented in a period of 5 years.

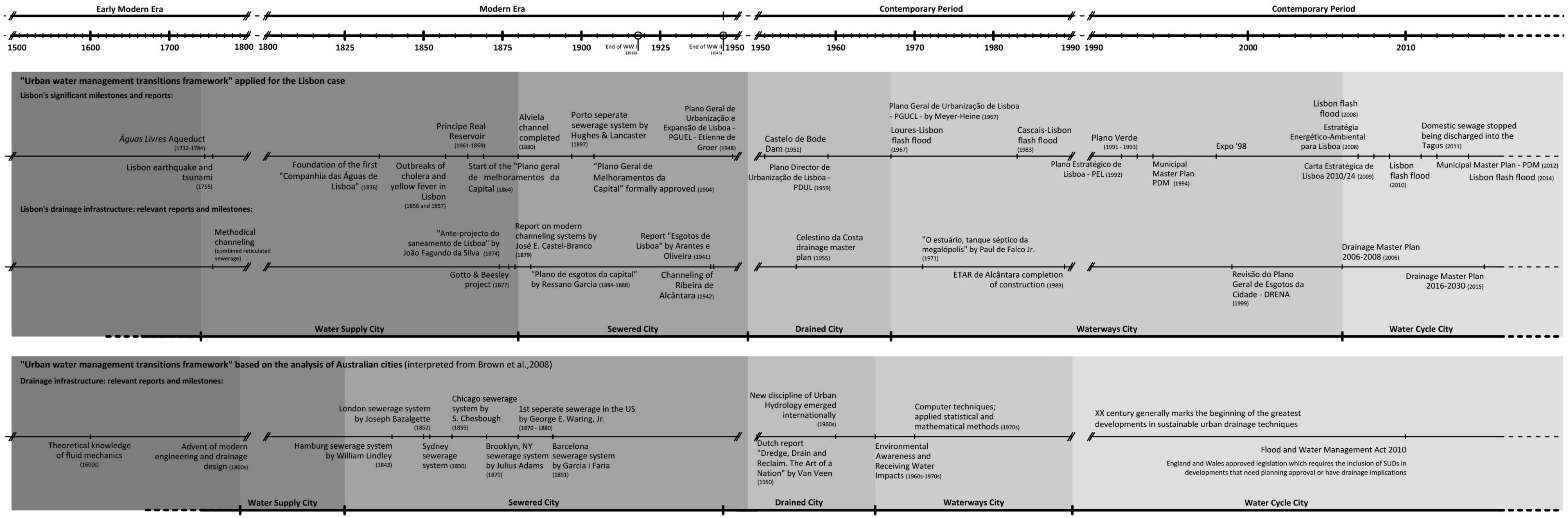


Figure 5.30 - "Urban water management transitions framework" applied to the Lisbon case. Significant milestones related to the city of Lisbon and the evolution of its drainage infrastructure as well as important international milestones and reports regarding the general evolution of drainage infrastructure. Source: developed by the author.

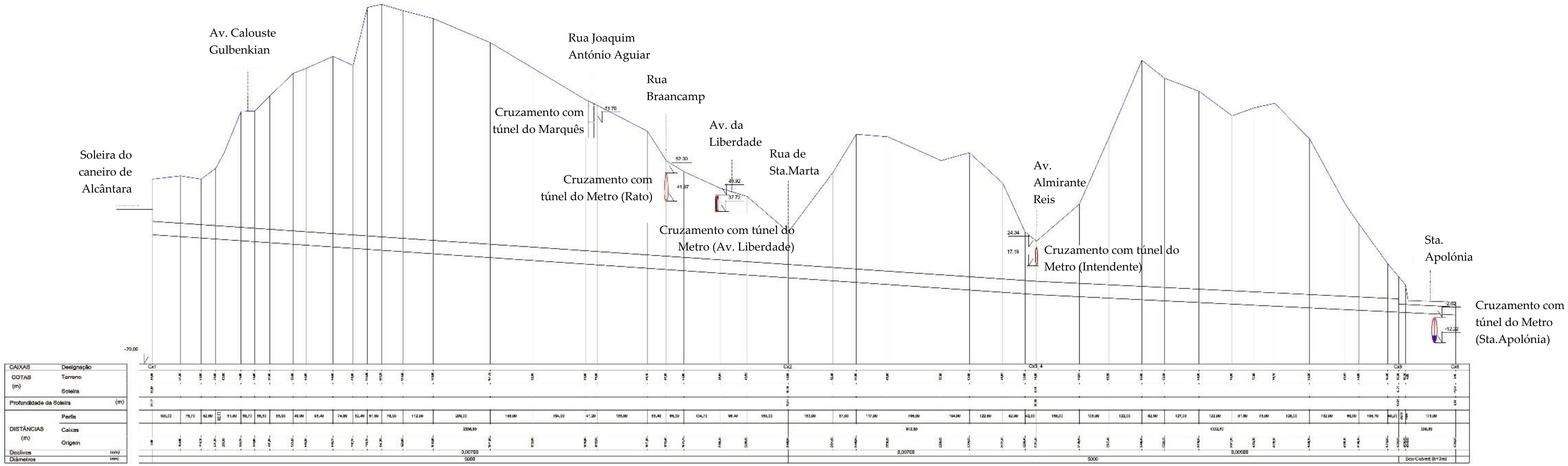


Figure 5.31 - Longitudinal profile of the tunnel Monsanto / St.ª Marta / St.ª Apolónia. Source: Hidra, Engidro and Bluefocus, 2015. Plano Geral de Drenagem de Lisboa 2016-2030. Monteiro, A., Matos, J. S., Oliveira, R. P. d., Guerreiro, A., Braunschweig, F., Estudante, M., Pinheiro, M., Leboeuf, Y., Fernandes, Z., Guimarães, J., Simões, J., Ribeiro, P. and Ferreira, F. eds.: Câmara Municipal de Lisboa. p.177.

5.3 Discussion

Every year at least some parts of Lisbon are severely affected by floods. Throughout the years, research has therefore consolidated the knowledge regarding these specific floods. In brief, it is generally recognized that there is a meteorological and topographical predisposition to flash floods. More specifically, Lisbon floods usually occur as a result of heavy rainfalls of short duration within relatively small hydrographic basins of steep slopes. Furthermore, these are aggravated due to the high level of imperviousness associated with an underground drainage system that is currently undersized or obsolete and can be damaged or ruptured easily. An equally important aggravating factor is the interaction between stormwater discharge and the tides of the Tagus River. More specifically, when high tides are combined with wet weather discharge they cause a buffering effect in the city's drainage system, which almost directly leads to marginal flooding.

Considering climate change projections, although it is generally expected for precipitation to decrease, i.e. less consecutive days of rainfall, situations of heavy precipitation in short periods of time are projected to increase. Other projections which can significantly aggravate Lisbon's floods, include the increase of SLR and the frequency and intensity of storm surges. While precipitation regimes and associated extreme events are the phenomenon in which more uncertainty relies, there is a higher level of confidence on the increase in sea level and storm surge events. Whilst considered as less likely and thus potentially less impactful, other climate change factors contributing towards flooding in Lisbon, include the magnitude increase of progressive Tagus foods as well as wind and undulation.

Overall, projected climate change scenarios for Lisbon indicate an increase of flooding events. An anticipated situation that, together with current vulnerabilities, will bring unprecedented challenges that must be critically confronted. Indeed, climate change points towards the need to understand and act upon these projected changes. It is no coincidence that insurance companies, such as the Portuguese Association of Insurers (APS), have already acknowledged that the risk is real and it is likely to increase (Santos et al. 2014). Questions such as whether or not to adapt our urban territories, and more specifically its infrastructure, are particularly important to discuss as they are designed for long timeframes. Yet while contemporary discourse strongly advocates climate change adaptation approaches in this regard, most endeavours are still generally bounded in the scope of policies and strategies.

In light of precedent studies, Lisbon's recently approved Master Plan (2012) has clear intentions on how it aims to solve the recurrent flooding episodes. Two proposed measures were highlighted, these being the underground reservoirs (later replaced by underground deviation tunnels) and the open retention and infiltration basins, with a clear preference given to the former over the latter proposal.

There is no doubt that Lisbon is presently faced with a considerable drainage problem, a problem can only be rapidly and efficiently tackled through the use of hard infrastructural works. Quoting PGDL (2006-2008) "Source control measures (such as retention and infiltration basins), applied in heavily consolidated urban areas such as the city of Lisbon, are not sufficiently effective measures for the control of stormwater of high return periods" (ChiRoN et al. 2006b, p.116, author's translation). Yet hard infrastructural works, such as the ones detailed in the recent PGDL, and particularly if climate change projections are to be confirmed, provide a very limited spectrum of alternatives and therefore limited outcomes.

Lisbon's floods, presented as the main topic of this chapter, are not and must not be considered as exceptional events. As such, undertakings targeted at eradicating this phenomenon, which is further expected to become even more frequent and intense, can be counterproductive. By contrast, the aim to reduce vulnerabilities and improve the adaptive capacity of our territories, not only moderates potential hazards, but also exploits existing opportunities. By learning how to live with floods, beneficial outcomes may namely arise from water purification processes, water storage and consumption, amongst others. Indeed, although technology and specialization is often presented before us as the only way of solving complex problems, bearing in mind its incapacity in acknowledging the wider network of relations between things, it sometimes solves one problem only to create others.

In light of climate change projections as well as previous international adaptation experiences, improved drainage plans must consider, beyond discourse, even more extended horizons. Only extended horizons enable the acknowledgment of the whole, from the small to the large scale; a perspective that is vital for the adaptation of our urban territories in the face of impending flood events. Municipal drainage plans must thus include a wider scope of measures in order to strengthen a future integrated strategy towards a more adapted city. A strategy that moves further ahead from the "Waterways City", effectively enters the "Water Cycle City" and prepares the grounds for the "Water Sensitive City" (concepts outlined by Brown et al. 2008 as previously mentioned).

Recalling the findings from the former chapter, a Conceptual Framework of urban flood adaptation measures applicable to the design of public spaces was proposed. The framework, which through an identification and systematization process, organizes a wide range of adaptation measures, does not advocate “softer” measures over “harder” technical measures. By combining and classifying an encompassing variety of specifically targeted solutions, the Conceptual Framework rather questions conventional processes devoted to traditional mono-functional measures.

Targeted at supporting the initial conceptual stages of a design process, the knowledge presented by the proposed framework can therefore be considered as particularly pertinent for the Lisbon case and its municipal adaptation agenda.

Through the presented analysis of the Lisbon case, one may understand how several local factors determine the characteristics of floods. One may further exploit and reinforce the Conceptual Framework’s contents, namely the identification and characterization of the proposed adaptation measures and strategies, through the analysis of flood related municipal undertakings, and applied examples, implemented throughout the years.

Yet it is important to restate that the Conceptual Framework encompasses a systematization process that, as envisioned, provided results of a general nature, i.e. potentially applied in any geographical context. Therefore, it is up to any individual involved in a respective public space design project with flood adaptation purposes to decide upon what is the best measure to be applied in a specific place. While it can be common for designers to be inspired by recognised precedents or best practices, they must relentlessly acknowledge the location’s overall uniqueness.

One may thus summarize that the utility of the Conceptual Framework is dependable upon 1) whether a city is vulnerable to floods, 2) whether projected climate change scenarios point towards an increase of flood occurrences regardless of continued uncertainties and 3) whether the city is yet far from the “Water Sensitive City” stage, which addresses flood management through multifunctional and integrated adaptation strategies. These three criteria are not only present in the Lisbon case but are also likely existent in other urban territories.

Chapter 6

Assessment of the proposed Conceptual Framework in the Lisbon case

In order to assess how the developed Conceptual Framework can be of use in a specific context such as Lisbon, chapter six starts by analysing the conducted municipal endeavours up to the present time, which are specifically related to urban flood adaptation applied in public spaces. In compliance with the major chosen municipal strategies, it is assessed whether the proposed Conceptual Framework provides additional types of flood adaptation measures needing to be considered.

Supplementary types of adaptation measures highlighted by the Conceptual Framework, are assessed with regard to their application and infrastructural relevance. More specifically, the new adaptation measures identified as potentially adequate, are evaluated through preliminary design studies in concrete situations and through a quantitative estimate of their infrastructural value. In light of the presented results, which have confirmed the infrastructural benefits of the measures additionally proposed, new discussions emerge specifically regarding Lisbon's municipal flood adaptation management and its relation with public space design.

6.1. Lisbon's Municipality adaptation response

Triggered by the projected inevitability of climate change impacts, which is widely recognised among climate scientists, adaptation endeavours have been reinforced in the international urban agenda (Costa 2013). Following the discussion presented in chapter one, although mitigation undertakings have long been acknowledged, only recently did the adaptation concept become a constant presence in municipal urban planning reports for most of the developed countries. In accordance, and instigated by recurrent flood episodes, which are projected to become progressively worse, Lisbon has been directing specific efforts towards urban flood adaptation. Once urban climate change adaptation has become a fairly recent subject, it is a matter that will be accompanied by major questions, namely questions regarding the processes of selection and design of adaptation measures.

Regardless of the existing examples of adaptation measures implemented in Lisbon through private initiatives or other punctual short of synergies, the following comments will focus on assessing the essential municipal intentions present within the constituent, and accompanying elements of the cities' Municipal Master Plan (PDM) which is currently in effect. An approach that is essentially bound to the fact that the 2012 Lisbon's PDM is the most updated land management tool, and the only mandatory document which determines the classification and qualification of land use. Most importantly, it is the instrument which configures urban planning intentions for the Lisbon of the future. In addition, in line with European and Portuguese climate change adaptation policies and strategies (whose dates of major reports can be found in Figure 5.8 timeline in chapter five), it comes as no surprise that climate change is present within one of the seven main objectives of Lisbon's 2012 PDM. In particular, the objective to: "Meet the challenges of climate change, natural hazards of environmental sustainability and energy efficiency, by reducing the number of circulating vehicles and increasing green areas and building's energy efficiency" (CML 2012b, p.33, author's translation).

Before assessing Lisbon's municipal adaptation plans, it is important to note that the city's PDM took into account findings from previously established strategies, reports and plans. Amongst others, "Plano Verde de Lisboa" (1997), "Plano Geral de Drenagem para Lisboa" / Drainage Master Plan" (PGDL 2006-2008), "Estratégia Energético-Ambiental para Lisboa" / Lisbon's Energy and Environment Strategy (2008), "Carta Estratégica de Lisboa 2010-2024" / Lisbon Strategic Charter 2010-2024 - A commitment to the future of the city' and "Avaliação Ambiental Estratégica" / Strategic Environmental Strategy' (2011) were the ones that influenced the proposed flood tackling adaptation measures the most. In other words, the strategies and solutions pointed out by these plans were critically considered within the ongoing PDM revisions and some were adapted accordingly. For example, one of the five reservoirs proposed in the PGDL 2006-2008 was substituted by a retention and infiltration basin (at Rua Eduardo da Bairrada) and another reservoir was additionally proposed (at Campo Grande, Cidade Universitária) despite having been least recommended in the Drainage Master Plan. Similarly, in the same way that the two proposed retention and infiltration basins suggested in PGDL 2006-2008 were maintained, dozens were additionally proposed in light of other conducted studies, such as the development of the municipal Ecological Network Plan. Currently, Lisbon's Municipal Master Plan in effect indicates a proposal of five reservoirs, one infiltration trench and thirty nine retention and infiltration basins (see Figure 5.24 in chapter five). Also the "Lisbon's Energy and Environment Strategy" and the following "Lisbon Strategic Charter 2010-2024 - A commitment to the future of the City", greatly influenced municipal adaptation undertakings, as they specifically encompassed climate change on its double approach of mitigation and adaptation. In these reports, the influence of urban systems in the energy consumption matrix is particularly recognized, as well as the importance of the ecological structure as an adaptation and mitigating element of the extreme effects of temperature rise and intense rainfall, further stating that, "the ecological structure plays a fundamental role that goes far beyond ideological or personal sensitivities, which are now heritage of a common culture" (CML 2012b, p.61). In brief, the overall strategy advocates: 1) to increase the municipal ecological structure, enhancing continuities between the various green spaces; 2) to free valleys from existing occupation or programmed occupation within previous territorial management instruments; 3) to increase the permeability of public areas and preserve permeable interior patios; 4) to increase the leaf surface area, namely through green roofs; 5) to implement wells and infiltration trenches; and 6) to meet targets for energy sectors, water and waste recycling (CML 2012b). One can therefore promptly recognize a notable effort within Lisbon"s PDM in order to encompass the adaptation and mitigation measures supported by these strategies.

With the purpose of assessing Lisbon's municipal adaptation response, a contrasting analysis between the specific types of adaptation measures identified within Lisbon's PDM (2012), and the existence of other possible types of measures presented by the Conceptual Framework, will be undertaken. More specifically, in a first stage, and following the same methodology as the one conducted for the creation of the Conceptual Framework, for each constituent and accompanying element of the PDM, all mentioned categories and types of adaptation measures (as considered in the scope of this research, i.e. flood tackling operational measures applicable in the design of a public space) will be outlined. In a second stage, all the highlighted measures will be synthetized into the essential proposed measures. Finally, these will be compared with the Conceptual Framework in search for potential additional relevant types of measures.

Table 6.1 highlights the initial undertaken analysis, which aimed to identify flood adaptation measures specifically proposed by the PDM in effect. As such, it specifically analyses all respective constituent and accompanying elements of Lisbon's PDM, namely the Accompanying Documents 1) Master Plan Report and 2) Environmental Report, Strategic Environmental Assessment (2011) and the Constituent Elements 3) Regulations, 4) Technical Guide and 5) Planning Maps. All information that is accessible online through the Municipality website (www.cm-lisboa.pt).

In grey, on the left side, are the original transcripts of the identified references of adaptation measures included in each respective document. The tree columns on the right side refer to the matching of these references with their counterparts, specifically encompassed within the Conceptual Framework. While some correlations correspond to direct translations, such as "Bacias de Retenção" to "Bioretention Basins" or "Trincheira de Infiltração" to "Infiltration Trench"; others references had to be interpreted, such as "Libertação de vales de ocupação", which can be translated as "Free valleys from obstructions", is here interpreted as the adaptation category of "Stream recovery". Further identified references refer to strategies rather than to specific measures, yet they were also considered in this analysis. For example, the strategies to "Increase the green areas" ("Aumento das áreas verdes") and to "Increase the permeable areas" ("Aumento das áreas permeáveis"), present in the Constituent Element 3) Regulations - Encouragements for environmental efficiency, were correlated with the strategies of Harvest and Infiltrate, respectively, from the Conceptual Framework.

As further evidenced in Table 6.1, possibly as a result of a superficial understanding of the adaptation concept, in the Accompanying Document 1) Master Plan Report, it was possible to identify direct references on adaptation measures as well as indirect references. Indirect mentions include the references that, although were either considered as mitigation measures or were not considered as neither mitigation or adaptation measures in the Master Plan Report, are considered as adaptation measures in the scope of this research, namely as they highlight flood tackling operational measures applicable in the design of a public space. In accordance, among the sixteen adaptation measures specifically mentioned in the 1) Master Plan Report, only five are considered as adaptation measures in the scope of this research. Following the same line of reasoning, among the twenty six mitigation measures identified in the analysed report, four measures where considered as adaptation measures and not mitigation measures. Furthermore, within the main and accompanying report of the plan, an additional ten adaptation measures were considered and identified regardless of them not being explicitly mentioned or related to climate change adaptation or mitigation measures. In the Constituent Elements 3) Regulations, eleven measures were identified and in the 4) Technical Guide, four. Within the 5) Planning Maps, only three adaptation measures were disclosed with spatial representation

Table 6.1 - Identification of the adaptation measures[89] mentioned in each constituent report of Lisbon's PDM (2012).

Constituent reports of Lisbon's PDM (2012)		**Matching strategies, categories and types of adaptation measures with the Conceptual Framework**		
		Main strategy	**Category**	**Type**
Elementos de acompanhamento **Accompanying documents:**				
Relatório da proposta de plano 1) Master Plan Report				
Directly mentioned as adaptation measures:				
Reforço e melhoria das condições de funcionamento do Sistema Hidrológico	*Bacias de Retenção*	Store	Bioretention	Bioretention basins
	Pavimentação permeável	Infiltrate	Permeable paving	
	Captação e armazenamento nos edifícios;	Store	Reservoirs	Cisterns

[89] In the scope of this research the considered "adaptation measures" are the ones that include flood tackling operational measures applicable in the design of a public space.

Requalificação do solo em áreas aluvionares, promovendo a respetiva reafectação à estrutura ecológica urbana …	Convey	Stream recovery	
Promoção da recolha e armazenamento de águas pluviais;	Harvest, Store, Infiltrate		

Directly mentioned as mitigation measures but here considered as adaptation measures:

Aumento da área total de Estrutura Verde e da sua continuidade espacial e aumento do número de árvores na Cidade;	Harvest, Infiltrate	Urban greenery	
Incremento da superfície folhear da cidade	Harvest	Urban greenery	
Concretização de novos eixos urbanos arborizados;	Harvest		Tree alignments
Intervenção sobre a rede de drenagem, com vista a reduzir os efeitos de inundações urbanas e fazer a prevenção na origem.	Harvest, Store, Infiltrate		

Other adaptation measures not directly mentioned as adaptation or mitigation measures:

Bacias de infiltração/retenção a céu aberto	Store	Bioretention	Bioretention basins
Preservar e aumentar a permeabilidade do solo urbano	Infiltrate		
Revestimento vegetal de coberturas e fachadas	Harvest	Urban greenery, Rooftop retention	Green walls, green roofs
Aumentar a área de superfície vegetal da cidade	Harvest	Urban greenery	
Poços ou trincheiras de infiltração	Infiltrate	Infiltration techniques	Infiltration trenches, Leaky well
Reservatórios de atenuação de caudais	Store	Reservoirs	
Renaturalização de vales	Convey	Stream recovery	
Libertação de vales de ocupação	Convey	Stream recovery	

Relatório Ambiental, Avaliação Ambiental Estratégica (2011) /

2) Environmental Report, Strategic Environmental Assessment (2011)

Aumento áreas permeáveis em zonas de infiltração	Infiltrate		
Aumentar a capacidade de escoamento superficial e subsuperficial	Infiltrate, Convey		

Elemento constituintes

Constituent elements:

Regulamento

3) Regulations

Incentivar eficiencia ambiental

Encouragements for environmental efficiency

Aumento das áreas verdes	Harvest, Infiltrate		

Aumento das áreas permeáveis		Harvest, Infiltrate		
Requalificação e valorização dos cursos de água e respectivas margens		Convey	Stream recovery	
Promover sistema de retenção e infiltração de águas pluviais	*Bacias de retenção/infiltraçã o da água pluvial*	Store, Infiltrate	Bioretention	Bioretention basins
	sistemas autónomos de infiltração e armazenagem de águas pluviais (poços, trincheiras e cisternas)	Infiltrate, Store	Infiltration techniques, Reservoirs	Infiltration trenches, Leaky well, Cisterns
III Espaços verdes: âmbito, objetivos e regime / III Green spaces: scope, objectives and rules				
Pavimentos permeáveis		Infiltrate	Permeable paving	
Modelação de terreno que permita a infiltração in situ		Infiltrate, Store	Reservoirs, Bioretention, Infiltration techniques	
Manual técnico 4) Technical Guide				
Parâmetro da "Superfície vegetal ponderada" (Svp)	*Superfícies vegetais sobre laje*	Harvest	Urban greenery, Rooftop retention	Green roofs
	Poços de infiltração	Infiltrate	Infiltration techniques	Leaky well
Implementar a revalorização e requalificação biofísica dos cursos de linhas de água e respetivas margens ...		Convey	Stream recovery	Rehabilitation, Restoration
… estruturar e promover a infiltração de águas e a regularização hidrológica…		Infiltrate		
Plantas de Ordenamento 5) Panning Maps				
Estrutura Ecológica Municipal Municipal Ecological Structure				
Bacias de retenção / infiltração pluvial		Store	Bioretention	Bioretention basins
Condicionantes de Infra-estruturas Infrastructure Constraints				
Bacias de retenção / infiltração pluvial		Store	Bioretention	Bioretention basins
Reservatório proposto		Store	Reservoirs	Underground reservoirs
Trincheira de infiltração		Infiltrate	Infiltration techniques	Infiltration trenches

In light of the presented analysis it was possible to evidence that there is a strong emphasis given to the source control strategy, that is, to the types of adaptation measures whose primary functions are: 1) Harvest (mentioned more than nine times throughout the analysed documents) such as Green walls, Green roofs or Tree alignments; 2) Store (mentioned more that twelve times) such as Bioretention basins, Cisterns or Underground reservoirs; or 3) Infiltrate (mentioned more that sixteen times) such as Permeable paving, Infiltration trenches or Leaky well.

Albeit more discreetly present one other strategy that can be recognized throughout the PDM constituent and accompanying documents, is the 4) Convey strategy (mentioned more than six times). In light of the overall guiding principles of the general plan, this former strategy is associated with the need to preserve and increase superficial and underground drainage storm flows, together with the "requalification and valorisation of water courses and its respective margins" (CML 2012b, e.g. p.93, author's translation), here correlated to the types of measures of Stream rehabilitation and restoration. As a summary, Table 6.2 presents the essential flood adaptation measures proposed by Lisbon's PDM (2012).

Table 6.2 – Resume of the adaptation measures directly and indirectly proposed by Lisbon's Municipal Master Plan in effect (2012).

	Main strategy	**Category**	**Type**
1	Harvest	Urban greenery, Rooftop retention	Green walls, Green roofs Tree alignments
2	Store	Retention	Retention basins
		Bioretention	Bioretention basins
		Reservoirs	Cisterns Underground reservoirs
3	Infiltrate	Permeable paving	
		Infiltration techniques	Infiltration trenches, Leaky well
4	Convey	Stream recovery	Rehabilitation, Restoration

6.1.1. Brief discussion in light of the given results

Although Infiltrate strategy is more often considered throughout the PDM, specifically in the form of permeable pavement and infiltration techniques, there is a tendency towards a stronger commitment to the application of retention basins. In contrast, and regardless of its presence in both report and planning maps, there is a clear detachment in the implementation of underground reservoirs. On the one hand, they are not included in the PDM's "Implementation Program and Financing Plan"

(Author’s translation for “Programa de Execução e Plano de Financiamento do Plano Director Municipal de Lisboa”, 2012, p.98) and on the other hand they are mentioned only once throughout the report and with superficial detail, whereas the retention and infiltration basins are repeatedly mentioned and some of its particular characteristics are noted. Moreover, while the underground reservoirs are solely included in the “Infrastructural Constraints Spatial Plan”, the retention and infiltration basins are identified in the previous plan and in the “Ecological Network Spatial Plan” (author’s translation for “Condicionantes de Infra-estruturas” and “Estrutura Ecológica Municipal”, respectively), essentially highlighting the dual ecological/infrastructural function of this measure.

It should be further noted that one of the six key messages present within “Lisbon Strategic Charter 2010-2024” include references on the importance to improve urban public spaces. Also the Strategic Environmental Assessment of 2011 recognized that “the urban environment is strongly connected to the quality of public spaces” further stating that “public spaces and the urban environment should have been the subject of a specific (and transversal) policy” (in CML 2012a, p.10/11, author's translation). This matter specifically reinforces the pertinence and purpose of the foundation underneath the proposed Conceptual Framework. More specifically, and as argued in chapter three, by addressing the matter of urban flooding adaptation through public space design, multiple advantages may arise from the complementarity amongst other comprehensive strategies supported by the municipality, such as “Pavimentar Lisboa 2015 - 2020” or “Uma Praça em cada Bairro” programms. Integrative opportunities, which further support the claim of the role of public spaces as the generators of urban form (Martin 2007). Overall, not only do the analysed documents related to Lisbon’s municipality emphasise the relevance of some of the categories and types of adaptation measures present in the proposed Conceptual Framework, but they also underline the importance of good quality public spaces in the city of the future.

When considering the most recent municipal climate change adaptation endeavours, one must mention the updated Drainage Master Plan envisioned for 2017-2030, as well as the involvement of the municipality in the recent research project ClimAdapt.Local (Santos et al. 2015). As explored in the previous chapter, the Drainage Master Plan 2017-2030 reinforces the convey strategy through the replacement of the previously proposed reservoirs with the construction of great deviation tunnels that lead pluvial waters from the upper drainage basins towards the river (see Figure 5.27 in chapter five). On the other hand, the recent

ClimAdapt.Local research project aims to develop the integration of municipal climate change adaptation strategies and measures that rather prioritize and bolster the source control strategy.

According to the latest disseminated findings form ClimAdapt.Local, such as the ones expressed within Lisbon's stakeholders' workshop, held on the 3rd of November 2015, "adaptation options" were ordered as the following: 1. Investigate cost-benefit ratio between the costs of preventing and repairing damage; 2. Promote the revision of regulations and the design of public space occupation and the placement of precarious structures; 3. Articulate climate change adaptation with municipal spatial planning plans (PMOT's); 4. Study the territory's aptitude for construction of cellars; 5. Ensure regular campaigns for the cleaning of gutters/sinks; 6. Increase the continuity of naturalized areas; 7. Implement autonomous rainwater retention and infiltration systems; 8. Study the effects of heat-wave upon the population; 9. Promote the passive energy efficiency in the rehabilitation of buildings; 10. Study storm surge events and tidal effects and their impacts.

As can be noted, regardless of a lingering partial understanding of the adaptation concept, efforts continue mainly in tackling the strategic level. With the exception regarding the so-called "hard engineering" measures, such as underground reservoirs, or deviation tunnels, what the presented Municipal undertakings have in common is their significant distance to the specification of concrete adaptation actions, namely concerning detailed implementation designs. Recalling upon the fact that the proposed Conceptual Framework is specifically targeted at supporting public space design processes with flood adaptation purposes, namely as it particularly considers operational measures, it can be considered as particularly useful in situations that need to move beyond strategic thinking and into concrete practical endeavours. Along the same line of reasoning, although one may evidence a gap between consolidated strategies and adaptation action specifically identified in the city of Lisbon, the Conceptual Framework can also be useful in other municipalities faced with similar constraints.

Besides promoting action in line with municipal goals for more adapted cities, the next lines will focus upon the question of whether the proposed framework can also provide the possibility to easily grasp an encompassing range of measures to be additionally considered. Although this assessment regarding the Conceptual Framework's capability will be particularly applied to the Lisbon case, the conceptual and general nature of its contents also make it potentially valuable for other urban situations faced with the need for flood adaptation.

6.1.2. Additional types of adaptation measures presented by the Conceptual Framework

As previously highlighted, the most significantly advocated strategy for flood adaptation in Lisbon's PDM (2012) refers to source control, that is, to the types of adaptation measures whose primary functions are Harvest, Store or Infiltrate. The preference for this strategy goes in line with the particular characteristics associated to Lisbon's floods, namely the meteorological and topographical predisposition to flash floods as exposed in the previous chapter.

Focusing uniquely upon the source control supported strategy, the recommended types of measures within Lisbon's PDM include: Green walls, Green roofs, Tree alignments, Bioretention basins, Cisterns, Underground reservoirs, Infiltration trenches, Leaky well and Permeable pavement, as identified in points 1, 2 and 3 of Table 6.2. When confronting these types with the types of measures highlighted in the Conceptual Framework, by having the primary strategies of Harvest, Store or Infiltrate, nine additional types of measures arise as potential solutions to be considered, namely: Inverted umbrellas, Art installations, Blue roofs, Water plazas, Cisterns, Bioswales, Bioretention planters, Rain gardens and Green gutters.

If further considering the measures entailing source control as a secondary strategy, a wider range of supplementary options arise as highlighted in grey in Figure 6.1. More specifically, types of measures such as: #28 "Floating platform" within the "Floating structures" category, which encompass Tolerate as the primary infrastructural strategy and Harvest as a secondary infrastructural strategy; #30 "Submergible parks" type of measure within the "Wet-proof" category, which encompass Tolerate as the primary infrastructural strategy and Harvest, Store, Infiltrate and Convey as secondary infrastructural strategies; or #34 "Multifunctional defence" type of measure within the "Coastal defences" category, which encompass Avoid as the primary infrastructural strategy and Tolerate, Harvest, Store and Infiltrate as secondary infrastructural strategies.

The following content of this chapter will specifically assess the applicability of some of the aforementioned additional alternatives that can be considered in the Lisbon case. It will further aim to prompt new discussions about municipal flood adaptation management and public space design.

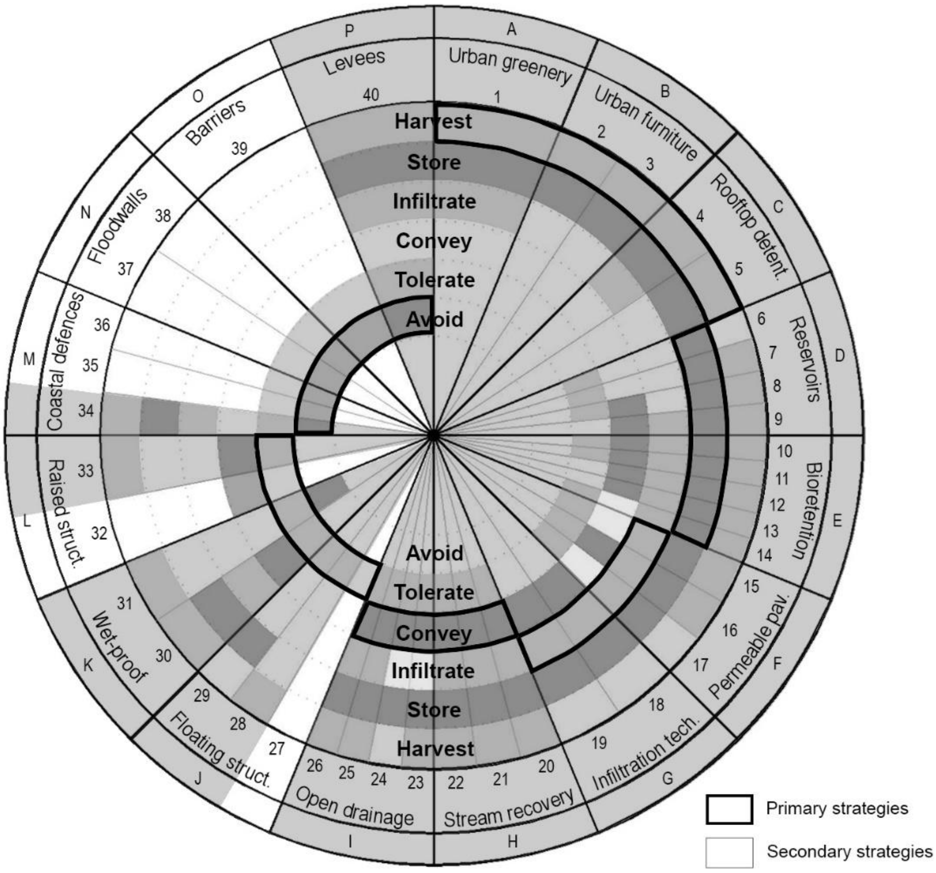


Figure 6.1 - Highlighted categories and types of measures within the proposed Conceptual Framework, which encompass the infrastructural strategies to Harvest, Store and Infiltrate floodwaters, i.e. source control strategies. Source: author's design.

Legend:
1.Green walls
2.Inverted umbrellas
3.Art installations
4.Green roofs
5.Blue roofs
6.Artificial detention basins
7.Water plazas
8.Underground reservoirs
9.Cisterns
10.Wet bioretention basins
11.Dry bioretention basins
12.Bioswales
13.Bioretention planters
14.Rain gardens
15.Open cell pavers
16.Interlocking pavers
17.Porous paving
18.Infiltration trenches
19.Green gutter
20.Stream rehabilitation
21.Stream restoration
22.Daylighting streams
23.Street channels
24.Extended channels
25.Enlarged canals
26.Check dams
27.Floating pathway
28.Floating platform
29.Floating islands
30.Submergible parks
31.Submergible pathways
32.Cantilevered pathways
33.Elevated promenades
34.Multifunctional defences
35.Breakwaters
36.Embankments
37.Sculptured walls
38.Glass walls
39.Demountable barriers
40.Gentle slope levees

6.2. Source control adaptation strategy applied in Alcântara Upper Basin

In order to assess the applicability of the aforementioned additional alternatives that can be considered in the Lisbon case, as well as their overall infrastructural significance, a particular representative area was chosen for subsequent analysis. The area corresponds to the "Alcântara Upper Basin" (AUB), topographically the highest half of the Alcântara valley that significantly contributes to the severe periodic downstream flooding. As displayed in Figure 6.2, it covers an area of almost 3.000ha. Even without considering the Lower Alcântara Basin, the UAB is still the biggest hydrographic basin affecting the city of Lisbon. The fact that the limits of UAB exceed the limits of Lisbon's Municipality, and also form part of Amadora's Municipality, is paradigmatic of the fact that the hydrological processes, and floods in particular, are self-determinant and know no institutionalized boundaries.

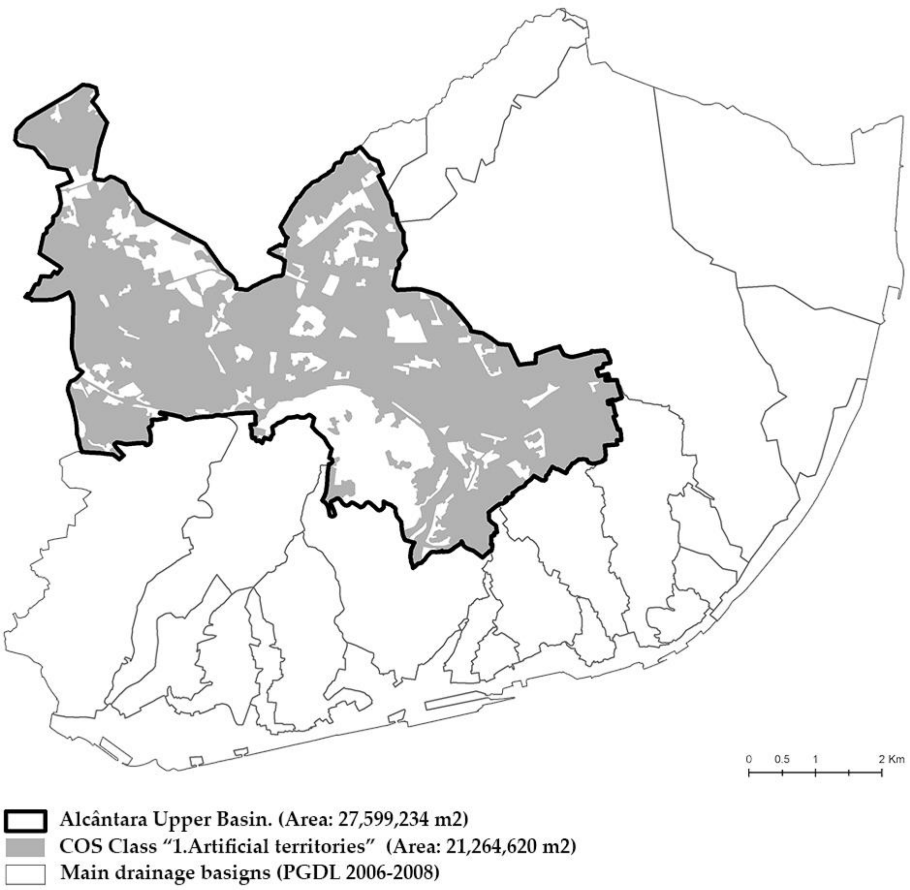


Figure 6.2 - Delimitation of the Alcântara Upper Basin (AUB) and respective identification of the Land Use Occupation class "1. Artificial territories". Source: COS 2007 combined by the author using GIS software ArcMap 10.1.

6.2.1. Estimate of potential areas for public space adaptation

Recalling that the principal focus of the presented research refers to the importance of public space design in climate change adaptation processes, the following lines are centred on the identification of the potential areas for public space flood adaptation within the AUB.

A deepened analysis is developed upon the most comprehensive available spatial data, which, in the case of Lisbon, corresponds to the "Land Use Map / Land Cover for Continental Portugal 2007" (COS 2007)[90], made available and free of charge in 2015 for investigation purposes. It is therefore specifically focused on the "ground plane of public spaces" (as in Brandão(Coord.) et al. 2002), which slightly reduces the potential area of intervention, yet contributes to the conservative nature of the developed estimate. For example, types of measures such as Green walls and Roofs will not be considered in the following analysis.

The nomenclature and structure of COS 2007 consists on a hierarchical system of occupation classes of land use that entails five levels of precision[91]. Once this analysis is focused upon urban territories, only the occupation class one, 1. "Artificial territories", was considered (Figure 6.2). In its most detailed level (level five), and specifically regarding the AUB area under study, occupation class number one (1. "Artificial territories") encompasses sixteen succeeding classes[92] (Table 6.3).

In the search for the potential areas for public space adaptation, i.e. impermeable public spaces that contribute to the overload of the sewerage and drainage system, the following two-stepped analysis has been developed: 1) firstly, the impermeable areas within each of the

---

[90] COS 2007 is based on the visual interpretation of aerial images with high spatial resolution and four spectral bands (blue, green, red and near infrared). The cartographic information of COS2007 is presented in vector format and has one hectare as the minimum unit.

[91] The more comprehensive level of precision (level 1) encompasses five occupation classes (1."Territórios artificializados" / "Artificial territories"; 2. "Áreas agrícolas e agro-florestais"/ "Agricultural and agro-forestry áreas"; 3. "Florestas e meios naturais e semi-naturais" / "Forests and natural and semi-natural areas; 4. "Zonas húmidas" / "Humid zones" and 5."Corpos de água" / "Water bodies".

[92] The sixteen classes under Occupation Class one, 1. "Artificial territories" include: 'Predominantly vertical continuous urban fabric' (1.1.1.01.1), 'Roads and associated spaces' (1.2.2.01.1), 'Public and private facilities' (1.2.1.04.1), 'Predominantly horizontal continuous urban fabric' (1.1.1.02.1), 'Industry' (1.2.1.01.1), 'Rail network and associated spaces' (1.2.2.02.1), 'Parking lot and courtyard areas' (1.1.1.03.1), 'Commerce' (1.2.1.02.1), 'Other sports facilities' (1.4.2.01.2), 'Areas in construction' (1.3.3.01.1), 'Parks and gardens' (1.4.1.01.1), 'Discontinuous urban fabric' (1.1.2.01.1), 'Abandoned areas in artificialized territories' (1.3.3.02.1), 'Cemeteries' (1.4.1.02.1), 'Cultural facilities and historic areas' (1.4.2.03.1) and Discontinuous sparse urban fabric (1.1.2.02.1)

sixteen identified COS sub-classes are identified; and 2) secondly, considering the COS sub-classes with higher percentages of impermeable areas, an estimation of the corresponding impermeable public space areas is developed.

The first analysis was developed through the use of GIS software ArcMap 10.1. Within the study area of AUB, land use occupation class "1.Artificial territories" (Figure 6.3) was "Intersected" with the area 100% impermeable as indicated in latest EEA soil sealing raster information (EEA 2013). This raster data includes a continuous degree of soil sealing ranging from 0 - 100% in an aggregated spatial resolution of 20 x 20 m. The specific value of being 100% impermeable was used for the development of this research, and not "over 80%" or "over 90%", in order to pursue the standards of a conservative analysis. Results are presented by Figure 6.4 and Table 6.3.

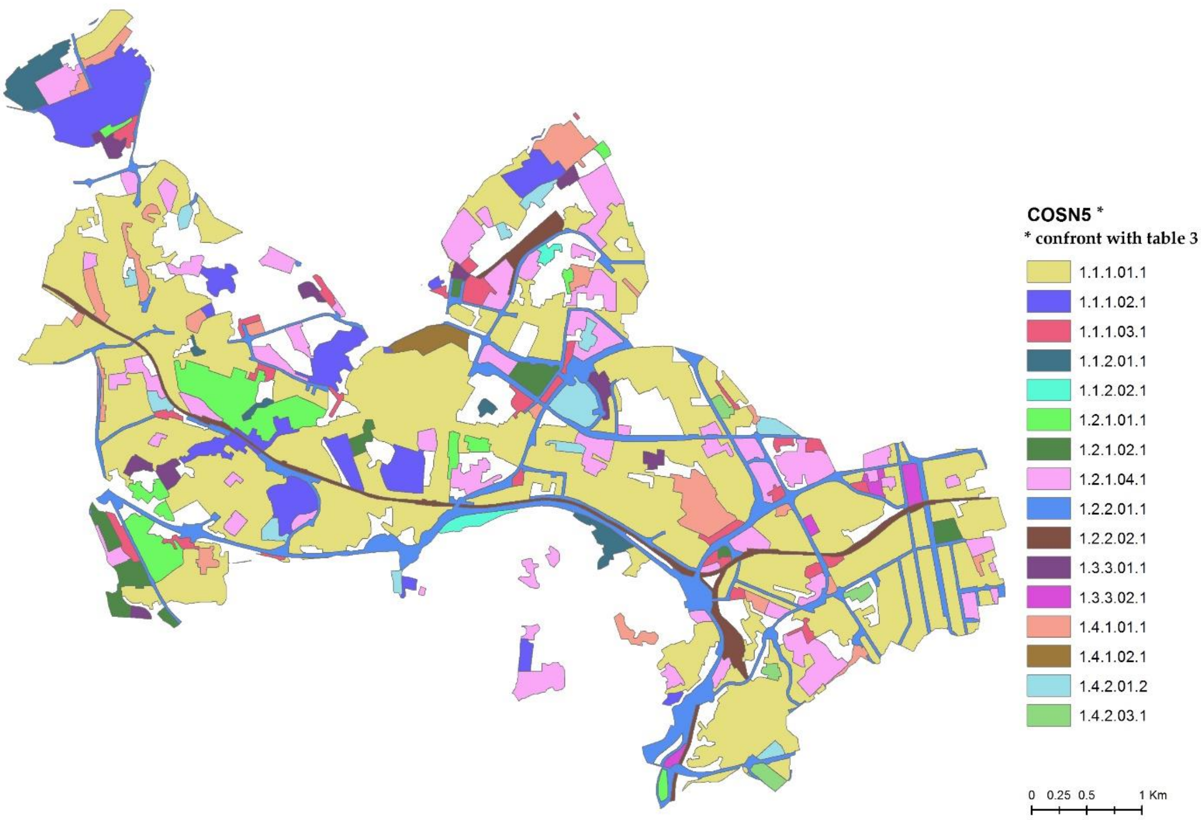


Figure 6.3 - Alcântara Upper Basin (AUB) Land Use Occupation class 1. "Artificial territories" and its corresponding sixteen succeeding classes. Source: (COS 2007) geographic information combined by the author using GIS software ArcMap 10.1.

Figure 6.4 – Area with 100% of soil sealing over Alcântara Upper Basin land use occupation classes Source: (EEA 2013) and (COS 2007) geographic information combined by the author using GIS software ArcMap 10.1.

Table 6.3 – Resulting areas form the "intersection" between "Artificial territories" land use occupation classes (COS 2007) and the area with 100% of soil sealing (EEA 2013), for the study area of Alcântara Upper Basin (AUB).

COS 2007			Soil Sealing EEA	
COS(N5)	**Description (English, author's translation)**	**Total area (m2)**	**Area 100% Impermeable (m2)**	**%**
1.1.1.01.1	Predominantly vertical continuous urban fabric	10,869,901.61	7,217,630.00	53.49%
1.2.2.01.1	Roads and associated spaces	2,309,890.69	1,519,023.00	11.26%
1.2.1.04.1	Public and private facilities	2,321,941.99	1,313,419.00	9.73%
1.1.1.02.1	Predominantly horizontal continuous urban fabric	1,395,900.20	853,389.00	6.32%
1.2.1.01.1	Industry	777,098.10	639,609.00	4.74%
1.2.2.02.1	Rail network and associated spaces	532,952.94	478,908.00	3.55%
1.1.1.03.1	Parking lot and courtyard areas	507,111.25	362,809.00	2.69%
1.2.1.02.1	Commerce	352,647.64	264,515.00	1.96%
1.4.2.01.2	Other sports facilities	407,243.30	224,606.00	1.66%
1.3.3.01.1	Areas in construction	264,533.38	194,699.00	1.44%

1.4.1.01.1	Parks and gardens	808,027.26	115,036.00	0.85%
1.1.2.01.1	Discontinuous urban fabric	293,741.14	98,838.00	0.73%
1.3.3.02.1	Abandoned areas in artificialized territories	110,107.04	95,584.00	0.71%
1.4.1.02.1	Cemeteries	116,858.47	57,287.00	0.42%
1.4.2.03.1	Cultural facilities and historic areas	113,161.32	53,476.00	0.40%
1.1.2.02.1	Discontinuous sparse urban fabric	83,503.35	4,395.00	0.03%
	Total areas (m2)	21,264,619.68	13,493,223.00	100.00%

Before the presented quantitative area results, only the seven COS sub-classes with greater impermeable rates were chosen for subsequent analysis (Table 6.3 – results over 2% are outlined in grey).

In order to estimate the potential areas for public space adaptation within each of the seven outlined COS sub-classes, three representative study areas for each sub-class are spatially outlined, analysed and compared. More specifically, for each of these outlined study areas, the percentage of impermeable public spaces was calculated through the subtraction of the areas of buildings, roads and rail-lines with the respectively identified 100% impermeable area.

The resulting comparison among the three representative areas for each of the six COS sub-classes, enabled the conservative generalisation arising out of the lowest identified percentage of impermeable public space. For example, for the COS sub-class 1.2.2.01.1 designated "Roads and associated spaces", the percentage of existing impermeable public space was calculated for the streets 1) Av. Berna, 2) Av. dos Combatentes and 3) Av. Dos Condes de Carnide. Results corresponded to 12.95%, 27.23% and 16.41% of impermeable public spaces, respectively. As such, 13% was used as the general percentage of impermeable public spaces for all COS sub-class 1.2.2.01.1 "Roads and associated spaces". In the same line of reasoning, for the COS sub-class 1.2.1.04.1 designated "Public and private facilities", the percentage of existing public space was calculated for three representative areas. Results corresponded to 81.41%, 69.04% and 71.60% of impermeable public spaces. In accordance, 69% was used to determine the overall impermeable public spaces within COS sub-class 1.2.1.04.1 "Public and private facilities".

The same methodology was applied for the remaining sub-classes, giving rise to the impermeable public space areas for each class or, in other words, the "Potential Area for Public Space Adaptation" (Table 6.4).

Table 6.4 – "Potential Area for Public Space Adaptation" within each analysed COS sub-class. Source: developed by the author.

COS 2007			Soil Sealing EEA	Potential Area for Public Space Adaptation (within area 100% impermeable)		
COS(N5)	**Description** (author's translation)	**Total area (m2)**	**Area 100% Impermeable (m2)**	**%**	**m2**	**% of the Total AUB area**
1.1.1.01.1	Predominantly vertical continuous urban fabric	10,869,901.61	7,217,630.00	63%	4,547,106.90	41.83%
1.2.2.01.1	Roads and associated spaces	2,309,890.69	1,519,023.00	13%	197,472.99	8.55%
1.2.1.04.1	Public and private facilities	2,321,941.99	1,313,419.00	69%	906,259.11	39.03%
1.1.1.02.1	Predominantly horizontal continuous urban fabric	1,395,900.20	853,389.00	73%	622,973.97	44.63%
1.2.1.01.1	Industry	777,098.10	639,609.00	0%	0.00	0.00%
1.2.2.02.1	Rail network and associated spaces	532,952.94	478,908.00	10%	47,890.80	8.99%
1.1.1.03.1	Parking lot and courtyard areas	507,111.25	362,809.00	95%	344,668.55	67.97%
	Total areas (m2)	18,714,796.78	12,384,787.00		6,666,372.32	35.62%

In light of the presented analysis, the land use sub-class "Parking lot and courtyard areas" (1.1.1.03.1) is where most opportunities rely for public space adaptation, in which 67.97% of its respective total analysed area (507,111.25 m3) is likely to be adequate for intervention.

Further significant opportunities for public space adaptation are evidenced in the land use classes of "Predominantly horizontal continuous urban fabric" (1.1.1.01.1), "Predominantly vertical continuous urban fabric" (1.1.1.01.1) and "Public and private facilities" (1.2.1.04.1), with a potential area for adaptation action of 44.63%, 41.83% and 39.03%, respectively. Comparatively, reduced opportunities can be noticed in the land use classes of "Roads and associated spaces" (1.2.2.01.1) and "Rail network and associated spaces" (1.2.2.02.1). Moreover there are seemingly null opportunities in areas occupied by Industry.

Overall, the 35.63% of total percentage of potential area for Public Space Adaptation in relation to the total analysed area (18,714,796.78 m2), is significant enough to be considered when analysing available assets and opportunities regarding flood adaptation action.

6.2.2. Illustrative designs and their infrastructural significance

In order to assess the infrastructural significance of some of the highlighted types of adaptation measures that entail source control strategies applicable in the "ground plane of public spaces" (as in Brandão(Coord.) et al. 2002), a basic premise was followed. This premise specifically consists on the capacity of the adaptation measures to retain a minimum of 25 mm height of rainfall from "first flush" [93] precipitation that falls over a given impermeable area. The choice to specifically retain 25 mm as the minimum value of height of rainfall to be retained by the source control adaptation measures applied in the city of Lisbon, is justified in Annex V. In part, this methodology is similar to the ones used in some American cities such as New York City within its "Green Infrastructure Plan", Philadelphia within its "Green Streets Program" or London within its "Drain London Programme" (see chapter two).

In the interest of verifying the applicability of the given premise in concrete situations within the city of Lisbon, and assess its infrastructural significance through quantifiable means, three preliminary study projects were developed. The first, in a residential area at Carnide; the second in a parking lot at Campolide and a third in part of the six-way street of Av. Ceuta (Figure 6.5).

These projects have included some of the additional measures previously identified as potentially adequate for the flood adaptation agenda of Lisbon's municipality. More specifically, bearing in mind their specific characteristics, namely as explored in chapter four, the flowing measures were considered: Bioretention planters, Bioswales with Check dams, Rain Gardens and Green Gutters (Figure 6.6). Other types of adaptation measures, with primary capacities for source control, could have been used, such as cisterns, art installations or water plazas (as presented in Figure 6.1). Most of which have the general characteristics of not being limited to the existence of large available unbuilt territories in order to justify their application, when compared to retention and infiltration basins or underground detention reservoirs. Indeed, the options that will be used in the next illustrative designs entail small yet expansive interventions, which are possible to apply in all urban territories, being it compact of disperse.

[93] First flush is the initial surface runoff of a rainstorm (see glossary for more details).

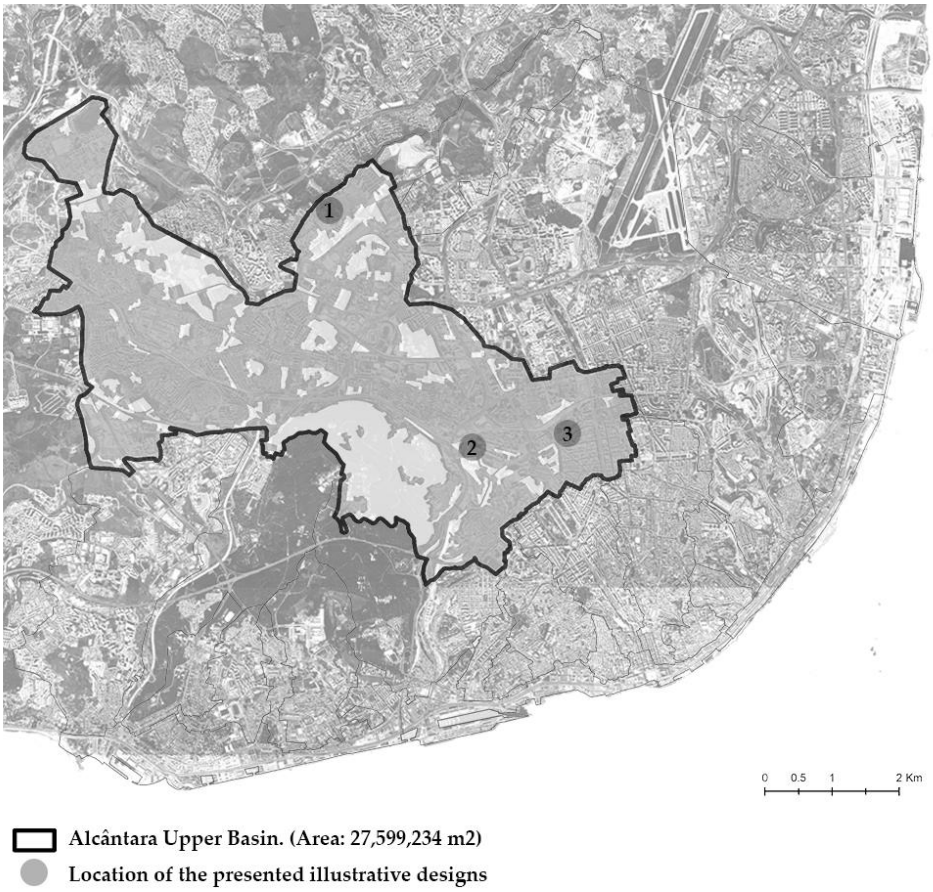


Figure 6.5 - Location of the presented illustrative designs: 1) Residential area at Carnide; 2) parking lot at Campolide and 3) part of the six-way street of Av. Ceuta. Source: spatial information combined by the author.

Figure 6.6 - Above left: Bioswale between a parking lot and a sidewalk. Image credits: © justsmartdesign, 2006.

Above right: Rain Garden filled with water. Image credits: Murdoch de Greeff, 2009.

Below left: Check dams made of wood. Image credits: Environment Oregon.

Below right: Green Gutter. Image credits: Philadelphia Green Streets Design Manual.

The first studied site consists on an impermeable tributary area of 4,581.43 m2 at a residential area of Carnide. In accordance with the mentioned premise, which expects the retention of the first 25 mm of stormwater that falls within this area, adaptation measures must specifically manage at least 114.54 m3 of stormwater. To this end, two types of adaptation measures are proposed: 1) Bioswales with Check dams and 2) Rain gardens.

The Bioswales with check dams are designed longitudinally along both sides of the sloped street, between the parking area and the sidewalk. Each bioswales are expected to have the same length as the parking area, which is around 18m; and a width of around 3m. In order to maintain the material character of the existing streetscape, which is essentially composed by traditional Portuguese limestone paving, and concrete curbs and boundaries, check dams are projected as small limestone barriers with a length of approximately 3m and a depth of 0.5m (Figure 6.7). No other additional peripheral boundaries are projected for this measure. Moreover, in order to promote water purification and infiltration, and to avoid mosquitos breeding, it is further envisioned for these bioswales with check dams to be composed by appropriate native vegetation. More specifically, small bushes and grasses such as *Eleocharis palustris* (L.) R.S., *Sparganium erectum* L. or *Polypogon monspeliensis* (L.) Desf. Lastly, the bioswales with check dams are designed to comprise a soil layer with 0.3m depth and a storage layer with 0.2m. In accordance with the expected storage capacity volume of each layer[94] and a standardized infiltration rate[95], it is estimated for the total storage capacity of this measure to be 42.49m3 (Preliminary design 1, p.382).

Rain gardens are projected to be implemented in the underused sidewalk areas derived from the roadway crossing (Figure 6.8). Each rain garden, with an approximate area of 45m2, will have a concave shape. Its central point will be 0.7 m below the level of the sidewalk and it will comprise a borderline boundary made out of concrete curbs. The curbs will be individually spaced apart in the borders that collect stormwater in order to enable water flows into the Rain garden. The proposed curbs will also be slightly elevated in order to serve as a physical trespassing impediment for cars and people.

Envisioned to fulfil high rates of rainwater absorption, the projected Rain gardens are to be planted with deep-rooted filtrating shrubs, perennials and trees. More specifically, vegetation such as *Alisma plantago-aquatica* L., *Schoenus nigricans* L., *S. fluitans* L., *Iris pseudacorus* L. or *Typha latifolia* L. (Figure 6.9). The soil layer of the Rain gardens will have a depth of 0.4m

[94] The storage capacity volume of each layer corresponds to the available void space of the corresponding material used; usually it is considered 15-25% for Soil; 33-50% for broken stone and 33-50% for pervious concrete (Green Streets Program, Philadelphia).

[95] If unknown, the infiltration rate of existing soil may be considered to be 0.508 cm/hr (Green Streets Program, Philadelphia).

and the storage layer a depth of 0.5m. In accordance, is estimated for the total storage capacity of this measure to be 76.71 m3.

By adding the two "Partial Stormwater Volumes Managed" (42.49m3 + 76.71 m3) it is possible to estimate the "Total of Stormwater Volumes Managed" in this area of intervention, which is 119.20m3. In other words, through an intervention in solely 9% of the total impermeable area, it is possible to manage 119.20 m3 of first flush stormwater volumes. As this sum of managed volumes of stormwater is greater than the expected retention of the first 25 mm of stormwater volume falling over the selected impermeable area of intervention, i.e. greater that 114.54 m3, the designed intervention fulfils the proposed objective (Preliminary design 1, p.382).

Figure 6.7 - 3d sketches of the proposed check dams measure (and likely stormwater flow directions) to be implemented in a residential area at Carnide, namely at Rua Professor Pais da Silva. Source: Author's skecth.

Figure 6.8 - 3d sketches of the proposed Rain gardens (and likely stormwater flow directions) to be implemented in a residential area at Carnide, namely at the intersection of Rua Professor Pais da Silva with Rua Professor Almeida Lima. Source: Author's skecth.

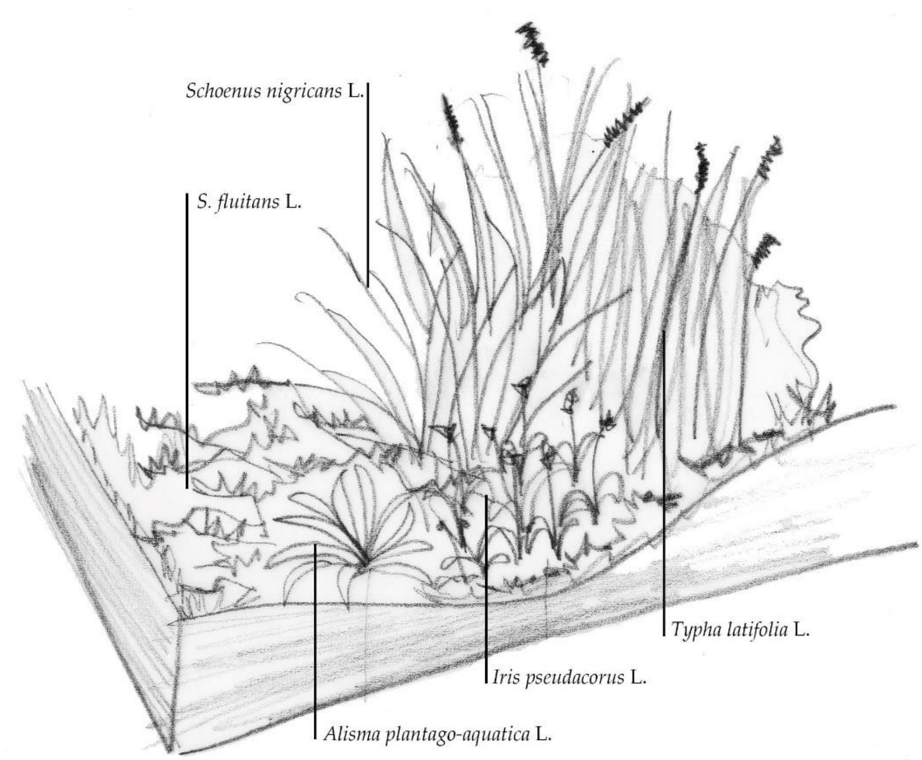


Figure 6.9 - Planting scheme for the proposed Rain garden. Source: Author's skecth.

The second studied site encompasses a parking lot in Campolide with a total impermeable area of 2,456.41 m2. In light of the aforementioned premise, in this situation, the goal consists on managing at least 61.41 m3 of stormwater volume. For this purpose, Bioretention planters are proposed in approximately half of the parking lot perimeter limit (Preliminary design 2, p.383), in a total area of 225.71 m2.

Figure 6.10 - 3d sketches of the proposed Bioretention planters (and likely stormwater flow directions) to be implemented in a parking lot at Campolide, namely by the lower end fo Rua de Campolide. Source: Author's skecth.

The proposed Bioretention planters are vegetated depressed planters, whose ground base is approximately 0.4 m below the pre-existing street-level. The proposed Bioretention planters are surrounded by two different types of boundaries. When facing the parking lot and the car road, Bioretention planters will be bordered by a permeable curb, i.e. by individual curbs linearly spaced apart, which allows stormwater to enter into the planter and serves as a physical obstacle (Figure 6.10). When facing the sidewalk, a metal barrier is proposed in order to avoid occasional stumble into its lower sunken area. Moreover, these planters are composed by native small bushes and grasses or even threes, in order to facilitate water storage and filtration and infiltration processes. These species may include *Scipus lacustris* L., *Equisetum ramosissimum* Desf., *Polygonum hydropiper* L. or *Peucedanum lancifolium H. L. ex L.*. It is also proposed for the soil layer to have 0.45m of depth and the storage layer to be 0.25m in depth. In accordance, it is estimated that these measures are able to manage at least 62.78 m3 volume of stormwater. The abovementioned proposed goal, to manage 61.41 m3 volume from first flush storm waters in this site, is thus accomplished by an intervention in solely 9% of the total impermeable area (Preliminary design 2, p.383).

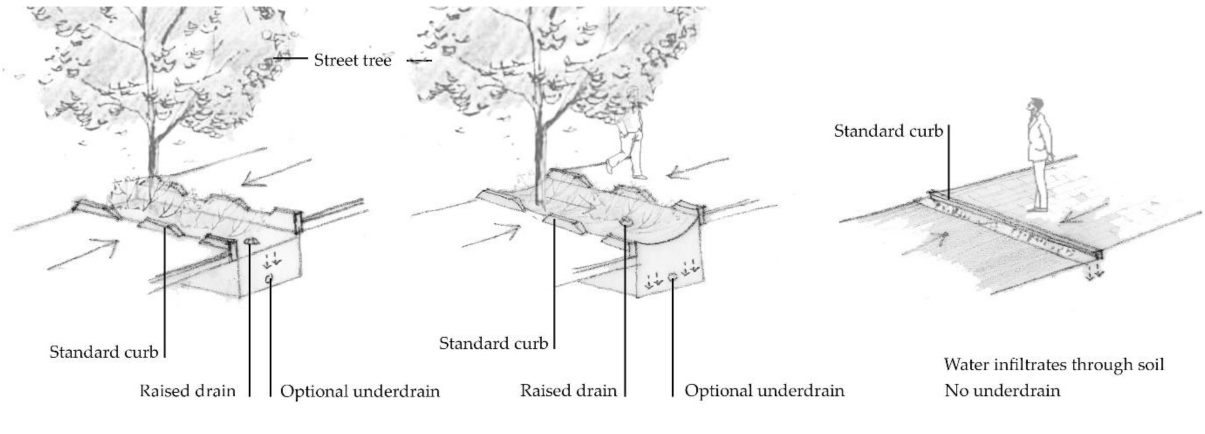


Figure 6.11 - Sketches comparing the different proposed measures of Bioretention planters, Bioswales and Green gutters. Source: Author's skecth.

The third area considered here corresponds to part of the six-way street of Av. de Berna and comprises an impermeable area of 5,123.34 m2. In line with the initially presented premise, the goal therefore corresponds to the retention of at least 128.08 m3 of stormwater volume. In order to fulfil this objective, two types of adaptation measures are proposed: 1) Bioswales and 2) Green gutters (Preliminary design 3, p.384).

Bioswales are designed over the pre-existing central road spacer with an approximate width of 2m. They are formed by a longitudinal depression designed to collect, convey and infiltrate runoff. This depressed linear channel is also bounded by concrete curbs individually spaced apart, so that stormwater can flow into them, and slightly elevated from the street level for safety purposes (Figure 6.11). In the proposed intervention the existing trees *Tipuana tipu*, already carrying a significant size, are to be maintained. Yet it is proposed the additional plantation of native vegetation such as the following small bushes and grasses: *Galium palustre* L., *Rumex conglomeratus* M., *S. fluitans* L., *Ranunculus repens* L. or *Juncus inflexus* subsp. *Inflexus.* These bioswales are specifically designed to enable the stormwater management of 119,78 m3 volume, comprising a soil layer of 0.5m of depth and a storage layer with 0.65m.

Green gutters, which consist on a thin shallow landscaped strip, are proposed to be implemented between the sidewalk and the parking area, at the North side of the road. Besides providing a tenuous physical separation between pedestrians and cars, this measure is envisioned to manage stormwater runoff mostly through the process of infiltration (Figure 6.12). It is therefore projected to be additionally composed by native grasses such as *Antinoria agrostidea* (DC.) Parl.. Moreover, in this case, and unlike the previously proposed measures, an underdrain connected to the existing drainage system is unrequired. Overall, this measure is expected to manage 11.52 m3 of stormwater volume, comprising a soil layer and storage layer of 0.45m of depth each.

When adding the two “Partial Stormwater Volumes Managed” (119,78m3 + 11.52 m3) it is possible to estimate the “Total of Stormwater Volumes Managed” for this area of intervention, which corresponds to 131.30 m3. In other words, through an intervention in solely 5% of the total impermeable area, it is possible to fulfil the above-mentioned goal to manage at least 128.08 m3 of stormwater volume from first flush (Preliminary design 3, p.384).

Figure 6.12 - 3d sketches of the proposed Bioswale and Green gutter (and likely stormwater flow directions) to be implemented in Av. de Ceuta street. Source: Author’s skecth.

With the exception of the Green gutters, all proposed types of measures are connected to the existing drainage network so that overflows are managed. In accordance, all of these measures are additionally composed by a raised drain that leads overflows into the sewerage system (Figure 6.13 and Figure 6.14). In situations where a separate sewerage system is established, measures may further entail perforated pile lines along the bioretention layers which conduct the excesses of filtered stormwater into the pluvial drainage outflows.

Moreover, all types of proposed measures are inadequate to be placed adjacent to buildings in order not to deteriorate their foundations, namely by the permanent or temporary belowground water and humidity excesses.

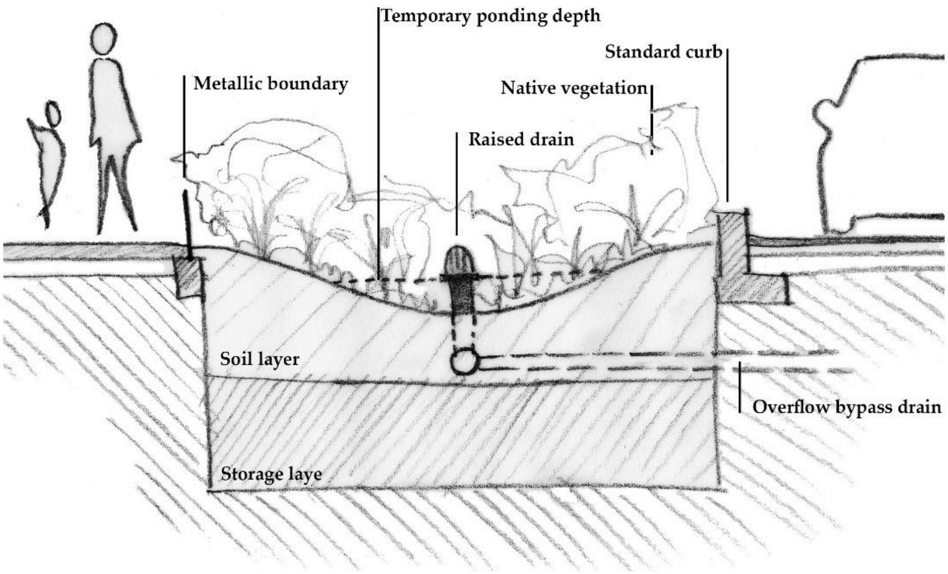
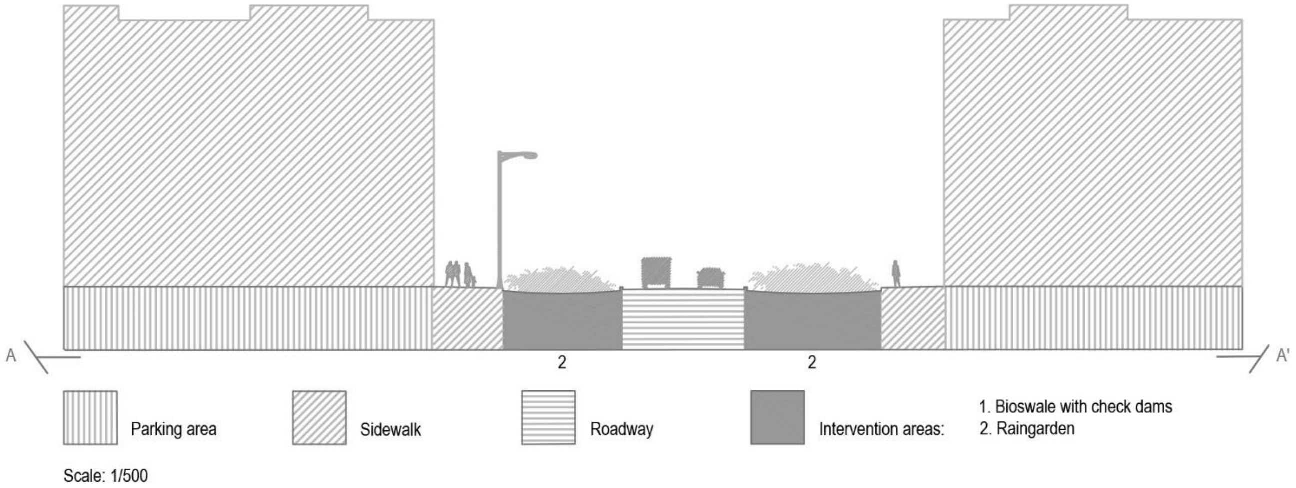
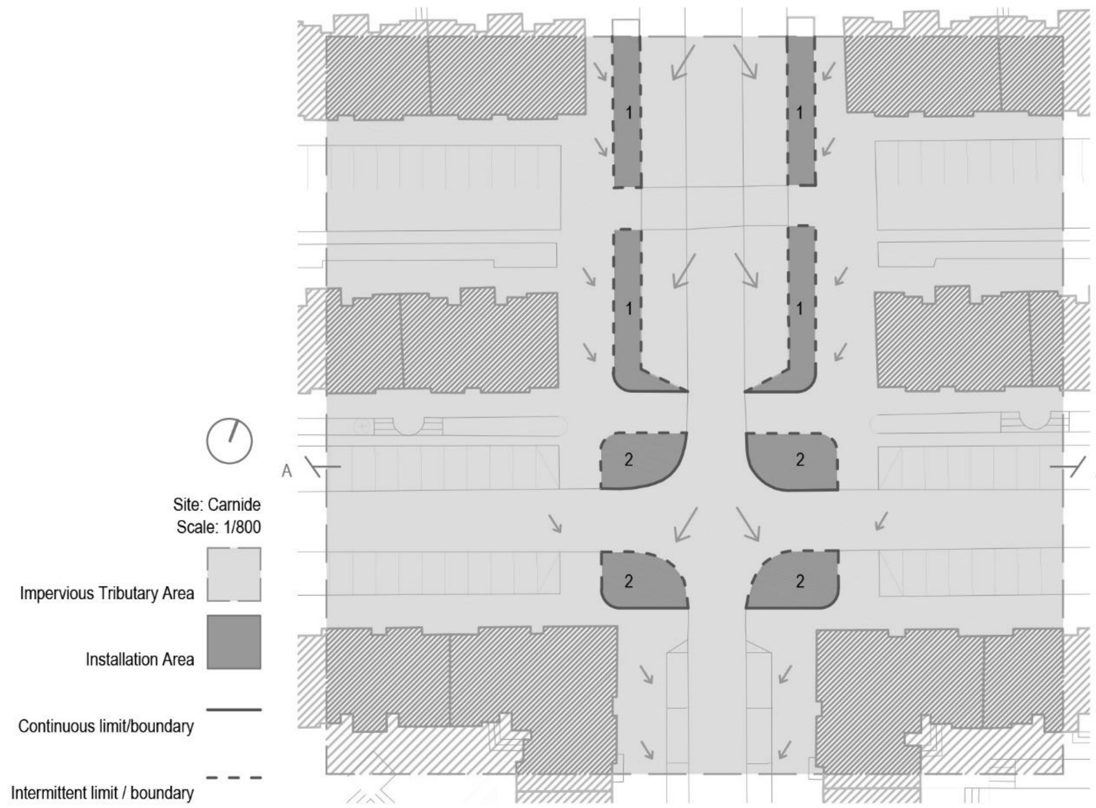


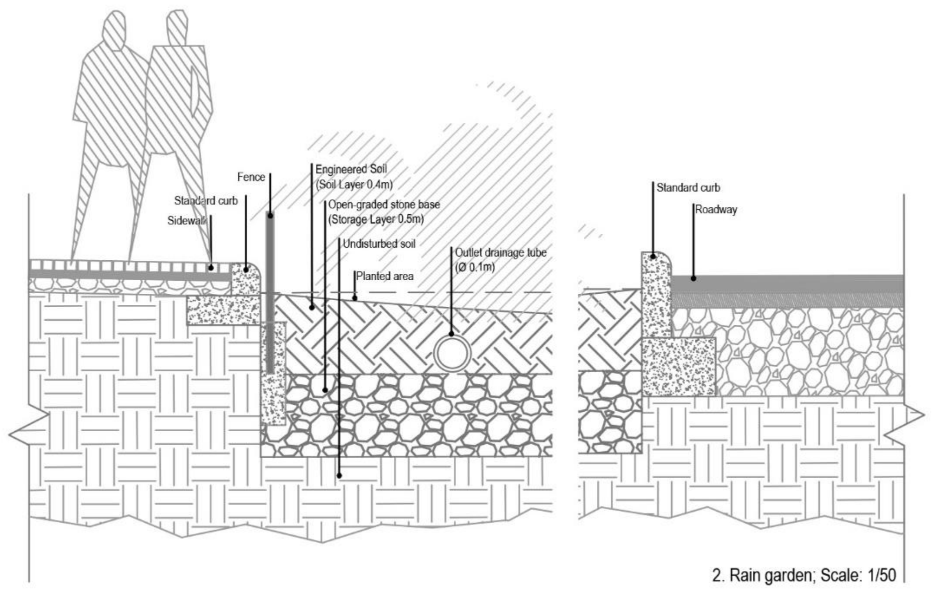
Figure 6.13 - Sketch of a raised drain implemented in a Bioswale. It consists on an overflow/bypass drain that manages occasional exceeding stormwater. Source: Author's skecth.

Figure 6.14 - Two examples of implemented raised drains. Left: Image credits: © Scott Murdoch, www.mdidesign.ca; Right: Image credits: © Aaron Volkening, 2015.

Besides the presented ideas, other projects, with additional or alternative types of measures, could have been proposed for the same areas. Indeed, the three developed preliminary studies serve the primary purpose to exemplify and illustrate how the proposed types of adaptation measures can be applied in specific situations within the city of Lisbon. They are not considered as sole solutions. For example, in the first project, green roofs could be proposed for the surrounding buildings. The collected stormwater, initially filtered by the Green roof, could be further directed into Cisterns that would water the Bioswales and the Rain gardens in the dry periods or simple serve to wash the streets. In the second project, the parking lot pavement could be additionally replaced by a permeable pavement, which would increase the amount of total stormwater volume managed. With regard to the third proposed design, although the sidewalk on the South side of the road has a smaller width, for instance green gutters could also be here implemented.



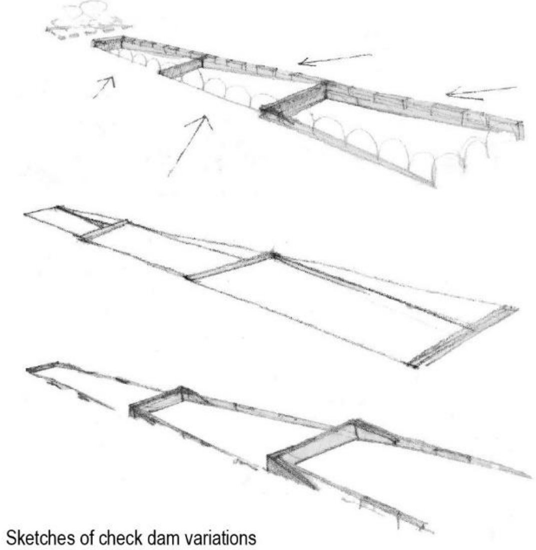




2. Rain garden; Scale: 1/50

Worksheet for the calculation of managed stormwater volume:

Implementation Area		
"Impervious Tributary Area" (m2)	4,581.428	
0.025m stormwater Volume (m3)	114.536	
Stormwater Volume Managed		
	Bioswale with check dams (0.3+0.2)	Rain Garden (0.4+0.5)
Installation Geometry		
Installation Volume (m3)	147.771	176.735
Installation Area (m2)	197.028	196.372
Infiltration Data		
Infiltration Design Rate (cm/hr)	0.508	0.508
Infiltration Period (hr.)	8	8
Estimate Infiltration Volume (m3)	8.007	7.981
Soil Layer		
Volume of Soil (m3)	59.108	78.549
Porosity of Soil (%)	25%	25%
Storage Volume of Planting Soil	14.777	19.637
Storage Layer		
Volume of Storage Layer (m3)	39.406	98.186
Porosity of Storage Layer (%)	50%	50%
Storage Volume of Drainage Layer (m3)	19.703	49.093
Partial Stormwater Volume Managed	**42.487**	**76.711**
Estimated Total of Stormwater Volume Managed	**119.198**	



Sketches of check dam variations

Options amongst herbaceous and shrub species from the Portuguese riparian vegetation.

Images source: Flora-on web database

Rain Garden | **Bioswales with check dams**

Alisma p-aquatica L.

Eleocharis palustris

S. fluitans L.

Sparganium erectum L.

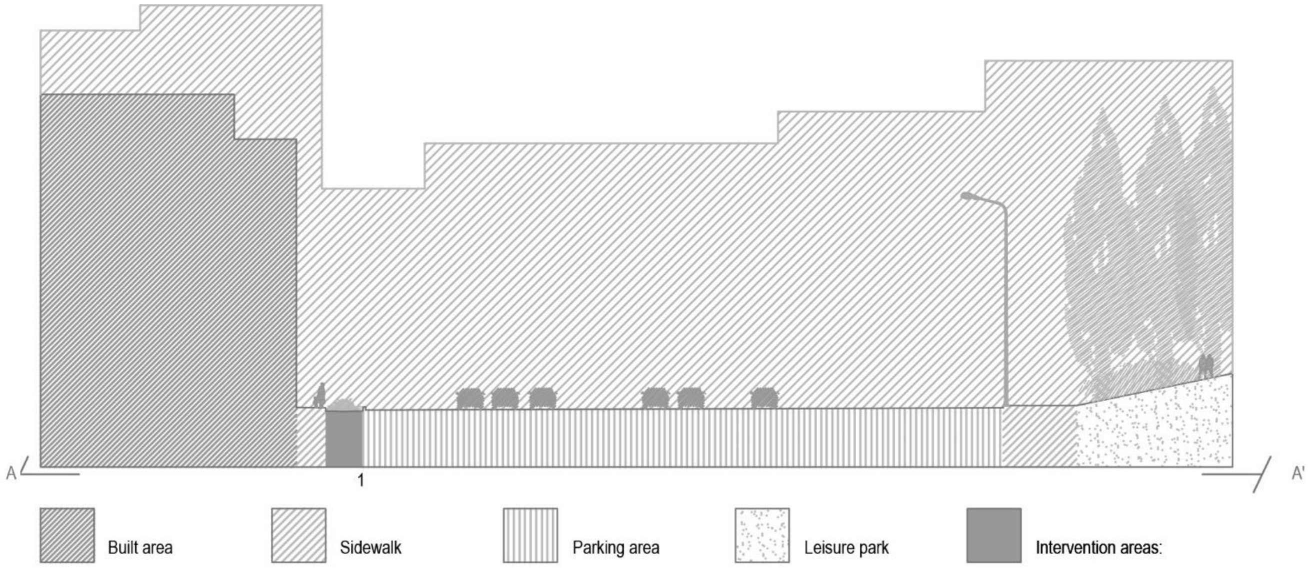
Schoenus nigricans L.

Polypogon monspeliensis

Iris pseudacorus L.

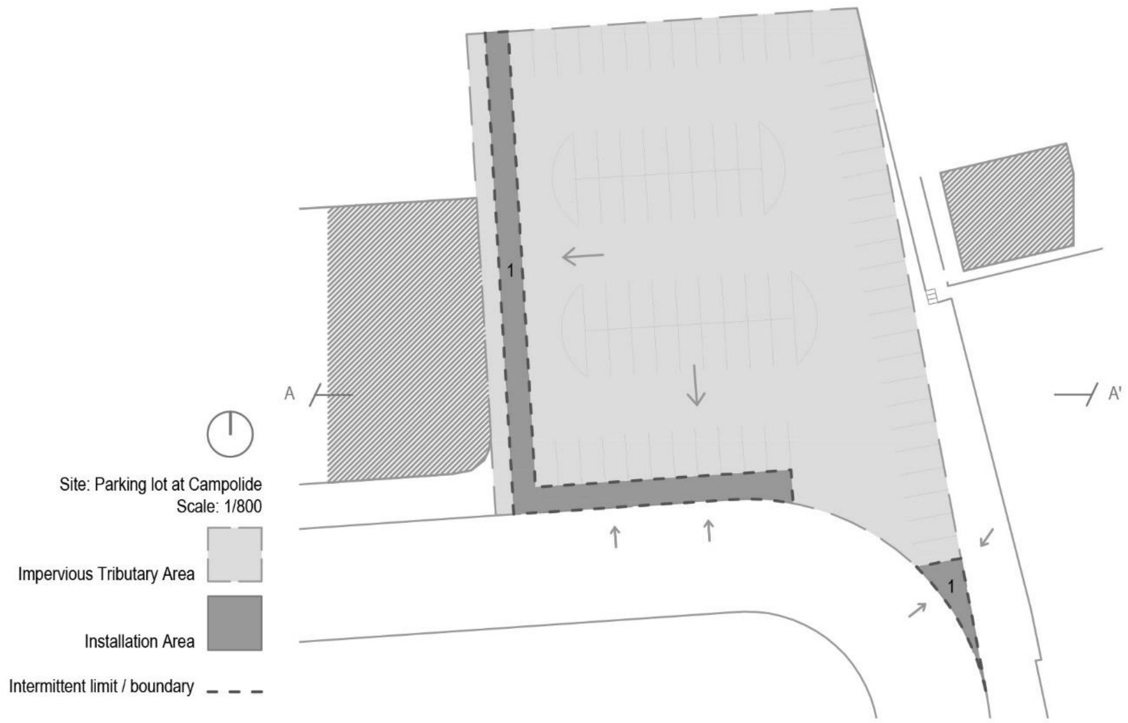
Typha latifolia L.

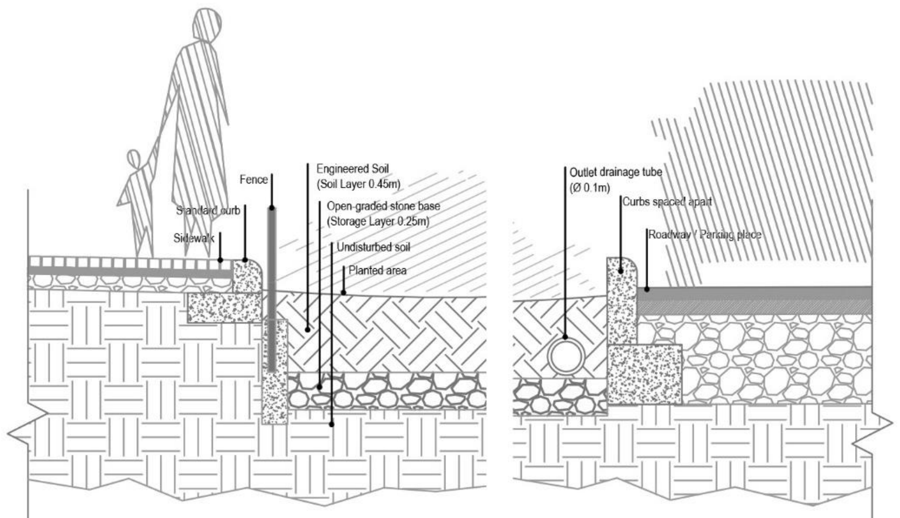
Preliminary design 1
for the installation of flood adaptation measures in a residential area at Carnide



Scale: 1/500

1. Bioretention planters

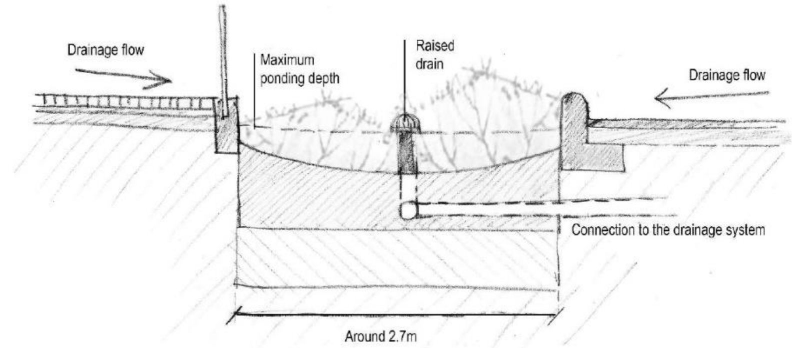




Bioretention planter; Scale: 1/50

Worksheet for the calculation of managed stormwater volume:

Implementation Area	
"Impervious Tributary Area" (m2)	2,456.409
0.025m stormwater Volume (m3)	61.410
Stormwater Volume Managed	Bioretention Planters (0.45+0.25)
Installation Geometry	
Installation Volume (m3)	158.000
Installation Area (m2)	225.715
Infiltration Data	
Infiltration Design Rate (cm/hr)	0.508
Infiltration Period (hr.)	8
Estimate Infiltration Volume (m3)	9.173
Soil Layer	
Volume of Soil (m3)	101.572
Porosity of Soil (%)	25%
Storage Volume of Planting Soil	25.393
Storage Layer	
Volume of Storage Layer (m3)	56.429
Porosity of Storage Layer (%)	50%
Storage Volume of Drainage Layer (m3)	28.214
Partial Stormwater Volume Managed	
Estimated Total of Stormwater Volume Managed	**62.780**



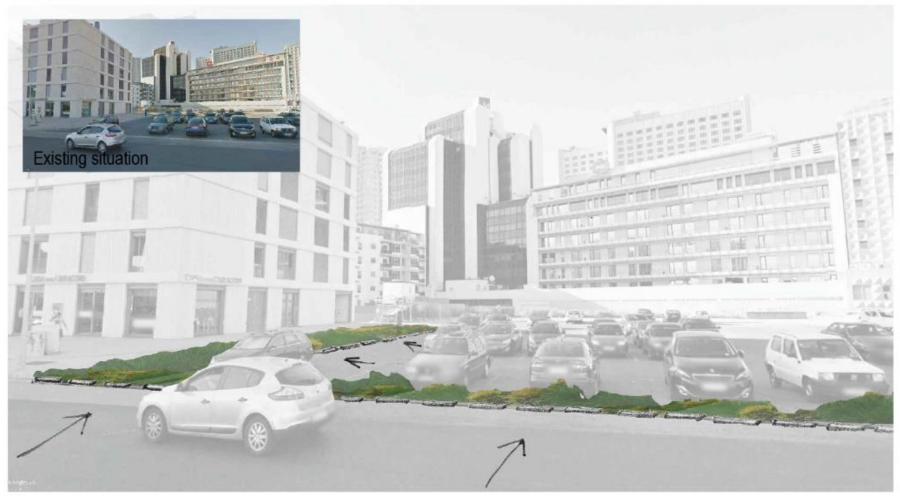
Overflow catchment sketch for the bioswale.

Approximate dimensions, stormwater flow directions and proposed boundaries.

Elevated drain for the overflow catchment system

The following type or similar: RD-300 High Volume Roof Drain (wwatts - water and technology).

Description: Watts Drainage RD-300 epoxy coated cast iron roof drain with flashing clamp with integral gravel stop, self-locking polyethylene dome (standard), and no hub (standard) outlet.



Options amongst herbaceous and shrub species from the Portuguese riparian vegetation.

Images source: Flora-on web database

Bioretention planter

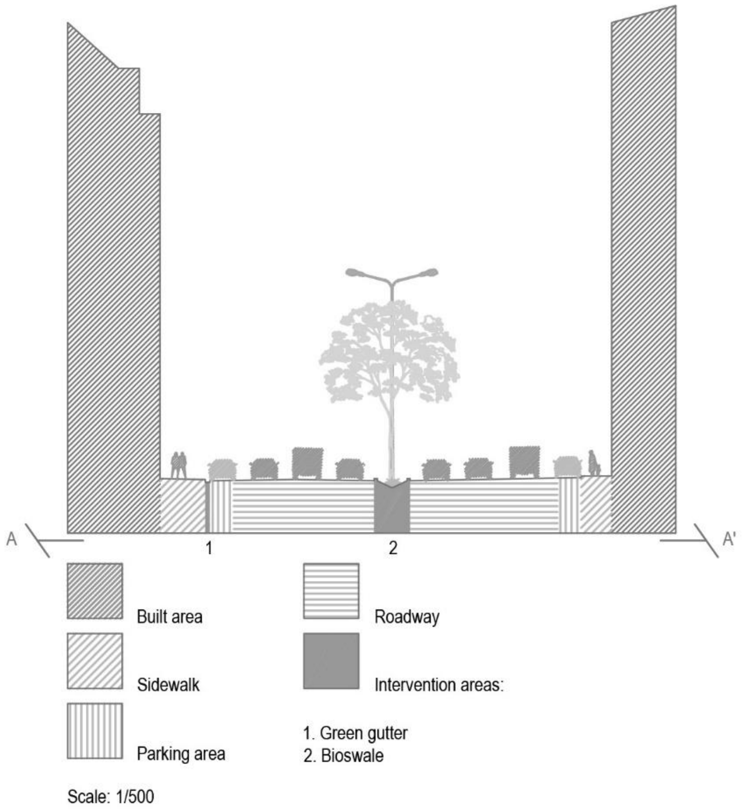
Scipus lacustris L.

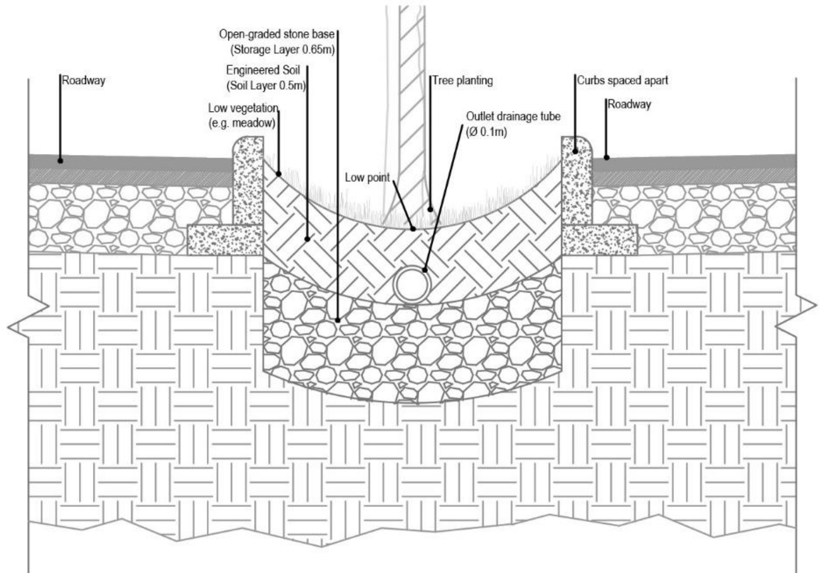
Equisetum ramosissimum

Polygonum hydropiper L.

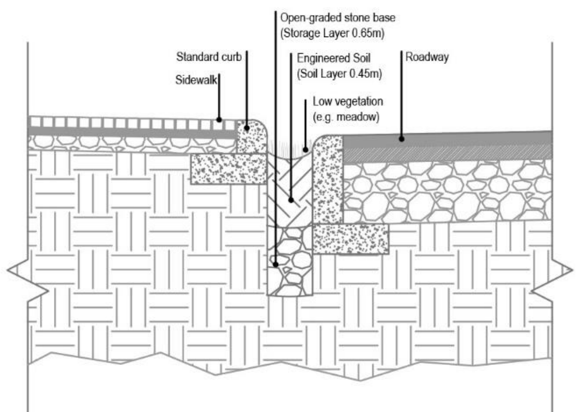
Peucedanum lancifolium

Preliminary design 2
for the installation of flood adaptation measures in a parking lot at Campolide

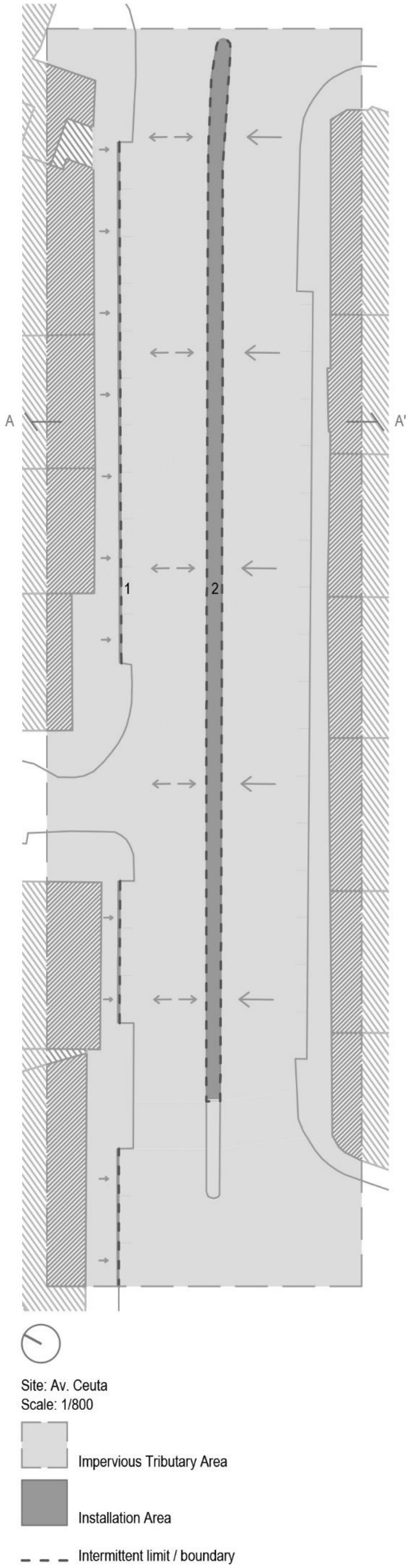




2. Bioswale; Scale: 1/50

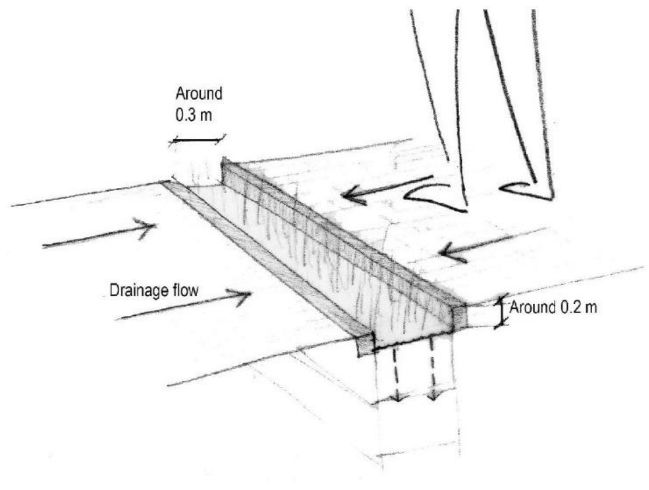


1. Green gutter; Scale: 1/50



Worksheet for the calculation of managed stormwater volume:

Implementation Area		
"Impervious Tributary Area" (m2)	5,123.335	
0.025m stormwater Volume (m3)	128.083	
Stormwater Volume Managed	Bioswales (0.5+0.65)	Green gutters (0.45+0.45)
Installation Geometry		
Installation Volume (m3)	280.756	27.418
Installation Area (m2)	244.136	30.464
Infiltration Data		
Infiltration Design Rate (cm/hr)	0.508	0.508
Infiltration Period (hr.)	8	8
Estimate Infiltration Volume (m3)	9.922	1.238
Soil Layer		
Volume of Soil (m3)	122.068	13.709
Porosity of Soil (%)	25%	25%
Storage Volume of Planting Soil	30.517	3.427
Storage Layer		
Volume of Storage Layer (m3)	158.688	13.709
Porosity of Storage Layer (%)	50%	50%
Storage Volume of Drainage Layer (m3)	79.344	6.854
Partial Stormwater Volume Managed	**119.783**	**11.520**
Estimated Total of Stormwater Volume Managed	**131.302**	



Sketch of the green gutter.

Approximate dimensions and ideal stormwater flow directions.

Options amongst herbaceous and shrub species from the Portuguese riparian vegetation.

Images source: Flora-on web database

Bioswales | Green gutter

Galium palustre L.

Antinoria agrostidea

Rumex conglomeratus M.

Ranunculus repens L.

Juncus inflexus subsp. Inflexus

Preliminary design 3
for the installation of flood adaptation measures the street Av. Ceuta

6.2.3. Projected scenarios for flood adaptation through public space retrofits

Expansive, yes. Expensive, no.

Advertising slogan of "The Economist",
www.economist.com, 2015.

When transposing the previously tested premise - to manage the first 25 mm of stormwater falling over a given impermeable area - into the entire study area of AUB, it is possible to evidence how a spatially and timely extensive approach of small scaled and conservative public space retrofits may have a considerable impact in urban flood adaptation undertakings.

More specifically, looming into the whole AUB area, if interventions are focused in solely 5% of all its impermeable public spaces, it is estimated the management of around 8,000.00 m3 of stormwater *in loco*, i.e. a total volume that does not enter in the sewerage system, and therefore does contribute to its overload. In the same line of reasoning, and as advanced by Table 6.5, if interventions are applied to 15% of the existing impermeable public spaces, the volume of stormwater managed would be circa 24,500.00 m3. Furthermore, if interventions are applied to 25% of the existing impermeable public spaces, the volume of stormwater managed would be around 41,500.00 m3

Yet bearing in mind the known pressures and limitations of any urban system, such as Lisbon, the opportunity for a widespread implementation of these measures may only arise within a strategic approach that encompasses an extended timeframe. More specifically, the proposed types of measures must not only be extensively implemented along public space retrofits throughout the city, but must also be implemented throughout and extensively within a timeframe. In accordance, different scenarios were developed for the next 20, 50 and 100 years. The first 20 years were divided in four periods of 5 years and the next stages encompassed a period of 30 years (reaching the timeframe of 50 years from 2017) and a period of 50 years (reaching the timeframe of 100 years from 2017) (Table 6.5 – Annex VI encompasses a comprehensive version of this table).

In light of the different proposed timeframes, different percentages for public space adaptation retrofits were proposed for each range of years. The proposed scenarios maintained the widespread conservative approach in this exercise. For example, in developed scenarios for the next 20 years (2017-2037) it is envisioned as a possibility to retrofit 15% of the potential areas for public space adaptation, i.e. retrofits in 15% of impermeable public spaces within each analysed COS class. This scenario is further divided in four periods of 5 years, each entailing a percentage of impermeable public space adaptation of 2%, 3%, 5% and 5%. For the subsequent 30 years (2017-2067) it is projected that adaptation measures can be applied in more than 10% of the potential area for intervention. In the following 50 years (2017-2117) it is projected that adaptation measures can be applied in more than 20% of the potential areas for intervention. Considering the entire time-lapse for the next 100 years, from 2017 to 2117, little by little, small interventions after small interventions entailed within a bigger strategy, it can be possible to retrofit and adapt 45% of the existing impermeable public spaces.

Moreover, one must bear in mind that the percentage of adapted area does not correspond to the actual area of intervention, where adaptation measures are applied. More specifically, in order to fulfil the premise to manage the first 25 mm of stormwater, the previous illustrative designs implied public space retrofits of around 9% of the total area under analysis. Recalling upon this fact, when adapting 45% of AUB impermeable tributary public spaces, only 9% of this area is expected to entail the concrete application of adaptation measures. In other words, as illustrated in Figure 6.15, implemented adaptation measures may cover 45% of an impermeable area by being merely implementing in 9% of the same area.

Considering the infrastructural source control significance of each aforementioned scenarios, if adapting 5% of the impermeable public spaces of AUB, a minimum of 8,161.92 m3 of stormwater volume can be managed (Table 6.5). If 45% of potential impermeable public spaces are adapted, around 75,000.00 m3 of stormwater volume can be managed. Just like a very small mosquito may seem harmless and unimpressive, when provided with specific circumstances it may lead to a significant impact[96]. This impact is further increased when combining every potential episode, every small piece, in a wider mosaic. Likewise, while adapting only 5% of impermeable public spaces may apparently provide insignificant outcomes, if adapting 5% extensively along impermeable public space tributary areas and throughout an extended timeframe, important achievements can be accomplished in the process of urban flood adaptation.

[96] "If you think you are too small to have an impact, try going to bed with a mosquito in the room" Anita Roddick (1942-2007, best known as the founder of "The Body Shop" company)

Table 6.5 - Projected scenarios for flood adaptation through public space retrofits, along 20, 50 and 100 years. Source: Developed by the author.

Projected scenarios for flood adaptation through public space retrofits

COS 2007 Description (author's translation)	2017 -2022 (5 yrs.)		2022 - 2027 (5 yrs.)		2027 - 2032 (5 yrs.)		2032 - 2037 (5 yrs.)		2037 -2067 (30 yrs.)		2067 - 2117 (50 yrs.)	
	Impermeable Public Space Area to be adapted											
	%	m2	%	m2	%	m2	%	m2	%	m2	%	m2
Predominantly vertical continuous urban fabric	2	90942.138	3	136413.207	5	227355.345	5	227355.345	10	454710.69	20	909421.38
Roads and associated spaces	2	3949.4598	2	3949.4598	5	9873.6495	3	5924.1897	9	17772.569	20	39494.598
Public and private facilities	2	18125.1822	3	27187.7733	5	45312.9555	5	45312.9555	9	81563.32	20	181251.822
Predominantly horizontal continuous urban fabric	1	6229.7397	1	6229.7397	1	6229.7397	2	12459.4794	8	49837.918	15	93446.0955
Industry	-	-	-	-	-	-	-	-	-	-	-	-
Rail network and associated spaces	1	478.908	1	478.908	1	478.908	2	957.816	5	2394.54	15	7183.62
Parking lot and courtyard areas	5	17233.4275	5	17233.4275	10	34466.855	10	34466.855	15	51700.283	30	103400.565
Total areas (m2)		136958.8552		191492.5153		323717.4527		326476.6406		657979.3191		1334198.081
% of Impermeable Public Space Area to be adapted		2%		3%		5%		5%		10%		20%
Minimum stored volume* (m3)		3423.97138		4787.31288		8092.936318		8161.91602		16449.483		33354.952
		2%		**5%**		**10%**		**15%**		**25%**		**45%**
Minimum accumulated stored volume*(m3)		**3423.97138**		**8211.28426**		**16304.22058**		**24466.1366**		**40915.62**		**74270.5716**
Accumulated impermeable Public Space Adaptation area (m2)		136958.8552		328451.371		652168.8232		978645.464		1636624.8		2970822.86
								Along 20 years		Along 50 years		Along 100 years

Notes:

*Design must manage at least 25mm of stormwater runoff from first rainstorm

A comprehensive version of this table may be consulted in Annex VI.

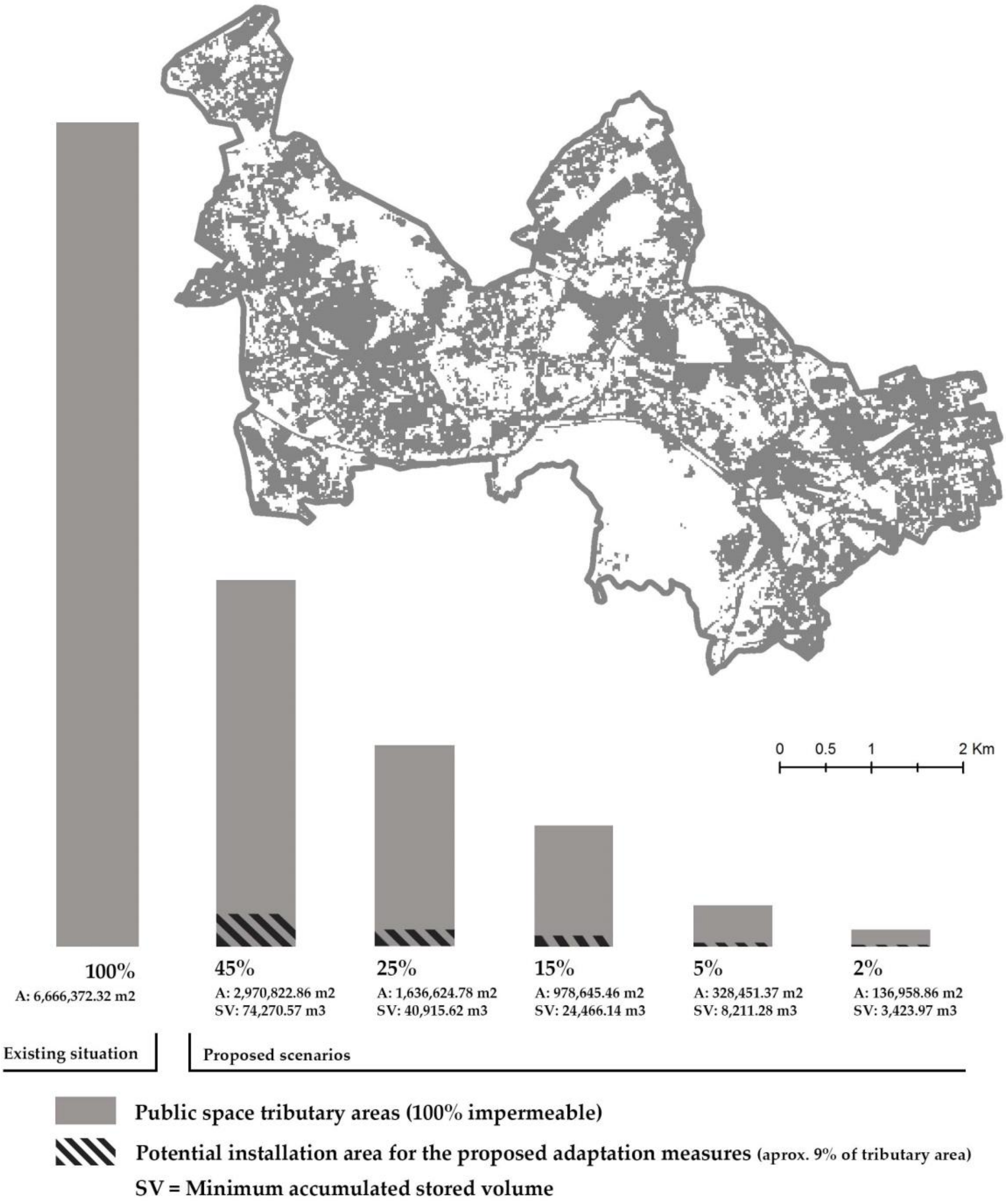


Figure 6.15 - Spatial analysis of the areas entailed in each proposed scenario and the corresponding potential areas for the installation of adaptation measures. Source: developed by the author.

Indeed, a volumetric analysis is particularly adequate to assess source control measures, whose primary functions entail the upstream harvest, retention and infiltration of first flush volumes. Moreover, as a common variable, it enables the comparison among different types of measures, such as the underground reservoirs presented in PGDL 2006-2008 and in the Municipal Master Plan (2012).

More specifically, for the particular area under study of AUB, two underground reservoirs are proposed in Lisbon's PDM in effect. These two reservoirs were envisioned for the underground drainage branches of "Avenidas Novas" and "Campolide-Benfica", each one enabling 13400 and 38100m3 of stormwater storage, respectively. Both reservoirs would comprise a total potential storage of 51.500 m3. In the updated version of the PGDL 2017-2030, the possibility to maintain and enlarge the same proposed reservoirs is further analysed. More specifically, the "Avenidas Novas" reservoir is upgraded to the capacity of 30.000m3 and the "Campolide-Benfica" reservoir to the capacity of 65.000m3, comprising a total of 95.000m3. When comparing the storage volumes from these projected reservoirs with the potential managed volumes estimated in Table 6.5, one can note a significant similarity in scale of managed volumes between the two different approaches. If adapting 25% of the impermeable public spaces, it is possible to manage at least 40.900m3 of stormwater volume. And if adapting 45% of the impermeable public spaces, it is possible to manage at least 74.000m3 of stormwater volume.

Besides the similarity in scale of volume managed, it is important to emphasize the discrepancy in regard to the adjacent benefits provided by each of the proposed types of measure: Underground reservoirs *vs* source control adaptation measures (such as Bioswales, Rain gardens, Bioretention planters, Green gutters, among others). Whereas underground reservoirs, or other type of large scale hard drainage infrastructure, such as deviation tunnels, may be particularly efficient in solving intense flood hazards in a relatively short period of time, the proposed source control adaptation measures, which require extensive implementations and longer timeframes, have the added value of significantly contributing to the overall quality of water bodies and of the urban environment (namely in regards to microclimatic melioration, biodiversity enrichment, among others). In addition, by being specifically applied within the design of a public space, the proposed adaptation measures may serve as social beacons for change.

Indeed, recalling the premise to retain the first 25 mm from first flush precipitation that falls over a given impermeable area (Annex V - Justification for the choice of 25 mm as the minimum value of height of rainfall to be retained by the source control adaptation measures applied in the city of Lisbon), the source control measures here proposed are insufficient to manage the projected increase of floods resulting from intense rainfall. Yet they encompass a critical contribution to the ultimate and greatest purpose of adapting the urban territory to the more frequent, albeit less impactful flood events.

It is therefore here argued that the added alternatives here analysed, should move beyond a rhetoric presence in reports and effectively enter the processes of concrete implementation action. As recognized by Saldanha Matos in a public presentation, structural measures, of individual nature, are crucial to solve Lisbon's current problems, but they are not sufficient in extended time frames (Ponto de Encontro Lisboa E-Nova, 10th November 2015). In his view, in order to promote an advanced management of urban drainage systems, hard infrastructural measures must be accompanied by real time monitoring and by "complementary solutions", of a more local nature, or the so called "soft infrastructure" (Hidra et al. 2015, p.19).

6.3. Discussion

In order to assess the applicability of the developed Conceptual Framework, Lisbon's municipal endeavours regarding flood adaptation are primarily highlighted. In conformity with the identified main strategy chosen by the municipality, the application of additional adequate types of adaptation measures, evidenced by the developed Conceptual Framework, are proposed and discussed. Through design exercises, supplementary adaptation measures are specifically applied in particular situations and their infrastructural significance is quantitatively estimated. Lastly, a discussion is incited regarding the relevance of new untraditional flood management approaches combined with the design of public spaces.

Although some prematurity may be identified in the handing of concepts, particularly in what may or may not be considered as an adaptation measure, Lisbon's "second generation" municipal plan of 2012 stands out for its achievements, particularly by having included the critical subject of climate change in the elaboration of its revision, and by having proposed the implementation of several possible adaptation actions. Yet, naturally, it can be expected that a lot of work still needs to be done in regards to adaptation endeavors within municipal undertakings.

One of the most strongly advocated strategies concerned with urban flood tackling present within Lisbon's Municipal Master Plan in effect, is the source control strategy. Among the publicly available reports, specific adaptation measures within this strategy comprise: Green walls, Green roofs, Tree alignments, Retention basins, Bioretention basins, Cisterns, Underground reservoirs, Infiltration trenches, Leaky wells and Permeable pavements.

In light of the Conceptual Framework, five additionally relevant types of measures under the same strategy are identified, namely: Inverted umbrellas, Art installations, Blue roofs, Water plazas, Cisterns, Bioswales, Bioretention planters, Rain gardens and Green gutters. In order to assess the applicability of some of these types of measures, three illustrative preliminary designs are proposed. In line with the advanced designs, in order to assess the overall infrastructural significance of the proposed measures, estimate calculations together with projected implementation scenarios are developed for the Alcântara Upper Basin, the upper half of the biggest hydrographical basin that strongly contributes to Lisbon's floods.

The presented results, from the designs and spatial analysis, enabled the verification that the efficiency of the types of adaptation measures here proposed can be compared with the so-called "structural measures", or mono-functional hard infrastructure, when considering wider time-frames as supported by the climate change literature consulted so far. In other words, when considering the extensive application of the additionally highlighted types of measures, both in space and time, the capacity to retain first flush volumes in order to avoid sewerage overflow is worthy of comparison. For example, in PGDL 2006-2008 the retention of 9,400m3 of stormwater would already justify the construction of a reservoir, namely at Rua Eduardo da Bairrada. In addition, 65,000m3 of stormwater storage is the capacity of the biggest reservoir proposed in PGDL 2017-30, namely for the branch of "Campolide-Benfica". In contrast, if adapting 5% of the impermeable public spaces within the studied area (retrofitting, or physically altering, only around 9% of the total 5% of impermeable public spaces), a minimum of 8,161.92 m3 of stormwater volume can be managed. Likewise, if 45% of potential impermeable public spaces are adapted (again, through interventions in around 9% of the respective area), around 75,000.00 m3 can be managed.

It is important to highlight that the presented estimated calculations were especially conservative, namely by the consideration of unambitious scenarios and the fact that, considering the available official spatial information, only "ground plane public spaces" were included in the analysis. More specifically, types of measures such as Green roofs or Green walls were excluded, thus contributing to an underestimation. Indeed, improved and more comprehensive results could have been attained with available spatial information of higher quality and detail.

It is further important to highlight that, through punctual interventions focused on a particular goal, mono-functional and "hard" infrastructural measures may be particularly effective. Undoubtedly, reservoirs can be built in just a few years and are able to retain considerable volumes of stormwater, regardless of the duration and proximity of rainstorms. In comparison, "soft" source control infrastructures, such as the ones here proposed, require an extensive spatial application that, in light of urban dynamics, are only likely to occur after a considerable period of time.

In addition, the types of measures here proposed for Lisbon encompass only a natural storage capacity for stormwater volume, inevitably providing only enough confidence on the efficiency to store waters from first flushes. Whereas in opposition to the conventional advocated measures of hard engineering, the measures here detailed entail multiple co-benefits, which go from microclimatic amenity to the purification of polluted water, from the enrichment of biodiversity to the upgrading of pleasurable urban spaces. Although "It is hard for us to accept that the way natural ecosystems work is exemplary" (Pope Francis 2015, p.17), the proposed measures are particularly flexible and adaptable in light of the expected, and continuously evolving changes, in weather regimes.

Moreover, by addressing the matter of urban flooding adaptation through public space design, the proposed types of measures highlight the value and opportunities underlying place-based solutions, that appropriate hydrological conditions and climate change adaptation as generators of urban form (Backhaus and Fryd 2012). Other advantages may arise from the complementarity amongst other comprehensive strategies supported by the municipality, namely by programs such as "Pavimentar Lisboa 2015 - 2020" or "Uma Praça em cada Bairro" currently ongoing in Lisbon.

Bearing in mind that adaptation alone will not be the miraculous sole answer to the problem of climate change (Adger and Barnett 2009), and regardless of the recognised necessity to further explore the pros and cons of both mentioned types of measures, the results presented in this chapter do not intend to disregard strategies that use hard infrastructural measures. It rather aims to question the current mainstream strategies, as proposed by White and Howe (2004), and to reinforce the legitimacy of other possible types of measures so they may promptly enter current and future planning discussions.

Through the proposed exercise and estimate calculations, it is here endorsed that additional source control measures applied through public space retrofits entail a range of further solutions, which should be considered in Lisbon's flood adaptation undertakings. Undoubtedly, institutional change is fundamental for the upgrading of flood risk management practices. Through the integration of flood adaptation measures in the design of public spaces, which can look for synergies alongside general urban planning processes, significant opportunities arise that can enhance the city's environmental, social and landscape quality.

Overall one may conclude that, in a dual perspective, not only 1) Lisbon's PDM reinforces the pertinence of the Conceptual Framework but also 2) the Conceptual Framework is capable of supporting Lisbon's flood adaptation agenda. More specifically, Lisbon's PDM evidences the need for a stronger practical approach that encompasses further knowledge regarding the design of adaptation measures. The proposed Conceptual Framework may help to fulfil this breach, as one of its main purposes consists of aiding a multitude of professionals during the initial exploratory phases of public space projects that incorporate flooding adaptation capacities. Moreover, some of the adaptation measures previously included in the Conceptual Framework were incorporated within Lisbon's PDM. This fact further reinforces the relevance of those particular measures to be part of the Conceptual Framework.

As further highlighted in this chapter, the measures identified by the Conceptual Framework to be additionally applied in the Lisbon case, and more specifically in the Alcântara Upper Basin, also epitomize a complementary practice to the traditional mainstreamed approaches, whose benefits namely include the advantages inherent to public spaces.

Finally, it should be noted that many other cities, which are also vulnerable to floods, where the projected climate change scenarios point towards an increase of flood occurrences and where conventional flood management practices are still the mainstreamed approach, might also find the proposed framework useful. Through the Conceptual Framework, each municipality may explore what types of flood adaptation measures are best suited for each particular situation and each envisioned infrastructural strategy. How to use the Conceptual Framework will therefore expectedly vary across contexts. Either through reactive of proactive endeavours, our urban future is dependent on how cities and societies confront flood events exacerbated by climate change.

Final considerations

Floods are among the most frequent human-enhanced urban hazard, albeit paradoxically experienced as an exceptional event attributed to nature. Supported by extensive literature, climate change projections estimate an increase in the frequency and intensity of floods. Furthermore, public spaces are amongst the most vulnerable areas to flooding as these are where impacts are more acutely experienced.

Approaching the identified concerns as challenges rather than hindering constraints, this research reinforces the premise that the design of public spaces is a key component on the urban adaptation to current and expected flooding events.

The climate change adaptation agenda has been inflicting revolutions that go beyond the restrictive arenas of climatic science, specifically within political arenas, flood risk management and public space design. In light of a deepened analysis concerning the concept of climate change adaptation, hereinafter referred simply as adaptation, it was possible to understand its meaning as a continuous learning adjustment process, which aims to reduce climate related vulnerabilities whilst seeking the advantage of beneficial opportunities. In contrast with sustainability planning, which supports decision making by analysing past trends, adaptation processes base the options upon the recognition of possible future climates through projections and simulations. Adaptation therefore embraces the multiple possibilities of learning with mistakes.

The city, and more specifically its public spaces, is extraordinarily adaptable, however, under a pattern of relatively stable changes. **When facing unprecedented and potentially extreme changes, public spaces may not have the same autonomous adaptation capacity.** It is in this context that planned adaptation gains strength against "business as usual".

Supported by literature, there is an increasing concern on the need to act in the face of uncertainty. **Adaptation therefore presents itself as an instrument that helps the management of uncertainty**. Not only the uncertainty that is natural to the evolutionary processes of any city, but also the uncertainty of future climate-driven projections. Both uncertainties that were once thought of as unattainable, but whose inclusion in planning practices is now widely discussed.

In line with an increasing ambition to face the urban impacts stressed by climate change research, countries such as the Netherlands, United States and the United Kingdom, have undergone several regional and local adaptation undertakings. As it is consensually agreed and recognized in literature, adaptation is prompting new urban planning approaches. Beyond this finding, it was evidenced that **public spaces can lead effective adaptation undertakings** that are explicitly influencing urban design practices as we know them.

Specifically, regarding the recurrent phenomenon of urban flooding, **climate change research has been warning to the fact that traditional flood risk management practices must be reassessed**, namely if projected impacts are to be managed, such as the likely increased frequency and greater intensity of storms (precipitation and storm surges) together with a rise in sea level.

When analysing an overview of the flood risk management practices throughout history, it was possible to further verify an **emerging change from the conventional focus from the goal to reduce the probability to experience floods, to the aim to reduce society's vulnerabilities**. As an increasingly discussed perspective, this former notion will inevitably change the relationship between the city and (its) water.

In addition, it was possible to highlight how **the goal to tackle social vulnerability might be related with the management and integration of risk and uncertainty in flood management practices, notably by fully acknowledging and welcoming the processes of the natural water cycle amongst public spaces**. However this is an argument that calls for improved knowledge. By making climate change visible, namely by incorporating the natural processes within the design of a public space, the social impact may have opposite repercussions and rather lead towards increased vulnerability. A fact that is particularly associated with how people and communities perceive and sense the risk of flooding.

Within a number of intrinsic roles, such as being a civic place of social and economic exchanges, or a gathering place where cultures mix, **public spaces have found an enhanced protagonism in light of the recognized need of a change of paradigm in current flood risk management practices**. This finding is demonstrated by cities such as Rotterdam, New York and London, which have matured their relationship with water, namely through the design of public spaces that, by recognizing water's bountiful and resilient capacities, promote an approximation between society and flood risk management infrastructure.

Through the inclusion of flood adaptation measures within public spaces, reinforced challenges arise before contemporary urbanism and urban design practices. Amongst those challenges are: 1) the acknowledgment that total flood protection is unrealistic and unwise; 2) a need for "out of the box" thinking; 3) a requirement to abide with further expanded horizons, whose actions must be periodically monitored and revisited; 4) the compliance with the notion of public space as an urban system; 5) the articulation with other municipal agendas or ongoing programs; and 6) a search for a combination of multiple strategies and solutions. In accordance, **public space design has found new horizons of multidisciplinary and interdisciplinary practice, which may instigate further creativity**. New horizons that will not only bring new approaches and technologies into the frontline of innovation, but also stimulate the re-encounter of culture and tradition.

Under the further bibliographical analysis, it was possible to highlight that: 1) hazards are more acutely felt at a local level; 2) it is within local communities that lies the most know-how and experience to deal with existing vulnerabilities; 3) local action entails immediate repercussions on the reduction of societies' vulnerabilities; and 4) local action influences global climate, which may consequently also reduce future vulnerabilities. As such, and as additionally demonstrated by the cities under study, one may argue that **competent and politically autonomous municipalities, which are close to its citizens, are more likely to conduct effective adaptation action**.

As particularly evidenced by the Barcelona Model, local initiatives, such as specific public space interventions, can raise the standard for good quality cities. As a result, one may additionally argue that **the quality of future cities can be influenced by the quality of adaptation measures applied in public spaces**. Indeed, through public spaces, extended opportunities for experimental learning and monitoring, inherent to adaptation processes, are provided without neglecting values such as local identity or sense of place.

Overall, it is argued that through public spaces, which provide the opportunity to integrate and reveal the complex intermingling connections between natural, social and technical processes, and in particular **through public space design, traditional flood management practices may be enhanced to the contemporaneity of our time**.

In light of the identified examples of public spaces with flood adaptation purposes, **it was possible to identify some of the potential benefits that**

may specifically arise from the inherent characteristics provided by public space. Among them are: 1) the favouring of interdisciplinary design, 2) the embracement of multiple purposes, 3) the promotion of community engagement, 4) the support on an extensive physical system, 5) the opportunity to expose and share value and, finally, 6) the prospect of promoting risk diversification and communal monitoring.

After recognizing 1) the enhanced protagonism of public spaces in light of the paradigm shift in current flood risk management practices as well as 2) the potential benefits that may specifically arise from the intrinsic characteristics provided by public space, it becomes necessary to explicitly identify how public space can accommodate flood adaptation measures. Through a particularly targeted literature review, together with a semantics analysis, **it was possible to identify and systematize forty types of flood adaptation measures applicable in the design of public spaces, covered by sixteen categories** (Table 7.1).

Table 7.1 - Flood adaptation categories and types of measures applicable in the design of public spaces

Flood adaptation measures applicable in the design of public spaces

Categories	Types	
A.Urban greenery	1.Green walls	21.Stream restoration
B.Urban furniture	2.Inverted umbrellas	22.Daylighting streams
C.Rooftop detention	3.Art installations	23.Street channels
D.Reservoirs	4.Green roofs	24.Extended channels
E.Bioretention	5.Blue roofs	25.Enlarged canals
F.Permeable paving	6.Artificial detention basins	26.Check dams
G.Infiltration techniques	7.Water plazas	27.Floating pathway
H.Stream recovery	8.Underground reservoirs	28.Floating platform
I.Open drainage systems	9.Cisterns	29.Floating island
J.Floating structures	10.Wet bioretention basins	30.Submergible parks
K.Wet-proof	11.Dry bioretention basins	31.Submergible pathways
L.Raised structures	12.Bioswales	32.Cantilevered pathways
M.Coastal defences	13.Bioretention planters	33.Elevated promenade
N.Floodwalls	14.Rain gardens	34.Multifunctional defence
O.Barriers	15.Open cell pavers	35.Breakwaters
P.Levees	16.Interlocking pavers	36.Embankments
	17.Porous paving	37.Sculptured walls
	18.Infiltration trenches	38.Glass walls
	19.Green gutter	39.Demountable barrier
	20.Stream rehabilitation	40.Gentle slope levees

These categories and types of measures are consequently classified and organized in a Conceptual Framework of flood adaptation measures applicable in the design of public spaces, which is particularly directed at featuring their infrastructural relevance. More specifically, each type of measure is classified in light of the six infrastructural strategies of: Harvest, Store, Infiltrate, Convey, Tolerate and Avoid.

Ultimately, the Conceptual Framework is expected to converge into a stable layout that displays all of the possible and impossible synergies amongst the different infrastructural strategies encompassed within each category and type of flood adaptation measure, applicable in the design of a public space.

The proposed Conceptual Framework is targeted at facilitating and accelerating the initial stages of a public space design project with flood adaptation ambitions, namely by exposing an extensible body of available options. Developed with the purpose to offer a commonly-used vocabulary and simple technical notions, the Conceptual Framework further aims to support and promote communication and exchange of know-how.

The designed circular diagram as well as the matrix of the sketched typologies, synthetize the Conceptual Framework's contents in a manageable format where options may be easily apprehended and combined, further endorsing creative and multifunctional public spaces.

Both in method and structure, the Conceptual Framework acknowledges the advantageous possibility to add new knowledge as it becomes available. It is therefore an unlimited work in progress, prepared to evolve and to be restructured in light of new teachings, concepts or approaches. Although the categories and types of measures highlighted by the framework can provide a very useful starting point, most likely, and most fortunately, they will also change and develop as new challenges arrive.

Prompted by the urging need to adapt our cities when facing potential climate change and unprecedented flood events, **the proposed Conceptual Framework of flood adaptation measures applicable in the design of public spaces offers a different approach to tackle the well-known problem of urban flooding**. Through a different perspective, one that highlights the importance of public space design in adaptation undertakings, the Conceptual Framework presents a specific group of measures that confront traditional flood risk management practices. Through the design of public spaces with flood adaptation capabilities, our urban territories can become better adapted for the present and projected flood impacts.

Through the Conceptual Framework, this advocated approach can be assessed in the city of Lisbon that specifically suffers from a meteorological and topographical predisposition to flash floods. Indeed, Lisbon at this moment in time has a considerable drainage problem on its hands, which is aggravated in light of projected climate change scenarios.

Under the developed overview analysis regarding the applied flood management practices in Lisbon and their relation with public spaces, it was possible to verify an increasing concern, related to the potential unprecedented challenges that climate change may bring upon an already fragile drainage situation. It was further possible to argue how the city is yet still distant from the envisioned paradigm shift in flood risk management practices. Indeed, **Lisbon still mostly relies on the optimization and enlargement of singular mono-functional and conventional infrastructures.** By contrast, integrated, multifunctional and interdisciplinary flood risk management is still only present in rhetoric accounts, with little consideration regarding effective plans and designs.

The most significantly supported strategy for flood adaptation in Lisbon's Municipal Master Plan (2012) currently in effect refers to source control, that is, to adaptation measures whose primary functions are Harvest, Store or Infiltrate. Specifically, the mentioned types of measures include: green walls, green roofs, tree alignments, retention basins, bioretention basins, cisterns, underground reservoirs, infiltration trenches, leaky wells and permeable pavements. By confronting these types of measures, and advocated strategy, with the types of measures included in the proposed Conceptual Framework, it is possible to evidence that other solutions may be additionally considered, namely: inverted umbrellas, art installations, blue roofs, water plazas, cisterns, bioswales, bioretention planters, rain gardens and green gutters. With this in mind, **through the use of the Conceptual Framework, Lisbon is faced with new opportunities for flood adaptation through public space design**.

When considering an extensive application of some of the additionally suggested types of measures, both in space and in timescale, the presented results enabled the verification that the retention capacity of first flush volumes of the measures proposed in the Conceptual Framework are comparable with the retention capacity of the conventionally advocated mono-functional types of measures such as underground reservoirs. In other words, in light of the conducted estimations, **the same retention capacity provided by one type of hard infrastructure can be alternatively accomplished by different types of measures extensively implemented in public spaces**. However, in contrast, with a "hard" infrastructure that can be built in just a few years and is able to retain considerable volumes of stormwater, the approach encouraged by the measures highlighted in the Conceptual Framework depends upon public authorities following a consistent policy over time. On the other hand, by integrating flood adaptation measures in the design of public spaces, significant opportunities arise that can enhance the city's environmental, social and landscape qualities.

These results do not intend to disregard strategies that use hard infrastructural engineering, but rather to discuss current mainstreamed strategies and reinforce the legitimacy of other possible types of measures, in so much as they may promptly enter municipal undertakings. Certainly, the additionally proposed types of measures to be applied in the case of Lisbon are limited by the duration and proximity of rainstorms, providing only enough confidence to assess their efficiency on storage capacity regarding first flushes. Regardless of these findings, **Lisbon municipality evidenced the need for a stronger practical flood adaptation approach that encompasses further interdisciplinary knowledge regarding the design of different types of adaptation measures**. **As set out in this thesis, the proposed Conceptual Framework can help to fulfil this need**.

*

With all the above mentioned results considered, it is possible to conclude that **the design of public spaces is a key component in the urban adaptation to current and expected flooding events.**

*

Flood risk management in particular has been essentially controlled by specific technical and specialized disciplines that have authoritatively decided upon the actions required, with regards to coastal, riverine or pluvial flooding. Yet, this research proposes a different perspective, one that highlights the importance of public space design in climate change adaptation processes associated to urban flooding. An approach where efforts are targeted at assembling related disciplines and enabling their convergence. It implies a multidisciplinary practice, simply because it involves the expertise of a number of disciplines, such as urban planning, engineering, architecture, landscape architecture, climatology, among others. It also implies an interdisciplinary practice, since without an effective integration amongst the required multidiscipline, the adaptation measures here proposed are destined to fail their purpose. **Adaptation is therefore not only challenging established professions, which previously assumed climate was generally stationary, but is now also instigating the need to redefine disciplinary competences, as well as the need for intricate professional collaboration**.

Landscape architects, urban designers and geographers are skilled in the integration between man-made infrastructure and ecological systems and may therefore play a fundamental role in the processes of adaptation actions. Yet in light of the discussed process, which intends to branch the ecological network (and the natural water cycle in particular) into the public space network, **landscape architects can be considered as particularly responsible for successful interventions**. As professionals that aim to cooperate with nature in order to fulfil Man's needs, landscape architects are particularly experienced, not only in the integration process between the physical system (geology/lithology, soil, water and climate) and the biological system (habitat and vegetation), but also in its combined integration with the human system (namely the system of public spaces and its interactions). However, underlying this objective, one is faced with the obstacles of a profession still establishing its identity and role within urban environments. In order for landscape architects to explore their skills and knowledge for the benefit of our cities, mainstreamed practices should extend from the customary complementary projects.

Another prominent defiance on the advocated inclusion of flood adaptation measures within public spaces, is the assumed reliance on local scale social response. As previously argued, people and communities are not only targets but can also be active agents in the management of vulnerability. This potential propensity to facilitate adaptation action can be namely instigated through the design of public spaces that make climate change visible and hence meaningful. Yet, by providing an additional source of knowledge through the design of a public space, counterproductive misunderstandings may also occur; possibilities that might rather contribute to maladaptation. **By questioning the assurance of local scale social response, the advocated need for continuous monitoring and learning alongside adaptation undertakings is reinforced**. These remaining questions can be developed, namely through the implementation of pilot projects whose interactions among concerned professional disciplines and community can be closely and regularly evaluated.

Although limited confidence is provided on what extent can local empowerment favour or harm "bottom-up" adaptation processes, it has been evidenced that positive outcomes arise when the design of a public space with flood adaptation capacities involves local people and communities. In general terms, one can note that **if science and "top-down" approaches can provide important knowledge, then local "bottom-up" approaches can provide critical wisdom**. Nevertheless, both approaches are important and must not be isolated. If local adaptation is not associated to a bigger strategy, it will get lost in scale and lose its strength, and if "top-down" approaches are deprived from specific local hindrances, they can fail to reach communities and fail to tackle the most prominent vulnerabilities.

The exploratory content of the final chapter of this dissertation should also be noted. Indeed, throughout the chapter it is possible to recognize multiple opportunities and challenges for further research. Among them is the possibility to improve spatial and hydrological estimations with upgraded quantifiable data. Other questions include the limits of design, and public space design in particular, as a tool to manage and integrate continuous change, risk and uncertainty.

Nevertheless, important climate change adaptation advances may be achieved by incorporating the measures here proposed alongside everyday planning practices, from municipal public space design regulations to specific requirements for urban regeneration projects.

Curiously, although anthropogenic climate change, and associated adaptation action was one of the main triggers which propelled this research, the overall outcomes presented by this thesis are not only recognized as part of the urban agenda on future climates, but also as part of the present urban agenda. In other words, **flood adaptation measures applicable in the design of public spaces are promoting the anticipated paradigm change in contemporary flood risk management practices, which is necessary for today and not only for tomorrow**. Indeed, taking into account the inertia of climatic systems, plus the fact that adaptation is an ongoing learning process with many advances and setbacks, acting upon this now is crucial.

Bibliography

Book

Aboutaleb, A., *et al.*, 2014. *IABR - 2014 - Urban by Nature.* Rotterdam: International Architecture Biennale Rotterdam.

AECOM, 2011. *Climate Design. Design and Planning for tyhe age of climate change. A collection of works from academics and AECOM's thought leaders.* Berkeley: Publishers Group West. 223 pp.

Amaral, F. K., 1969. *Lisboa, uma cidade em transformação.* Lisboa: Publicações Europa-América. 237 pp.

Andjelkovic, I., 2001. *Guidelines on non-structural measures in urban flood management.* Paris: Unesco.87 pp.

Andresen, T., 2001. *Francisco Cadeira Cabral.* United Kingdom: LDT monografs No3. 213 pp.

Arendt, H., 1998[1958]. *The Human Condition.* 2nd Edition ed. Chicago University of Chicago Press. 349 pp.

Ascher, F., 2010[2001]. *Novos Principios do Urbanismo seguido de Novos Compromissos Urbanos. Um Léxico.* 2ª edição ed. Lisbon: Livros Horizonte.174 pp.

Balica, S.-F., 2012. *Applying the Flood Vulnerability Index as a Knowledge base for flood risk assessment.* TU Delft, Faculty of Civil Engineering and Geosciences, Dep. Hydraulic Engineering: CRC Press/Balkema.152 pp.

Bammer, G., *et al.*, 2008. *Uncertainty and Risk: Multidisciplinary Perspectives.* London: Earthscan. 391 pp.

Barreiros, M. H., 2001. *Lisboa: conhecer, pensar, fazer cidade.* Câmara Municipal de Lisboa - Urbanismo. 119 pp.

Bates, B., *et al.*, 2008. *Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change.* IPCC Secretariat, Geneva. 210 pp. .

Beatley, T., 2011. *Biophilic Cities: Integrating Nature Into Urban Design and Planning.* Washington DC: Island Press. 191 pp.

Beck, U., 1992. *Risk Society: Towards a New Modernity.* SAGE Publications.260 pp. .

Berkes, F., Colding, J. and Folke, C., 2003. *Navigating Social-Ecological Systems. Building Resilience for Complexity and Change.* Cambridge University Press.

Bíblia Sagrada, 1991. 5a ed. Lisboa: Difusora Bíblica.1692 pp.

Bicknell, J., Dodman, D. and Satterthwaite, D., 2009. *Adapting Cities to Climate Change. Understanding and Addressing the Development Challenges.* International Institute for Environment and Development, Earthscan, UK. 397 pp.

Boer, F., Jorritsma, J. and Peijpe, D., 2010. *De Urbanisten and the wondrous water square.* Rotterdam: 010 Publishers. 46 pp.

Bohigas, O., 1986. *Reconstrucción de Barcelona.* Madrid: Edicions 62. 299 pp.

Borja, J., 2003. *La ciudad Conquistada.* Madrid: Alianza Editorial. 381 pp.

Borja, J. and Muxí, Z., 2003. *Espacio público: ciudad y ciudadanía.* 3ª ed. Barcelona: Electa. 415 pp.

Brandão, P., 2008. *A identidade dos lugares e a sua representação colectiva. Bases de orientação para a concepção, qualificação e gestão do espaço público.* Lisboa: Europress, Editores e Distribuidores de Publicações, Lda.57 pp.

Brandão, P., 2011. *La Imagen de la ciudad: estrategias de identidad y comunicación.* Barcelona, Spain: Publicacions i edicions de la Universitat de Barcelona.195 pp.

Brandão, P., 2011. *O Sentido da Cidade. Ensaios Sobre o Mito da Imagem Como Arquitectura.* Lisboa: Livros Horizonte.296 pp.

Brandão, P., *et al.*, 2003. *A Alma do Design: artesanato e design, estranho, fronteiras do design.* Centro Português de Design.154 pp.

Brandão, P. and Remesar, A., 2003. *Design de espaço público: deslocação e proximidade.* Lisboa: Centro Português de Design.110 pp.

Brandão(Coord.), P., Carrelo, M. and Águas, S., 2002. *O chão da cidade. Guia de Avaliação do Design de Espaço Publico.* Lisboa: Centro Português de Design. 199 pp.

Brinke, W. t., Karstens, S. and Deen, J. v., 2010. *Sustainable water management under climate change - how to develop strategies for an uncertain future.* Delft: Deltares - Enabling Delta Life.

Busquets, J., 2004. *Barcelona: La construción urbanística de una ciudad compacta.* Barcelona: Ediciones del Serbal. 471 pp.

Cabral, F. C., 2003[1993]. *Fundamentos da Arquitectura Paisagista.* 2ª ed. Lisboa: Instituto de Conservação da Natureza. 220 pp.

Calthorpe, P., 2011. *Urbanism in the age of Climate Change.* Washington DC: Island Press. 139 pp.

Capel, H., 2005. *El Modelo Barcelona: Un Examen Crítico.* Barcelona: Ediciones del Serbal. 119 pp.

Carmona, M., Magalhães, C. d. and Hammond, L., 2008. *Public space: the management dimension.* Oxon, New York: Routledge. 232 pp.

Carmona, M., *et al.*, 2010. *Public Places - Urban Spaces: The Dimensions of Urban Design* 2nd, 1st ed. 2003 ed. UK: Architectural Press, Elsevier.

Castel-Branco(Cood.), C., *et al.*, 2010. *A Água nos Jardins Históricos* Lisboa: Scribe. 151 pp.

CCIAM, 2014. *Cartas de Inundações e de Risco em Cenários de Alterações Climáticas (CIRAC)* Associação Portuguesa Seguradores (APS), Centre for Climate Change Impacts Adaptation & Modelling: Gráfica Maiadouro. 67 pp.

Choay, F., 1965. *L'Urbanism. Utopied et Réalités. Une anthologie.* Paris: Editions du Seuil. 448 pp.

Choay, F. and Merlin, P., 1988. *Dictionnaire de L'Urbanism et de L'amenagement.* Paris: Presses Universitaires de France. 723 pp.

Corominas, M. and Busquets, J., 2009. *Cerdà i la Barceloma del Futur.* Centre de Cultura Contemporània de Barcelona ed. Barcelona: Diputació de Barcelona.253 pp.

Costa, J. P., 2013. *Urbanismo e Adaptação às Alterações Climáticas, as frentes de água.* Lisboa: Livros Horizonte.183 pp.

Costa, J. P., *et al.*, 2014. *Climate Change Adaptation in Urbanised Estuaries. Contributes to the Lisbon Case.* Óbidos: Várzea da Rainha Impressores. 296 pp.

Cowan, R., 2005. *The Dictionary of Urbanism.* Streetwise Press. 468 pp.

Creswell, J. W., 2008. *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches: Qualitative, Quantitative, and Mixed Methods Approaches.* SAGE Publications. .

Cullen, G., 2004[1971]. *Paisagem Urbana.* Lisboa: edições 70. 202 pp.

Cullen, H., 2010. *The Weather of the Future: Heat Waves, Extreme Storms, and Other Scenes from a Climate-Changed Planet.* New York: HarperCollinsPublishers. 329 pp.

Eco, U., 1989. *The Open Work.* Cambridge, Massachusetts: Harvard University Press. 285 pp. .

Eco, U., 2010[1977]. *Como se faz uma tese em ciências humanas.* 16th ed.: Editorial Presença. 238 pp.

Erell, E., Pearlmutter, D. and Williamson, T., 2011. *Urban Microclimate: Designing the Spaces Between Buildings.* London, Washington DC: earthscan. 266 pp.

Fabos, J. G. and Ahern, J. F., 1996. *Greenways: The Beginning of an International Movement.* Amsterdam: Elsevier. 491 pp.

Fadigas, L., 2010. *Urbanismo e Natureza - Os desafios.* Lisboa: Edições Sílabo. pp.149.

Fonseca, J. D., 2005. *1755 O Terramoto de Lisboa.* Lisboa: Argumentum. 139 pp.

França, J.-A., 1989[1980]. *Lisboa: Urbanismo e Arquitectura.* 2ª ed. Lisboa: Instituto de Cultura e Lingua Portuguesa. Ministério da Educação. 133 pp.

França, J.-A., 2009[2008]. *Lisboa, História Física e Moral.* Livros Horizonte 872 pp.

GCRP, 2009. *Global Climate Change Impacts in the United States.* New York, US: Global Change Research Program, Cambridge University Press.196 pp.

Gehl, J., 1987. *Life Between Buildings: Using Public Space* New York: Island Press. 46 pp.

Gehl, J., 2010. *Cities for People.* Washington, Covelo, London: Island Press. 269 pp.

Gehl, J. and Svarre, B., 2013. *How to Study Public Life.* Washington DC: Island Press. 179 pp.

Goitia, F. C., 2010[1982]. *Breve História do Urbanismo.* 8ª ed. Lisboa: Editorial Presença. 209 pp.

Hall, P., 2014[1932]. *Cities of Tomorrow: an intellectual history of urban planning and design since 1880.* Fourth ed. 624 pp.

HM Government, 2013. *The National Adaptation Programme. Making the country resilient to*

a changing climate. London: The Stationery Office, UK.182 pp.
Hooimeijer, F., *et al.*, 2005. *Atlas of Dutch Water Cities.* Amsterdam SUN. 220 pp.
Hough, M., 2004[1995]. *Cities and Natural Processes. A basis for sustainability.* 2nd ed. New York: Routledge. 292 pp.
Howard, E., 1966[1898]. *Garden Cities of tomorrow.* 2ª ed. Cambridge: MIT Press. 168 pp.
Howe, C. and Mitchell, C., 2012. *Water Sensitive Cities.* IWA Publishing. 278 pp.
Howe, C. A., *et al.*, 2011. *Sustainable Water Management in the City of the Future.* Findings from the SWITCH Project 2006-2011 ed. The Netherlands: UNESCO-IHE. 182 pp. .
Innerarity, D., 2006. *El nuevo espacio público.* Espasa Calpe.320 pp.
IPCC, 2000. *Special Report on Emissions Scenarios (SRES) - Summary for Policymakers.* Intergovernmental Panel on Climate Change. 27 pp. .
IPCC, 2007. *Climate Change 2007: Impacts, Adaptation and Vulnerability [Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change].* Cambridge University Press, Published for the Intergovernmental Panel on Climate Change. 976 pp. .
IPCC, 2007. *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Geneva, Switzerland. 104 pp. .
IPCC, 2007. *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, United Kingdom and New York, USA: Cambridge University Press. 996 pp.
IPCC, 2014. *Climate Change 2014: Impacts, Adaptation and Vulnerability. Part B: Regional Aspects. Contribution of Working Groups II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing V. R. Barros and C. F.Field (eds.)].* Geneva, Switzerland.1820 pp.
Izembart, H. and Boudec, B. L., 2003. *Waterscapes. El tratamiento de aguas residuales mediante sistemas vegetales.* Barcelona: Editorial Gustavo Gili, sa. 192 pp.
Jacobs, J., 1992[1961]. *The Death and Life of Great American Cities.* New York: Random House. .
Jellicoe, G. and Jellicoe, S., 1995[1975]. *The Landscape of Man: Shaping the Environment from Prehistory to the Present Day.* London: Thames and Hudson. 408 pp.
Jha, A. K., Bloch, R. and Lamond, J., 2012. *Cities and Flooding. A Guide to Integrated Urban Flood Risk Management for the 21st Century.* Washington: The World Bank. 631 pp.
Karin de Bruij, *et al.*, 2009. *Flood risk assessment and flood risk management - An introduction and guidance based on experiences and findings of FLOODsite.* FLOODsite Consortium.139 pp.
Kostof, S., 1991. *The City Shaped: Urban Patterns and Meanings Through History.* London: Thames & Hudson. 352 pp.
Kravčík, M., *et al.*, 2007. *Water for the Recovery of the Climate - A New Water Paradigm.* Publication printed with the financial support of: Municipalia a.s. and TORY Consulting a.s. ed.: Krupa Print, Žilina. 94 pp.
Krier, R., 1979. *Urban Space.* London: Academy Editions. 173 pp.
Lisboa, M. H., 2002. *Os engenheiros em Lisboa: urbanismo e arquitectura (1850-1930).* Livros Horizonte. 293 pp.
Loftus, A.-C., 2011. *Adapting urban water systems to climate change. A handbook for decision makers at the local level.* ICLEI European Secretariat GmbH. 53 pp.
Lourenço, T. C., *et al.*, 2014. *Adapting to an uncertain climate : lessons from practice.* Springer International Publishing. 182 pp. .
Luís, A. M. and Cruz, M. J., 2014. *Contribuição para o Estudo das Alterações climáticas e Adaptação do Ciclo Urbano da água.* Lisboa: EPAL, Empresa Portuguesa das Águas Livres S.A. .49 pp.
Lyle, J. T., 1985. *Design for Human Ecosystems.* New York: Van Nostrand Reynolds Company. 279 pp.
Lynch, K., 1996[1960]. *A imagem da cidade.* Lisboa: edições 70. 205 pp.
Maciel, M. J., 2009. *Vitrúvio - Tratado de Arquitectura* 3ª edição ed. 456 pp.
Madanipour, A., 2007. *Designing the City of Reason. Foundations and Frameworks.* New

York: Routledge. 342 pp.
Magalhães, M. R., 2001. *A Arquitectura Paisagista - Morfologia e Complexidade.* Lisboa. 525 pp.
Margolis, L. and Robinson, A., 2007. *Living Systems: Innovative Materials and Technologies for Landscape Architecture.* Basel, Boston, Berlin: Birkhäuser.190 pp.
Marshall, R., 2001. *Waterfronts in Post-Industrial Cities.* Spon Press.194 pp.
Martins Barata, J. P., 1989. *Pensar Lisboa.* Lisboa: Livros Horizonte. 95 pp.
McHarg, I. L., 1992[1967]. *Design with Nature.* New York, Chichester, Brisbane, Toronto, Singapore: John Wiley & Sons, Inc. 197 pp.
Meyer, H., 1999. *City and Port - Transformation of Port Cities. London, Barcelona, New York, Rotterdam.* Utrecht: International Books. 424 pp.
Meyer, H., Bobbink, I. and Nijhuis, S., 2010. *Delta Urbanism. The Netherlands.* Chicago: Planners Press.188 pp.
Mumford, L., 1989[1961]. *The City in History.* San Diego, New York, London: Harcourt Inc. 657 pp.
Novotny, V., Ahern, J. and Brown, P., 2010. *Water centric sustainable communities: planning, retrofitting,an building the next urban environment.* Hoboken, New Jersey: John Wiley & Sons, Inc. 606 pp.
Olgyay, V., 1962. *Design with Climate. Bioclimatic Approach to Architectural Regionalism*. New Jersey: Princeton University Press. 190 pp.
Oliveira, E. d. A. e., 2004[1941]. *Esgotos de Lisboa: estudos de ante-projecto.* Câmara Municipal de Lisboa, Ed. fac-similada. 594 pp.
Oliveira, E. F., 1885. *Elementos para a história do município de Lisboa.* Lisboa: Typographia Universal. tomo I, p.463.660 pp.
Olthuis, K. and Keuning, D., 2010. *Float! Building on Water to Combat Urban Congestion and Climate Change.* Amsterdam: Frame Publishers. 304 pp.
Philip, R., 2011. *SWITCH Training Kit - Integrated Urban Water Management in the City of the Future.* Freiburg, Germany: ICLEI European Secretariat GmbH | Gino Van Begin. 51 pp.
Popper, K., 1982. *The Open Universe An Argument for Indeterminism From the Postscript to The Logic of Scientific Discovery.* London and New York: Routledge. 186 pp.
Portas, N., 2011[1968]. *A Cidade Como Arquitectura.* Livros Horizonte. 212 pp.
Portas, N., *et al.*, 2003. *Políticas Urbanas I - Tendências, estratégias e oportunidades.* Lisboa: Fundação Calouste Gulbenkian. 295 pp.
Portas, N., *et al.*, 2011. *Políticas Urbanas II - Transformações, Regulação e Projectos.* Lisboa: Fundação Calouste Gulbenkian. 395 pp.
Pötz, H. and Bleuzé, P., 2012. *Urban green-blue grids for sustainable and dynamic cities.* Delft: coop for life. 608 pp.
Prominski, M., *et al.*, 2012. *River.Space.Design: Planning Strategies, Methods and Projects for Urban Rivers.* Berlin, Switzerland: Birkhauser 295 pp.
Ramos, Á. M., *et al.*, 2004. *Lo Urbano - en 20 autores contemporáneos.* Bracelona: Edicions UPC and ETSAB. 229 pp.
Rapoport, A., 1977. *Human Aspects of Urban Form Towards a Man—Environment Approach to Urban Form and Design.* Oxford: Pergamon Press. 438 pp.
Read, C., 2012[1898]. *Logic, Deductive and Inductive.* London: Tredition Classics. 392 pp. .
Reis, P., 2000. *Manuel Salgado. Espaços Públicos.* Lisboa: Fundaçao Banco Comercial Português. 45 pp.
Remesar, A., *et al.*, 2003. *Public Art and Urban Design. Interdisciplinary and Social perspectives.* Barcelona: E-Polis nº 1. 174 pp.
Remesar(Coord.), A., *et al.*, 2005. *Do Projecto ao Objecto. Manual de Boas Prácticas de Mobiliário Urbano em Centros Históricos.* 2ª ed. Lisboa: Centro portugês de Design. 119 pp.
RIBA, 2010. *Climate Change Toolkit 07: Designing for Flood Risk.* Royal Institute of British Architects. 32 pp.
Ribeiro, O., 1994. *Opúsculos Geográficos, Temas Urbanos, Volume V.* Lisboa: Fundação Caloust Gulbenkian. 560 pp.
Roggema, R., 2009. *Adaptation to Climate Change: A Spatial Challenge.* Dordrecht,

Netherlands: Springer
Rossi, A., 2001[1966]. *A Arquitectura da Cidade.* 2ª ed. Lisboa: Edições Cosmos. 258 pp.
Salgueiro, T. B., 2001. *Lisboa, periferia e centralidades.* Oeiras: Celta Editora. 230 pp.
Santos, F. D., Forbes, K. and Moita, R., 2002. *Climate Change in Portugal Scenarios, Impacts and Adaptation Measures - SIAM I.* Lisboa: Gradiva - Publicações. 456 pp. .
Santos, F. D., Miranda, P. and et.al., 2006. *Alterações Climáticas em Portugal. Cenários, Impactos e Medidas de Adaptação - SIAM II.* Lisboa: Gradiva - Publicações. 506 pp.
Saraiva, G., 1999. *O rio como paisagem: gestão de corredores fluviais no quadro do ordenamento do território.* Fundação Calouste Gulbenkian. 512 pp.
Secchi, B., 2006[2000]. *Primeira lição de urbanismo.* São Paulo: Editora Perspectiva S.A. 207 pp.
Sheppard, S. R. J., 2012. *Visualizing Climate Change. A Guide to Visual Communication of Climate Change and Developing Local Solutions.* Abingdon, United Kingdom: Routledge.514 pp.
Smith, K. and Ward, R. C., 1998. *Floods : Physical Processes and Human Impacts.* UK: John Wiley & Sons, Ltd. 381 pp. .
Solís, J. B., 2009. *Diccionario urbano: conceptual y transdisciplinar.* Ediciones del Serbal. 185 pp.
Swaffield, S., 2002. *Theory in Landscape Architecture: A Reader.* University of Pennsylvania Press. 625 pp.
Swart, R., *et al.*, 2009. *Europe Adapts to Climate Change Comparing National Adaptation Strategies.* PEER - Partnership for European Environmental Research ed. Helsinki: Finnish Environment Institute (SYKE). 283 pp.
Tarragó, F., 1996. *Cerdà. Ciudad y Territorio. Una visión de futuro.* 3rd ed. Madrid: ELECTA. 381 pp. .
Telles, G. R., 1997. *Plano Verde de Lisboa.* Lisboa: Edições Colibri. 200 pp.
Tenedório(Coord.), J. A., *et al.*, 2003. *Atlas da Área Metropolitana de Lisboa.* Lisboa: Área Metropolitana de Lisboa. 321 pp.
Three Regions Climate Change Group, 2008. *Your Home in a Changing Climate. Retrofitting Existing Homes for Climate Change Impacts. Report for Policy Makers.* Greater London Authority.76 pp.
Tojo, J. F., 2001. *La ciudad y el medio natural.* 2ª ed. Madrid: Akal textos de arquitectura. 342 pp.
Travassos, D., *et al.*, 2009. *– Guia dos parques, jardins e geomonumentos de Lisboa.* Câmara Municipal de Lisboa.
Trip, J. J., 2007. *What makes a city? Planning for 'quality of place'. The case of high-speed train station area redevelopment.* The Netherlands: IOS Press. Delft University Press. 255 pp.
United Nations, 2014. *World Urbanization Prospects: The 2014 Revision, Highlights* Department of Economic and Social Affairs, Population Division. 27 pp.
Urban, J., 2008. *Up By Roots.* Champaign, Illinois: International Society of Arboriculture. 479 pp.
Veelen, P. C. v., 2013. *Adaptive strategies for the Rotterdam unembanked area.* The Netherlands: National Research Programme Knowledge for Climate. 72 pp.
Veen, J. V., 1962[1950]. *Dredge, drain e reclaim: the Art of a Nation.* 5th ed. The Hauge, The Netherlands: Martinus Nijhoff. 200 pp.
Vidiella, A. l. S. n. and Zamora, F., 2011. *Paisajismo Urbano - Barcelona - Urban Landscape.* Barcelona: Imatge i Serveis Editorials Municipals. 343 pp.
Watson, D. and Adams, M., 2010. *Design for Flooding: Architecture, Landscape, and Urban Design for Resilience to Climate Change.* New Jersey: John Wiley & Sons. 298 pp.
White, W., 1980. *The Social Life of Small Urban Spaces.* New York: Project for Public Spaces Inc. 125 pp.
Woods-Ballard, B., *et al.*, 2007. *The SuDS manual.* London, United Kingdom CIRIA. 599 pp.

Book Section

Alcoforado, M. J. and Andrade, H., 2008. Global Warming and the Urban Heat Island.

In: Marzluff, J. M., *et al.* eds. *Urban Ecology - An International Perspective on the Interaction Between Humans and Nature* Springer US, 249-262.

Barros, A. A. S. d., 2014. Os canos na drenagem da rede de saneamento da cidade de Lisboa antes do terramoto de 1755. *In:* Carita, H. ed. *Cadernos do Arquivo Municipal - Lisboa Joanina (1700-1755).* Lisboa: Câmara Municipal de Lisboa.

Burton, I., 1996. The Growth of Adaptation Capacity: Practice and Policy. *In:* Smith, J., *et al.* eds. *Adapting to Climate Change.* Springer New York, 55-67.

Burton, I., *et al.*, 2001. Adaptation to Climate Change in the Context of Sustainable Development and Equity. *Climate change 2001: impacts, adaptation, and vunerability.* Cambridge: Cambridge University Press, 879-906.

Cabezas, L., 2001. El Manual Contemporáneo. *In:* Molina, J. G., Cabezas, L. and Bordes, J. eds. *El Manual de Dibujo. Estrategias de su enseñanza en el siglo XX.* Madrid: Cátedra, 139 - 497.

Cabral, F. C., 1980. O Continuum Naturale e a conservação da natureza. Lisboa: Serviços de Estudos do Ambiente, 35-54.

Coelho, C. D., *et al.*, 2014. Thinking Lisbon for 2100 – "What if?" essays on the climate change adaptation agenda. *In:* Cavallo, R., *et al.* eds. *New Urban Configurations.* EAAE / ISUF International Conference, Delft: IOS Press, 981 - 987.

Costa, J. P., Matos Silva, M. and Oliveira, D., 2012. A adaptação às alterações climáticas, os processos ecológicos e o desenho da infraestrutura de gestão das inundações urbanas. *In:* AEAULP ed. *Palcos da Arquitectura.* Lisboa: Academia de Escolas de Arquitectura e Urbanismo de Língua Portuguesa, 506 - 515 pp.

Dias, L. and Santos, F. D., 2014. Climate Change scenarios, Lisbon and the Tagus Estuary. *In:* Costa, J. P. and Sousa, J. F. d. eds. *Climate Change Adaptation in Urbanised Estuaries Contributes to the Lisbon Case.* Óbidos: Várzea da Rainha Impressores (in press), 157 - 173.

Fadigas, L., 2014. Working on Lisbon's riverfront in preparation for possible climate change impacts. *In:* Costa, J. P. and Sousa, J. F. d. eds. *Climate Change Adaptation in Urbanised Estuaries Contributes to the Lisbon Case.* Óbidos: Várzea da Rainha Impressores (in press), 232 - 245.

Figueira de Sousa, J., *et al.*, 2014. Lisbon riverfront climate change, impacts: buildings, public space, infrastructures, transports, and accessibilities, monuments, and public art. *In:* Costa, J. P. and Sousa, J. F. d. eds. *Climate Change Adaptation in Urbanised Estuaries Contributes to the Lisbon Case.* Óbidos: Várzea da Rainha Impressores (in press), 176-211.

Hebbert, M. and Webb, B., 2007. Towards a Liveable Urban Climate: Lessons from Stuttgart. *Liveable Cities: Urbanising World: Isocarp 07.* Manchester: Routledge, 1-18.

Kay, J. J. and Schneider, E., 1995. Embracing Complexity the Challenge of the Ecosystem Approach. *In:* Westra, L. and Lemons, J. eds. *Perspectives on Ecological Integrity.* Dordrecht: Springer Netherlands, 49-59.

Kondolf, M., 2009. An environmental perspective in city-river relationships. *In:* Saraiva, M. G. ed. *Cidades e Rios. Perspectivas para uma relação sustentável.* Lisboa: Parque Expo, 147-157.

Lister, N.-M., 2005. Ecological Design for Industrial Ecology: Opportunities for Re(dis)covery. *In:* Coté, R., Tansey, J. and Dale, A. eds. *Linking Industry and Ecology: A Question of Design.*: UBC Press, 15-28.

Magrinyà, F., 1996. Las infraestruturas de servicios en las propuestas urbanísticas de Cerdà. *In:* Fomento, M. d. ed. *Cerdà. Ciudad y Territorio. Una visión de futuro.* 3rd ed. Madrid: ELECTA, 189 - 203.

Martin, L., 2007. The grid as generator. *In:* Carmona, M. and Tiesdell, S. eds. *Urban Design Reader.* Oxford, UK: Architectural Press, 70-82.

Matos Silva, M. and Costa, J. P., 2016. Climate Change and Urbanism. A new role for public space design? *In:* A.Remesar ed. *The Art of Urban Design in Urban Regeneration. Interdisciplinarity, Policies, Governance, Public Space.* Barcelona: Publicacions i Edicions de la Universitat de Barcelona, 62 - 86.

Matos Silva, M. and Nouri, A., 2014. Adaptation measures on riverfronts, an overview of the concepts. *In:* Costa, J. P. and Sousa, J. F. d. eds. *Climate Change Adaptation in*

Urbanised Estuaries Contributes to the Lisbon Case. Óbidos: Várzea da Rainha Impressores, 131-150.

Matos Silva, M., Ochoa, R. and Nouri, A., 2014. Lisbon riverfront climate change impacts: local scale and public space management. *In:* Costa, J. P. and Sousa, J. F. d. eds. *Climate Change Adaptation in Urbanised Estuaries Contributes to the Lisbon Case.* Óbidos: Várzea da Rainha Impressores (in press), 214-229.

Nouri, A. S. and Matos Silva, M., 2013. Climate change adaptation and strategies: an overview. *In:* Helena Bártolo, *et al.* eds. *Green Design, Materials and Manufacturing Processes.* Lisbon: Taylor and Francis, 501-507 pp.

Portas, N., 2003. Espaço Público e a cidade emergente - Os novos desafios. *In:* Brandão, P. and Remesar, A. eds. *Design de espaço público: deslocação e proximidade.* Lisboa: Centro Português de Design, 16-19.

Roberts, R. D. and Roberts, T. M., 1984. Ecological considerations in rural planning: overview. *In:* Roberts, R. D. and Roberts, T. M. eds. *Planning and Ecology.* London: Chapman & Hall, pp. 153-156.

Soares, A. L. and Castel-Branco, C., 2007. As Árvores da cidade de Lisboa. *In:* Silva, J. S. ed. *Floresta e Sociedade.* Lisboa: Publico Comunicação Social SA, Fundação Luso-Americana para o Desenvolvimento, 289-334.

Stone, K., *et al.*, 2012. Integrating flood risk management and urban design through climate change adaptation. *In:* Klijn, F. and Schweckendiek, T. eds. *Comprehensive Flood Risk Management: Research for Policy and Practice.* CRC Press, 292-298.

Telles, G. R., 2011. Paisagem Global. Um conceito para o futuro. *In:* Serrão(Coord.), A. V. ed. *Filosofia da Paisagem. Uma Antologia.* Lisboa: Centro de Filosofia da Universidade de Lisboa, 476-485.

Valera, S., 1996. Psicología Ambiental: bases teóricas y epistemológicas. *In:* Íñiguez, L. and Pol, E. eds. *Cognición, representación y apropiación del espacio.* Barcelona: Publicacions Universitat de Barcelona., 1-14.

Valera, S., 2001. La percepció del risc. *In:* Mir, N. ed. *Com "sentim" el risc.* Observatori del Risc. Informe 2001 ed. Barcelona: Beta Editorial, 235-261.

Van Der Linden, S., 2014. Towards a new model for communicating climate change. *In:* S. Cohen, *et al.* eds. *Understanding and governing sustainable tourism mobility: Psychological and behavioural approaches.* Routledge: Taylor and Francis Group, 243-275.

Zaitzevsky, C., 2001. The "Emerald Necklace": An Historic Perspective. *In:* Walmsley, T. and Pressley, M. eds. *Emerald Necklace Parks: Master Plan.* Commonwealth of Massachusetts, Department of Environmental Management, 27-42.

Catalog

Andresen(Coord.), T., 2003. Do Estádio Nacional ao Jardim Gulbenkian. Lisboa: Fundação Calouste Gulbenkian, 319 pp.

Gameiro, R., 1925. Lisboa Velha. Lisboa: Tipografia da Emprêsa do Anuário Comercial.

Silva, R. H., 1989. Lisboa de Frederico Ressano Garcia 1874-1909. Lisboa: Fundação Calouste Gulbenkian, Camara Municipal de Lisboa, 93 pp.

Conference Proceedings

Ahern, J., Theories, methods and strategies for sustainable landscape planning. *From landscape research to landscape planning. Aspects of integration, education and application*, 2006 Dordrecht, The Netherlands, 119-131.

Ahern, J., Cultivation of Novel Nature for Urban Resilience. *Landscape: A Place of Cultivation*, 2014 Porto, Portugal, 45-57.

Angelakis, A. N., Koutsoyiannis, D. and Papanicolaou, P., On the Geometry of the Minoan Water Conduits. *3rd IWA Specialized Conference on Water&Wastewater* 2012 Istanbul, Turkey, 172-177.

Antunes, C., Monitorização da Variação do Nível Médio do Mar. *1as Jornadas de Engenharia Hidrográfica*, 21-22 de Junho 2010 Lisbon, 273-276.

Belden, E. and Morris, K., The Elmer Avenue Neighborhood Demonstration Project:

Measuring the success of green infrastructure. In: watershedhealth.org, *10th Annual StormCon proceedings*, 2011 Anaheim, California, United States, 1-9.

Brandão, P. A. and Piqueiro, F., Interceptor Douro. Sistema centenário de saneamento da cidade do Porto. *6.as Jornadas de Hidráulica, Recursos Hídricos e Ambiente*, 2011 Faculdade de Engenharia da Universidade do Porto, Portugal, 56-81.

Brown, R., Keath, N. and Wong, T., Transitioning to Water Sensitive Cities: Historical, Current and Future Transition States. *11th International Conference on Urban Drainage*, 2008 Edinburgh, Scotland, UK, 1-10.

Coombes, P. J. and Barry, M., A Systems Framework of Big Data for Analysis of Policy and Strategy. *WSUD & IECA*, 2015, 1-12.

Ferreira, H. S. and Leitão, A. B., Integrating landscape and water-resources planning with focus on sustainability. *From landscape research to landscape planning. Aspects of integration, education and application*, 2006 Dordrecht, NL, 143-159.

Guerreiro, M., *et al.*, Impacte da subida do nível médio do mar na inundação marginal no estuário do tejo. *11º SILUSBA Zonas Costeiras* 2013 Maputo, Moçambique, 1-19.

Matos, J., *et al.*, The lisbon drainage master plan - problems, challenges and solutions. *Urban Flood Forecast as a Part of Integrated Urban Drainage Management Workshop*, 2009 Imperial College, UK, 1-4.

Matos Silva, M., Urban flood adaptation through public space. *DeltanNet International Conference*, 2011 Sant Carles de la Rapità, Barcelona, Spain.

Matos Silva, M., New approaches on water management infrastructure. *Soil Bioengineering and Land Management - New Challenges: Sustaining Our Land, Water and Life in Changing Climate*, 2012 Cascais, 88-97 pp.

Matos Silva, M., Urban adaptation through flood risk management infrastructure and public space design. *Landscape: A Place of Cultivation*, 2014 Porto, Portugal, 292 - 296.

Matos Silva, M. and Costa, J. P., Urban flood adaptation through public space design. A contribute to a conceptual framework. *EFLA Regional Congress 2011- Mind the Gap. Landscapes for a new era.* , 2011 Tallinn, Estonia, Acta Architecturae Naturalis ISSN: 2228-1320.

Matos Silva, M. and Costa, J. P., Flood adaptation measures applicable in the design of public spaces: identification and characterization. Joanaz de Melo et al. eds. *Rethinking Sustainability Models and Practices: Challenges for the New and Old World Contexts. 22nd Annual International Sustainable Development Research Society Conference (ISDRS)*, 13-15 July 2016 Lisbon, Portugal, Universidade Nova de Lisboa, 713-731.

Mendes, A. and Oliveira, R. P. d., Conseguem os modelos climáticos simular a precipitação diária máxima anual e horária máxima observada em Portugal Continental? *Congresso da Água, APRH*, 2012 Lisboa, 1-15.

Nirupama, N. and Murty, T. S., Similarities and differences in tsunami and storm surge mitigation. *International Conference on Disaster Management*, 2012 Kumamoto, Japan, 189 - 194.

Pinto, A. J., Remesar, A. and Brandão, P., Networks and anchors: from morphology to the strategy of urban cohesion. *Urban Morphology in Portugal: Approaches and Perspectives. 1st Portuguese Network on Urban Morphology*, 2011 Lisbon, 1-3.

Stokman, A., Water Purificative Landscapes – Constructed Ecologies and Contemporary Urbanism. *Transforming with water: Proceedings of the 45th World Congress of the International Federation of Landscape Architects IFLA 2008*, 2008 Wageningen, 51-61.

R&D Project Grant

Costa, J. P., *et al.*, 2013. Research project "Urbanized Estuaries and Deltas. In search for a comprehensive planning and governance. The Lisbon case." PTDC/AUR-URB/100309/2008. Faculdade de Arquitectura - Universidade de Lisboa and Faculdade de Ciências Sociais e Humanas - Universidade Nova de Lisboa: Funded by FEDER through the Operational Competitiveness Programme - COMPETE and by national funds through FCT - Portuguese Foundation for Science and Technology.

Santos, F. D., *et al.*, 2015. ClimAdaPT.Local - Estratégias Municipais de Adaptação às Alterações Climáticas. Climate Change, Impacts, Adaptation and Modelling

(CCIAM), Faculty of Sciences University of Lisbon: Managed by the Portuguese Environment Agency (APA) and financed by FPC (85%) and EEAGrants (15%).

Santos, F. D., *et al.*, 2014. Cartas de Inundações e de Risco em Cenários de Alterações Climáticas (CIRAC). Centre for Climate Change Impacts Adaptation & Modelling (CCIAM), Faculdade de Ciências da Universidade de Lisboa (FCUL): Associação Portuguesa de Seguradores (APS).

Dataset

EEA, 2013. Raster dataset of built-up and non built-up areas including continuous degree of soil sealing ranging from 0 - 100% in aggregated spatial resolution (100 x 100 m and 20 x 20m). *European Environment Agency (EEA).*

COS, 2007. "Land Use Map / Land Cover for Continental Portugal 2007". Portuguese Geographic Institute.

Journal Article

Adger, W. N. and Barnett, J. 2009. Four Reasons for Concern about Adaptation to Climate Change. *Environment and Planning A,* 41(12), 2800-2805.

Ahern, J. 2011. From fail-safe to safe-to-fail: Sustainability and resilience in the new urban world. *Landscape and Urban Planning,* 100(4), 341-343.

Ahmad, S. S. and Simonovic, S. P. 2012. Spatial and temporal analysis of urban flood risk assessment. *Urban Water Journal,* 10(1), 26-49.

Alcoforado, M.-J., *et al.* 2009. Application of climatic guidelines to urban planning: The example of Lisbon (Portugal). *Landscape and Urban Planning,* 90(1–2), 56-65.

Alexander, C. 1965 A City is Not a Tree. *Architectural Forum,* 122(1 - Part I), 58-62.

Amaral, I. d. 1968. As inundações de 25/26 de Novembro de 1967 na região de Lisboa *Finisterra. Revista Portuguesa de Geografia,* Volume III(Numero 5), 80-87.

Angelakis, A. N. and Zheng, X. Y. 2015. Evolution of Water Supply, Sanitation, Wastewater, and Stormwater Technologies Globally. *Water,* 7(2), 455-463.

Angelakis, A. N., *et al.* 2014. Urban Water Supply, Wastewater, and Stormwater Considerations in Ancient Hellas: Lessons Learned. *Environment and Natural Resources Research,* Vol.4(No.3), 95-102.

Antunes, C. and Taborda, R. 2009. Sea level at cascais tide gauge: data, analysus and results. *Journal of Coastal Research,* SI 56 (Proceedings of the 10th International Coastal Symposium), 218 - 222.

Backhaus, A. and Fryd, O. 2012. Analyzing the First Loop Design Process for Large-Scale Sustainable Urban Drainage System Retrofits in Copenhagen, Denmark. *Environment and Planning B: Planning and Design,* 39(5), 820-837.

Balibrea, M. P. 2001. Urbanism, culture and the post-industrial city: Challenging the 'Barcelona model'. *Journal of Spanish Cultural Studies,* 2(2), 187-210.

Banerjee, T. 2001. The Future of Public Space: Beyond Invented Streets and Reinvented Places. *Journal of the American Planning Association,* 67(1), 9-24.

Barnett, J. and O'Neill, S. 2010. Maladaptation. *Global Environmental Change,* 20(2), 211-213.

Bierbaum, R., *et al.* 2013. A comprehensive review of climate adaptation in the United States: more than before, but less than needed. *Mitigation and Adaptation Strategies for Global Change,* 18(3), 361-406.

Broecker, W. S. 1975. Climatic Change - Are We on Brink of a Pronounced Global Warming. *Science,* 189(4201), 460-463.

Burian, S., *et al.* 1999. Historical Development of Wet-Weather Flow Management. *Journal of Water Resources Planning and Management,* 125(1), 3-13.

Castel-Branco, C. and Ishikawa, M. 2016. Sustainable Post-Disaster Solutions—London 1666, Lisbon 1755 and Japan 2011—Learning from the Past. *Journal of Environmental Science and Engineering A 5,* (6), 196-218.

Chen, X. 2011. Why do people misunderstand climate change? Heuristics, mental models and ontological assumptions. *Climatic Change,* 108(1-2), 31-46.

Cook, J., *et al.* 2013. Quantifying the consensus on anthropogenic global warming in the

scientific literature. *Environmental Research Letters,* 8(2), 1-7.
Coombes, P. J., Argue, J. R. and Kuczera, G. 1999. Figtree Place: a case study in water sensitive urban development (WSUD). *Urban Water,* 1(4), 335-343.
Coombes, P. J. and Barry, M. E. 2007. The effect of selection of time steps and average assumptions on the continuous simulation of rainwater CD harvesting strategies. *Water Science and Technology,* 55(4), 125-133.
Coumou, D. and Rahmstorf, S. 2012. A decade of weather extremes. *Nature Climate Change,* 2(7), 491-496.
Couzin, J. 2008. Living in the Danger Zone. *Science,* 319(5864), 748-749.
Crutzen, P. and Stoermer, E. 2000. The 'Anthropocene'. *Global Change Newsletter,* (41), 17-18.
Crutzen, P. J. 2002. Geology of mankind. *Nature,* 415(6867), 23-23.
d'Angremond, K. 2003. From disaster to Delta Project: the storm flood of 1953. *Terra Aqua,* 90(3), 3-7.
Einfalt, T., *et al.* 2009. URBAS: forecasting and management of flash floods in urban areas. *Urban Water Journal,* 6(5), 369-374.
Fletcher, T. D., *et al.* 2015. SUDS, LID, BMPs, WSUD and more - The evolution and application of terminology surrounding urban drainage. *Urban Water Journal,* 12(7), 525-542.
Folke, C. 2006. Resilience: The emergence of a perspective for social-ecological systems analyses. *Global Environmental Change,* 16(3), 253-267.
Füssel, H. M. 2007. Adaptation planning for climate change: concepts, assessment approaches, and key lessons. *Sustainability Science,* 2(2), 265-275.
Gaudio, R., Penna, N. and Viteritti, V. 2015. A combined methodology for the hydraulic rehabilitation of urban drainage networks. *Urban Water Journal*, 1-13.
Gersonius, B., *et al.* 2013. Climate change uncertainty: building flexibility into water and flood risk infrastructure. *Climatic Change,* 116(2), 411-423.
Giddens, A. 1999. Risk and Responsibility. *The Modern Law Review,* 62(1), 1-10.
Groisman, P. Y., *et al.* 2005. Trends in Intense Precipitation in the Climate Record. *Journal of Climate,* 18(9), 1326-1350.
Hallegatte, S. 2009. Strategies to adapt to an uncertain climate change *Global Environmental Change,* 19(1), pp. 240-247.
Hartmann, T. and Driessen, P. 2013. The flood risk management plan: towards spatial water governance. *Journal of Flood Risk Management*, 1-10.
Hebbert, M. and Jankovic, V. 2013. Cities and Climate Change: The Precedents and Why They Matter. *Urban Studies,* 50(7), 1332-1347.
Jacobeit, J., *et al.* 2014. Statistical downscaling for climate change projections in the Mediterranean region: methods and results. *Regional Environmental Change,* 14(5), 1891-1906.
Jones, H. P., Hole, D. G. and Zavaleta, E. S. 2012. Harnessing nature to help people adapt to climate change. *Nature Climate Change,* 2(7), 504-509.
Kharin, V., *et al.* 2007. Changes in Temperature and Precipitation Extremes in the IPCC Ensemble of Global Coupled Model Simulations. *Journal of Climate,* 20(8), 1419-1444.
Kwadijk, J. C. J., *et al.* 2010. Using adaptation tipping points to prepare for climate change and sea level rise: a case study in the Netherlands. *Wiley Interdisciplinary Reviews: Climate Change,* 1(5), 729-740.
Lennon, M., Scott, M. and O'Neill, E. 2014. Urban Design and Adapting to Flood Risk: The Role of Green Infrastructure. *Journal of Urban Design,* 19(5), 745-758.
Lorenzoni, I. and Pidgeon, N. F. 2006. Public views on climate change: European and USA perspectives. *Climatic Change,* 77(1-2), 73-95.
Madanipour, A. 1997[1972]. Ambiguities of urban design. *Town Planning Review,* 68(3), 363-383.
Matos, J. d. S. 2003. Aspectos Históricos a Actuais da Evolução da Drenagem de Águas Residuais em Meio Urbano. *Engenharia Civil - UM* (Número 16), 13-23.
Matos Silva, M. and Costa, J. 2016. Flood Adaptation Measures Applicable in the Design of Urban Public Spaces: Proposal for a Conceptual Framework. *Water,* 8(7), 284.
McEvoy, D., Fünfgeld, H. and Bosomworth, K. 2013. Resilience and Climate Change

Adaptation: The Importance of Framing. *Planning Practice & Research,* 28(3), 280-293.
Meyer, H. 2010. Urban design in a dynamic delta. *Proceedings of the Institution of Civil Engineers,* Urban Design and Planning, 1 - 13.
Milly, P. C. D., *et al.* 2008. Climate change - Stationarity is dead: Whither water management? *Science,* 319(5863), 573-574.
Min, S.-K., *et al.* 2011. Human contribution to more-intense precipitation extremes. *Nature,* 470(7334), 378-381.
Morin, E. 1974. Complexity. *International Social Science Journal,* 26(4), 555-582.
Oliveira, P. E. and Ramos, C. 2002. Inundações na cidade de Lisboa durante o século XX e seus factores agravantes. *Finisterra,* XXXVII(74), 33-54.
Pall, P., *et al.* 2011. Anthropogenic greenhouse gas contribution to flood risk in England and Wales in autumn 2000. *Nature,* 470(7334), 382-385.
Pelling, M. 1997. What determines vulnerability to floods; a case study in Georgetown, Guyana. *Environment and Urbanization,* 9(1), 203-226.
Rahmstorf, S. 2007. A Semi-Empirical Approach to Projecting Future Sea-Level Rise. *Science,* 315, 368-370.
Rahmstorf, S. 2010. A new view on sea level rise *Nature Reports Climate Change,* 4, 44 - 45.
Ramos, C. 2013. Perigos naturais devidos a causas meteorológicas: o caso das cheias e inundações. *e-LP Engineering and Technology Journal,* vol. 4, 11-16.
Ramos, C. and Reis, E. 2001. As cheias no sul de Portugal em diferentes tipos de bacias hidrográficas. *Finisterra. Revista Portuguesa de Geografia,* XXXVI(71), 61-82.
Rebelo, F. 2008. Um novo olhar sobre os riscos? O exemplo das cheias rápidas (flash floods) em domínio mediterrâneo. *Territorium,* 15, 7-14.
Rebelo, F. and Ganho, N. 1998. As inundações do Outono de 1997 no Sul de Portugal. *Territorium,* (5), 25-30.
Remesar, A., *et al.* 2012. Inclusion and empowerment in public art and urban design. *on the w@terfront,* 24, 3-32.
Ribeiro, L. and Barão, T. 2006. Greenways for recreation and maintenance of landscape quality: five case studies in Portugal. *Landscape and Urban Planning,* 76(1–4), 79-97.
Ricart, N. and Remesar, A. 2013. Reflexiones sobre el Espacio Publico *on the w@terfront,* 25, 5-35.
Rignot, E., *et al.* 2011. Acceleration of the contribution of the Greenland and Antarctic ice sheets to sea level rise. *Geophysical Research Letters,* vol. 38 (L05503), 1-5.
Rijke, J., *et al.* 2012. Room for the River: delivering integrated river basin management in the Netherlands. *International Journal of River Basin Management,* 10(4), 369-382.
Riley, R. 1990. Editorial Commentary: Some Thoughts on Scholarship and Publication. *Landscape Journal,* 9(1), 47-50 pp.
Ruddell, D., *et al.* 2012. Scales of perception: public awareness of regional and neighborhood climates. *Climatic Change,* 111(3-4), 581-607.
Schaeffer, M., *et al.* 2012. Long-term sea-level rise implied by 1.5[thinsp][deg]C and 2[thinsp][deg]C warming levels. *Nature Clim. Change,* 2(12), 867-870.
Schiermeier, Q. 2011. Increased flood risk linked to global warming. *Nature,* 470(7334), 378-381.
Schueler, T. R. 2000. The Importance of Imperviousness. *Watershed Protection Techniques,* (Reprinted in Center for Watershed Protection, Ellicott City, MD), 7-18.
Sheppard, S. R. J. 2015. Making climate change visible: A critical role for landscape professionals. *Landscape and Urban Planning,* 142, 95-105.
Smit, B., *et al.* 2000. An anatomy of adaptation to climate change and vulnerability. *Climatic Change,* 45(1), 223-251.
Soares, P. M. M., *et al.* 2015. Climate change and the Portuguese precipitation: ENSEMBLES regional climate models results. *Climate Dynamics,* 45(7-8), 1771-1787.
Solomon, S., *et al.* 2009. Irreversible climate change due to carbon dioxide emissions. *Proceedings of the National Academy of Sciences of the United States of America,* 106(6), 1704-1709.
Somerville, R. C. J. and Hassol, S. J. 2011. Communicating the science of climate change. *Physics Today,* 64(10), 48-53.
Stern, P. C. 2011. Contributions of Psychology to Limiting Climate Change. *American*

Psychologist, 66(4), 303-314.
Tschakert, P. and Olsson, L. 2005. Post-2012 climate action in the broad framework of sustainable development policies: the role of the EU. *Climate Policy,* 5(3), 329-348.
Valera, S. 1996. Analises de los aspectos simbólicos del espacio urbano. Perspectivas desde la psciologia ambiental. *Revista de psicología Universitas Tarraconenses,* 18(1), 63-84.
Vernon, B. and Tiwari, R. 2009. Place-Making through Water Sensitive Urban Design. *Sustainability,* 1, 789-814 pp.
Vidal, T. and Pol, E. 2005. La apropiación del espacio: una propuesta teórica para comprender la vinculación entre las personas y los lugares. *Anuario de Psicología,* 36(3), 281-297.
Wada, Y., *et al.* 2010. Global depletion of groundwater resources. *Geophysical Research Letters,* 37(20), 1-5.
White, I. and Howe, J. 2004. The mismanagement of surface water. *Applied Geography,* 24(4), 261-280.
Wilbanks, T. and Kates, R. 1999. Global Change in Local Places: How Scale Matters. *Climatic Change,* 43(3), 601-628.
Wilby, R. L. and Keenan, R. 2012. Adapting to flood risk under climate change. *Progress in Physical Geography,* 36(3), 348-378.
Zevenbergen, C., *et al.* 2008. Challenges in urban flood management: travelling across spatial and temporal scales. *Journal of Flood Risk Management,* 1(2), 81-88.

Legal Rule or Regulation

DR 9/2009, Decreto Regulamentar, Conceitos técnicos nos domínios do Ordenamento do Território e do Urbanismo.
Directive 2007/60/EC, Assessment and management of flood risks 2007 (European Parliament and of the Council, Official Journal of the European Union, L 288/27, 23 October).
DL 115/2010, Avaliação e gestão dos riscos de inundações (Diário da República, 1.ª série - N.º 206).
ENAAC, Estratégia Nacional de Adaptação às Alterações Climáticas. Presidência do Conselho de Ministros 2010 (Diário da República, 1ª Série - Nº 64 - 24/2010 de 1 de Abril).
PDML, Plano Director Municipal de Lisboa 2012 (Diário da República, 2.ª série - N.º 168 de 30 de agosto de 2012).

Magazine Article

Balibrea, M. P., 2003. Memória e espaço público na Barcelona pós-industrial. *Revista Crítica de Ciências Sociais.* Lisboa, Portugal, 31-54.
Brandão, P., 2013. Entrevista. *ArqA - Arquitectura e Arte - Novas Colectibidades.* Lisboa, Portugal, 28-30.
Cabezas, L., 2002. Concepción y representación de la arquitectura. La enseñanza de los nuevos medios y un antiguo debate. *PSIAX - Estudos e reflexões sobre desenho e imagem.* 3-9.
CML, 1945. Grandes problemas de Lisboa: caneiro de Alcântara. *Revista Municipal. nº 27.* Câmara Municipal de Lisboa, Portugal, 41-46.
Ferreira, F. V. M., 1924. Apontamentos para o estudo dos esgotos de Lisboa. *Revista de Obras Públicas e Minas e das Sciencias Aplicadas à Indústria, nº 629 (Jun.).* 26-33.
Garcia, R. R., 1933. O problema dos esgotos. *Revista da Associação dos Engenheiros Civis Portugueses. - A. 64, nº 693 (Mar.).* 87-96.
Leal, J. C., 2013. Sobre a Paisagem da Baixa. *Rossio - Estudos de Lisboa.* Lisboa, Portugal: Gabinete de Estudos Olisiponenses, 12-21.
Mital, S., 2013. A rain catcher whose mission is to simplify RWH. *The New Indian Express.* ENS - Bangalore, India, 1-2.
Remesar, A., 2005. Reflexiones sobre la privatización del espacio público. *intervir.* Câmara Municipal da Moita, Portugal: Departamento de Planeamento e Gestão

Urbanística 32-37.
Silva, J. F. d., 1874. Ante-projecto do saneamento de Lisboa. *Revista de obras públicas e minas, Tomo 5, nº49 (Jan).* 1-4.
Verschoor, M., 2009. Climate Hot Spot investigation, Stakeholders demand regional research data. *Change Magazine.* Copenhagen, Denmark: Ministery of Climate and Energy 24-29.
Xavier de Brito, M., 1954. O relevo da cidade de Lisboa e as enxurradas. *Revista Municipal nº62.* Publicação Cultural da Câmara Municipal de Lisboa, Portugal, 41-47.
Zheng, X., 2007. The Ray and Stata Center. *TOPOS The International Review of Landscape Architecture and Urban Design, nº59. Water: Design and Management.* Germany: Callwey, 45 - 49.

Online Multimedia

CP4-FVI-MAPS [Google Fusion Tables]. (2014). CIRAC. Available from: https://www.google.com/fusiontables /cp4-fvi-maps [Accessed 15 July 2015].
Apresentação publica do Plano de Drenagem 2016-2030 [Video]. (2015). CML. Available from: https://vimeo.com/133367990 [Accessed 16th August].
As Cheias de 1967 [Video]. (1973). Costa, L. F. Available from: www.rtp.pt/arquivo/?article=732 [Accessed July 15th].
O Urbano e a Urbanística ou os tempos das formas [Video]. (2012). Portas, N. Available from: http://www.culturgest.pt/actual/01/01-nunoportas.html [Accessed 29th January 2012].

Archive Sources

Celestino da Costa, P. C., 1956. Determinação dos caudais pluviais urbanos: generalização do método racional. *Lisboa: Instituto Superior Tecnico* 1-8. Cota: 002331DF BAHOP.
CML, 1881. Esgotos de Lisboa: parecer e actas da Comissão nomeada em 4 de Agosto de 1880. *Lisboa: Typ. Universal.* 1-511. Cota: 001723C BAHOP.
Júnior, P. d. F., 1971. O estuário, tanque séptico da megalópolis. Administração-Geral do Porto de Lisboa (trad. de Manuel Pereira), 7 pp. Cota: 001132DF BAHOP.
Silva, A. V. d., 1950. Planta da Cidade de Lisboa. *Câmara Municipal de Lisboa: Gabinete de Estudos Olisiponenses (GEO).* Quota MP 59.

Report

Aguiar, R., 2010. *Plano Estratégico de Cascais face às Alterações Climáticas (PECAC).* Santos, F. D. and Aguiar, R. eds.: Câmara Municipal de Cascais. 27 pp.
AMS, 2012. *An Information Statement of the American Meteorological Society.* Boston: American Meteorological Society. 7 pp.
ARH-Tejo, 2009. *Informação Técnica da Administração da Região Hidrográfica do Tejo.* Lisboa, Portugal, GOT-00093-OFI-2009. 8 pp.
ARH-Tejo, 2009. *Informação Técnica da Administração da Região Hidrográfica do Tejo.* Lisboa, Portugal, GOT-00037-OFI-2009. 16 pp.
ASC, 2011. *Adapting to climate change in the UK - measuring progress.* Adaptation Sub-Committee of the Committee on Climate Change. 101 pp.
Bahinipati, C. S., 2011. *Economics of Adaptation to Climate Change: Learning from Impact and Vulnerability Literature.* Madras Institute of Development Studies, Working paper no. 213. 27 pp.
Brandão, C., Rodrigues, R. and Costa, J. P. d., 2001. *Análise de Fenómenos Extremos - Precipitações Intensas em Portugal Continental.* Lisboa: Direcção dos Serviços de Recursos Hidricos. 57 pp.
CABE, 2008. *Public space lessons - Adapting public space to climate change.* Taylor, D. ed. London: CABE Space. 8 pp.
Carmin, J., Nadkarni, N. and Rhie, C., 2012. *Progress and Challenges in Urban Climate Adaptation Planning: Results of a Global Survey.* Cambridge: MA: MIT. 30 pp.

CCAP, 2011. *The Value of Green Infrastructure for Urban Climate Adaptation.* Foster, J., Lowe, A. and Winkelman, S. eds. Washington, DC: The Center for Clean Air Policy. 35 pp.

ChiRoN, *et al.*, 2006. *Plano Geral de Drenagem de Lisboa. Fase A: Relatório.* Matos, J. S., *et al.* eds. Miraflores. 108 pp.

ChiRoN, *et al.*, 2006. *Plano Geral de Drenagem de Lisboa. Fase B: Diagnóstico de desempenho do sistema.* Matos, J. S., *et al.* eds. Miraflores. 270 pp.

ChiRoN, *et al.*, 2006. *Plano Geral de Drenagem de Lisboa. Fase C: Desenvolvimento do Plano Geral de Drenagem.* Matos, J. S., *et al.* eds. Miraflores. 270 pp.

CIRCLE-2, 2013. *Adaptation Inspiration Book - 22 implemented cases of local climate change adaptation to inspire European citizens.* Climate Impact Research & Response Coordination for a Larger Europe, The Netherlands: Drukkerij Tienkamp. 162 pp.

City of New York, 2010. *NYC Green Infrastructure Plan.* Holloway, C. and Bloomberg, M. R. eds. New York City. 141 pp.

City of New York, 2011. *PlaNYC: A Greener, Greater New York.* New York City. 197 pp.

City of New York, 2013. *Coastal Climate Resilience: Designing for Flood Risk.* R.Bloomberg, M. and Burden, A. M. eds. United States: New York Department of City Planning. 46 pp.

City of New York, 2013. *PlaNYC: A Stronger, More Resilient New York.* New York City. 438 pp.

City of Philadelphia, 2014. *Green Streets Design Manual.* Philadelphia, US: Mayor's Office of Transportation and Utilities. 96 pp.

CML, 2008. *Carta de Vulnerabilidade ao Risco de Inundação, no concelho de Lisboa.* Câmara Municipal de Lisboa, Departamento de Protecção Civil. Cartography. 1 p.

CML, 2010. *Relatório de caracterização biofísica de lisboa revisão no âmbito da Revisão do Plano Director Municipal de Lisboa.* Lisboa: Câmara Municipal de Lisboa. 43 pp.

CML, 2012. *Avaliação Ambiental Estratégica. Relatorio Ambiental: Plano Director Municipal de Lisboa.* Departamento de Planeamento e Reabilitação Urbana, Lisboa: Câmara Municipal de Lisboa. 146 pp.

CML, 2012. *Relatorio Plano Director Municipal de Lisboa.* Lisboa: Departamento de Planeamento e Reabilitação Urbana, Câmara Municipal de Lisboa (CML). 249 pp.

DEFRA, 2008. *Adapting to Climate Change in England: A Framework for Action.* Department for Environment, Food and Rural Affairs. 51 pp.

Deltacommissie, 2008. *Working together with water - A living land builds for its future.* Veerman, C. ed.: independent Committee of State (the Delta Committee). 138 pp.

Deltares, 2013. *Design concepts of multifunctional flood defence structures.* Oderker, M. and Vermeer, D. eds. The Netherlands, Grant Agreement No: 243401. 60 pp.

DEP, 2013. *NYC Green Infrastructure Annual Report.* NYC Department of Environmental Protection. 35 pp.

Department of the Army, 2011. *Sea-Level Change Considerations for Civil Works Programs.* Washington, DC: U.S. Army Corps of Engineers, EC 1165 -2-212. 32 pp.

Dias, L., *et al.*, 2015. *Manual para a avaliação de vulnerabilidades futuras. Para a elaboração de Estratégias Municipais de Adaptação às Alterações Climáticas* ClimAdaPT.Local ed.: Portuguese Environment Agency (APA), Portuguese Carbon Fund (FPC) and EEAGrants. 26 pp.

EA, 2009. *TE2100 Plan Consultation Document - Managing flood risk through London and the Thames estuary.* London: Environment Agency. 216 pp.

EA, 2011. *Temporary and Demountable Flood Protection Guide.* Ogunyoye, F., Stevens, R. and Underwood, S. eds. Bristol, United Kingdom: Environment Agency. 282 pp.

Easterling, W., Hurd, B. and Smith, J., 2004. *Coping with Global climate change: The Role of Adaptation in the United States.* Pew Center on Global Climate Change. 40 pp.

EEA, 2005. *Vulnerability and adaptation to climate change in Europe.* Copenhagen, Denmark: European Environment Agency, Technical report No 7/2005. 79 pp.

EEA, 2009. *Report on good practice measures for climate change adaptation in river basin management plans.* Cornelius Laaser, *et al.* eds. Copenhagen, Denmark: European Environment Agency, Report No EEA/ADS/06/001. 116 pp.

EEA, 2011. *Green infrastructure and territorial cohesion: The concept of green infrastructure* *and its integration into policies using monitoring systems.* Copenhagen, Denmark: European Environment Agency, Report No 18/2011. 138 pp.

EEA, 2012. *Climate change, impacts and vulnerability in Europe 2012. An indicator-based report.* Copenhagen, Denmark: European Environment Agency, Report No 12/2012. 300 pp.

EEA, 2012. *Towards efficient use of water resources in Europe.* Copenhagen, Denmark: European Environment Agency, Report No 1/2012. 70 pp.

EEA, 2012. *Urban adaptation to climate change in Europe: Challenges and opportunities for cities together with supportive national and European policies.* Copenhagen, Denmark: European Environment Agency, Report No 2/2012. 300 pp.

EEA, 2013. *Adaptation in Europe: Addressing risks and opportunities from climate change in the context of socio-economic developments.* Copenhagen, Denmark: European Environment Agency, Report No 3/2013. 132 pp.

European Commission, 2004. *Flood risk management; Flood prevention, protection and mitigation.* Brussels, Belgium: Commission of the European Communities. 11 pp.

European Commission, 2009. *White paper on adapting to climate change: Towards a European framework for action.* Brussels, Belgium: Commission for the European Communities, COM 147 final. 16 pp.

European Commission, 2013. *Adaptation Strategies for European Cities.* Ricardo-AEA ed.: European Commission Directorate General Climate Action. 148 pp.

GLA, 2015. *London Sustainable Drainage Action Plan. Draft for public consultation.* Mayor of London. Greater London Authority. 73 pp.

Hecq(coord.), W., *et al.*, 2008. *ADAPT - Towards an integrated decision tool for adaptation measures - Case study : floods. Final report (phase 1).* Bruxelles: Belgian Science Policy. 129 pp.

Hidra, Engidro and Bluefocus, 2015. *Plano Geral de Drenagem de Lisboa 2016-2030.* Monteiro, A., *et al.* eds.: Câmara Municipal de Lisboa. 345 pp.

ICCATF, 2010. *Recommended Actions in Support of a National Climate Change Adaptation Strategy.* Sutley, N. H., Lubchenco, J. and Abbot, S. eds. The White House Council of Environmental Quality: Executive Office of the President of the United States, Progress Report of the Interagency Climate Change Adaptation Task Force. 72 pp.

ICCATF, 2011. *Federal Actions for a Climate Resilient Nation.* U.S. Global Change Research Program, Progress Report of the Interagency Climate Change Adaptation Task Force. 25 pp.

ICCATF, 2014. *Climate Change Impacts in the United States: The Third National Climate Assessment.* Melillo, J. M., Richmond, T. T. C. and Yohe, G. W. eds. U.S. Global Change Research Program: Interagency Climate Change Adaptation Task Force. 841 pp.

IM, 2010. *Boletim Climatológico Anual.* Ministério da Ciência, Tecnologia e Ensino Superior: Instituto de Meteorologia, I. P. 12 pp.

IPCC, 1994. *Technical Guidelines for Assessing Climate Change Impacts and Adaptations* Univerdity College-London, UK and Centre for Global Environmental Research. Tsukuba, Japan: Prepared by IPCC Working Group II [Carter, T.R., M.L. Parry, H Harasawa, and S. Nishioka (eds.) and WMO/UNEP. CGE-IO15-'94] 59 pp.

IPCC, 2012. *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation.* Field, C. B., *et al.* eds. Cambridge, UK, and New York, NY, USA: Cambridge University Press. 582 pp.

IPCC, 2012. *Summary for Policymakers.* Field, C. B., *et al.* eds. Cambridge, UK, and New York, NY, USA. 19 pp.

IPCC, 2014. *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 [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)].* Geneva, Switzerland. 151 pp.

IPCC, 2014. *Summary for policymakers. In: 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.* Field, C. B., *et al.* eds. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA,. 32 pp.

ISC, 2010. *Promising Practices in Adaptation & Resilience. A Resource Guide for Local Leaders.* Institute for Sustainable Communities. Produced in partnership with Center for Clean Air Policy. 98 pp.

Jacqueline Hoyer, *et al.*, 2011. *Water Sensitive Urban Design. Principles and Inspiration for Sustainable Stormwater Management in the City of the Future. Manual.* HafenCity Universität, Hamburg, Germany, Deliverable 5.1.5. 115 pp.

John Weyant, *et al.*, 2009. *Report of 2.6 Versus 2.9 Watts/m2 RCPP Evaluation Panel* Geneva, Switzerland: IPCC Secretariat. 81 pp.

Kress, A., 2007. *Adaptation and Mitigation: an integrated climate policy approach (AMICA).* Climate Alliance. Interrreg IIIC - Project part-financed by the European Union. 15 pp.

LAAP, 2013. *Two Page Summary for Local Government.* National Adaptation Programme (NAP), United Kingdom: Local Adaptation Advisory Panel. 2 pp.

Lehrer, M., *et al.*, 2010. *Compton Creek. Earthen Bottom Enhancement Feasibility Study.* City of Compton: Coastal Conservancy. 207 pp.

LNEC, 1983. *Contribuição para o estudo da drenagem de águas pluviais em zonas urbanas. Vol. 2.* Abreu(coord.), M. R. ed. Lisboa, Portugal: Laboratório Nacional de Engenharia Civil. 242 pp.

Magnan, A., *et al.*, 2009. *The future of the Mediterranean. From impacts of climate change to adaptation issues.* Paris, France: Institut du développement durable et des relations internationales (IDDRI), CIRED-Météo France. 42 pp.

Moreira(Coord.), N., *et al.*, 2008. *Cheias de 18 de Fevereiro de 2008.* Lisboa, Portugal: Instituto de Meteorologia, I.P., DMC/CIME-01/2008. 143 pp.

Niria, K., 2009. *Sewer Systems Module for Higher Professional Education.* The Hague: Nlingenieurs Sewer Systems Workgroup. 203 pp.

Papacharalambous, M., *et al.*, 2013. *Greater New Orleans Urban Water Plan: Implementation.* Waggonner & Ball Architects ed. 225 pp.

PECAC, 2010. *Plano Estratégico de Cascais face às Alterações Climáticas.* Relatório Executivo e Integrador. F.D. Santos and R. Aguiar (eds). Câmara Municipal de Cascais. 59 pp.

RCI, 2009. *Rotterdam Climate Proof Adaptation Programme. The Rotterdam Challenge on Water and Climate Adaptation.* Rotterdam Climate Initiative. City of Rotterdam. 22 pp.

RCI, 2010. *Rotterdam Climate Proof Adaptation Programme. The Rotterdam Challenge on Water and Climate Adaptation.* Rotterdam Climate Initiative. City of Rotterdam. 30 pp.

RCI, 2013. *Rotterdam Climate Change Adaptation Strategy.* Rotterdam Climate Initiative. City of Rotterdam. 134 pp.

RCI, 2013. *Rotterdam Climate Proof Adaptation Programme. Connecting Water with Opportunities.* Rotterdam Climate Initiative. City of Rotterdam. 8 pp.

Robinson, D., *et al.*, 2009. *Facing up to Rising Sea-Levels: Retreat? Defend? Attack?* Peel, C. ed.: Institution of Civil Engineers, Building Futures, RIBA. 15

Schipper, E. L. F., 2007. *Climate Change Adaptation and Development: Exploring the Linkages.* Tyndall Centre for Climate Change Research - Working Paper No 107. 13 pp.

Sliedrecht, M., *et al.*, 2007. *Waterplan 2 Rotterdam. Working on water for an attractive city.* Jacobs, J., *et al.* eds. Rotterdam: Municipality of Rotterdam, Schieland and Krimpenerwaard Water Control Board, Hollandse Delta Water Authority, Delfland Water Control Board. 160 pp.

Strijkers, D., 2011. *Toolbox Adaptive Measures.* policopied document by Doepel Strijkers Architects, Rotterdam, The Netherlands 15 pp.

TCPA, 2001. *Climate Change Adaptation By Design: a guide for sustainable communities* Shaw, R., Colley, M. and Connell, R. eds.: Town and Country Planning Association 49 pp.

Voorendt, M. Z., 2015. *Examples of multifunctional flood defences - working report.* TU Delft University of Technology: Department of Hydraulic Engineering. 80 pp.

WEF, 2016. *The Global Risks Report 2016.* Switzerland: World Economic Forum, REF: 080116. 97 pp.

Thesis

Biesbroek, G. R., 2014. *Challenging barriers in the governance of climate change adaptation.* (Doctoral Degree). Wageningen University, The Netherlands.

Brandão Estêvão, A. L. G., 2015. *A incerteza no proceso urbano. A produção do espaço na Margem Sul do Estuário do Tejo.* (Doctoral degree). Universitat de Barcelona, Spain. (http://tdx.cat/handle/10803/320178).

Brandão, P., 2004. *Ética e profissões, no Design Urbano. Convicção, responsabilidade e interdisciplinaridade. Traços da Identidade Profissional no Desenho da Cidade.* (Doctoral degree). Universitat de Barcelona, Spain. (http://hdl.handle.net/2445/35424).

Cardoso, M. A., 2008. *Avaliação do desempenho de sistemas de drenagem urbana.* (Doctoral degree). Universidade Técnica de Lisboa, Portugal.

Costa, J. P., 2007. *La Ribera entre Proyectos. Formación y transformación del territorio portuario, a partir del caso de Lisboa.* PhD Thesis. TU Catalonia, Barcelona Technical Superior Scholl of Architecture.

Dias, L., 2016. *As alterações climátocas, as inundações e a cidade.* (Doctoral dregree). Faculty of Architecture, University of Lisbon, Portugal.

Lozano, D. E., 2014. *El diseño del suelo: el papel del pavimento en la creación de la imagen de la ciudad.* (Doctoral degree). Universitat de Barcelona, Spain (http://hdl.handle.net/2445/55839).

Martí, A. M., 1997. *La configuració del paisatge medieval:el comtat de Barcelona fins el segle XI.* (Doctoral Degree). Universitat de Barcelona, Spain.

Matos Silva, M., 2008. *O Desenho como Processo no Projecto de Arquitectura Paisagista.* (Landscape Architecture). Instituto Superior de Agronomia, Universidade Técnica de Lisboa, Portugal.

Matos Silva, M., 2011. *El Modelo Barcelona de espacio público y diseño urbano: Public Space and Flood Management / Dipòsits d'aigües pluvials.* (Master Degree). Universitat de Barcelona, Spain. (http://hdl.handle.net/2445/17762).

Ochoa de Castro, A. R., 2011. *Cidade e Frente de Água. Papel articulador do espaço público.* (Doctoral degree). Universitat de Barcelona, Spain. (http://hdl.handle.net/2445/43144).

Oliveira, P., 2003. *Inundações na cidade de Lisboa - Estudo de Hidrogeografia Urbana.* (Master Degree). Universidade de Lisboa, Portugal.

Pinto, A. J., 2015. *Coesão urbana: o papel das redes de espaço público.* (Doctoral degree). Universitat de Barcelona, Spain (http://hdl.handle.net/2445/67852).

Quintino, M. I., 2011. *A água enquanto matéria construtora no projecto de arquitectura paisagista.* (Master Degree). Instituto Superior de Agronomia, University of Lisbon, Portugal.

Reis, G. T. d., 1989. *Parque periférico de Lisboa.* (Landscape Architecture). Instituto Superior de Agronomia, Universidade Técnica de Lisboa, Portugal.

Santacruz, R., 2012. *El Modelo Barcelona de Espacio Público y Diseño Urbano. El espacio público en la regeneración de frentes fluviales: el parque fluvial del Besòs.* (Master Degree). Universitat de Barcelona, Spain.

Web

ADAM, 2009. *ADAM Digital Compendium — Home* [online]. Available from: http://adam-digital-compendium.pik-potsdam.de/ [Accessed 6th July 2012].

ADAPT, 2005. *Towards an integrated decision tool for adaptation measures. Case study: floods* [online]. Available from: http://dev.ulb.ac.be/ceese/ADAPT/home.php [Accessed 11th June 2012].

AECOM, 2016. *Liverpool Pier Head* [online]. Available from: http://www.aecom.com/projects/liverpool-pier-head/ [Accessed 14th July 2016].

AMICA, 2006. *Matrix of Adaptation Measures* [online]. Available from: http://www.amica-climate.net/online_tool.html [Accessed 4th June 2012].

APL, 2011. *Tabela de marés* [online]. Administração do Porto de Lisboa, Instituto Hidrográfico. Available from: http://www.portodelisboa.pt/ [Accessed 1st January 2014].

Buster Simpson, 2015. *Public Art Works* [online]. Available from:

http://www.bustersimpson.net/ [Accessed 26th July 2016].
CAKE, 2010. *About CAKE* [online]. Available from: http://www.cakex.org/about-cake [Accessed 5th June 2012].
CcSP, 2004. *Climate 'changes' Spatial Planning programme* [online]. Available from: http://www.climatechangesspatialplanning.nl/ [Accessed 2th June 2012].
Cerdà, I., 1867. *Teoría General de la Urbanización de sus Principios y Doctinas a la Reforma y Ensanche de Barcelona* [online]. Available from: http://www.anycerda.org [Accessed 2nd April 2015].
Ci:Grasp, 2008. *The Climate Impacts: Global and Regional Adaptation Support Platform* [online]. Available from: http://pik-potsdam.de/cigrasp-2/ [Accessed 1th July 2012].
City of New York, 2016. *East Side Coastal Resiliency Project - Vision* [online]. NYC.org. Available from: http://www1.nyc.gov/site/escr/vision/vision.page [Accessed 13th April 2016].
CLABSA, *Clavegueram de Barcelona, S.A.* [online]. Available from: http://www.clabsa.es/ [Accessed 4th of January 2011].
Climate-ADAPT, 2012. *About us* [online]. Available from: http://climate-adapt.eea.europa.eu/about [Accessed 28th June 2012].
ClimWatAdapt, 2010. *Why this project?* [online]. Available from: http://www.climwatadapt.eu/ [Accessed 1st July 2012].
CML, *Hemeroteca Digital* [online]. Câmara Municipal de Lisboa. Available from: http://hemerotecadigital.cm-lisboa.pt/.
CML, 2015. *Pavimentar Lisboa 2015-2020* [online]. Available from: http://www.cm-lisboa.pt/pavimentar-lisboa [Accessed 16th August 2015].
CML, 2015. *Urbanismo - Uma Praça em Cada Bairro-Intervenções em Espaço Público* [online]. Available from: http://www.cm-lisboa.pt/viver/urbanismo [Accessed 16th August 2015].
De Urbanisten, 2013. *Water Square Benthemplein* [online]. Available from: www.urbanisten.nl [Accessed 31st May 2016].
Dias, L., *et al.*, 2014. *Guia metodológico para a produção de cartografia de risco de inundações* [online]. Available from: http://cirac.apseguradores.pt/ [Accessed 7 of June 2014].
Dutch Dialogues, 2011. *About Dutch 'Dialogues'* [online]. Available from: www.dutchdialogues.com [Accessed April 2011].
EEA, 2011. *Urban morphological zones 2006* [online]. European Environment Agency Available from: www.eea.europa.eu [Accessed July 20th 2015].
ESPACE, 2007. [online]. Available from: http://www.espace-project.org/ [Accessed 3rd June 2012].
Flood Control International, *Glass Barriers - Data Sheet* [online]. www.floodcontrolinternational.com. [Accessed 14th May 2015].
Giddens, A., 1999. *Runaway World, Lecture 2 – Risk – Hong Kong* [online]. Reith Lectures: BBC online Network. Available from: http://news.bbc.co.uk/hi/english/static/events/reith_99/week2/week2.htm [Accessed 15th August 2015].
GRaBS, 2008. *Green and Blue Space Adaptation for Urban Areas and Eco Towns* [online]. Available from: http://www.ppgis.manchester.ac.uk/grabs/ [Accessed 10th July 2012].
IPCC, 2015. *Organization - IPCC - Intergovernmental Panel on Climate Change* [online]. Available from: http://www.ipcc.ch [Accessed 16th September 2015].
Jones-Bos, R., 2012. *Closing Keynote Speech: New Paradigm - Living with Water* [online]. Available from: http://www.planningreport.com/2012/04/17/dutch-ambassador-ren-e-jones-bos-cost-comes-benefit [Accessed 17.12 2012].
Kwon, K.-W., 2007. *Cheong Gye Cheon Restoration Project, a revolution in Seoul* [online]. Seoul, South Korea: Seoul Metropolitan Government. Available from: http://worldcongress2006.iclei.org [Accessed 2nd April 2016].
Landscape Institute, 2014. *Case studies library* [online]. Inspiring great places. Available from: http://www.landscapeinstitute.org/casestudies/ [Accessed 22nd Mach 2014].
LLDC, 2016. *Landscaping the park* [online]. Available from: http://queenelizabetholympicpark.co.uk/ [Accessed 22 January 2016].

mvvainc, 2012. *Projects: Corktown Common* [online]. Michael van Valkenburgh Associates. Available from: http://www.mvvainc.com/ [Accessed 18th July 2016].

Neue Ufer, 2013. *Home* [online]. Available from: http://www.neue-ufer.de [Accessed 16th July 2016].

Oppenheimer, M., 2010. *Ice Sheets, Sea Level Rise, and the Increasing Risk to Deltas* [online]. Rotterdam: Key Speech at 'Deltas in Times of Climate Change' International Conference. Available from: http://www.climatedeltaconference.org/results [Accessed 25th January 2011].

Pope Francis, 2015. *Encyclical letter Laudato Si' of the Holy Father Francis* [online]. Vatican: Vatican Press. Available from: http://w2.vatican.va/content/vatican/en.html [Accessed 5th October 2016].

PPS, 2003. *What Makes a Successful Place?* [online]. Project for Public Spaces. Available from: http://www.pps.org/reference/grplacefeat/ [Accessed 27 June 2013].

Rebuild By Design, 2013. *BIG team final proposal* [online]. Available from: http://www.rebuildbydesign.org/project/big-team-final-proposal/ [Accessed 13th April 2016].

Remesar, A. and Pol, E., 1999. *Repensar el río. Taller de Participación ciudadana "Usos Sociales del Río Besòs"* [online]. Publicacions i Edicions UB. Available from: http://www.ub.edu/escult/usos_besos/SOcial_uses.pdf [Accessed 2nd May 2016].

Robinson, A. and Hopton, H. M., 2011. *Case study of Elmer Avenue Neighborhood Retrofit* [online]. Landscape Architecture Foundation. Available from: http://landscapeperformance.org/ [Accessed 12 January 2016].

Seelemann, G., 2015. *Opening-up the rivers in Leipzig* [online]. On behalf of Development Association Neue Ufer Leipzig e.V. Available from: http://www.urban-project.lviv.ua/ [Accessed 16th Juky 2016].

Simonet, G., 2010. *The concept of adaptation : interdisciplinary scope and involvement in climate change* [online]. S.A.P.I.EN.S, 3.1. Available from: http://sapiens.revues.org/997 [Accessed 24th September 2015].

Smith, M., 2010. *Moving Edges* [online]. Rotterdam: Key Speech at 'Deltas in Times of Climate Change' International Conference. Available from: http://www.climatedeltaconference.org/results [Accessed 25th January 2011].

Solà-Morales, M. d., 2012. *Scheveningen Den Haag, 2006-2012* [online]. Available from: http://manueldesola-morales.com [Accessed 26th January 2016].

Susdrain, 2012. *Susdrain Case Studies* [online]. CIRIA. Available from: http://www.susdrain.org/case-studies [Accessed 14th April 2016].

SWITCH, 2006. [online]. Available from: www.switchurbanwater.eu [Accessed 4th June 2012].

The Flood Observatory, 2016. *Active Archive of Large Floods, 1985-Present* [online]. Available from: http://floodobservatory.colorado.edu/ [Accessed 18th August 2016].

Turenscape, [online]. Available from: http://www.turenscape.com/ [Accessed 1st of June 2016].

UKCIP, 2012. *About us* [online]. Available from: http://www.ukcip.org.uk/about-ukcip/ [Accessed 28th June 2012].

United Nations, 2015. *Statements made during the Leaders Event at the Paris Climate Change Conference - COP 21 / CMP 11* [online]. United Nations Framework Convention on Climate Change. Available from: http://unfccc.int/meetings/paris_nov_2015/items/9331.php [Accessed 18th August 2016].

Voltaire, 1785. *Oeuvres completes de Voltaire* [online]. Société Littéraire-Typographique. 504 pp. Available from: https://archive.org/details/oeuvrescomplete43volt [Accessed 3rd August 2016].

WATERFRONToronto, 2009. *Explore projects: Corktown Common* [online]. Available from: www.waterfrontoronto.ca [Accessed 18th July 2016].

weADAPT, 2011. *About weADAPT* [online]. Available from: http://weadapt.org/knowledge-base/guidance/overview-of-weadapt [Accessed 4th June 2012].

Glossary

Adaptation – The process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In natural systems, human intervention may facilitate adjustment to expected climate and its effects (see chapter two detailed analysis).

Adaptive Capacity – The combination of the strengths, attributes, and resources available to an individual, community, society, or organization that can be used to prepare for and undertake actions to reduce adverse impacts, moderate harm, or exploit beneficial opportunities (IPCC 2012, p.556).

Albedo – Albedo is the proportion of incident solar radiation reflected by a surface. Typically given as a decimal fraction, having a value between '0' and '1'. (Erell et al. 2011).

Catchment – The area of surface water flow contributing to a point on a drainage or river system. One catchment basin can include multiple sub-catchments.

Channel – An open conduit either naturally or artificially created which periodically or continuously contains moving water, or which forms a connecting link between two bodies of water (Lehrer et al. 2010).

Climate impact – The effects of climate change on natural and human systems.

Climate Model - A numerical representation of the climate system that is based on the physical, chemical, and biological properties of its components, their interactions, and feedback processes, and that accounts for all or some of its known properties. The climate system can be represented by models of varying complexity, that is, for any one component or combination of components a spectrum or hierarchy of models can be identified, differing in such aspects as the number of spatial dimensions, the extent to which physical, chemical, or biological processes are explicitly represented, or the level at which empirical parameterizations are involved. Climate models are applied as a research tool to study and simulate the climate, and for operational purposes, including monthly, seasonal, and inter-annual climate predictions (IPCC 2012).

Climate scenario – A plausible and often simplified representation of the future climate, based on an internally consistent set of climatological relationships that has been constructed for explicit use in investigating the potential consequences of anthropogenic climate change, often serving as input to impact models. Climate projections often serve as the raw material for constructing climate scenarios, but climate scenarios usually require additional information such as about the observed current climate. (IPCC 2012).

Climate-driven – related to changes in climate.

Co-benefits – The positive effects that a policy or measure aimed at one objective might have on other objectives.

Combined Sewage Overflows (CSO's) – CSO's occur when, in combined sewage systems, wet stormflows exceed the sewage treatment plant capacity and are consequently directly diverted onto a receiving water body.

Combined Sewage System (CSS) – Wastewater and stormwater are collected in one pipe network.

Conference of the Parties (COP) – The COP is the supreme decision-making body of the Convention. All States that are Parties to the Convention are represented at the COP, at which they review the implementation of the Convention and any other legal instruments that the COP adopts and take decisions necessary to promote the effective implementation of the Convention, including institutional and administrative arrangements. (www.unfccc.int).

Conveyance – Movement of water from one location to another.

First flush – First flush is the initial surface runoff of a rainstorm. During this phase, water pollution entering storm drains, and subsequently surface waters, is typically more concentrated compared to the remainder of the storm. First flush runoff typically carries a very large amount of both suspended and dissolved pollutants (Lehrer et al. 2010).

Flood – The overflowing of the normal confines of a stream or other body of water, or the accumulation of water over areas not normally submerged. Floods include river (fluvial) floods, pluvial floods, coastal floods, groundwater floods, sewer floods or artificial drainage floods, and glacial lake outburst floods.

Flood risk – In the European flood directive (2007/60/EC) flood risk is described as "the combination of the probability of a flood event and of the potential adverse consequences for human health, the environment, cultural heritage and economic activity associated with a flood event" (2007/60/EC 2007). 'Risk' is therefore the result of the function between the probability of occurrence and the consequence of the impact. While the first is dependent on climate regimes and the physical characteristics of the catchment basins by which floods are conveyed, the latter is associated to the magnitude of a flood (peak flow, volume, duration, etc.) together with the vulnerability of whatever is exposed to a that particular event (Karin de Bruij et al. 2009).

Greenhouse gas (GHG) – A gas in the atmosphere, of natural and human origin, that absorbs and emits thermal infrared radiation. Water vapour, carbon dioxide (CO_2), nitrous oxide (N_2O), methane (N_2O) and ozone (O_3) are the main greenhouse gases in the Earth's atmosphere. Their net impact is to trap heat within the climate system.

Grey literature – Grey literature is generally defined as academic literature that is not formally published. Examples of grey literature include patents, technical reports from government agencies or scientific research groups, working papers from research groups or committees, white papers, and preprints.

Groundwater – Water located beneath the ground surface in soil pore spaces and in the fractures of lithologic formations (Lehrer et al. 2010).

Groundwater Recharge – A hydrologic process where water moves downward from surface water to groundwater. Recharge occurs both naturally (through the water cycle) and anthropologically (i.e., "artificial groundwater recharge"), where rainwater and or reclaimed water is routed to the subsurface (Lehrer et al. 2010).

Hydrological cycle – The Hydrological cycle is the cycle in which water evaporates from the oceans and the land surface, is carried over the Earth in atmospheric circulation as water vapour, condenses to form clouds, precipitates over ocean and land as rain or snow, which on land can be intercepted by trees and vegetation, provides runoff on the land surface, infiltrates into soils, recharges groundwater, discharges into streams and ultimately flows out into the oceans, from which it will eventually evaporate again. The various systems involved in the hydrological cycle are usually referred to as hydrological systems (IPCC 2014b).

Levee effect – The levee-effect symbolizes the false sense of safety given by dams, levees and other flood protections. These structures increase flood losses because they incite new developments in floodplains, thus promoting catastrophic damages when these man-made flood protections for some reason fail. Examples where this phenomenon was felt are numerous, among the most disastrous are: 1421 St. Elizabeth's flood at the North Sea, The Netherlands; 1953 North Sea floods, at The Netherlands and United Kingdom and 2005, Hurricane Katrina floods at New Orleans.

Microclimate – A local atmospheric zone where the climate differs from the surrounding area.

Mitigation – A human intervention to reduce the sources or enhance the sinks of greenhouse gases.

Ocean acidification – A reduction in the pH of the ocean over an extended period, typically decades or longer, which is caused primarily by uptake of carbon dioxide from the atmosphere.

Phytodepuration – Phytodepuration is an ecological treatment technique that replicates natural purification processes in a controlled environment.

Projection – A potential future evolution of a quantity or set of quantities, often computed by a model. Projections involve assumptions that may or may not be realized, and are therefore subject to substantial uncertainty; they are not predictions.

Representative Concentration Pathways (RCPs) – RCPs are greenhouse gas concentration trajectories used by IPCC for its AR5 in 2013-14. It replaced the former Special Report on Emissions Scenarios (SRES) projections published in 2000 (namely the scenario families A1, A2, B1 and B2). The four greenhouse gas concentration pathways describe four possible futures depending on how much greenhouse gases are emitted in the years to come. RCP2.6, RCP4.5, RCP6, and RCP8.5, are named after a possible range of radiative forcing (climate science concept) values in the year 2100 relative to pre-industrial values (+2.6, +4.5, +6.0, and +8.5 W/m2, respectively) (John Weyant et al. 2009).

Resilience – The capacity of social, economic, and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity, and structure. For Folke, the most resilient social-ecological systems are characterised not only by their ability to endure disturbance but also by their capacity to learn and adjust if necessary (Folke 2006, p. 259).

Runoff – Runoff is the part of precipitation that does not evaporate and is not transpired, but flows through the ground or over the ground surface and returns to the water bodies (IPCC 2014b).

Sensitivity / Susceptibility – Sensitivity or susceptibility determines the degree to which the system is affected (beneficially or adversely wise) in regards to a given weather exposure. Sensitivity or susceptibility is typically conditioned by natural and physical conditions of the system (e.g. its topography, soils resistance to erosion, their type of occupation, among others) and the human activities that affect the natural and physical conditions of the system (e.g. agricultural practices, resource management and the forms of pressures related to settlements and population) (Dias et al. 2015).

Separate sewage system – Wastewater and stormwater are collected in two separate networks.

Singel – A particular type of Dutch canal, typically from the 19th century, that runs through the city

Source control – The control of stormwater runoff at or near its source (Fletcher et al. 2015).

Stoplogs – hydraulic engineering control element that is used in floodgates to adjust the water level or flowrate in a river, canal, or reservoir. Stoplogs are typically long rectangular timber beams or concrete boards that are placed on top of each other and dropped into premade slots inside a weir, gate, or channel.

Storm surge – A storm surge consists in a mass of water that, though the effects of strong winds and/or the suction effects of low pressure, exceeds above the level expected from the tidal variation alone at that time and place. (IPCC 2012).

Sustainable development – Development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

Sustainable urban drainage systems (SUDS) or Sustainable drainage systems (SuDS) – "SUDS consist of a range of technologies and techniques used to drain stormwater/surface water. (…) They are based on the philosophy of replicating as closely as possible the natural, pre-development drainage from a site" (Fletcher et al. 2015, p.529).

Urban Heat Island (UHI) – The relative warmth of a city compared with surrounding rural areas. Temperatures are higher in cities than the corresponding temperatures in the surrounding rural areas. This phenomenon can be exacerbated by the large areas of low albedo surfaces, such as dark paving or roofing materials. It is generally defined as the difference between the highest air temperatures recorded in the urban canopy and the lowest recorded in the surrounding rural areas . Outlining the evolution of urban climatology since 1950, Hebbert and Jankovic highlight the fact that the urban heat island effect is the longest studied category of urban-scale climate research (Hebbert and Jankovic 2013).

Urban Morphological Zone (UMZ) – An UMZ can be defined as "A set of urban areas laying less than 200m apart. Those urban areas are defined from land cover classes contributing to the urban tissue and function" (EEA 2011).

Vulnerability – The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt (IPCC 2014a). See concepts of sensitivity or susceptibility.

Water security – Secure access to an acceptable quantity and quality of water for health, livelihoods and production.

Water table – the planar, underground surface beneath which earth materials, as soil or rock, are saturated with water.

Abbreviations and acronyms

ADAM	ADaptation And Mitigation Strategies: supporting European climate policy
ADAPT	Towards an integrated decision tool for adaptation measures
AMICA	Adaptation and Mitigation: an Integrated Climate Policy Approach
APA	Portuguese Environment Agency Agência Portuguesa do Ambiente www.apambiente.pt
APL	Administação do Porto de Lisboa Lisbon's Port Authority
APS	Portuguese Association of Insurers Associação Portuguesa de Seguradores www.apseguradores.pt
AR4	Forth Assessment Report
AR5	IPCC Fifth Assessment Report
ARs	Assessment Reports
AUB	Alcântara Upper Basin Zona Alta da Bacia de Alcântara
BMPs	Best Management Practices
CABE	Commission for Architecture and the Built Environment
CAKE	Climate Adaptation Knowledge Exchange
CCIAM	Climate Change, Impacts, Adaptation and Modelling research group www.sim.ul.pt/cciam
CcSP/KvR	Climate 'changes' Spatial Planning/Klimaat voor Ruimte
ci:grasp	The Climate Impacts: Global and Regional Adaptation Support Platform
CIAAC	Interministerial Commission on Air and Climate Change Comissão Interministerial do Ar e Alterações Climáticas
CIRAC	Flood Risk and Vulnerability Mapping in Climate Change Scenarios Cartas de Inundações e de Risco em Cenários de Alterações Climáticas www.siam.fc.ul.pt/cirac/
CIRCLE-2	Climate Impact Research & Response Coordination for a Larger Europe
CLIMAAT II	Impactos e Medidas de Adaptação às Alterações Climáticas no Arquipélago da Madeira
Climate-ADAPT	European Climate Adaptation Platform
ClimWatAdapt	Climate Adaptation: modelling water scenarios and sectorial impacts
CML	Câmara Municipal de Lisboa Lisbon's Municipality
COP	Conference of the Parties from the UNFCCC

CSO	Combined Sewage Overflow
CSS	Combined Sewage System
DEFRA	Department for Environment, Food and Rural Affairs
DN	"Diâmetro Nominal" de tubos. The same as NPS - Nominal Pipe Size
EA	Environment Agency, United Kingdom
EEA	European Environment Agency www.eea.europa.eu
ENAAC	National Climate Change Adaptation Strategy Estratégia Nacional de Adaptação às Alterações Climáticas
EPAL	Empresa Pública das Águas Livres, S.A.
ESPACE	European Spatial Planning: Adapting to Climate Events
ETAR	Estação de Tratamento de Águas Residuais (=WWTP)
ETC/ACC	European Topic Centre on Air and Climate Change
EU	European Union
FAR	First Assessment Report
FPC	Portuguese Carbon Fund Fundo Português de Carbono
GCMs	General Circulation Models
GCRA	Global Change Research Act www.globalchange.gov
GCRP	Global Change Research Program, United States
GHG	Greenhouse Gas
GHO	Global Health Observatory www.who.int
GRaBS	Green and Blue Space Adaptation for Urban Areas and Eco Towns
ICCATF	Interagency Climate Change Adaptation Task Force
IPCC	Intergovernmental Panel on Climate Change www.ipcc.ch
ISC	Institute for Sustainable Communities
IWRM	Integrated Water Resources Management
KP	Kyoto Protocol
LAAP	Local Adaptation Advisory Panel, United Kingdom
LID	Low Impact Development
LNEC	Laboratório Nacional de Engenharia Civil

NPCC	New York City Panel on Climate Change
NPS	Nominal Pipe Size. The same as “Diâmetro Nominal” DN, in Portuguese.
PDM	Municipal Master Plan / Plano Director Municipal
PECAC	Plano Estratégico de Cascais face às Alterações Climáticas
PECSAC	Plano Estratégico do Concelho de Sintra face às Alterações Climáticas
PGDL	Lisbon's Drainage Master Plan Plano Geral de Drenagem de Lisboa
PNAC	(Portuguese) National Programme for Climate Change Programa Nacional para as Alterações Climáticas
PNALE	National Allocation Plan for Emissions Plano Nacional de Atribuição de Licenças de Emissão
PPS	Project for Public Spaces www.pps.org
PV	Plano Verde de Lisboa
QEPiC	Strategic Framework for Climate Policy Quadro Estratégico de Politica Climática
R&D	Research and Development
RCI	Rotterdam Climate Initiative, The Netherlands
RCMs	Regional Climatic Models
RCPs	Representative Concentration Pathways
RIBA	Royal Institute of British Architects
RNBC	National Low Carbon Roadmap 2050 Roteiro Nacional de Baixo Carbono 2050
SAR	Second Assessment Report
SFBDCC	San Francisco Bay Conservation and Development Commission www.bcdc.ca.gov
SIAM	Climate Change in Portugal Scenarios, Impacts and Adaptation Measures Alterações Climáticas em Portugal. Cenários, Impactos e Medidas de Adaptação www.siam.fc.ul.pt
SIMTEJO	Concessionary Company of the integrated sanitation of the municipalities of the Tagus and Trancão rivers
SLR	Sea Level Rise
SNIERPA	National Emissions Inventory System Sistema Nacional de Inventário de Emissões por Fontes e Remoção por Sumidouros de Poluentes Atmosféricos
SPeM	National System for Policies and Measures Sistema Nacional para Políticas e Medidas
SSO	Sanitary Sewage Overflow
SSS	Separate Sewage Systems

SUDS	Sustainable urban drainage systems (SUDS) or Sustainable drainage systems (SuDS)
SWITCH	Managing Water for the City of the Future
TAR	Third Assessment Report
TCPA	Town and Country Planning Association
UHI	Urban Heat Island
UKCIP	United Kingdom Climate Impacts Programme
UMZ	Urban Morphological Zone
UNDP	United Nations Development Program
UNEP	United Nations Environment Programme www.unep.org
UNFCCC	United Nations Framework Convention on Climate Change www.unfccc.int
USGCRP	U.S. Global Change Research Program
WeADAPT	Adaptation Planning, Research and Practice
WMO	World Meteorological Organization www.wmo.int
WSUD	Water Sensitive Urban Design
WWTP	Wastewater Treatment Plant (=ETAR)

Index of figures and tables

Figures:

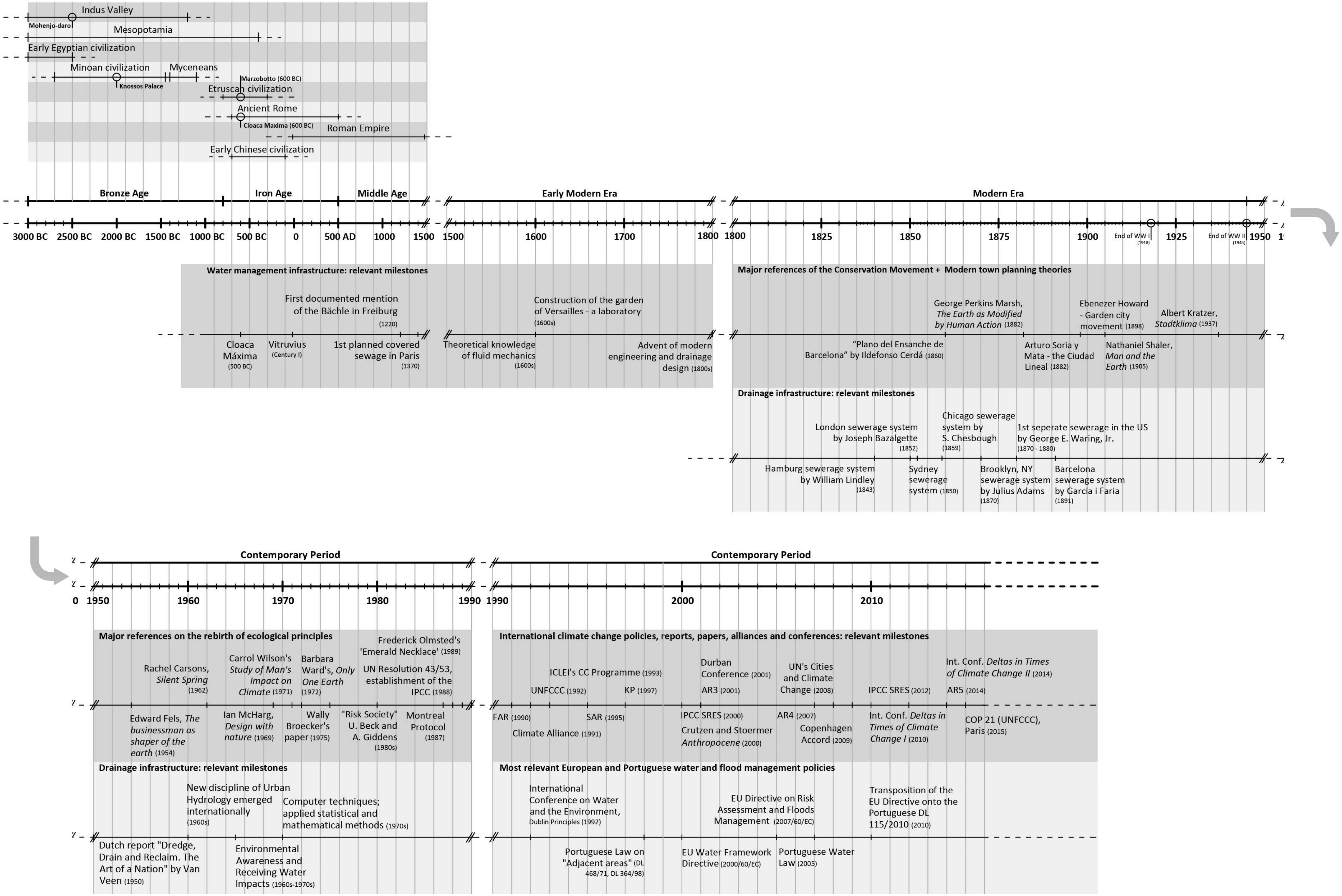
Tables:

General index

ANNEX

I.

Relevant milestones regarding the evolution of flood management practices



Source: developed by the author.

II.

Examples of public spaces with flood adaptation purposes classified in light of the Public Space Typologies presented by Brandão (2011).

Annex II - Examples of public spaces with flood adaptation purposes classified in light of the Public Space Typologies presented by Brandão (2011).

Following the public space typology presented by Brandão (2011)1, in Table A.1, each example is classified according to a particular type of public space. **X**, in bolt, evidences the type of public space to which the respective example mostly relates. Normal X, evidences other types of public space to which the respective example can relate.

Table A.1 – Portfolio screening classified in light of the Public Space typologies presented by Brandão (2011).

Examples		**Public Space Typologies** (translated by the author)					
#	**Project name**	**"Layout spaces"**	**"Landscape spaces"**	**"Itinerating spaces"**	**"Memory spaces"**	**"Commerce spaces"**	**"Generated spaces"**
1	Caixa Forum plaza	**X**		X	X		X
2	Westblaak' car park silo			**X**			
3	Woolworths Shopping playgr.					X	**X**
4	North Road					X	**X**
5	Expo Boulevard	**X**					X
6	Jawaharlal Planetarium Park		**X**				X
7	'Water Table / Water Glass'	**X**					X
8	Whole Flow'	X		**X**			
9	Dakpark		X	**X**		X	X
10	Promenade Plantée		**X**	X	X		X
11	European Patent Office	X	**X**				
12	Womans University campus	X	X				**X**
13	High Line Park	X	**X**	X	X		
14	Waltebos Complex		X			**X**	
15	Stephen Epler Hall						
16	Parc de Diagonal Mar	X	**X**	X	X		X
17	Parc del Poblenou	X					**X**
18	Benthemplein square	**X**	X				X
19	Tanner Springs Park	**X**	X				X
20	Parc de Joan Miró	X	**X**	X		X	
21	Escola Industrial *		X				**X**
22	Potsdamer Platz	**X**		X		X	X
23	Museumpark car park			X			X
24	Place Flagey	**X**		X			
25	Stata Center	**X**	X	X		X	

[1] Brandão, P., 2011. *O Sentido da Cidade. Ensaios Sobre o Mito da Imagem Como Arquitectura.* Lisboa: Livros Horizonte.296 pp. ISBN: 978-972-24-1704-4.

26	The Circle	X	X	**X**			X
27	Georgia Street	**X**		X		**X**	
28	Parque Oeste		**X**				
29	Qunli park		**X**				
30	Emerald Necklace		**X**		X	X	X
31	Quinta da Granja	X	**X**			X	
32	Parque da Cidade	X	**X**			X	X
33	Trabrennbahn Farmsen	X	**X**	X	X	X	X
34	Elmhurst parking lot	X		**X**			
35	Ecocity Augustenborg	**X**	X				X
36	Museum of Science	X					**X**
37	High Point 30th Ave			**X**			
38	Moor Park		**X**	X			X
39	Ribblesdale Road	**X**	X	X		X	X
40	South Australian Museum	**X**	X	X			X
41	Columbus Square	**X**	X	X			
42	Derbyshire Street	X	X	X		X	**X**
43	Onondaga County	**X**	X	X			
44	Edinburgh Gardens		**X**	X			X
45	Taasinge Square	**X**	X				X
46	Australia Road	**X**	X				X
47	East Liberty Town Square	X			X		**X**
48	Can Caralleu	X	X	**X**		X	X
49	Zollhallen Plaza	**X**		X		X	
50	Green park of Mondego		**X**				X
51	Bakery Square 2.0	**X**	X	X			
52	Praça do Comércio	X	X	X	**X**	X	X
53	Percy Street	**X**					
54	Greenfield Elementary						**X**
55	Etna Butler Street	**X**	X	X		X	X
56	Community College		**X**				X
57	Elmer Avenue Neighbourhood						
58	Green streets design manual***	**X**	X	X			
59	Ribeira das Jardas	X	**X**				
60	Ahna	X	**X**				
61	River Volme	**X**					
62	Promenada	**X**					
63	Catharina Amalia Park	X	**X**			X	
64	Kallang River		**X**	X			
65	Alb		**X**				

66	Westersingel	X	**X**	X			
67	Thornton Creek						
68	Cheonggyecheon River	**X**	X	X	X		X
69	Soestbach	**X**	X				
70	Banyoles	**X**		X	X		
71	Freiburg Bächle	**X**		X	X	X	X
72	Roombeek						
73	Solar City streets	**X**					
74	Pier Head			X	**X**		
75	Olympic park	X	**X**	X			
76	Kronsberg	X	**X**	X			
77	Renaissance Park		**X**		X		
78	21st Street	**X**					
79	West India Quay	X	X	X			**X**
80	Ravelijn Bridge	X					**X**
81	Yongning River Park		**X**				
82	Landungsbrücken pier	X		**X**		X	
83	Spree Bathing Ship						X
84	Leine Suite						X
85	Rhone River Banks		**X**				
86	Parque fluvial del Gallego		X				
87	Rio Besòs River Park		**X**	X			
88	Buffalo Bayou Park		X				
89	Parc de la Seille	X	**X**				X
90	Park Van Luna		X				
91	Passeio Atlântico	X	**X**				X
92	Quai des Gondoles			**X**			X
93	Elster Millraces	X	X	X	**X**		
94	Terreiro do Rato	**X**	X				X
95	Waterfront promenade	**X**					
96	Tagus Linear Park		**X**				
97	Elbe promenade	X	**X**	**X**	X		
98	Dike of 'Boompjes'	**X**	X				
99	Zona de Banys del Fòrum	X	**X**	X	X		X
100	Molhe da Barra do Douro		**X**		X		
101	Jack Evans Harbour		**X**				
102	Schevenigen	X	**X**	X	X	X	
103	Sea organ	**X**	X		X		
104	Main riverside	X	**X**	X		X	
105	Blackpool Seafront	X	**X**		X		
106	Westhoven	X	X				

107	Waalkade promenade	**X**	X				
108	Kampen waterfront	**X**					X
109	Landungsbrücken building				X		**X**
110	Corktown Common		**X**	X			
111	Westzeedijk	X	X	**X**	X		
112	Anfiteatro Colina de Camões		**X**		X		X

III.

Comprehensive frameworks that encompass adaptation measures related to flood risk management – Table 4.1 extended

Table A.2 - Comprehensive frameworks that encompass adaptation measures related to flood risk management – Table 4.1 extended

	Name (Acronym)	Start–End Year	Origin/Branch of	Used Deliverable(s)			
				Name of Deliverable	Main Characteristics	Scale Extent	Scope
Research centers							
1	Adaptation Planning, Research and Practice (WeAdapt)	2005	Stockholm Environment Institute (SEI)	Articles, Case studies and 'Adaptation Layer'	Online database and sharing platform	General	General
2	UK Climate Impacts Programme (UKCIP)	2007	Environmental Change Institute (\ECI), University of Oxford	Adaptation case studies, AdOpt	Online database, sharing platform and report (34 pp.)	General (Europe)	General
3	Climate Adaptation Knowledge Exchange (CAKE)	2010	EcoAdapt NGO and Island Press	Case Studies Database	Online database and sharing platform	General (USA)	General
4	European Climate Adaptation Platform (Climate-ADAPT)	2012	European Commission and European Environmental Agency (EEA)	Adaptation support tool:database	Online database and sharing platform	Europe	General
R&D projects							
5	European Spatial Planning: Adapting to Climate Events (ESPACE)	2003–2007	Hampshire County Council, Environment Agency and South East England Regional Assembly (SEERA)	SEERA toolkit (2005)	Report (68 pp.)	General (case studies mostly U.K.)	Water management
6	Climate 'changes' Spatial Planning/Klimaat voor Ruimte (CcSP/KvR)	2004–2011	National Programme for Spatial Adaptation to Climate Change	Final report COM11: Deltas on the move	Report (97 pp.)	National (Netherlands)	Water management
				Report A11, Routeplanner 2010–2050	Report (145 pp.)		General
7	Foresight project on Flood and Coastal Defence (Foresight projects)	2004	U.K. Government Office for Science	Future Flooding, Volume 2 (2007)	Report (405 pp.)	National (U.K.)	Flooding
8	Adaptation and Mitigation - an Integrated Climate Policy Approach (AMICA)	2005–2007	Climate Alliance, Klima-Bündnis, Alianza del Clima	Adaptation Tool	Online database	General	General
9	ADaptation And Mitigation Strategies: supporting European climate policy (ADAM)	2006–2009	U.K.'s Tyndall Centre for Climate Change Research	Adam Digital Compendium, Adaptation Catalogue	Online database	Generic	General
10	Towards an integrated decision tool for adaptation measures. Case study: floods (ADAPT)	2006–2008	Université Libre de Bruxelles (ULB), Centre d'Etudes Economiques et Sociales de l'Environnement (CEESE)	Final report (Phase I)	Report (129 pp.)	General	Water management

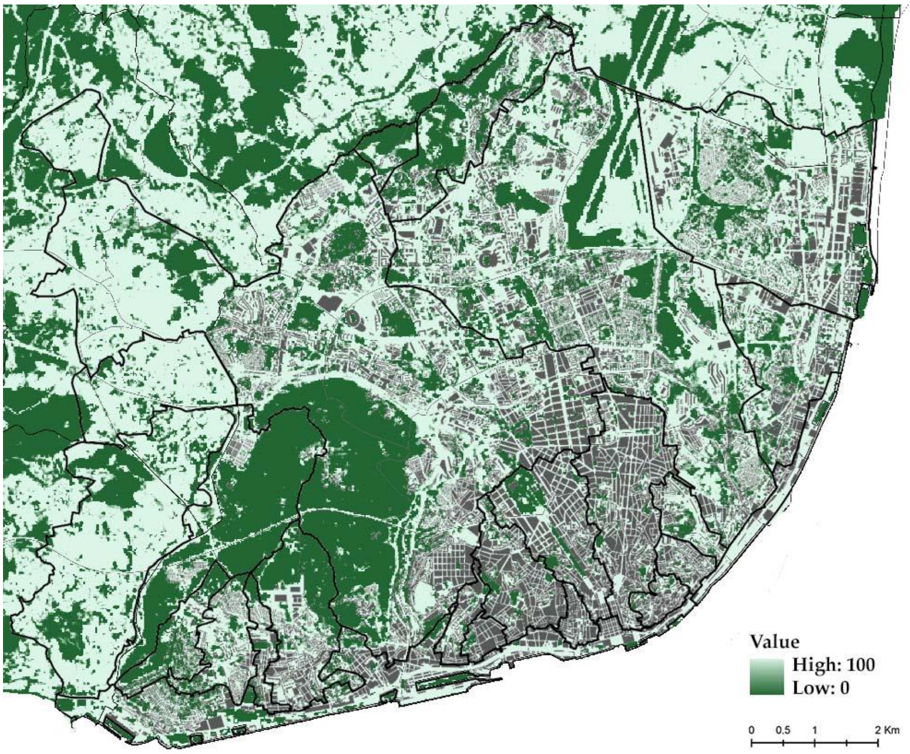
11	Managing Water for the City of the Future (SWITCH)	2006–2011	Consortium of 33 partners from 15 countries	Deliverable 5.1.5	Report (115 pp.)	General	Water management
				Handbook Adapting urban water systems to climate change	Report (53 pp.)	General	
12	Green and Blue Space Adaptation for Urban Areas and Eco Towns (GRaBS)	2008–2011	Consortium of 14 project partners, drawn from 8 EU Member States	Adaptation Action Planning Toolkit	Online database	General	General
13	The Climate Impacts: Global and Regional Adaptation Support Platform (ci:grasp)	2008–2012	German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU)	Adaptation project database	Online database and sharing platform	General	General
14	Climate Adaptation – modelling water scenarios and sectoral impacts (ClimWatAdapt)	2010–2011	Centre for Environmental Systems Research (CESR), European Commission, Directorate General Environment	Inventory of adaptation measures	Database	General	Water management

Books and report

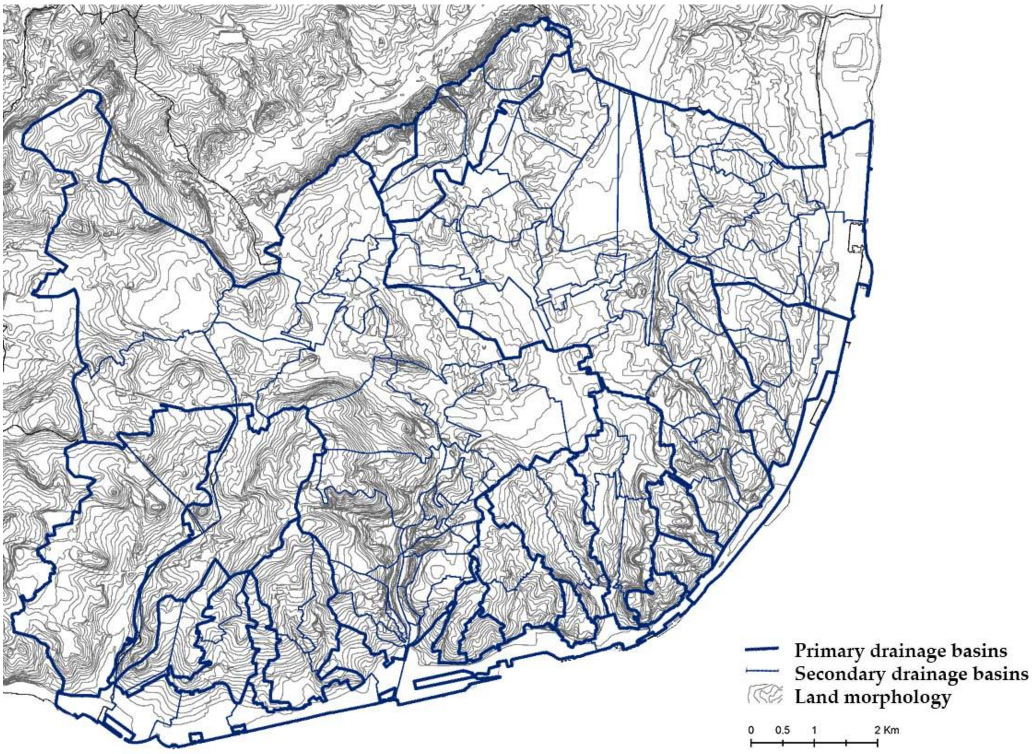
15	European Environmental Agency (EEA)	1993	Agency of the European Union with 33 member countries	Technical No. 2/2012	Report (143 pp.)	General	General
				Technical No. 18/2011	Report (138 pp.)		General
				EEA/ADS/06/001	Report (116 pp.)		Water management
16	Climate Change adaptation by design – a guide for sustainable communities (TCPA Guide)	2007	Town and Country Planning Association (TCPA)	–	Report (49 pp.)	Generic (case studies from U.K.)	General
17	Climate Impact Research & Response Coordination for a Larger Europe (CIRCLE-2)	2010-2014	–	–	Book (162 pp.)	Europe	General
18	Toolbox Adaptive Measures by Doepel Strijkers Architects (Toolbox)	2011	Water & City Conference (13–15 June 2012, TU Delft University)	–	Policopied document	General	Flooding
19	Planning Strategies, Methods and Projects for Urban Rivers (River.Space.Design)	2012	R&D project "process-oriented design of urban river spaces" at Leibniz University Hanover	–	Book (295 pp.)	Europe	Urban river landscapes
20	Adaptation Strategies for European Cities	2013	R&D project "Adaptation Strategies for European Cities"	Ricardo-AEA/R/ED57248 Final Report	Report (148 pp.)	Europe	General
21	Green Streets Design Manual	2014	Mayor's Office of Transportation and Utilities (City of Philadelphia)	-	Design Manual (95 pp.)	Generic (case studies from U.S.)	Stormwater management

IV.

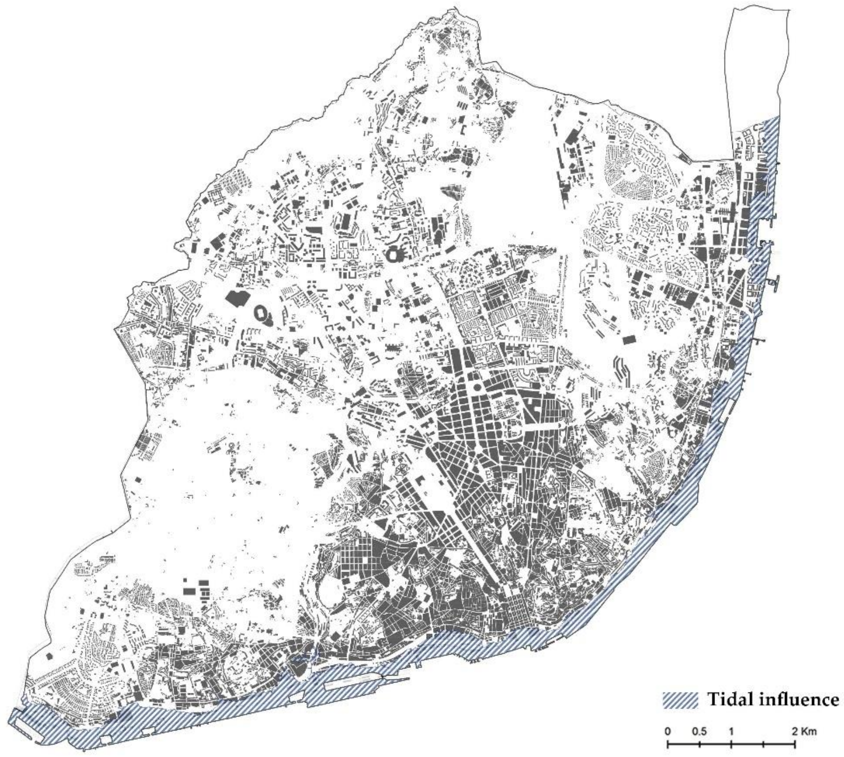
Spatial data regarding the city of Lisbon



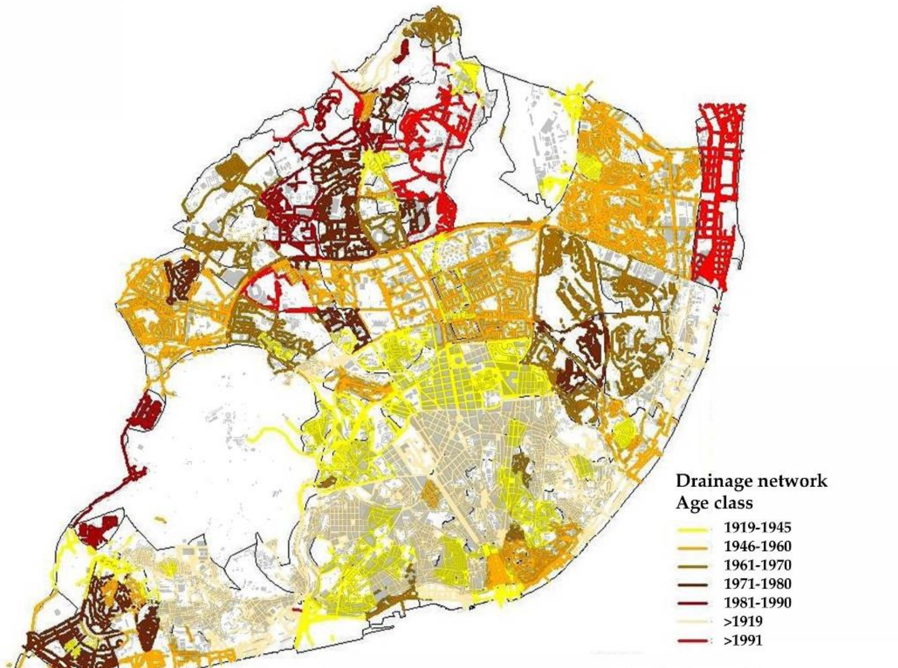
Map 1 – Lisbon's urban matrix over European Soil Sealing Raster data. European Soil Sealing Raster data is set of built-up and non built-up areas including continuous degree of soil sealing ranging from 0 - 100%. Aggregated spatial resolution (20m x 20m). Made available on 26 Jan 2010. Source: Combined information from Forma Urbis lab. Faculty of Architecture, University of Lisbon, 2015; and European Environment Agency (EEA), Copenhagen, 2013, respectively.



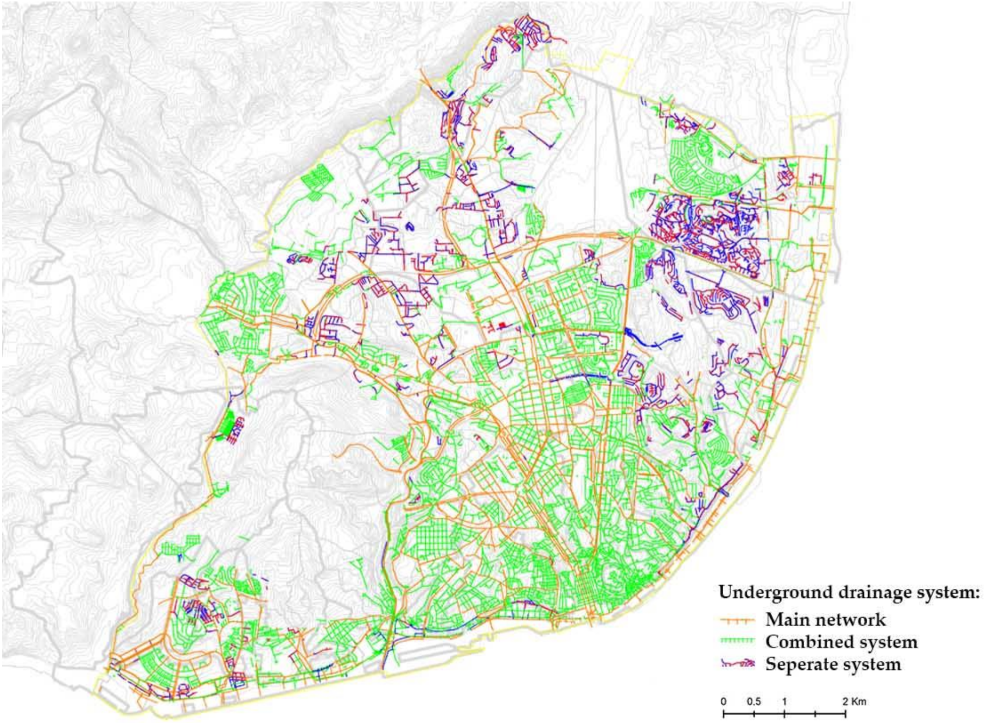
Map 2 - Delimitation of Lisbon's main underground drainage basins over the cities' land morphology. Source: Combined information from (ChiRoN et al. 2006a).



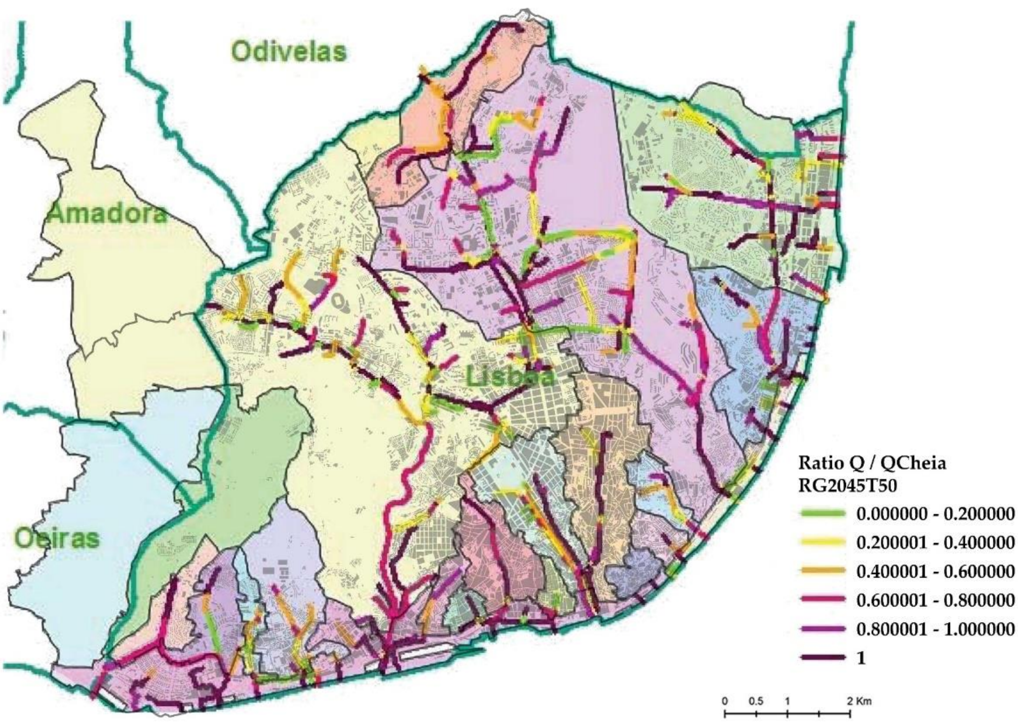
Map 3 - Area susceptible to direct tidal influence over Lisbon's urban matrix. The tidal values presented in Lisbon's Municipal Master Plan cartography were calculated by the Astronomical Tide Forecast Model of the Faculty of Science, University of Lisbon (FCUL). Source: Combined information from the Constituint element of Lisbon's Municipal Master Plan Cartography "Riscos Naturais e Antrópicos I" (PDML 2012).



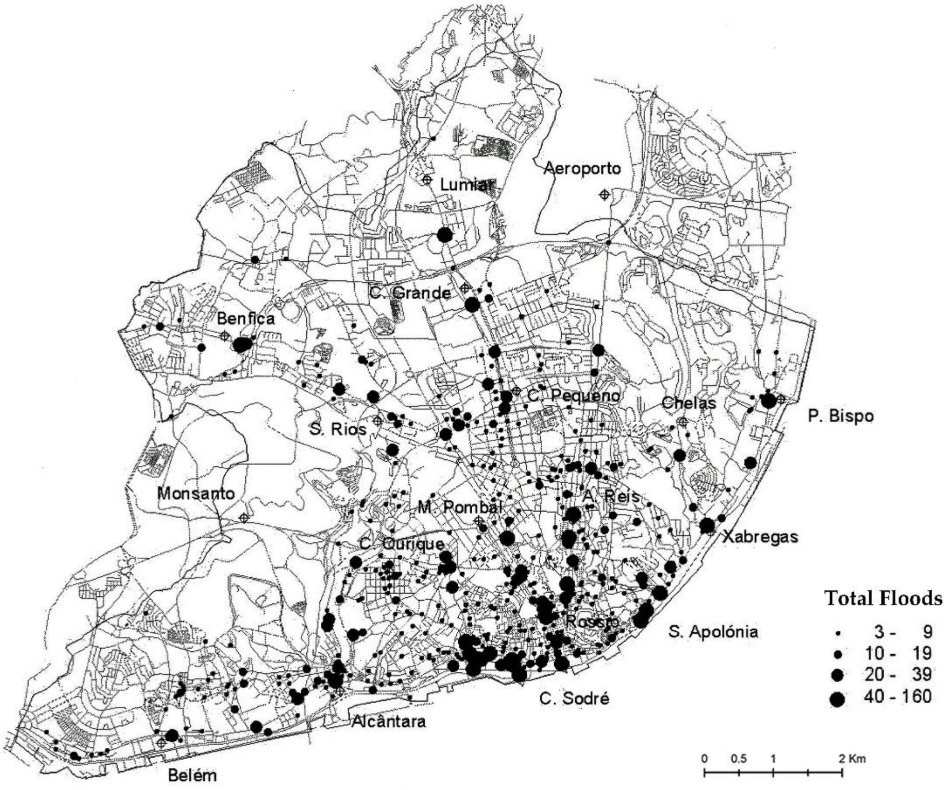
Map 4 – Lisbon's drainage network divided by classes of age. Source: (CHIRON, ENGIDRO, HIDRA, 2008, Avaliação da rede de drenagem de Lisboa para a EPAL in Hidra et al. 2015, p.61).



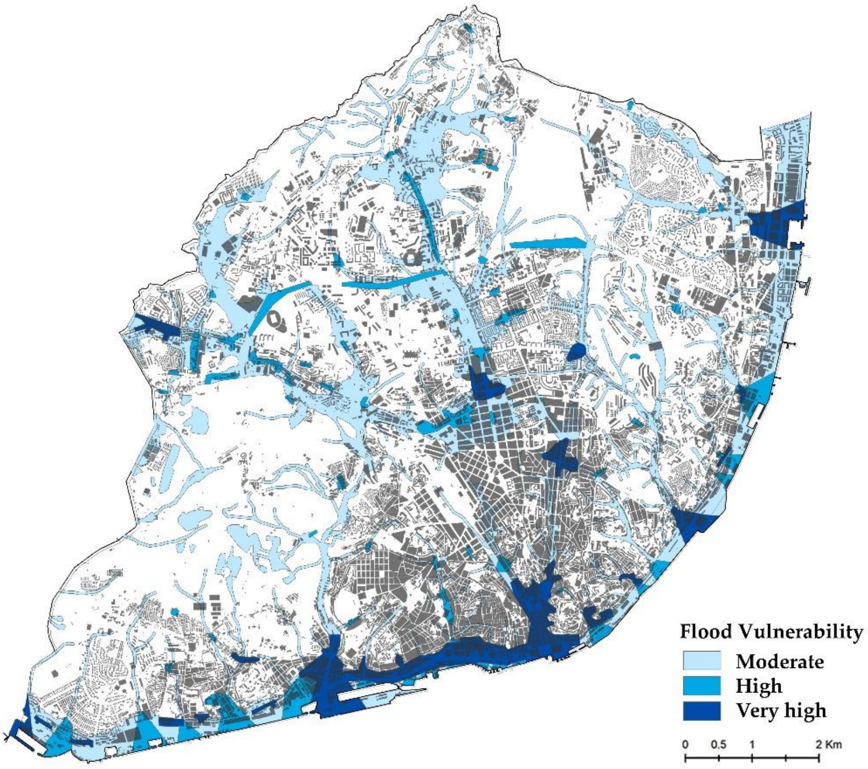
Map 5 - Identification of the existing combined and separate underground sewerage systems of Lisbon. Source: (Adapted from ChiRoN et al. 2006a)



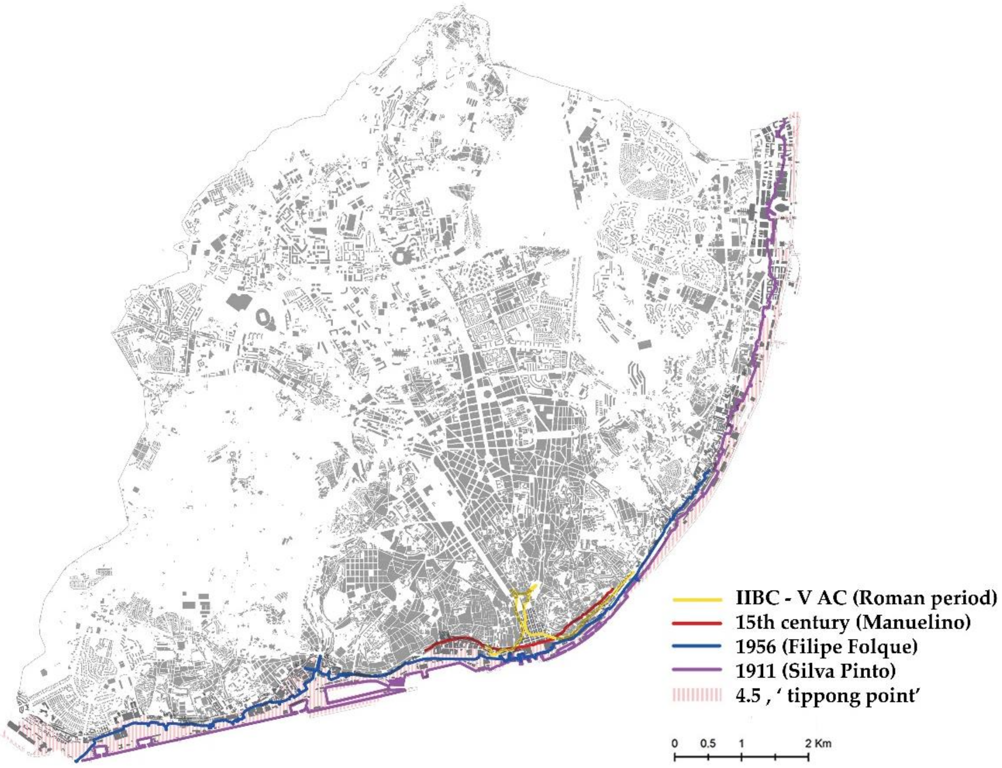
Map 6 - Evaluation of the drainage capacity of the existing sewerage system in the event of a stormwater flow with a return period of 50 years. Source: (ChiRoN et al. 2006b, p.110).



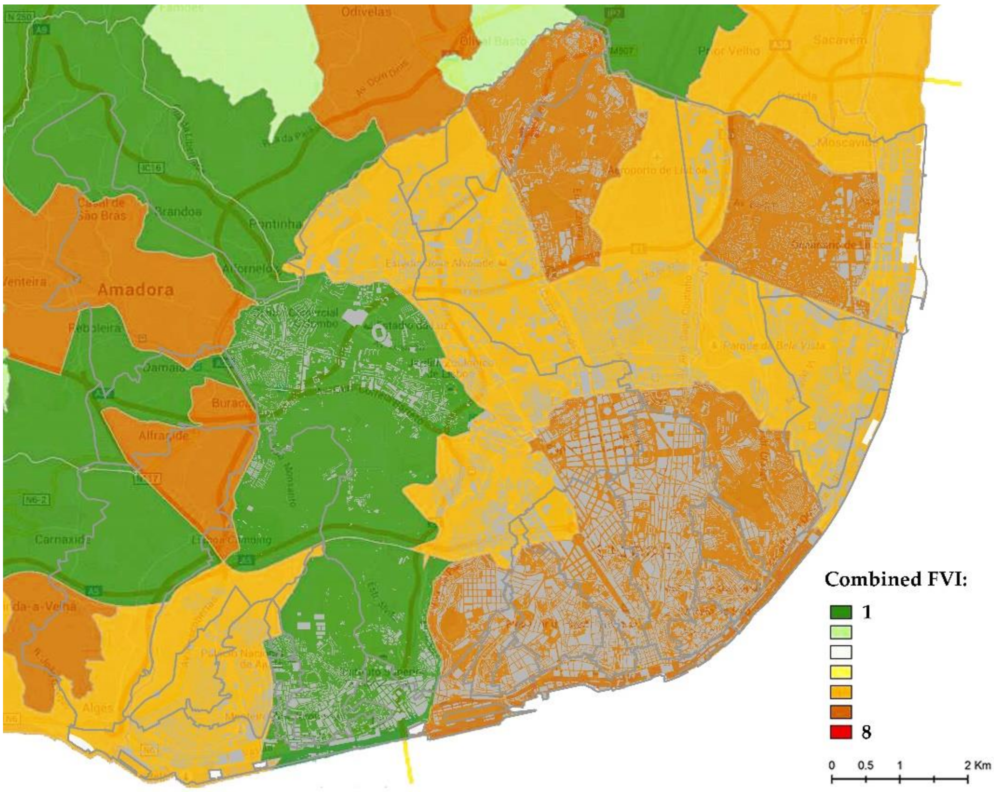
Map 7 - Total number of floods, with more than two episodes, by location in Lisbon, between 1918/19 and 1997/98. Source: (Oliveira 2003, p.112).



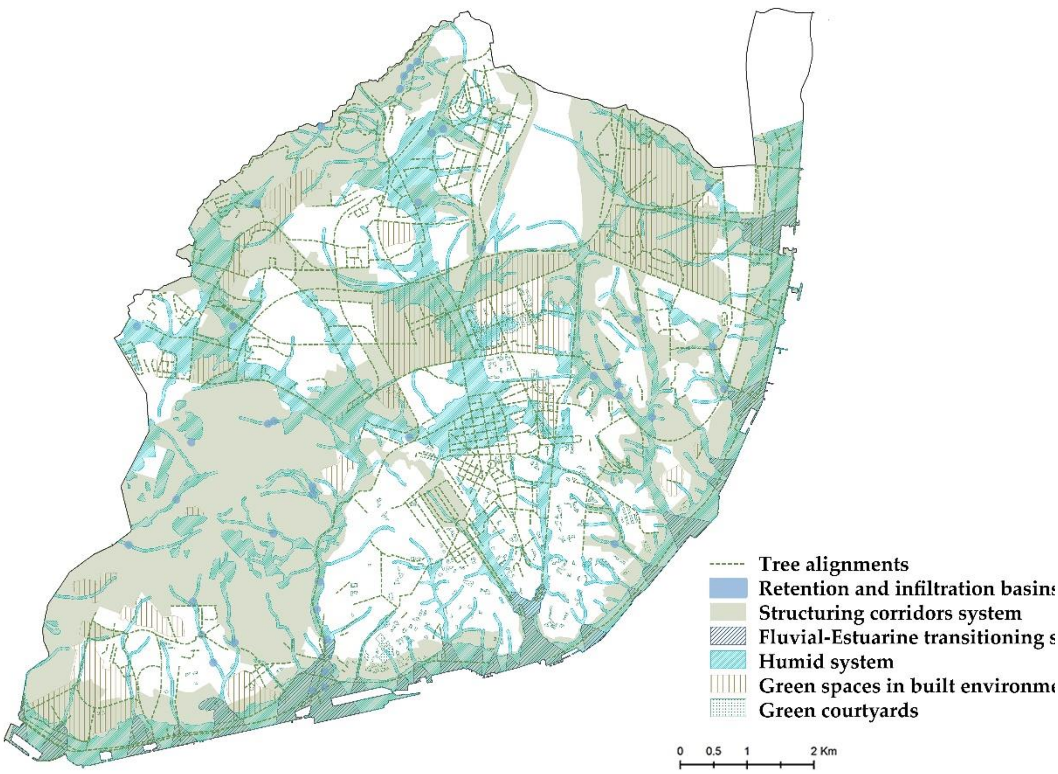
Map 8 – Lisbon's Flood Vulnerability Map over the cities' urban matrix. Flood vulnerability classes include "Moderate", "High" and "Very High" vulnerability: Source: Combined information from constituent element of Lisbon's Municipal Master Plan Cartography "Riscos Naturais e Antrópicos I" (PDML 2012) and Forma Urbis Lab. Faculty of Architecture, University of Lisbon, 2015.



Map 9 – Lisbon's different profiles throughout the years, together with the highlighted area below the 4.50m quota. Source: FCT R&D project, Urbanized Estuaries and Deltas, FA/ULisbon and FCSH/UNL, 2012 and Forma Urbis Lab. Faculty of Architecture, University of Lisbon, 2015.



Map 10 - Detail, encompassing the city of Lisbon, of the Portuguese Flood Vulnerability maps in climate change scenarios developed by CIRAC over the cities' urban matrix. Legend:Class description of the Combined Flood Vulnerability Index (CFVI): 1) Low Physical Susceptibility (PS), Exposure (E) and Precipitation (P); 2) Low PS and P and high E; 3) Low PS and E and high P; 4) Low PS and high E and P; 5) High PS and low E and P; 6) High PS and E and low P; 7) High PS and P and low E; 8) High PS, E and P. Source: Combined information from (CIRAC 2014, p.36).

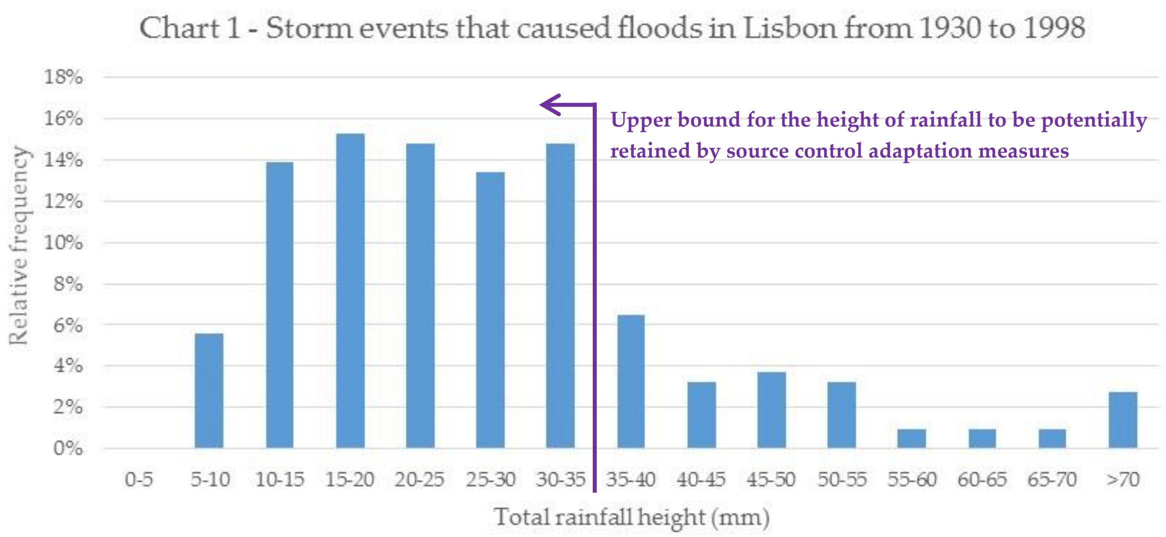


Map 11 - Lisbon's Municipal Ecological Structure. Source: Lisbon's Municipal Master Plan Cartography "Estrutura Ecológica Municipal" (PDML 2012).

V.

Justification for the choice of 25 mm as the minimum value of height of rainfall to be retained by the source control adaptation measures applied in the city of Lisbon

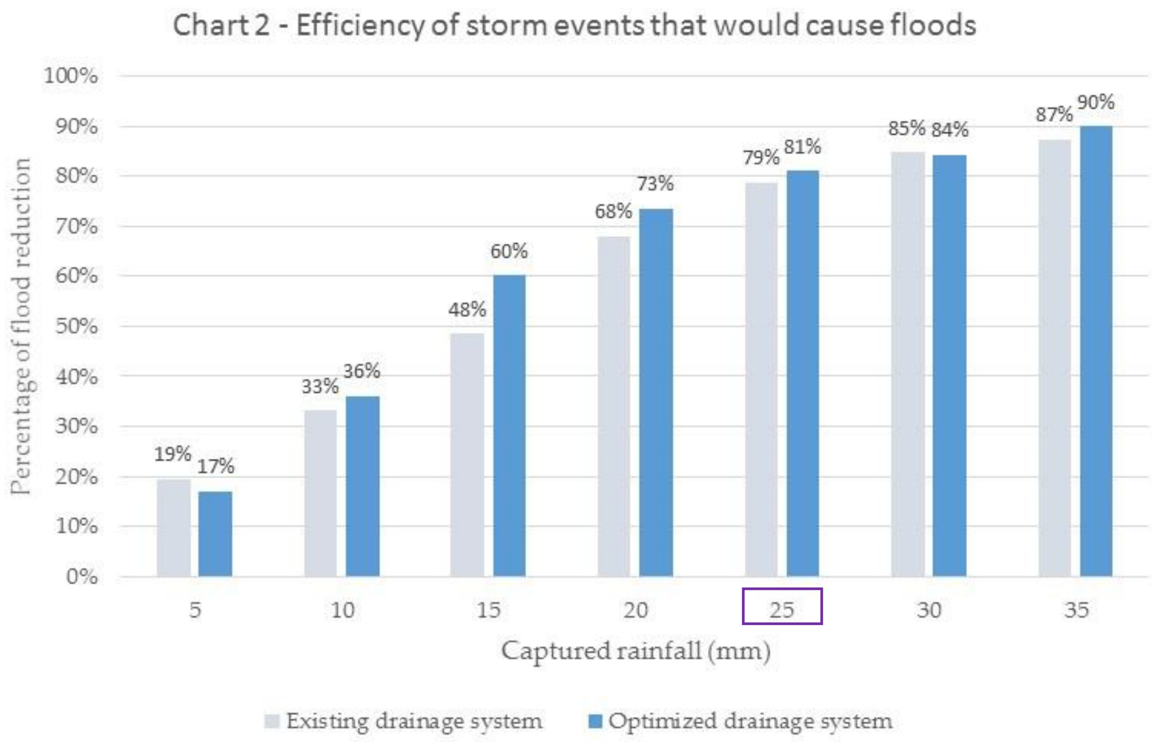
Based on the data presented by Oliveira (2003), namely all the storm events that caused floods in Lisbon from 1930 to 1998, one can determine an upper bound for the height of rainfall to be retained by the source control adaptation measures. In light of the Chart 1, which is a more discretized chart than the one presented in Oliveira (2003, Figure 11, p.55), one may observe that increasing the capacity to store more than 35 mm of rainfall would only have produced effect in less than 22% of the storms that caused floods.



Source: adapted from (Oliveira 2003).

Considering a hypothetical future situation in which the first 5, 10, 15, 20, 25, 30 or 35 mm of rainfall on 100% of the impervious areas in Lisbon were captured, and in light of the same rainfall data form the period of 1930 to 1998 (Oliveira 2003), the storm events that would cause floods would be reduced with the efficiency presented in the following Chart 2.

Chart 2 is further based on a simplified interpretation of results presented by Oliveira (2003), which considered that 1) the total net rainfalls (Total net rainfall = Total rainfall – Captured rainfall) of less than 10 mm would not cause floods and 2) in a scenario of drainage system optimization, only total net rainfalls higher than 15 mm would cause floods.



Source: adapted from (Oliveira 2003).

In consonance with this reading, flood adaptation measures that are capable of managing the first 25 mm of rainfall could prevent 79% or 81% of the floods considering the existing or an optimized drainage system respectively.

VI.

Projected scenarios for flood adaptation through public space retrofits, along 20, 50 and 100 years.

Comprehensive version of Table 6.5

Study area: Alcântara Upper Basin

COS 2007		Soil Sealing EEA	Potential Area for Public Space Adaptation (tributary area 100% impermeable)			**Projected scenarios for flood adaptation through public space retrofits**											
Description (author's translation)	Total area (m2)	Area 100% Impermeable (m2)				2017 -2022 (5 yrs.)		2022 - 2027 (5 yrs.)		2027 - 2032 (5 yrs.)		2032 - 2037 (5 yrs.)		2037 -2067 (30 yrs.)		2067 - 2117 (50 yrs.)	
			%	m2	% of the Total area	%	m2	%	m2	%	m2	%	m2	%	m2	%	m2
Predominantly vertical continuous urban fabric	10869901.61	7217630	63%	4547106.9	0.4183209	2%	90942.138	3%	136413.207	5%	227355.345	5%	227355.345	10%	454710.69	20%	909421.38
Roads and associated spaces	2309890.693	1519023	13%	197472.99	0.0854902	2%	3949.4598	2%	3949.4598	5%	9873.6495	3%	5924.1897	9%	17772.5691	20%	39494.598
Public and private facilities	2321941.985	1313419	69%	906259.11	0.3903022	2%	18125.1822	3%	27187.7733	5%	45312.9555	5%	45312.9555	9%	81563.3199	20%	181251.822
Predominantly horizontal continuous urban fabric	1395900.201	853389	73%	622973.97	0.4462883	1%	6229.7397	1%	6229.7397	1%	6229.7397	2%	12459.4794	8%	49837.9176	15%	93446.0955
Industry	777098.1022	639609	0%	0	0	-	-	-	-	-	-	-	-	-	-	-	-
Rail network and associated spaces	532952.9447	478908	10%	47890.8	0.0898593	1%	478.908	1%	478.908	1%	478.908	2%	957.816	5%	2394.54	15%	7183.62
Parking lot and courtyard areas	507111.2456	362809	95%	344668.55	0.6796705	5%	17233.4275	5%	17233.4275	10%	34466.855	10%	34466.855	15%	51700.2825	30%	103400.565
Total areas (m2)	18714796.78	12384787		6666372.32	0.3562086		136958.8552		191492.5153		323717.4527		326476.6406		657979.3191		1334198.081
					% of Impermeable Public Space Area to be adapted		2%		3%		5%		5%		10%		20%
					Minimum stored volume* (m3)		3423.97138		4787.31288		8092.936318		8161.916015		16449.48298		33354.95201
							2%		**5%**		**10%**		**15%**		**25%**		**45%**
					Minimum <u>accumulated</u> stored volume*(m3)		**3423.97138**		**8211.28426**		**16304.22058**		**24466.1366**		**40915.61957**		**74270.57159**
					Accumulated impermeable Public Space Adaptation area (m2)		136958.855		328451.371		652168.8232		978645.4638 Along 20 years		1636624.783 Along 50 years		2970822.863 Along 100 years

*Design must manage at least 25mm of stormwater runoff from first rainstorm