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Manuel Franco Torres

Framing Urban Water

Doctoral thesis

NTNU
Norwegian University of Science and Technology
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Abstract

In recent decades, Western societies have been experiencing accelerated growth in diversity, connectivity, complexity, and uncertainty. In the urban water sector, this evolution has thus far manifested in the emergence of new water-related needs and risks. Some good examples are those derived from climate change, resource scarcity, financial instability, infrastructure decay, cybersecurity and bioterrorism, emergence of new pollutants, and many others that connect water to energy, food, health, transportation, urban planning and liveability.

Since approximately the turn of the century, it has become increasingly accepted among scholars that the traditional infrastructures, management styles, and governance modes for urban water—or what conforms to the traditional configuration of urban water systems (UWSs)—are inadequate for the satisfactory and sustainable management of the emerging needs and risks. Despite the adoption of several technical and social innovations, system-wide transitions towards more sustainable UWSs have been sluggish and disappointing. While there is no doubt that technological advancements have made the provision of basic urban water services safer, todays UWSs are still, in general terms, astonishingly similar to those that were in place a century ago.

The UWSs of today must undergo a comprehensive transformation in order to adapt to an increasingly complex and uncertain reality. To understand this transition, and identify strategies to accelerate it, the present thesis considers the *frames of reference* of UWSs. These are the underlying aspirations, values, beliefs, assumptions, etc., within and beyond the urban water sector, which shape UWSs in terms of particular infrastructures, management and governance. The work explores different forms of these frames of reference such as paradigms, institutional logics and cultural frameworks.

In this thesis, it is claimed that all isolated and slowly-emerging innovations in infrastructure, management and governance reflect an emergent urban water paradigm that attempts to replace the dominant "old" paradigm underpinning traditional UWSs. Indeed, a growing number of scholars have argued that a complete and purposive paradigm shift is the most effective path towards sustainable UWSs. However, the paradigm shift has been also rather sluggish, preventing innovations in infrastructure, management and governance from becoming more widespread. Some factors that hinder this transition are explored in this thesis, although there are two, in particular, which must be highlighted. A prime factor may be the inertia of the old paradigm, which is embedded and entrenched in the elements that it shapes. These elements, which include physical infrastructures, management tools, rules, organization systems and language, are hard to change. This then results in a negative feedback loop; without a paradigm shift, there can hardly be innovations, and a lack of innovations will also prevent the occurrence of a paradigm shift. The second key factor that may hinder the adoption of a new paradigm is the fact that the new paradigm remains unacknowledged, vague and impractical, which limits the capacity of actors to transcend old ways of thinking and doing.

The goals of this thesis are:

- to understand what frames of reference/paradigms of UWSs are.
- to define the new urban water paradigm as a coherent system of philosophies which ascribe meaning to emerging changes in the governance, management and infrastructures of recent decades.to investigate how broad social transformations influence the transformation of the urban water paradigm.
- to advance the understanding of governance as a critical element of urban water services, and the knowledge of how it is shaped by different frames of reference.
- to suggest ideas which may accelerate the transition towards a new urban water paradigm and, hopefully, towards more sustainable urban water systems.

This work includes four peer reviewed academic papers and an extended introduction. The extended introduction provides a general outline to the topic through a conceptual framework, a description of research design, a summary of results, some highlighted general conclusions, and practical advice derived from the study.

Paper 1 presents a framework for analysis of urban water paradigms and their role in shaping UWSs (infrastructures, management and governance). This framework is employed for the description and juxtaposition of the old and new urban water paradigms, and is made up of data collected from an extensive literature review. The paper concludes that the old paradigm is underpinned by methodological principles that promote stationarity, homogeneity, reductionism and centralization. The new paradigm, meanwhile, is found to shape UWSs by promoting continuous learning, diversity, integration and distribution.

Paper 2 presents an investigation into the roots of the old and new paradigms. It argues that these paradigms are a reflection of evolving, society-wide frames of reference (cultural frameworks) throughout the last two centuries. It describes an old paradigm rooted in the philosophy of the Enlightenment and ideas of modernity. This frame of reference evolves during the second half of the 20th century under the influence of two contrasting cultural frameworks, postmodernism and reflexive modernization. On the one hand, postmodernism influences the UWS against the core tenets of modernity, promoting participation, decentralization, multidisciplinarity and the acceptance of complexity. On the other hand, reflexive modernization insists even more forcefully on core modern principles such as control, prediction and technological solutionism. This framework, however, replaces the unrestrained maximization of outputs (proper to modernity) by efficiency, optimization, risk management and ecological awareness. Paper 2 also takes as its basis the idea that since the turn of the century, we have been witnessing the emergence of a new cultural framework, or the framework of metamodernism, which represents a response to an increasingly complex and uncertain reality. Metamodernism shapes the new urban water paradigm by oscillating between postmodernity and reflexive modernization. It promotes the coexistence of centralization and decentralization in distributed systems, control through adaptation, and the certainty of uncertainty.

An important lesson to be taken from papers 1 and 2 is that while the old paradigm focuses on infrastructures and management of water, the new paradigm focuses its attention on governance. During the last decade, the idea that water crises are primarily crises of governance has become a broadly accepted assumption—despite the fact that *governance* is a vaguely defined concept in the field. Paper 3, therefore, explores the link between frames of reference and governance, seeking to contribute to the concretization of the concept. The article suggests a framework for the analysis of different modes or styles of urban water governance, which are presented as reflections of different frames of reference (in this case, institutional logics). From this perspective, governance can be understood as an area where multiple frames of reference meet, collaborate or compete.

Following the conclusions of paper 3, paper 4 suggests that governance crises are often brought about by deep-rooted issues of collaboration among different frames of reference, which impede the transition towards sustainable UWSs. This article proposes a theory that explains how *boundary objects*—artefacts with interpretive flexibility such as ambiguous concepts, prototypes or narratives—can enable collaboration among diverse frames of reference and simultaneously accelerate the transition towards sustainable UWSs. This theory is illustrated by the case study of competing frames of reference in the stormwater management sector of Copenhagen, where the boundary object of "climate change adaptation" was used to implement effective collaboration and contribute towards a more sustainable city.

The main conclusion of this thesis is that frames of reference matter, and carry indisputable yet unrecognized importance for the development of UWSs. They determine how actors provide meaning to the world, how they behave, which goals are worth pursuing, what problems need to be solved, and, most palpably, how infrastructure, management and governance should be conducted. Frames of reference provide certainty, stability and social cohesion, but at the same time, can hinder adaptation and become an obstacle for sustainable development.

Furthermore, this thesis suggests that the frames of reference concept is particularly well-suited to articulate the negotiating conflicts between groups of people with different worldviews, which are known to be a frequent cause of water crises. While the general view among the urban water discussions of the last two decades has been that water crises are governance crises, this thesis proposes that it might be more accurate to conceptualize water crises as problems of framing. This study argues that the redefinition of frames of reference (reframing) is a prerequisite for the realization of sustainable urban water governance, management and infrastructures.

To conclude, this thesis summarizes various ideas that may orient and facilitate the creation of better/more adaptive frames of reference for our increasingly complex future (chapter 5), and makes some practical suggestions for urban water actors (chapter 6).

In general, the exploratory work presented in this thesis seeks to contribute to the necessary awareness of frames of reference that practitioners should develop if they are to support the transition towards sustainable UWSs.

Preface

> *There are these two young fish swimming along, and they happen to meet an older fish swimming the other way, who nods at them and says, "Morning, boys, how's the water?" And the two young fish swim on for a bit, and then eventually one of them looks over at the other and goes, "What the hell is water?"*
>
> *[…]*
>
> *The immediate point of the fish story is that the most obvious, ubiquitous, important realities are often the ones that are the hardest to see and talk about.*
>
> David Foster Wallace
> *This is Water, 2005*

This short story served as an introduction to a speech given by writer David Forster Wallace (1962 – 2008) at Kenyon College (Ohio, USA) in 2005, to introduce a graduation ceremony. Although Wallace's intention was to inform the students of the vicissitudes of adulthood and the value of education—something that is not directly related to the content of this dissertation—he indirectly referenced some underlying ideas that quite precisely reflect the core of this thesis. Wallace essentially referred to the existence of "default settings" in our minds which give meaning to reality, which are shared by most of us, and which seem so obvious that almost nobody discusses or reflects on them. We are, somehow, slaves to these settings. It is only through the effortful exercise of continuous attention and scepticism, he argued, that we may become conscious and aware, gaining the freedom to think, choose and act beyond the constraints of these settings.

I would argue that in my normal job as a consultant civil engineer of urban water infrastructures, the concept of "default settings" carries more positive than negative connotations. I believe that most of my colleagues interpret "default settings" to mean pre-approved solutions that save time and resources and, at best, require little or no modification in order to be adapted to solve real-life problems. However, this very thesis was born from my suspicion that our "default settings" of purely rational, technical and economic logic felt insufficient to ensure an engineering project's success. For instance, there are "perfect" engineering solutions which are "unreasonably" rejected by other stakeholders, or which are "inexplicably" never able to provide the intended results. This made me wonder if, during those years spent learning the ins and outs of the engineering profession at university, a key part of the study curriculum was left untaught. It is only now that I realize what the problem was, which was that despite learning the "default settings" for the design of water infrastructures, I had never been taught what "water" was. Consequently, "what is water?" became the core question of this thesis, although it was only now formulated using those exact words, at the moment of writing this preface. I thought, why not write a PhD, then, to try to answer this interesting question?

Traditional doctoral theses are developed inside the well-demarcated limits of a field of research. Their authors usually sit on the shoulders of giants, which not only allows them to see further away, but also provides them with warmth, comfort, security, coherence and legitimacy, from a community that sees the world from the same perspective. From that position, the traditional PhD candidate aims at maintaining their strength, hoping that future scholars will one day sit on their shoulders and be able to see even further away.

This is not, for better or for worse, one of these theses. From my previous education as an engineer, I am familiar with these giants from whose shoulders I could spot landscapes which may have been far away, but which looked almost exactly like what I knew from before. There was nothing astonishing on that horizon, nothing that deserved years of exclusive dedication. From there, my most major potential achievement would have been to stand on tiptoe and spot a tree, a stone or a stream that nobody had spotted before, and of course, to acquire the necessary training to raise myself onto tiptoes while looking carefully, in order to later identify many new trees, stones and streams.

Five years ago, applying an unconventional approach to answering my own question, I decided to climb down from the giant's shoulder onto the ground. I wandered across the inhospitable steppes of knowledge, full of academic rabbit holes and abundant quantities of that barbed wire which demarcates fields of research. Trying to find my way, I assumed at times the daunting task of climbing all the way up to the shoulders of newly discovered giants, where I sat and thought "Toto, I've a feeling we're not in Kansas anymore". This process was sometimes exasperating and confusing, and at others a highly gratifying task that allowed me to draw my own map of a new world of knowledge from multiple viewpoints.

These unplanned expeditions might not seem to be the perfect recipe for a doctoral thesis that will solve any of the most pressing problems of humanity. Nor do they seem to constitute an effective roadmap for a dissertation with spotless methodology and impeccable research discipline, which provides results that fit beautifully into, and expand the picture of, the reality drawn by their predecessors. However, this thesis does perfectly accomplish what, I would argue, is the primary objective of thesis-writing: to equip the PhD candidate with enhanced analytical and critical capacity, and provide a flexible system of thought that supports life-long learning, hopefully for the eventual benefit of society, and certainly for the benefit of the student.

So, this is not a "stand-on-tiptoe-and-look-carefully-to-fill-the-knowledge-gap-thesis". This is a thesis of exploration and adventure, of climbing up and down, of getting entangled in barbed wire, falling into rabbit wholes for weeks and months, appearing in unknown places, and trying to find the trail of breadcrumbs that would lead me back to a familiar place. Overall, it is a thesis of sketching new maps of the world that hopefully make sense not only to me, but also to others. Unfortunately, much was left untold, because I did not have the time, or I did not find the way to describe in a coherent and credible way all that I have witnessed, learned and thought.

Now, sitting in front of the screen, six years after I started this exploration, I think I can finally provide an answer to the fish's question, which I made my own: "what the hell is water?"

Water is part of everything. Water is in the air we breathe, the ground we stand on, the food we eat, the energy we consume, the cities we design, the machines we build, the rules we make, and the money we exchange. In the end, however, water is a story we tell, so water is what we want it to be.

> *"Understanding the world is about living inside stories. There's no place to be in the world outside of stories."*
>
> Donna Haraway
>
> *How like a leaf, 2000*

Acknowledgements

Firstly, I would like to thank my supervisors, Rita Ugarelli and Sveinung Sægrov for their support and advice throughout the years. I am particularly grateful for their trust in my unorthodox approach, despite my stubborn tendency to drift away from their fields of expertise. They gave me total freedom to develop my thesis, which became somewhat of a double-edged sword. On the one hand, the freedom liberated me from taking directions I had not chosen myself, from disciplinary limitations, and from research design constraints, making this "do-it-yourself" trip very enjoyable. On the other, the lack of "off-the-shelf" limitations pushed me to choose my direction at every crossroad. I am also grateful for that, as I feel that I learned much from this process, and like to believe that I became a better and more confident navigator by trusting my gut feelings.

I am also very grateful to Professor Rob Skinner, the deputy chair of the Cooperative Research Centre (CRC) for Water Sensitive Cities in Melbourne. I must thank him for inviting me to stay at the CRC and Monash University for six months in 2018. This stay was undoubtedly a tipping point in the development of this PhD. In this period, I had the good fortune of meeting Briony Rogers and all the other PhD candidates at the CRC. Briony not only became the co-author of two of my papers, but also contributed significantly to this PhD in a way that she probably never noticed. Simply put, she made me realize that my ideas could actually be turned into publishable articles. That is not a modest contribution, as that was a worry that hung over me during the first half of my PhD period, before I travelled to Melbourne.

I also had the fortune to meet a fantastic group of PhD candidates in Melbourne, who warmly welcomed me into the CRC. Special thanks to Vanessa, Josh, Beshaz and Wikke, for your enriching conversations, for opening the doors of your houses to me and my family, and for making us feel at home. I should also acknowledge here that in a 10-minute break over a cup of coffee Wikke decisively influenced this thesis by introducing me to the concept of boundary objects, an idea that became my own Copernican revolution.

Sincere thanks are also owed to the other co-authors of my papers. Robin Harder, the co-author of paper 4, became almost a paternal figure at the most difficult and chaotic point of my PhD, and I really appreciated his help in organising my thoughts. I should also thank Ragnhild Kvalshaugen, the co-author of paper 3, for her patience and for securing my way through the field of institutional logics. I would also like to include my thanks here to Timotheus Vermeulen, who did not become a co-author, but was an important contributor to paper 2 through commenting on the paper and affording me the support I needed to write about a topic that is several universes away from my comfort zone.

I would also like to express my sincere gratitude to Multiconsult, my employer, who economically funded this thesis alongside the Norwegian Research council. My leaders and supervisors at Multiconsult trusted me and gave me complete freedom to develop this piece of research in the direction that I considered most interesting for me and for the company. This freedom encouraged some unconventional choices, which undoubtedly allowed me to grow as a person and as a professional, and which I hope will also benefit the company in years to come. It is my true belief that this thesis contains lessons which can improve the service provided by Multiconsult to clients and to Norwegian society in general. Special thanks are owed to Elisabeth Schjølberg for her permanent support, encouragement, patience and interesting conversation, and to Sigmund Tøien for his trust and patience even when I was unable to explain exactly what I was researching, or why. It is truly due to Elisabeth and Sigmund that this PhD was made possible. I should also thank Siv Kristin Mellgren and Tor Håkonsen for their administrative help and moral support.

In the same way, I am deeply grateful to the Norwegian Research Council, who supported me not only economically, but also with trust and freedom. I would particularly like to thank Siri Haaland and Marie Haaland for their patience and assistance with all administrative issues. Thanks are also owed to the SFI Klima2050, and particularly to Åshild Hauge and Cecilie Flyen for welcoming me into the network.

I could not possibly conclude this list of acknowledgements without thanking my friends and family, because their support has been essential. Special mentions are warranted for the new friends that I made during this journey, and go out to Carlos, Vladimir and Chun Bo, who were my family in Trondheim, and Arthur Klingbeil, who was my best companion during a period of academic loneliness. I would also like to thank my old friends Luis, Kristin, Mar and Ola, for always being there.

I am grateful to my parents and sisters, Lisa and Sonia, for the trust they have always had in me, and to my Norwegian political family, for letting me be one of them.

Last, but certainly not least, I must dedicate this thesis to my very best friends. Thanks to my partner in life, Hanne, from the bottom of my arrhythmic heart for many, many things, but perhaps most concretely for having patience and giving me time. And to my two children, Ivo and Eira, forgive me for all the weekends and evenings I stole from you without permission. I promise I will make up for this lost time.

Thesis structure

Four peer-reviewed articles from international scientific journals are included in this thesis. They are presented as an appendix to the extended introduction and conclusion of the thesis, which is organized into six chapters.

Chapter 1 - Introduction

Chapter 1 provides a general introduction to the thesis, and includes the general problem statement, the aim of the study, the scope, the concrete research questions, and the objectives that guided the work.

Chapter 2 – Conceptual framework

Chapter 2 describes the conceptual framework that constitutes the core of the thesis, serving as a theoretical map that links all four papers into a coherent body of research. This conceptual framework combines ideas and theories already articulated in the papers, expands them, and relates them to newly introduced concepts and theories.

Chapter 3 – Research design

Chapter 3 presents the research design of the thesis. This chapter includes justifications for the research philosophy, methodology and research methods employed, and some final reflections on their suitability.

Chapter 4 - Results

Chapter 4 presents a brief description of the content of the four articles included in the thesis and the answers they provide to the research questions posed in chapter 1, taking as a consistent reference the theoretical conceptual framework articulated in chapter 2.

Chapter 5 – General conclusion

Chapter 5 focuses on the general conclusion and discussion of the thesis, looking at the four papers as an integrated whole. This chapter also articulates some ideas which transcend the research questions presented in chapter 2.

Chapter 6 – Practical advice

Chapter 6 provides some practical advice for all actors of the urban water sector, and some counsel specifically aimed at particular actors. The lessons derived from this research do not claim to be comprehensive, but rather aim to serve as an illustrative translation of what the thesis may mean in practice. The chapter also outlines some possible ideas for future research.

Appendix A

This appendix includes the four academic articles.

Appendix B

This appendix presents the co-authorship statements.

List of papers and contributions

Paper 1

Franco-Torres, Manuel, Briony C. Rogers, and Robin Harder. "Articulating the new urban water paradigm." *Critical Reviews in Environmental Science and Technology* 51(23) (2021): 2777-2823.

I was the main author of this paper. I conceived the idea of describing the new urban water paradigm in contrast with the old paradigm, and the design of the explanatory framework for paradigm analysis. I selected the methodology, carried out the meta-synthesis, and wrote the paper. I also produced all the figures and tables.

Briony Rogers provided concrete feedback (comments and edits) after the first draft, and made particularly significant contributions to the structure of the paper and its conclusions. Rogers also contributed to language editing.

Robin Harder provided concrete and continuous feedback (comments and edits), and made particularly significant contributions to the process of refining the analytical framework, the structure of the paper, and the provision of additional sources for meta-synthesis.

Paper 2

Franco-Torres, Manuel. "The path to the new urban water paradigm – from modernity to metamodernism" *Water Alternatives 14(3)* (2021): 820-840.

I was the sole author of this paper. The paper also benefited from commentaries by Timotheus Vermeulen, Robin Harder and Tapio Katko. In accordance with their views, their contributions were not deemed sufficient to include them as co-authors of the paper.

Paper 3

Franco-Torres, Manuel, Ragnhild Kvålshaugen, and Rita M. Ugarelli. "Understanding the governance of urban water services from an institutional logics perspective." *Utilities Policy* 68 (2021): 101159.

I was the main author of this paper. I conceptualized the idea of a framework for analysis of urban water systems governance from the perspective of institutional logics. I selected the methodology, carried out the literature review, and wrote the paper. I also produced all the figures and tables.

Rita Ugarelli contributed to the identification of the knowledge gap (the idea of studying the governance of urban water systems) and provided comments for the first draft.

Ragnhild Kvålshaugen commented on and edited the final versions of the paper, and contributed to changes in its structure.

Paper 4

Franco-Torres, Manuel, Briony C. Rogers, and Rita M. Ugarelli. "A framework to explain the role of boundary objects in sustainability transitions." *Environmental Innovation and Societal Transitions* 36 (2020): 34-48.

I was the main author of this paper. I identified the compromise between variety and cooperation needs among logics in the urban water sector, I conceived the idea of a theory which accounts for the role of boundary objects in overcoming this challenge, and I completed the case study of Copenhagen. I selected the methodology, carried out the literature review and interviews, and wrote the paper in its entirety. I also produced all the figures and tables. Rita Ugarelli provided comments on the first draft, and Briony Rogers contributed valuable discussions which helped me to identify the knowledge gap. Rogers also provided concrete feedback for all the versions of the paper, commented on and edited the paper, suggested changes to its structure, and contributed to language editing.

Extended introduction and conclusions

The extended introduction and conclusion of this thesis were conceptualized and written by me in their entirety. Both my supervisor (Rita Ugarelli) and my secondary supervisor (Sveinung Sægrov) reviewed and commented on the text.

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Abbreviations

AWM	Adaptive water management
BOIST	Boundary objects in sustainability transitions
CAS	Complex adaptive systems
IUWM	Integrated urban water management
IWRM	Integrated water resource management
STES	Socio-technical-ecological system
SuDS	Sustainable urban drainage systems
SUWM	Sustainable urban water management
UWS	Urban water system
WSUD	Water Sensitive Urban Design

Glossary

This glossary defines some terms that are central in this thesis, and which may have several interpretations. Only the interpretations shown here are applied in the text.

Complex systems	Systems of interdependent entities that lack a central controller and behave as a whole, exhibiting order, stability and self-regulation combined with high levels of entropy that allow them to reorganize and adapt to changes in their environment.
Conceptual framework	Metaphorically, Miles and Huberman (1984, p. 33, cited by Leshem & Trafford, 2007, p. 95) define a *conceptual framework* as “the current version of the researcher’s map of the territory being investigated”. In qualitative inquiry, a conceptual framework refers to a set of interconnected concepts and ideas employed by a researcher to orient research (help to define objectives and scope, pose questions, select methods, etc), make “sense” of observations, and contextualize findings within existing knowledge (Leshem & Trafford, 2007).
Cultural framework	A type of frame of reference that applies to society in its entirety during a certain epoch. In this thesis, it is used as an umbrella framework for other frames of reference; epistemes, cultural logics and structures of feeling.
Cultural logic	A type of cultural framework that is born as a counterpoint to a dominant episteme and its flaws, usually reflected in innovative or provocative ideas that defy established conventions.

Cybernetics	The study of systems of communication and regulation with circular causal relationships (feedback mechanisms) oriented towards a goal.
Episteme	A type of cultural logic that is deeply embedded in a society and defines its most basic structures. It is so deeply ingrained in the mind that it is impossible for actors to imagine other interpretations of reality.
Epistemic community	A network of diverse organizations (such as water utilities, regulatory agencies, formal authorities, constructors, consultors, suppliers, researchers, landowners, or consumers) convened around the provision of certain water services that share a frame of reference.
Explanatory framework	An output of research consisting of integrated description of complex phenomena, which coherently combines existing concepts and ideas (usually from different disciplines).
Governance	The collaborative social practices (politics), together with their supporting and resulting social structures (policy and polity), that set the scene for management of water services. Governance includes, for example, the definition of policies, rules, or roles, and the negotiation, collaboration, or mobilization of actors.
Ideal types	Archetypes of elements of a complex and transient reality. They function as heuristic devices that help to interpret and approximate what is happening in the real world, but they cannot be found in their “idealized” form in real life.

Infrastructures	Physical facilities, either manmade or natural, that regulate the environment and make the provision of urban water services physically possible. The infrastructure regulates the state of the resource; it extracts, transports, stores, cleans and disposes water.
Institutions	"The rules of the game in a society" (North, 1990, p. 447). They involve regulative, normative and cultural-cognitive systems (Scott, 2014).
Institutional logic	One of several co-existing frames of reference with characteristic core values, beliefs and rules that strive to influence the dominant paradigm.
Interpretive framework	A frame of reference that underpins a piece of qualitative research. It encompasses a coherent system of philosophical assumptions about the nature of reality (ontology), how we can gain knowledge about that reality (epistemology), the values that guide the pursuit of that knowledge (axiology), and the methods used (methodology). In qualitative inquiry or social research, it is more common to refer to interpretive frameworks as *research paradigms*, but the term *research paradigm* is avoided here as it is used with a broader significance throughout the thesis.

Frame of reference	An umbrella concept that includes similar ideas from multiple disciplines. All of them refer to a more or less coherent constellation of social constructions, such as assumptions, beliefs, biases, interests, values, or ideas, that is shared by a community and subsequently enables and constrains perception, meaning, purpose, communication, collaborationand transformation of the "real". Frames of reference become reified in all elements of an urban water system, such as infrastructures, rules, vocabularies, and modes of social organization.
Management	Activities that directly involve the regulation of infrastructure—such as monitoring, analysis, planning, design, construction, operation or maintenance—and other financial or human assets. Management requires information acquisition, technology development and use, risk-evaluation, economic planning, organization of human resources and decision-making.
Management framework	A recipe of management of UWSs that typically embody the new urban water paradigm. Management frameworks such as water sensitive cities, integrated urban water management (IUWM), and sustainable urban water management (SUWM) exhibit varied degrees of abstraction.
Metamodernism	The emergent structure of feeling at the beginning of the 21st century in Western culture.

Middle range theory	The theory located between all-encompassing long-range theories that dominate a discipline, and situation-specific short-range theories that apply to day-to-day research.
Modernity	The episteme of Western countries since the 19th century.
Paradigm	A frame of reference that dominates a societal sector within a certain period of time, usually decades. Paradigms are particularly reified in the form of tools, infrastructures, processes and guidelines.
Postmodernism	A cultural logic from the second half of the 20th century, which emerged as a counterreaction to the modern episteme.
Rebundle	To construct ephemeral systems of loosely connected clusters, composed of richly connected elements that provide pragmatic, timely and locally adapted solutions.
Socio-technical-ecological systems (STESs)	Systems of social, technological and ecological elements that co-evolve and are somehow aligned towards the facilitation of urban water services through determined paths.
Structure of feeling	An emergent cultural framework that is ill-defined, and often incongruent and ambiguous. It is a new zeitgeist of an epoch that is hidden in discursive arenas, cultural expressions and innovations.
Theory	Structures of meaning for observations that have interpretive and predictive intentions.

Urban water system (UWS)	A system of infrastructures (such as pipes, pumps, reservoirs, green roofs, channels, water treatment plants, etc. that extract, clean, store and transport water); the elements and processes of the water cycle that the infrastructures aim to regulate; the ecosystems that the infrastructures affect; and the social structures that underpin collaborative work and make the exploitation of the resources possible (such as laws, rules, norms, contracts, technical codes, property rights, roles, social networks, etc.) in order to provide urban water services.
Wicked problems	Intractable problems characterized by their ambiguity (they are difficult to define), lack of structure (there are unclear connections between cause and effect), cross-cutting character (they cannot be approached solely from the lens of one discipline), relentless (they are without unique, optimal or definitive solutions), pervasive (interventions often result in unintended consequences and new problems), and controversial (they are impossible to resolve by resorting to rational explanations or facts, and lacking in an obvious single solution).

Chapter 1: Introduction

1.1 Problem statement

Water is a key element of urban sustainability. This is not only because it is a requisite for life, or because the most obvious urban water services (provision of potable water, firefighting, waste management, and protection against floods) are central to social, ecological and economic development, but also because water is intertwined with most societal functions (such as food and energy supply, public health, housing, transportation, jobs, security, communication, ecosystem health, and urban liveability). All things considered, water actually constitutes the fabric of modern urban life (Figure 1).

Figure 1. The water-centric Sustainable Development Goals. United Nations (UN, 2015) has defined 17 sustainable development goals, with number 6 addressing the need for clean water and sanitation. Makarigakis and Jimenez-Cisneros (2019) graphically arranged the 17 goals in a "water-centric" configuration, aiming to highlight the close association between some of the other goals and water services. (Reproduced under the terms of the Creative Commons Attribution 4.0 International License (http://creativecommons.org/licenses/by/4.0/))

In order to make all these water-related services possible, societies have developed what this thesis refers to as urban water systems (UWSs). These systems combine infrastructures (such as pipes, pumps, reservoirs, green roofs, channels, water treatment plants, etc. that extract, clean, store and transport water), the elements and processes of the water cycle that the infrastructures aim to regulate, the ecosystems that the infrastructures affect, and the social structures that underpin collaborative work and make the exploitation of the resources possible (such as laws, rules, norms, contracts, technical codes, property rights, roles, social networks, etc.).

The traditional configuration of UWSs has been undeniably successful in the fulfilment of basic water services since the mid-19th century, making significant contributions to improvements in life expectancy, economic development and quality of life. Although urban dwellers in developed countries take these basic urban water services for granted—and they therefore become “invisible” to most of the population—it should not be forgotten that the provision of these services involves highly complex technical and social organization, and represents a very recent achievement in the timeline of the history of mankind. In the Western world, some of our grandparents did not have access to these basic water services, and even today there are many cities in the South and East which are unable to provide basic urban water services to a large portion of their citizens (WHO and UNICEF, 2017).

It is also important to note that although the provision of urban water services in most Western cities may seem unproblematic from the citizens’ point of view, this does not necessarily imply that they are totally sustainable. On the contrary, there are certain social, economic and environmental drivers which can put the performance of the systems at risk (Table 1), and these seem to be on the rise in developed countries. Moreover, what is even more alarming is that countries are sometimes adopting solutions for these issues which actually aggravate, rather than improve, the previous situation.

A growing number of scholars, therefore, are starting to claim that the UWSs which facilitated unprecedented improvements in security and quality of life are, in reality, ill-equipped to deal with the emergent water-related challenges of the 21st century (e.g. Larsen et al., 2016; Marlow et al., 2013; Milly et al., 2008). Indeed, in recent decades several new water-related needs have emerged, which are not essential for life, but are closely connected to urban life quality. For example, although urban water is now expected to contribute to recreation, aesthetics, psychological health, and biodiversity (Fletcher et al., 2015; Saurí & Palau-Rof, 2017; S. Sørensen et al., 2006), the traditional configuration of UWSs does not attempt to address these needs.

Table 1. Selected emerging challenges in the urban water sector of industrialized countries.

Drivers of change	Effects on urban water services	Selected references
Accelerating climate change (Higher frequency, duration and intensity of extreme weather events)	More frequent and severe floods and droughts, decline in drinking water quality, point pollution of superficial water bodies due to combined sewer overflows, higher water treatment costs	(Conley et al., 2009; Díaz et al., 2016; Garrote, 2017; Groisman et al., 2005; Iglesias et al., 2007; IPCC, 2014; Jha et al., 2012; Mekonnen & Hoekstra, 2016; Milly et al., 2002; Rockström et al., 2009; Semadeni-Davies et al., 2008; Vörösmarty et al., 2010; Whitehead et al., 2009)
Growing rates of resource exploitation (Depletion of drinking water reservoirs and nutrients)	Higher costs of water provision, inequalities in access to water, and ecosystem degradation	(Fixen & Johnston, 2012; Gleeson et al., 2012; Gleick & Palaniappan, 2010; WWAP, 2015)
Urbanization (Increase in impervious surfaces)	More frequent and severe floods, diffused pollution of superficial water bodies and groundwater, alteration of groundwater and stream flow regimes	(Andoh et al., 2008; Chocat et al., 2001; Conley et al., 2009; Hopkins et al., 2014; Jha et al., 2012; Mirchi et al., 2014; Novotny, 2009; Schuch et al., 2017; Vörösmarty et al., 2005)

Increasingly stringent social, economic and environmental requirements. (Demands on efficiency gains and reductions in energy consumption, mitigation of contribution to climate change, improvements to urban aesthetics and community life, economic growth, or satisfaction of increasingly stringent human and environmental health standards)	Higher knowledge requirements, greater responsibility for water managers, conflicting interests and goals, and higher service costs	(Acreman et al., 2014; Backhaus & Fryd, 2013; Barraqué, 2003; Berardi et al., 2014; Kleerekoper et al., 2012; Marlow et al., 2013; Nair et al., 2014; Novotny et al., 2010; OECD, 2011, 2015; B. D. Richter et al., 2003; Rothausen & Conway, 2011; Vörösmarty et al., 2010; Wong, 2006)
Growing complexity (Interdependencies between multiple social, institutional, financial, technological and environmental factors)	Growing need for coordination and cooperation among actors, conflicting interests and goals, growing uncertainty and service vulnerability	(Chocat et al., 2007; Curmi et al., 2013; Gober et al., 2010; Gondhalekar & Ramsauer, 2017; Hoff, 2011; Ouyang, 2014; Rinaldi et al., 2001; Robert et al., 2003; Sivapalan et al., 2014; Steffen et al., 2011)
Institutional fragmentation	Conflicting goals and policies, low efficiency, higher service costs, social inequalities	(Brown & Farrelly, 2009; OECD, 2015, 2016)
Emergence of new security threats (Bioterrorism and cyber-attacks)	New sanitary and economic risks, higher service costs, vulnerability of the service.	(Clark et al., 2016; Copeland, 2010; Meinhardt, 2004)
Emergence of new contaminants (New pathogens, microplastics, pharmaceuticals and personal care products)	New sanitary and environmental risks, higher service costs	(Eerkes-Medrano et al., 2015; Jones et al., 2005; Kaplan, 2013; Lapworth et al., 2012; Pal et al., 2010; Pandey et al., 2014; Snyder et al., 2003; Verlicchi et al., 2012)

Ageing infrastructures (Backlog of deferred renovation and maintenance)	Growing service vulnerability, higher service costs, sanitary risks.	(ASCE, 2021; AWWA, 2012; Folkman, 2018; Hukka & Katko, 2015; Nair et al., 2014; Sharma et al., 2010; Tortajada, 2008)
Declining water consumption in industrialized cities	Decline in revenues, lower efficiency, lower drinking water quality and sanitary risks	(Baldino & i Pujol, 2018; Deoreo & Mayer, 2012; Donnelly & Cooley, 2015; Moss, 2016; OECD, 2015; Rockaway et al., 2011)
Growing austerity in fiscal policies (Higher levels of public debt, declining private investment and reduction of budgets)	Short term planning, lack of investment, aversion to risk which in turn hinders innovation and adaptation, deferred maintenance, lower efficiency, vulnerability of the service	(Bakker, 2010; OECD, 2015)

Between the inability of UWSs to tackle emerging challenges in the water sector, and their insufficient capacity to fulfil emerging needs, the idea that today's UWSs are unsustainable is gaining significant traction in academic circles.

Awareness of this unsustainability has prompted innovations that aim to solve such problems as those presented in Table 1 by employing isolated solutions. However, these solutions are just patches that are not always an adequate fit for traditional UWSs. Consider, for example, the difficulties encountered in attempts to introduce rainwater tanks in the Australian water sector, described by Sofoulis (2015), or the problems associated with implementing a European Water Framework Directive that was ahead of its time (Voulvoulis et al., 2017). Traditional, deep-rooted UWSs have significant inertia, are profoundly locked-in (Brown et al., 2011), and have the capacity to suppress changes even when evidence of their unsustainability is multiplying. As a result, there is a growing level of acceptance that change must occur at the system-level.

Over the last two decades, this need for system-level change has been interpreted by scholars and leading international organizations in the water sector as a need for better governance, rather than a need for new infrastructures. Governance is increasingly depicted as being fragmented into multiple organisms—at different social levels, and with different horizons and agendas—which have difficulty coordinating effectively (Borowski et al., 2008; Graham & Marvin, 2001; Segrave et al., 2014). However, *what* governance actually is, and *how* it needs to be changed, remains unclear for many.

A further interpretation of this necessary system-wide transformation is expressed in the form of new management frameworks. Examples include Integrated Urban Water Management (IUWM), Sustainable Urban Water Management (SUWM) or Water Sensitive Cities, which are also quite vaguely articulated and difficult to translate into practice.

Furthermore, over the last two decades, and at an even more abstract and imprecise level, the idea has emerged in academic circles that the required system-wide change should be interpreted as a new water paradigm (e.g. Gleick, 2000; Pahl-Wostl et al., 2011; Pinkham, 1999; Vlachos & Braga, 2005). This paradigm should be capable of properly addressing current and anticipated challenges by reshaping infrastructures, management and governance into more sustainable configurations. However, the definition of this new paradigm is also vague, leading to frequent descriptions by scholars as a set of elements lacking a clear structure. Indeed, it is often difficult to understand what scholars mean by the word *paradigm* at all.

There is consensus, however, on the idea that the incumbent paradigm is rigid, and prone to continued operation under the same beliefs and values despite expanded community expectations, increasingly complex societal needs, and evident issues of sustainability (Brown & Farrelly, 2009; Kiparsky et al., 2013; Roy et al., 2008). Consequently, there is a need for a well-defined paradigm that can be regarded as a credible alternative and pave the way to sustainable infrastructures, management and governance of urban water.

1.2 Goals

The core goal of this study is to understand the nature, origin, and consequences of the frames of reference[1] that shape urban water systems (UWSs), and the water services that they enable.

This overarching goal has been approached in the form of four more concrete sub-goals:

- to understand what frames of reference/paradigms of UWSs are (discussed in the introduction of the thesis)
- to define the new urban water paradigm as a coherent system of philosophies which ascribe meaning to emerging changes in the governance, management and infrastructures of recent decades.to investigate how broad social transformations influence the transformation of the urban water paradigm (paper 1).
- to investigate how broad social transformations influence the transformation of the dominant urban water paradigm (paper 2).
- to advance the understanding of governance as a critical element of urban water services, and the knowledge of how it is shaped by different frames of reference (paper 3)
- to suggest ideas which may accelerate the transition towards a new urban water paradigm and, hopefully, towards more sustainable urban water systems (paper 4).

1.3 Scope

Previous studies by Allan (2004) suggest that the transformation of urban water systems in developed countries (the North) has traditionally led to the evolution of urban water systems in the economies of the South. Since the 1970's, however, their paths have diverged. While the South has become entrenched in the modern paradigm (the hydraulic

[1] The term *frame of reference* is used in this thesis as an umbrella concept for similar concepts, among which I include *paradigm*. For a more detailed explanation, refer to heading 2.5.

mission), the North has focused instead on issues of risk management, and ecological, social and economic aspects of water management (reflexive modernization).

In the present thesis, I have chosen to dwell exclusively on the past, present and future transformations of Western economies (the North). There are three main reasons for this. The first is that transformation of the urban water paradigm in these countries can provide lessons which are applicable to the South. Ideally, countries with developing economies could learn from the mistakes of northern countries and thus avoid undesirable outcomes in the future. The second reason is that since the mid-19th century, urban water sectors in the North have exhibited similar development trends across countries, in spite of local differences owing to specific problems and historical contexts (Fuenfschilling & Truffer, 2014; Staddon et al., 2017). On the other hand, in the South and East, there is a larger heterogeneity of transformations to be observed, which are much more difficult to conceptualize. Finally, the third reason for focusing on UWSs of Western democracies is related to my own professional interest, as I work as an engineering consultant for urban water in Norway, and wish to develop knowledge that is applicable to my work and my context.

1.4 Research questions

This thesis has been conceptualized as an exploratory work of frames of reference in the urban water sector. Therefore, the questions which have guided the research thesis were not formulated at the outset, attempting to fill a knowledge gap with surgical precision. Instead, questions have emerged as the research has developed. In this section, the questions are not merely stated, but also accompanied by the logic which led from one to the next.

As described in the preface, this thesis originated from my suspicion that the unsustainability of the urban water sector was not a technical issue. After an introductory literature review, I recognized that this idea was closely related to the new paradigm that has been described in recent research. The first question, then, was as follows:

Question #1: What is an urban water paradigm?

This question was not explicitly or extensively approached in any of the four papers that comprise this thesis, but it is approached in the conceptual framework of the extended introduction (chapter 2).

The authors that have described a new paradigm in the water sector—some explicitly, and others implicitly—have contributed heterogeneous characteristics at different levels that are often hard to relate to each other. Therefore, the question that guided paper 1 was:

Question #2: What is the new urban water paradigm?

Paper 1 revealed significant coherence among the elements within the paradigm that seemed to have a common foundation. This observation led to the next question:

Question #3. How are urban water paradigms shaped?

Papers 1 and 2 showed that the transition towards the new paradigm represents a clear change in focus. Throughout the 20th century, the focus has moved from issues of resources to issues of infrastructures, and then to issues of management. From the beginning of the 21st century, issues of governance have received increasing attention. In fact, today there is an all-encompassing agreement among scholars and respected international organizations that water crises are crises of governance, i.e., problems related to institutions[2], policies and cooperation.

By relating this idea to the previous papers, the question approached in paper 3 became apparent:

Question #4. What is urban water governance and how does it relate to urban water paradigms?

The lessons learned in paper 3 seem to indicate that "crises of governance" could be understood as entrenched conflicts among co-existing frames of reference that

[2] In this thesis, the word institution does not refer to "organizations", but to "the rules of the game in a society" (North, 1990, p. 447).

continuously strive to shape the urban water sector. In recent decades, governance has suffered the growing fragmentation and diversity of (often confronting) frames of reference, which impede the capacity to adopt sustainable solutions. This diversity of frames of reference, however, is also associated with flexibility and the resilience required to adapt to new problems, and is a fundamental tool of the new paradigm. This paradox inspired the 5th question, which was approached in paper 4:

Question #5: What can be done to balance variety and integration of frames of reference in urban water?

The lessons learned through the course of this dissertation have led to the conclusion that the emergent urban water paradigm would not necessarily be an optimal or definitive paradigm, but rather an improvement in the path towards sustainability, when compared with the old paradigm. The conclusion of this thesis (chapter 5), therefore, approaches the following question:

Question #6: What characterizes a sustainable frame of reference in an epoch of growing complexity?

To conclude, chapter 6 dwells on the most pragmatic question:

Question #7: What can these results teach the actors of the urban water sector?

1.5 Objectives

The aforementioned research questions helped to shape corresponding research objectives which, in the same way as the questions, emerged as the work evolved.

Objective 1

Create an explanatory framework of frames of reference that can be applied to UWSs.

This objective is fulfilled in the extended introduction of this thesis (chapter 2).

Objective 2

Create an explanatory framework to understand and analyse urban water paradigms.

This objective is fulfilled in paper 1.

Objective 3

Use the explanatory framework (from objective 2) to define and juxtapose the old and new urban water paradigms.

This objective is also fulfilled in paper 1.

Objective 4

Create an historical analysis of the evolution of dominant urban water frames of reference which is parallel to the evolution of dominant frames of reference in Western society during the last two centuries.

This objective is fulfilled in paper 2.

Objective 5

Create an explanatory framework for the analysis of urban water governance from the perspective of frames of reference.

This objective is fulfilled in paper 3.

Objective 6

Create a theory that explains how diversity of frames of reference can provide flexibility to the urban water system without compromising integration, and how they can actually facilitate integration instead.

This objective is fulfilled in paper 4.

Objective 7

Create an explanatory framework that describes the necessary characteristics of a suitable/sustainable frame of reference for the urban water sector.

This objective is fulfilled in chapter 5 of this extended introduction.

Chapter 2: Conceptual framework

This chapter presents the conceptual framework[3] that links and serves as a shared foundation for the four papers included in this thesis. Although some repetition of the content of the papers is unavoidable in providing a solid foundation, this chapter is also used to elaborate on particular ideas, and introduce others that could not be included in the papers due to document length limitations imposed by the selected journals.

This conceptual framework presents four distinct ways to understand UWSs (sections 2.1-2.4), and an introduction to frames of reference (section 2.5).

[3] See section 3.3 for a detailed explanation of what is meant here by the term *conceptual framework*.

2.1 UWSs as socio-technical-ecological systems

I am sure you remember the plain citizen Jourdain in Molière's Le Bourgeois Gentilhomme who, nouveau riche, travels in the sophisticated circles of the French aristocracy and who is eager to learn. On one occasion his new friends speak about poetry and prose, and Jourdain discovers to his amazement and great delight that whenever he speaks, he speaks prose. He is overwhelmed by this discovery: "I am speaking Prose! I have always spoken Prose! I have spoken Prose throughout my whole life!"

A similar discovery has been made not so long ago, but it was neither of poetry nor of prose—it was the environment that was discovered. I remember when, perhaps ten or fifteen years ago, some of my American friends came running to me with the delight and amazement of having just made a great discovery: "I am living in an Environment! I have always lived in an Environment! I have lived in an Environment throughout my whole life!"

Heinz von Foerster

On Constructing a Reality, 1973

Throughout this thesis, UWSs are referred to as systems. This is because they are made up of a group of elements which connect interactively to perform certain functions. This is an assertion that hardly warrants discussion, but it should be noted that the understanding of precisely what elements these systems involve has evolved over the years.

UWSs as technical systems

Until the middle of the 19th century, urban water services in Western cities were supplied by isolated infrastructures—such as wells, cesspools, or ditches—that provided only localized services and could hardly be considered systems. By the beginning of the 20th century, however, capital-intensive, large scale and centralized infrastructure networks of drinking water, firefighting water, wastewater, and stormwater were flourishing in Western countries, constituting the fabric of modern cities (Tarr & Dupuy, 1988). These urban water networks were (and still are, in many cases) seen as purely technical systems, or city-wide machines that were assumed to be cultural and value-neutral.

UWSs as socio-technical systems

It was not until the second half of the 20th century when some scholars started to recognize that UWSs did not consist solely of technical elements (e.g. pipes, pumps, channels, water treatment plants, technical guidelines and computer models), evolving parallel to scientific and technical innovations, but were also strongly influenced by social and cultural factors. Subsequently, UWSs started to be regarded as socio-technical systems (Feenberg, 1999; Geels, 2002; Rotmans et al., 2001). Several scholars claimed that there was a co-evolution (mutual adaptation and feedback) of technologies and social structures (e.g. scientific knowledge, laws, contracts, regulations, markets, organizations, roles, power relationships, needs and values). Intertwined social and technical elements together constituted a “seamless web” with enough rigidity to provide stability and resist change, guaranteeing the provision of certain societal functions (Hughes, 1986; MacKenzie & Wajcman, 1985). According to Geels (2004), the modern man does not live in biotopes, but rather in technotopes, which enable and constrain our cognition and behaviour. At the same time, our technological context reflects our values, beliefs, assumptions and modes of social organization, as well as our general social, economic and political context.

This conceptualization of UWSs as socio-technical systems was revolutionary in three different ways. First, on account of the fact that—at least in some academic circles—the assumption that society is shaped by technological development (technological determinism) was gradually being replaced by the assumption that technological development is a reflection of social transformation (the social structuring of technology). Second, because the focus on pure technological advancements (form) was gradually being replaced by a focus on the societal services (function) that technology enabled and constrained. Third, because it bridged two fields of knowledge that were initially separate, opening the door for a new field of transdisciplinary research, to which the present thesis belongs, and affording a legitimacy to qualitative research that it did not possess in the past.

UWSs as social-ecological systems

In the same way that a growing body of researchers and disciplines have become aware of the inextricability of society and technology in recent decades, there is now a growing acceptance of the strong interdependence between societies and their biophysical context. Some refer to this interdependence as social-ecological systems (Berkes et al., 2008; McGinnis & Ostrom, 2014), or as human-environment systems. The idea is that the biosphere (climate, soil, topography, ecosystems, etc.) constrains and supports human cognition, behaviour and social organization, while humans have an undeniable influence on that same biophysical context. Some even believe that this influence is so significant that humans have defined a new geological age: the Anthropocene (Crutzen, 2002).

UWSs as socio-technical-ecological systems

By combining the two previous perspectives (UWSs as socio-technical systems and UWSs as socio-ecological systems), it is possible to conceptualize UWSs as socio-technical-ecological systems (STESs) (cf. Smith & Stirling, 2010). These are three closely intertwined spheres that have co-evolved and are aligned towards the facilitation of urban water services through determined paths.

Although this conceptualization of UWSs might seem rather obvious in the face of our contemporary water challenges—such as climate change—the traditional understanding of UWSs among practitioners has been overwhelmingly technocratic, downplaying the importance of the social and ecological spheres.

2.2 UWSs as systems of infrastructures, management and governance

In the four papers included in this thesis, the conceptualization of UWSs as systems of infrastructures, management and governance appears as a recurrent theme. Infrastructure refers to physical facilities, either manmade or natural, that regulate the environment and make the provision of urban water services physically possible. Infrastructure regulates the state of the resource; it extracts, transports, stores, cleans and disposes of water. Management refers to activities that directly involve the regulation of infrastructures—such as monitoring, analysis, planning, design, construction, operation, and maintenance—and other financial or human assets. Management requires information acquisition, technology development and use, risk-evaluation, economic planning, organization of human resources, and decision-making. Governance can be defined as the collaborative social practices (politics), together with their supporting and resulting social structures (policy and polity), that set the scene for management of water services. Governance includes, for example, the definition of policies, rules, or roles, and the negotiation, collaboration, or mobilization of actors.

As these definitions show, infrastructure, management and governance are three nested subsystems (Figure 2) of UWSs that determine the provision of urban water services. Governance shapes management, management shapes infrastructure, and infrastructure determines how the physical world is regulated and how urban water services are provided.

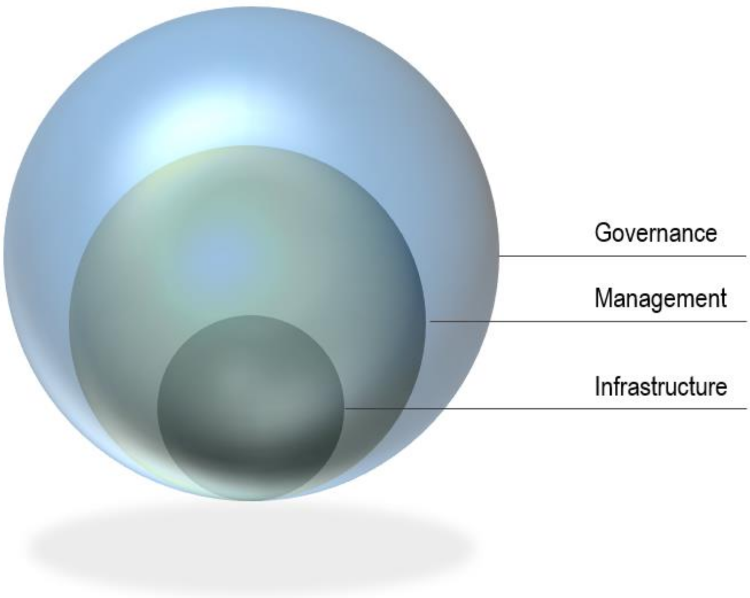

Figure 2. Infrastructure, management and governance as nested subsystems.

2.3 UWSs as complex systems

"Away from the safety of your home, the universe was not made for your convenience."

Edward Witten

> *"Let's face it, the universe is messy. It is nonlinear, turbulent, and chaotic. It is dynamic. It spends its time in transient behavior on its way to somewhere else, not in mathematically neat equilibria. It self-organizes and evolves. It creates diversity, not uniformity. That's what makes the world interesting, that's what makes it beautiful, and that's what makes it work."*
>
> Donatella H. Meadows
> *Thinking in Systems: A Primer, 2008*

The perspective shift from UWSs as purely technical systems to UWSs as STESs, or the perspective shift from UWSs as infrastructures to UWSs as infrastructure-management-governance, exhibit parallelism with the change of perspective from UWSs as simple systems to UWSs as complex systems. In this section, I will provide a condensed overview of what complexity means, why it is accelerating, and how this acceleration is reflected in UWSs.

There is no single unified theory of complexity, or even a single definition, that captures the majority of uses of the term. However, some recurring characteristics of complexity can be drawn from literature on the topic which proliferate in multiple fields of study (e.g. Cilliers, 1998; Funtowicz & Ravetz, 1993; Gibbons et al., 1994; Human, 2015; Kurtz & Snowden, 2003; Mikulecky, 2001; Morin, 2007; Page, 2010; Snowden & Boone, 2007; Stacey, 1996; Stacey & Mowles, 2016).

Subsequently, this section presents some of these basic characteristics of complex systems that seem to be widely accepted in this body of literature. To organize them characteristics, I have borrowed some categories from the explanatory framework constructed to analyse paradigms (paper 1). These categories include complexities ontology (what is the nature of complexity?), complexity's epistemology (how is complexity understood?), complexity's axiology (what is the system of values that complexity involves?), and complexity's methodology (how can complexity be managed?). For comparison, complicated and simple systems will be analysed in similar terms later on.

Complex systems

To put it briefly, I define complex systems[4] as systems of interdependent entities that lack a central controller and behave as a whole, exhibiting order, stability and self-regulation combined with high levels of entropy that allow them to reorganize and adapt to changes in their environment. Typical examples of complex systems include ecosystems, insect colonies, cities, markets, language, the internet, the human brain, and climate.

The individual entities that make up a complex system exchange information through signals, which are transmitted first to neighbouring entities and then diffused and modulated through long ranges to distant parts of the system. Recursive connections allow signals to be retrofitted in positive feedback loops (amplified), or retrofitted in negative feedback loops (suppressed), creating non-linear patterns of behaviour. This non-linearity is probably the most important characteristic of complex systems, and means, in practice, that small inputs can amplify, having exponential, oscillatory, chaotic and system-wide consequences. Meanwhile, large inputs can be absorbed by the system, producing minor outputs, or even totally suppressing the change. Non-linearity means that these complex systems do not follow what is known in statistics as a normal distribution or a bell curve; they are non-normal. Instead, they follow a power law, combining phases of stability and phases of exponential growth and exhibiting a behaviour far from equilibrium that results in a discontinued, evolutionary nature. The system is in a continuous mode of flux and adaptation.

On the one hand, complex systems can be resilient, can absorb changes, and can remain in homeostasis for long periods despite the presence of perturbations (as a result of

[4] My definition shares many similarities with what some call "complex adaptive systems" (CAS) (Holland, 1996; Levin, 1998). However, I omit the word "adaptive" because I think it is redundant, and that it should be taken as axiomatic that adaptability is a necessary property of complex systems.

negative feedback loops that "absorb" change). Lakes, for example, can tolerate relatively high concentrations of phosphorus (until a certain point, or a threshold) and maintain their ecological equilibrium, and cities are able to recover from natural catastrophes. Complex systems can lose parts of their components and still maintain their functionality. This is visible in such examples as a market economy, which can continue to function and provide services to consumers even when some companies go bankrupt and disappear.

On the other hand, complex systems can be flexible, and able to rapidly reorganize, developing new properties and structures that significantly differ from the characteristics of its constituent elements (emergent characteristics), or suffering abrupt changes which alter the character or function of the whole system. A common example of *emergence* in complex systems is the human conscience, which cannot be inferred from the isolated study of the neurons that compose the human brain, and even less from the atoms that compose the neurons.

What makes complex systems even more "complex" is that their characteristics are not limited to the system itself. Complex systems are typically open systems, exchanging matter, energy and information with their environment through a permeable and diffuse boundary, and reacting and adapting to its changes.

Interestingly, all the characteristics that make a system complex are at odds with human cognition, which relies on linear causality thinking. This cognitive approach assumes that events within the system can be explained through a single, linear and unidirectional chain of proportional cause and effect, which produces a simple narrative with a start and an end. The behaviour of complex systems, however, is in clear dissonance with this assumption.

Likewise, humans naturally tend to rely on the independent analysis of the system components (reductionism), and the selection of the most relevant system components (simplification), to build a model that can help to understand the behaviour of the system. These two epistemological tools, reductionism and simplification, erode the relational, non-normal, dynamic, emergent, self-regulatory and adaptive characteristics of the complex system, and yield models that are far from the reality that they seek to represent.

Moreover, complex systems cannot be immediately grasped and objectively described. The observer requires a point of view or a frame of reference[5], necessarily becoming partial or subjective. There is not a preferred point of view or unbiased perspective from which to observe the system, and descriptions can therefore only be regarded as subjective interpretations.

A football match is a good example of a complex system that serves to illustrate this epistemological characteristic. Even though a football match is usually narrated following the trajectory of the ball, there are many other things happening on the field, or even on the tribune, that determinately condition the game. Certainly, there are undeniable facts, such as the score of the game, but there is no objective way to describe all the interactions that have occurred during the game and led to that result. It is only possible to give descriptions in the form of narratives that inevitably stem from a certain point of view, highlighting some (subjectively relevant) aspects and ignoring others.

This subjectivity is particularly important in wicked problems (Reed & Kasprzyk, 2009; Weber & Khademian, 2008), a particular type of problem that is unique to complex systems. These are intractable problems characterized by their ambiguity (they are difficult to define), lack of structure (there are unclear connections between cause and effect), cross-cutting character (they cannot be approached solely from the lens of a discipline), relentless (they are without unique, optimal or definitive solutions), pervasive (interventions often result in unintended consequences and new problems), and controversial (they are impossible to resolve by resorting to rational explanations or facts, and lacking in an obvious single solution). A good example of wicked problem is climate change, which possesses all these characteristics.

In summary, complex systems are incompressible, and cannot be understood, predicted, controlled or solved in an objective way. The problems they create are also subjective and do not have a fixed optimal solution, but rather multiple dynamic and local optimal points. This does not mean that insights cannot be gained about complex systems, just that

[5] Frames of reference are described in section 2.5.

descriptions are inevitably partial and temporal. The understanding, interpretation and meaning of complex systems, then, is inevitably attached to needs and values. Wicked problems must be approached through controlled experimentation (safe-to-fail approaches) that lead to innovation, integration of varied perspectives and knowledge, and negotiation and compromise that facilitate the achievement of sub-optimal, satisfactory, and temporary solutions.

Complicated systems

The term *complicated system* is often erroneously used as a synonym of *complex system*. Like complex systems, complicated systems are composed of multiple, interconnected elements. However, the core ontological difference between the two is that the interdependencies of complex systems produce non-linear behaviours, while the interdependencies of complicated systems produce linear behaviours. Complicated systems lack circular feedback processes that create stability, self-reorganization and emergent properties, and they do not tolerate chaos. In addition, they are mostly isolated from their environment, separated from it by means of a clear boundary, and unable to respond to its changes. Therefore, complicated systems are not adaptive. They are "death" systems. They are not resilient, but merely robust within a predefined range of perturbations in their environment, unable to react to unforeseen events. A clock can be taken as a good example of a complicated system, as it is isolated to its context and not adaptive or resilient. If we eliminate a piece of a clock, it will stop working.

Given that they exhibit linear behaviours and lack strong circular feedback, complicated systems are potentially computable and predictable. With time and effort, these systems are algorithmizable and reducible to simpler models, bringing the system closer to simplicity. While uncertainty in complex systems is an inherent property of the system (ontological uncertainty), uncertainty in complicated systems is due to a lack of information (epistemological uncertainty).

The study of complicated systems focuses on rational and objective knowledge, provided by experts and gained though thorough observation and analysis, and continuously seeking the definition of objective facts, the elimination of uncertainty, and optimization.

Although the functioning of the systems and the cause-effect relationships are not obvious, they can be deduced through controlled experimentation, reductionism and simplification. While theoretically possible, the elimination of uncertainty or the identification of optimal points can, in practice, be impeded by a vast number of elements or relationships that cannot be measured. Consequently, the study of complicated systems must often resort to probabilistic approximations.

Simple systems

Unlike *complex* and *complicated systems*, *simple systems* are composed of elements that are just poorly connected, with limited exchange of information. Their collective behaviour is linear and isolated from its context, describing patterns that fluctuate within well-defined thresholds of variability.

Therefore, the understanding of simple systems is unproblematic. The correlation between inputs and outputs, the consequences of interventions (cause and effect), and the identification of optimal points are self-evident. The future state of the system is predictable, and uncertainty can be eliminated by gathering sufficient information.

In the study of simple systems, their functioning and control can seem so obvious and objective that values are often neglected. Problems are "tame": structured, undisputed and fully solvable through rational, objective and optimal solutions. These solutions are often achieved through predefined best practices that categorize and provide optimal responses.

As is described in paper 2, the Enlightenment thought that has dominated Western culture until today promotes an understanding of the world around us as an eminently simple system. The traditional (old) water paradigm, which has its foundations in this philosophy, assumes that biophysical phenomena (rain, infiltration, runoff, evaporation, ecosystems), the behaviour of technologies and infrastructures, and even the behaviour of men (rational optimizers), can be analysed, measured, predicted and controlled. This guarantees the fulfilment of basic and undisputed water needs, such as drinking water provision, conveyance of waste, drainage, and firefighting.

According to this paradigm, UWSs face only tame problems that present little uncertainty, while the few existing needs are objective, universal, undisputed and aligned. This perception of needs leads actors to focus their attention on the design of tools to control their context and deliver a narrow set of basic water services. The old paradigm, then, sees urban water management predominantly as a simple technical issue.

Omnipresence of complex systems

The Enlightenment's assumption of an eminently simple reality where the natural laws can be revealed through observation and reason started to crumble around the mid-20th century. Nowadays, it is slowly being replaced by the idea that most systems around us are complex, and dominated by an indomitable uncertainty. Some even argue that complex systems with non-linear behaviours are the norm, not the exception (Mikulecky, 2001). The mathematician Stanislaw Ulam actually argued that our world was essentially built by the non-linear phenomena that engender complex systems: "using a term like non-linear science is […] like referring to the bulk of zoology as the study of non-elephant animals" (cited by Campbell et al., 1985, p. 374).

Unfortunately, complexity is not always evident, and complex systems tend to appear either complicated or simple to us for two reasons. The first is that in complex systems a set of negative feedback reactions keep the system within a range of variation and an apparently predictable behaviour. That is, however, until unpredictable events emerge, such as natural catastrophes, social revolutions, financial crises, or a pandemic (Taleb, 2007). The second reason is expediency (Campbell et al., 1985). Humans tend to focus on things that we can understand, and neglect those that we cannot. Our brains are wired to think linearly, and non-linearity introduces uncertainty that our brains are not designed to comprehend. This problem results in what (Bhaskar, 1975) calls an *epistemic fallacy*[6]. This concept refers to the erroneous belief that our capacity to see and understand reality

[6] In the words of Bhaskar, the epistemic fallacy "consists in the view that statements about being can be reduced to or analysed in terms of statements about knowledge; i.e. that ontological questions can always be transposed into epistemological terms" (1975, p. 26).

matches the complexity of reality. Therefore, what we do not see or understand is deemed to be non-existent. “We do not see that we do not see” (von Foerster, 1979, p. 6).

Still, even if it is misguided, the process of taking a part of a complex system, isolating it from its context, and “incorrectly” regarding it as only complicated or only simple, often has a pragmatic utility. The effort that it takes to reduce complex systems “as-if” they were complicated is not wasted, as is clear from the advancements in life expectancy and quality of life that can be put down to the Enlightenment (Pinker, 2018). Newton laws, for example, are rough simplifications of complex systems which help us to “understand” reality and produce solutions that improve our welfare. They are explanations that “work”, but are far from absolute representations of reality.

Of course, it is essential to keep in mind that treating systems as simple does not eliminate their complexity, their non-linearity, or their inherent uncertainty, and treating complex systems as simple or complicated can be a source of unintended consequences and manufactured risks.

Why complexity is accelerating

Change is the only constant.

Yuval Harari
Sapiens, 2011

While approaches to complex systems “as-if” they were complicated have been the norm in our modern society, ideas of complexity have become more pervasive in recent decades, and therefore difficult to reduce. The growing complexity of our reality has been described by multiple authors through theories like reflexive modernization (Beck et al., 2003), postmodernism (Jameson, 1991), liquid modernity (Bauman, 2000), and network society (Castells, 2010). All these accounts describe an increasingly heterogeneous and dynamic society, with rich interactions among elements. This is a society that is full of uncertainties and risks, but also opportunities, and one that resists reductionist approaches and traditional modes of rationalistic control.

Among the main factors that contribute to growing complexity, we could name the technological and social developments which have no historical precedents in terms of velocity, scope and system impact (Schwab, 2016; Steffen et al., 2015). In general terms, our current reality is increasingly populated by more diverse elements that are increasingly interdependent. Things that were once separate, are now connected. Water services, for example, which used to depend solely on isolated water infrastructures, are now strongly interdependent on energy and communication infrastructures, environmental and ecological changes, economic cycles, and social transformations. Technological advancements have not only promoted growing levels of complexity through the multiplication of elements and enhancements in their connectivity, but have also contributed to the alteration of relatively stable natural systems. Many natural phenomena have seen amplifications in their range of variability (and uncertainty), threatening ecosystems, limiting access to resources, and creating new risks of disruptive events. While these natural systems that used to behave within "predictable" ranges were regarded as simple or complicated in the past, they are now starting to be seen as highly complex. Again, a prime example of this is how industrial development and alteration of the CO_2 cycle has provoked climate change, with dramatic and unpredictable consequences.

Regarding social developments, it can be argued that globalization, democracy and the economics of innovation have also greatly contributed to increasing complexity. Democracies, where multiple values and worldviews are not stifled or suppressed by authoritarian leaderships, tend to be more plural societies, with high diversity of needs, perspectives, actors, networks and rules.

Modern economies also make significant contributions to complexity. While focus in the past was placed on the production of higher volumes of few products and services, recent decades have transformed the objective into producing new products and services that fulfil needs that did not exist before. In addition, these products and services carry unintended consequences which, in turn, create a growing demand for innovative solutions.

The consequences of complexity in UWSs

During the second part of the 20th century, awareness about the growth of uncertainty, manufactured risk and conflicting values and needs stimulated the idea that UWSs were complicated systems that required a transdisciplinary approach. In the early 1990's, this transdisciplinarity was reflected into the emergent concept of sustainability, aiming at simultaneously and co-ordinately fulfilling social, ecological and economic needs. Therefore, this surge in the sustainability concept meant that urban water problems were no longer seen as purely technical issues. Instead, they became problems of management or decision-making that required more thorough analysis of information, the use of market tools, certain levels of negotiation, and the integration of knowledge from different disciplines.

Notably, from the beginning of the 21st century, there was simultaneous growth in diversity, interconnectivity and dynamicity in the social, technological, and environmental spheres of UWSs. It became increasingly evident that UWSs were complex systems, existing in an expansive, non-linear and dynamic state (Milly et al., 2008). UWSs became fluid amalgams of elements without centralized control, and as a result, new needs, manufactured risks (e.g., terrorism, climate change, financial crises, pandemics), legal requirements, and disruptive technologies and actors, began to emerge into the field at an accelerated pace. Urban water became increasingly linked to issues like urban planning and urban liveability, biodiversity and ecological health, climate change, public health, cybersecurity, financial markets, production of energy and food, transportation, recreation, tourism, social inequalities and justice, and even spirituality (e.g. Fu & Liu, 2017).

Consequently, urban water management has become significantly more intricate. In considering the complexity of the technological sphere alone, it can be observed that while rapid technological development has undeniably facilitated the effective and efficient provision of safer water services, it has also made their delivery more vulnerable.

Water, energy, and information infrastructures have grown to be intertwined, creating circular dependencies. These dependencies then increase the risk of a cascade of failures across networks of infrastructures that were once independent (Buldyrev et al., 2010; Ouyang, 2014). Technological developments have also allowed the abusive exploitation of natural resources, and resulted in local resource scarcity, environmental degradation, and climate change, putting the provision of water services at risk. Table 1 in chapter 1 shows many other examples of wicked problems that are a consequence of growing complexity. Paradoxically, technological development and innovation are also essential conditions for the sustainable development of UWSs, beyond the safe provision of water services (Eggimann et al., 2017). Efficient use of resources, for example, as well as detection and elimination of new pollutants, and implementation of circular economies, are all dependent on technological innovation and development.

The case study presented in paper 4 of this thesis is a suitable practical example of the expansion of complexity in stormwater management. The Municipality of Copenhagen (like virtually any other Western city) has traditionally conveyed stormwater into a network of buried pipes. These were regarded as a technical system that was physically separate from other urban services, and managed, in isolation, by the engineers of the municipal water utility. The emergence of new social needs, such as the desire for greener and more liveable cities where stormwater is a positive element of the landscape, new economic drivers, and more intense and frequent storms as a result of climate change, has brought about a transition during the last decade to stormwater management on the surface. This measure has, in turn, facilitated higher levels of complexity. Planning, design, construction and management of stormwater infrastructures on the surface creates conflicts and synergies among multiple sectors and actors, such as urban planners, landscape architects, road managers, ecologists, biologists, developers, economists, and insurance companies. Situations like this, where a growing variety of opposing needs and perspectives arise around issues like stormwater, generate wicked problems which lack an obvious and single solution.

Although there is expanding awareness within the academic literature of the increasing complexity of UWSs in Western democracies (particularly among researchers with an inclination towards the social sciences), this awareness is not as widespread among practitioners. Many of the former (particularly in technical disciplines), and most of the latter, treat this complexity “as-if” complicated. They assume that elimination of all uncertainty would eventually be possible, that the system would then be perfectly predicted and controlled, and that all perspectives and needs would be aligned in a universal and objective truth. They believe that only more time, resources, research, and data are necessary. A good example of this perspective is the growing expectations relating to the optimization and efficiency gains obtained with big data and machine learning.

However, the growing complexity of UWSs goes beyond the challenge of designing management solutions while lacking information (epistemological uncertainty), or technical processes with low efficiency. This growing complexity is about conflicts of perspectives, interests and values, and the inherent uncertainty of the system (ontological uncertainty) associated with non-linear phenomena and emergence. Indeed, water problems are not primarily regarded as problems of resources or infrastructures (as they would be in simple systems), or problems of management (as they would be in complicated systems), but rather increasingly as problems of governance (as in complex systems) (Bakker, 2010; Bos et al., 2015; Bucknall et al., 2006; GWP, 2002; McCormick et al., 2013; OECD, 2011, 2016; Pahl-Wostl, 2015; van Dijk, 2012). Governance problems cannot be solved using big data or machine learning, because they are about the identification of a variety of needs, interests, priorities and values, processes of negotiation, collaboration and mobilization, and the setting of rules. Indeed, all the elements involved in governance are highly dependent on how we perceive reality and what guides our behaviour.

2.4 UWSs as cybernetic systems

> *"People know what they do; frequently they know why they do what they do; but what they don't know is what what they do does."*
>
> Michel Foucault
>
> *Michel Foucault: Beyond Structuralism and Hermeneutics, 1983*

According to the Encyclopedia Britannica, the word *Cybernetics* comes from the Greek word *kybernetikos*, meaning "good at steering", a root it shares with *governance*. As a discipline, cybernetics was initially related to the fields of automatic control and physiology, but today is applied to any kind of system, including ecosystems or social systems. Although there is no general consensus as to a proper definition of the concept, perhaps the most widespread definition is that proposed by Wiener (1948), who states that cybernetics is "the scientific study of control and communication in the animal and the machine". Along with others which are similar, this definition focuses on "control" and has as such become somewhat outdated. In the last decades, cybernetics has become a broader field of study, occupied mostly with systems of communication and *regulation* with circular causal relationships (feedback mechanisms) oriented towards a goal.

The traditional example of a cybernetic system is a thermostat which regulates the temperature of a room. However, this example might be misleading, making the reader believe that cybernetic systems are exclusively technical systems. Actually, cybernetic systems are all around us, including all types of social, technical and ecological systems.

Figure 3 shows my own schematization of UWSs as cybernetic systems[7], inspired by Ashby (1958). In this cybernetic system, we can identify four elements that are linked through circular causal relationships: a context, an output, a sensor/controller, and a regulator.

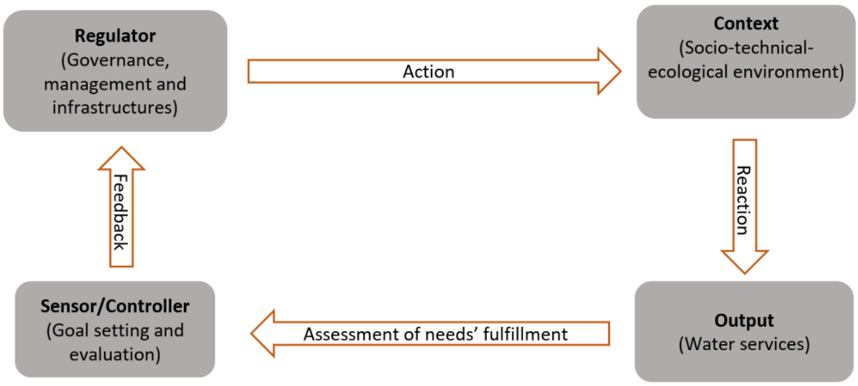

Figure 3. A cybernetic loop of UWSs.

In cybernetics applied to urban water, the context includes the dynamic, external socio-technical-ecological environment in which UWSs develop. The regulator accounts for the infrastructure, management and governance that alter/regulate the state of the context. The output refers to the urban water services (such as drinking water provision, sewerage or drainage) made possible through the regulation of the context. The sensor/observer/controller is the human/social component that sets the goals to be achieved in the cybernetic system (needs to be fulfilled); senses the state of the outputs (collects data); interprets the data (creates information); assesses the gap between the perceived states of the outputs and predefined goals; defines the adjustment measures required in the regulator in order to minimize the gap (such as new policies, rules, or infrastructures), and redefines the goals.

[7] This model should not be regarded as the standard way of representing cybernetic systems, but merely as an adapted interpretation designed for the purpose of this thesis.

This conceptualization of UWSs as cybernetic loops is useful in identifying and structuring a variety of interdependent elements and processes. The framework allows us to reflect on questions such as "how does a certain change in the urban water infrastructure contribute to the improvement of a certain water service?" or "how does the context behave?" However, this cybernetic conceptualization becomes even more interesting when the questions posed are related to the role of the sensor/observer/controller. For instance, "what data should be collected?", "how are outputs evaluated?" or "what are the system goals, who established them, and how?" At the beginning of the 1970's, these kinds of questions led to the idea that the observer must use a reduced model of external reality for the perception, interpretation, goal setting and decision-making that only exist in the observer's mind (Conant & Ashby, 1970). This simplified model is used as a blueprint to regulate the "real" cybernetic system. This perspective represents a reflexive approach to cybernetics that has been studied by (von Foerster, 2002b), who called it *second-order cybernetics*. While traditional (*first-order*) cybernetics focuses on how the "real" or "factual" system is shaped by circular loops of control and communication, *second-order cybernetics* is occupied with the study of the abstract or cognitive cybernetic model inside the observer's mind (Figure 4). von Foerster defined second-order cybernetics as "the control of control and the communication of communication", "the cybernetics of cybernetics" or as "a conceptual framework[8] which deals with *observing* and not only with *the observed*." (von Foerster, 2002a, p. 285).

This mental model of the "real" cybernetic system, which entirely determines the configuration of the UWSs—fundamentally shaping governance, management and infrastructures, and in turn greatly affecting the context and the urban water services provided—is the core of this thesis. In this extended introduction, I refer to it as the *frame of reference* of UWSs.

[8] Be aware that the term conceptual framework is used in this thesis with a different meaning (see section 3.3 and glossary)

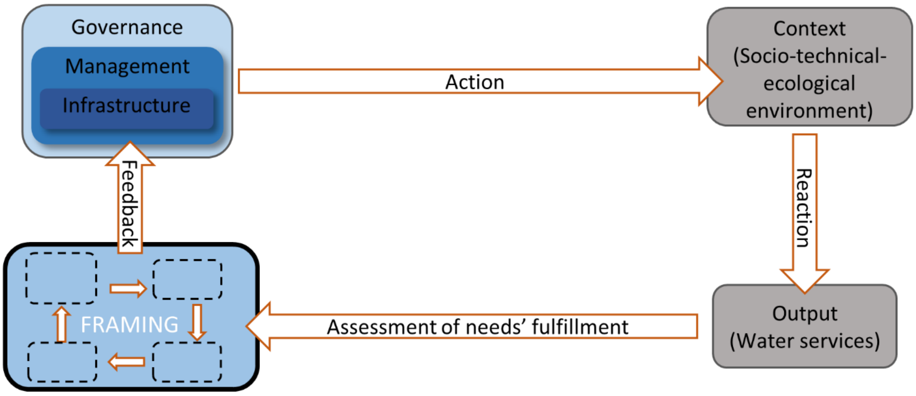

Figure 4. UWSs as a first and second-order cybernetic loop. The human sensor/observer/controller (bottom-left rectangle) contains a mental model (a frame of reference/second-order cybernetic loop) of the external/real/first-order cybernetic loop.

2.5 Frames of reference

> *Every discovery has a painful and a joyful side: painful, while struggling with a new insight; joyful, when this insight is gained. I see the sole purpose of my presentation to minimize the pain and maximize the joy for those who have not yet made this discovery; and for those who have made it, to let them know they are not alone. Again, the discovery we all have to make for ourselves is the following postulate.*
>
> *The Environment as We Perceive It Is Our Invention*
>
> Heinz von Foerster
> *On Constructing a Reality, 1973*

> *Remember, always, that everything you know, and everything everyone knows, is only a model.*
>
> Donatella H. Meadows
>
> *Dancing with systems, 2001*

> *If the doors of perception were cleansed every thing would appear to man as it is: Infinite. For man has closed himself up, till he sees all things thro' narrow chinks of his cavern.*
>
> William Blake
>
> *The Marriage of Heaven and Hell, 1790*

In this thesis, I use *frames of reference* as an umbrella concept that gathers the core characteristics of similar ideas which have emerged in disparate fields of study (Table 2). These ideas are not synonymous, and tend to differ in terms of disciplinary scope, social scale, pervasiveness or endurance. In common parlance, they are called rationalities, perspectives, schema, worldviews, cognitive lenses, cultural frameworks or mentalities.

All these terms have permeated other, secondary disciplines, to a more or less significant degree, where they have met with differing popularity levels and acquired nuances in their meaning.

Table 2. Selected terms that can be included in the umbrella concept *frame of reference*.

Concept	**Discipline**	**Selected reference**
Appreciative systems	social systems analysis	(Vickers, 1972)
Imaginaries	cultural political economy	(Sum & Jessop, 2013)
Mental models	organizational studies	(Senge, 1990)
Frames	sociology	(Benford & Snow, 2000; Goffman, 1974)
Social worlds	sociology	(Strauss, 1978)
Interpretive packages	sociology	(Gamson & Modigliani, 1989)
Social worlds	science studies	(Star & Griesemer, 1989)
Frames	psychology	(Kahneman, 2011; Tversky & Kahneman, 1981)
Paradigms	philosophy of science	(Kuhn, 1962)
Institutional logics	institutional theory	(Thornton et al., 2012; Thornton & Ocasio, 2008)
The software of the mind	social psychology	(Hofstede et al., 2010)
Epistemes	postmodern philosophy	(Foucault, 1970)
Metanarratives	postmodern philosophy	(Lyotard, 1984)
Cultural logics	postmodern philosophy	(Jameson, 1991)
Structures of feeling	cultural studies	(Vermeulen & van den Akker, 2010; Williams, 1977)

The difficulty in defining these concepts becomes particularly obvious when we observe that many were inconsistently described by the proposers themselves (for instance, Kuhn with the concept of *paradigm*), vaguely defined, or not defined at all. However, there are some more or less concise definitions which are worth noting (Table 3).

Table 3. Definitions of selected terms that can be regarded as *frames of reference*.

Concept	Definition
Paradigm (Kuhn, 1962, p. 175)	"[An] entire constellation of beliefs, values, techniques, and so on shared by the members of a given [epistemic] community"
Institutional logics (Thornton & Ocasio, 1999, p. 804)	"socially constructed, historical patterns of material practices, assumptions, values, beliefs, and rules by which individuals produce and reproduce their material subsistence, organize time and space, and provide meaning to their social reality"
Imaginaries (Sum & Jessop, 2013, p. 165)	"a semiotic ensemble (or meaning system) without tightly defined boundaries that frames individual subjects' lived experience of an inordinately complex world and/or guides collective calculation about that world"
Mental models (Senge, 1990, p. 11)	"deeply ingrained assumptions, generalizations, or even pictures or images that influence how we understand the world and how we take action"
Epistemes (Foucault, 1970, p. 183)	"In any given culture and at any given moment, there is always only one episteme that defines the conditions of possibility of all knowledge, whether expressed in a theory or silently invested in a practice"

In brief, I define frames of reference as a more or less coherent constellation of social constructions, such as assumptions, beliefs, biases, interests, values, or ideas, that is shared by a community and simultaneously enables and constrains perception, meaning, purpose, communication, collaboration and transformation of the "real".

I believe there are two primary reasons for which frames of reference are indispensable to the ability of humans to relate to reality. First, the human observer does not have direct access to the external reality because the nature of that reality transcends the inherent limitations of their cognitive abilities. The external reality is a complex, continuous, non-discrete entity, lacking any kind of a priori packaging or classification that makes it intelligible in its "pure" form. Second, reality lacks a sense of purpose. A frame of reference, then, constitutes a simplified model of the external reality, formatting it in discrete and relatable elements, and interpreting it in regard to the achievement of certain objectives. Frames of reference select the features of reality that are deemed relevant for the achievement of these objectives, and obscures those that are deemed irrelevant. The selected features of the observed reality are interpreted or "understood" by accommodating them within an a priori structure of meaning.

Although frames of reference are constructed with perceptions of reality, they are not precise mirrors of reality and can actually be far from it. There is undoubtedly an objective reality which is independent of human interpretation[9], but these facts are invisible and meaningless unless they are subjectively identified and interpreted through a frame of reference that makes them intelligible, debatable and tractable. Different frames of reference can offer different accounts of reality, departing from the same facts without contradicting them. Therefore, frames of reference are not right or wrong and cannot be falsified; they are just perspectives.

The observer navigates their frame of reference and is continuously nourished with selected and adapted observations of the real world. The frame of reference helps the observer to decide who they are and what their function is in the system. In addition, the frame of reference facilitates decision-making by providing a range of pre-approved recipes for evaluation and action (a rationality of behaviour) that avoid an unmanageable number of possibilities. The model provides *ontological security*[10] and "cognitive ease", because reality feels familiar, good, true and effortless (Kahneman, 2011).

Finally, while frames of reference are enacted by individuals, they are co-created, and only fully functional if they are shared by an epistemic community. This community

[9] Section 3.2 explains that critical realism is the interpretive framework that underpins this thesis. According to this philosophy, there is an objective reality independent of the human mind, but it is inaccessible to us in its pure form.

[10] Giddens (1991, p. 243) defines *ontological security* as "a sense of continuity and order in events, including those not directly within the perceptual environment of the individual."

usually takes them for granted, and tends to confuse them with the reality that they represent. Within this community, frames of reference have an important social binding function, enabling understanding and trust among individuals, and mediating the communication and cooperation that social endeavours require (Dewulf et al., 2009).

Although frames of reference only exist in people's collective imagination, they are reified as vocabularies, discourses, behaviours, rules, roles, techniques, tools, symbols and infrastructures. Individuals that adhere to the same frame of reference "see" the same "consensus reality", speak the same language, share the same assumptions, beliefs, values and objectives, and mediate through the same reified elements. These individuals enjoy a sense of belonging to a group, legitimacy, ontological security and collaboration that makes them more likely to achieve their goals. For example, the historian Yuval Harari (2015) describes how frames of reference like religions, nations, and money allow thousands or even millions of strangers to cooperate. When compared with other species, this ability is the definitive success factor of mankind.

> *A map is not the territory it represents.*
>
> Alfred Korzybsk
> *Science and Sanity, 1933*

Despite the numerous advantages and uses of frames of reference, they also present some important negative consequences, many of which are derived from the epistemic fallacy (Bhaskar, 1975) that generally makes frames of reference "invisible". This cognitive fallacy makes the observer prone to the mistaken belief that their frame of reference, the map, *is* the objective reality, the territory. Paradoxically, frames of reference that fulfil their function (to provide a credible and useful model of reality) make the human observer believe that they have direct contact with reality, and that frames of reference are non-existent or unnecessary.

Although, by definition, a frame of reference is adopted by an epistemic community, this community does not necessarily represent a whole societal sector, such as the urban water sector. In these sectors, different models of reality often co-exist, and may share some elements while differing on others. Shared elements allow the necessary cooperation for communication, effective work and problem solving across their epistemic communities, particularly when the system to be regulated is relatively simple. However, when a sector grows complex, wicked problems emerge, and a diversity of frames of reference also appears. These multiple epistemic communities strive to gain attention and impose their vision of reality and goals on others, creating contradictions and conflicts (Besharov & Smith, 2014; Hoffman, 1999; Thornton & Ocasio, 2008).

These conflicts among the advocates of different frames of reference are not exclusively related to their conflicting values, interests and goals, but also to two cognitive consequences of the epistemic fallacy, namely *naïve realism* and *cognitive closure*. In philosophy and social psychology, *naïve realism* refers to the assumption made by the observer that they perceive the world objectively. The observer will then believe that anybody exposed to the same observations would reach the same conclusions, and those who do not do so are ignorant, irrational, or corrupted by self-interest (Ross & Ward, 1996). This bias provokes misunderstandings, mistrust and conflicts among individuals that employ different frames of reference. Cognitive closure refers to the observer's "blindness" towards perceptions and knowledge that do not fit into their frame of reference. This phenomenon not only makes the observer neglect or ignore aspects of reality that may be highly relevant for the performance of the UWSs, but also opens the door to conflicts over groups of people with different frames of reference. Consequently, it impedes the negotiation and collaboration that complex problems require (E. Sørensen & Torfing, 2016a).

Frames of reference and their epistemic fallacy also contribute to higher risk exposure, due to the epistemic gap between reality and the simplified model of reality that a frame of reference represents. The observer is aware of the limitations of their knowledge within their frame of reference (*known unknowns*), but due to the epistemic fallacy, they are unaware of the uncertainty that lays outside their frame of reference (*unknown unknowns*) (di Baldassarre et al., 2016). Particularly in a context of growing complexity and volatility, these *unknown unknowns* are emergent events that have not been registered before, or cannot be deduced from existing knowledge (these are what Taleb (2007) calls *Black Swans,* and what Kuhn (1962) calls *anomalies*). These kinds of events lay outside the frame of reference until they materialize, often with destabilizing or undesired consequences, making the systems vulnerable and threatening their functionality. In general terms, this is the case for the COVID-19 pandemic, or to use an example that is specific to UWSs, Copenhagen's 2011 cloudburst, which is described in paper 4. Moreover, frames of reference not only overlook the possibility of events that lay outside their boundaries, but may also increase their probability of occurrence. Managing a complex system as if it was simple or complicated (as if it was fully represented by their frame of reference) in order to predict its behaviour and control it, can often lead to unintended, manufactured risks (Beck, 1992; Holling & Meffe, 1996; Ludwig et al., 1993).

Frames of reference for UWSs

Frames of reference, in any of the forms described above, are seldom explicitly named in relation to water management, and, at most, have been referred to as *paradigms* (e.g. Pahl-Wostl et al., 2006, 2011) or *institutional logics* (e.g. Brodnik & Brown, 2017; Fuenfschilling & Truffer, 2014).

It could be argued that this paucity of references to the concept is due to the fact that the mainstream study of urban water management has traditionally been dominated by a positivist philosophy, which rejects the subjective construction of models of reality and assumes that "what you see is all that is" (Kahneman, 2011). However, the more complex UWSs become, the more obvious the need for the study of their frames of reference.

The papers that comprise this PhD thesis describe different frames of reference in UWSs, and explain how they are reified in concrete modes of governance, management and infrastructures. These frames of reference are employed by an epistemic community[11] to create a shared understanding of what the water-related needs that must to be fulfilled actually are, the problems to be solved, the means to be employed, the roles to be fulfilled, and the rules to be followed. Nevertheless, as explained above, multiple frames of reference can often co-exist within the same UWS, with different levels of dominance.

Although the explicit study of frames of reference for urban water has thus far been rather discrete, it can be argued that during the last two decades the idea of frames of reference has been indirectly introduced by a growing reflexivity in the study of water management. This has been done in the form of an expanding body of research that explores and suggests new ways to manage management or govern governance. Good examples of meta-regulation or second-order cybernetics which reflect a frame of reference are the plethora of management frameworks popularized during the last two decades, such as *Integrated Urban Water Management* (IUWM) (Mitchell, 2006; Vairavamoorthy et al., 2015), *Adaptive Water Management* (AWM) (Georgakakos et al., 2012; Pahl-Wostl, 2007), *Sustainable Urban Water Management* (SUWM) (Hellström et al., 2000; Larsen & Gujer, 1996; Loucks, 2000; Marlow et al., 2013), *Water Sensitive Urban Design* (WSUD) (Ashley et al., 2013; Mouritz, 1996; Wong, 2006; Wong & Brown, 2009) or the "*soft path*" (Brooks & Holtz, 2009; Gleick, 2002).

The present thesis employs several types of frames of reference for UWSs, which can be classified into macro-, meso- and microlevels (Table 4). With frames of reference at the macroscale, I refer to the broadest systems of beliefs, values and "attitudes" about life that dominate in society or culture during a certain historical period, from decades to centuries. Rein and Schön (1993) call them metacultural frames of reference, but I refer to them as *cultural frameworks* (paper 2). I subsequently divide this concept into three categories: *epistemes*, *cultural logics*, and *structures of feeling*, which represent different

[11] In this case, the epistemic community encompasses a network of diverse organizations (such as water utilities, regulatory agencies, formal authorities, constructors, consultors, suppliers, researchers, landowners, or consumers) convened around the provision of certain water services that follow the same frame of reference.

timeframes and levels of maturity, pervasiveness and abstraction. The mesoscale of frames of reference refers to *paradigms* (paper 1), which apply to a concrete social sector (like the urban water sector), and shapes its rules, tools, techniques and vocabularies. Finally, frames of reference at the microscale are represented by *institutional logics* (papers 3 and 4), referring to co-existing models that influence the configuration of paradigms with their relative power.

Table 4. Taxonomy of the frames of reference used in this thesis.

	High reification	**Medium reification**	**Low reification (abstraction)**
Macrolevel - Society (cultural framework)	Episteme	Cultural logic	Structure of feeling
Mesolevel - Urban water sector	Paradigm		
Microlevel - Subgroup of the urban water sector	Institutional logic		

An *episteme* (Foucault, 1970) is the most coherent, rigid, settled and concrete of all cultural frameworks, so ingrained in the life of each member of a society (the observer) that it is taken for granted, and invisible. This concept is often used to refer to the spirit of modernity, which has shaped Western societies, their science, ideas, discourses, practices and physical artefacts over the last two centuries.

A *cultural logic* (Jameson, 1991) is often found emerging as a reaction to an episteme. It reveals alternative ways to interpret the cultural reality, and—to a minor degree than the episteme—reflects non-obvious changes in the day-to-day life of the members of society. Jameson labels *Postmodernism* as a cultural logic which, far from determining all social structures, represents a “force field” for “different kinds of cultural impulses”.

Even more diffuse and less explored is the idea of *structures of feeling* (Williams, 1977), which points towards an emerging sentiment or attitude about reality. Vermeulen and van den Akker (2010) identified the structure of feeling in early-21st century Western culture as *Metamodernism*.

While cultural frameworks involve general attitudes towards life and apply to the whole of society, *paradigms* are sector-specific translations of cultural frameworks, obtaining tangibility in the form of vocabularies, rules, techniques and physical structures. Thomas Kuhn's seminal work on paradigms (1962, p. 175) defined *a scientific paradigm* as an "entire constellation of beliefs, values, techniques, and so on shared by the members of a given [epistemic] community". Since Kuhn, the meaning of paradigm has been extrapolated from the scientific endeavour to a much wider usage[12]. The idea of paradigm has reached exponential popularity in recent decades, and today appears in all disciplines and sectors, ranging from nonlinear optics (Krasnok et al., 2018) to diarrheal diseases (M. A. Ferguson, 2018) in 2018 alone. The use of the concept, however, has grown lax. It is typically employed to refer to any type of innovative idea, and often lacks a coherent description of the mental model or underlying philosophy that brings that innovation about (e.g. Beal et al., 2013; Falkenmark & Rockström, 2006). To avoid this vagueness in the water sector, paper 1 contributes an explanatory framework that helps to concretize what a paradigm actually is.

Thornton and Ocasio (1999, p. 804) defined *institutional logics* as the "socially constructed, historical patterns of material practices, assumptions, values, beliefs, and rules by which individuals produce and reproduce their material subsistence, organize time and space, and provide meaning to their social reality". This type of frame of reference, then, represents a cultural context that stems from broader societal discourses (cultural frameworks), that permeates a certain sector (such as the urban water sector), and that becomes observable as institutions (formal or informal rules), in the vocabulary of discursive hotspots, or reified in physical objects. The main difference between *paradigms* and *institutional logics* that is understood in this paper is that paradigms are comprised of a more or less stable constellation of co-existing (cooperating or conflicting) institutional logics. The analytical utility of this distinction resides in being able to describe the coexistence of several institutional logics in a societal sector. These have

[12] See e.g. Creswell and Poth (2018) for *research paradigms,* Dosi (1982) for *technological paradigms,* Hall (1993) for *policy paradigms,* or Dunlap and van Liere (1978) *for environmental paradigms*.

aligned or conflicting values, assumptions and beliefs, create alliances, tensions and internal incoherencies (Besharov & Smith, 2014), and strive to influence the development of the paradigm.

Frames of reference and sustainability

Frames of reference carry indisputable yet unrecognized importance for UWSs because they provide interpretations of reality and point towards paths of development that determine the transformation of the system. They are models of reality that dictate which goals must be pursued, as well as why, how, where, when, and by whom. Therefore, an "unfit" frame of reference, a model that provides erroneous assumptions about the reality that it represents, or suggests unsustainable strategies, or creates conflict instead of cooperation within the sector, can have devastating consequences for the functionality and sustainability of UWSs.

Sustainability transitions, a field of research to which papers 3 and 4 can be related, is oriented towards the transformation of STESs into more sustainable configurations. Although the number of publications within this field of study has dramatically increased during the last decade, most of the research produced has shown surprisingly little awareness of the importance of frames of reference. Just recently, the work of Abson et al. (2017) and Fischer & Riechers (2019) (both based on the previous studies of Meadows (1999) in systems analysis and cybernetics) have claimed that the transformation of frames of reference (reframing) is the most significant intervention that can be made (the deepest leverage point) for the transformation of STESs towards sustainability (Figure 5).

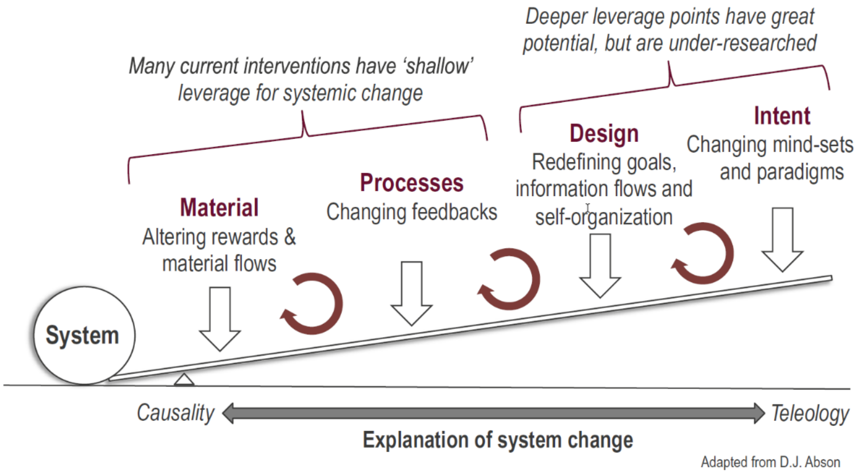

Figure 5. Four realms of leverage with different potential to bring about systemic transitions towards sustainability. Source: Fischer & Riechers (2019). The figure has been adapted, with permission, from an earlier version by Abson et al. (2017).

Shallow leverage points (changes that result in a minor and local transformation of the system) include changes in parameters, the size and structure of material stocks and flows, the system's feedback delays, and the strength of feedback loops. All of these are interventions that attempt to modify cause-effect relationships. These changes are reminiscent of what Argyris (1977) calls *single-loop learning*, and what Pahl-Wostl (2009, p. 359) defines as "Incremental changes in established practice and action [that] aim at improving the achievement of goals […] without questioning the underlying assumptions". These interventions have a limited effect on the overall system because they can only aspire to achieve optimization within the limits of their frame of reference, and not within the limits of the real world. However, despite their limited effects, shallow leverage points are the preferred measures of decision-makers and policy-makers. The main reasons for this are as follows: they are easy to understand (based on well-known cause-effect relationships), they are easy to implement, they exhibit more tangible effects, and they are measurable. Simply put, shallow leverage points or single-loop learning in UWSs refer to changes in the direct regulation of the resource through, for example, changes in the physical infrastructure such as using larger pipes to convey more water.

Middle depth leverage points include changes in system design. These can be changes in the information flow, rules, or capacity to modify the system structure. They are similar to what Argyris (1977) calls *double-loop learning*, and what Pahl-Wostl (2009, p. 359) defines as "revisiting of assumptions (e.g. about cause–effect relationships) within a value-normative framework [frame of reference]". This type of learning may correspond with changes in processes (changing feedbacks) and design (redefinition of information flows, rules, and the capacity to organize the system) (Figure 5). In UWSs, changes in design (middle depth leverage points) can be identified with changes in management and governance.

Changes in intent or purpose are the *deepest leverage points*, and correspond to the transcendence of a frame of reference (*reframing*). Other authors refer to this process as *triple-loop learning* (Swieringa & Wierdsma, 1992), *learning level III* (Bateson, 1972), or *paradigm shift* (Kuhn, 1962). The transition from a less sustainable to a more sustainable frame of reference involves transforming the underlying goals, values, beliefs, interests etc. of the epistemic community. This transition results in new interpretations of the world, different needs, problems and acceptable solutions, and a subsequent transformation towards more sustainable governance, management and infrastructures.

Reframing

Although reframing is probably the most effective way of transforming an UWS towards sustainability, it is also one of the most unacknowledged, under-researched, and difficult methods to purposefully implement. The following section constitutes an analysis of this important mechanism based on Kuhn's paradigm-shift theories[13].

[13] Kuhn's theory (1962) is used as a foundation for this explanation. Despite being a core topic of the four papers that compose this thesis, the theory is not elaborated in the papers due to length restrictions imposed by the journals. The explanation provided here is complemented by ideas from several other fields, with particular reference to concepts from the field of socio-technical transitions.

Frames of reference are living models of reality that co-evolve with it, adapt to it, and are reinforced by their use. While orienting, supporting, or limiting actions, these frames of reference are also the outcome of those actions[14]. This means that frames of reference adapt to local events, and to the transformation of broader societal discourses that permeate the epistemic community, while at the same time contributing to the creation of these local events and broad societal changes.

However, in most cases this change does not correspond to a linear evolution that represents increasing degrees of efficiency or adaptability to reality, as some historians or classical economists might argue, and as has been a common assumption in the evolution of UWSs (e.g. Brown et al., 2009; Novotny et al., 2010). Rather, the transformation of frames of reference is the result of cyclical or punctuated equilibria in a complex system, making social change abrupt and uncertain (cf. Thornton et al., 2012, p. 104). According to (Kuhn (1962), frames of reference (*scientific paradigms* for Kuhn) shift between stable (normality) and revolutionary periods, which end when a new paradigm replaces the old one.

In order to provide stability, consensus and ontological security, and in order to maintain the functionality of the system—in the language of Kuhn (1962), to remain in a phase of *normality*—frames of reference must have an inherent inertia. They must exhibit strong negative feedback loops that suppress the emergence of alternative frames of reference and keep the regulatory system (governance, management, infrastructures) virtually unchanged for long periods of time. Rigid and stable frames of reference are particularly important in simple systems with a relatively stationary context (as traditional UWSs are generally considered to be). For the managers of these types of systems, the objective of regulation is to keep the system in homeostasis for the constant provision of standard services.

However, this ability to remain stable also has a downside. Frames of reference, and the regulatory system that they shape, can remain locked in *normality* despite growing

[14] This is what Giddens (1984) famously called the duality of structure.

incompatibility with its context (Milly et al., 2008). As argued in paper 1, this is the case for contemporary UWSs, which remain relatively unchanged despite emergent problems and needs that demand new approaches to governance, management and infrastructure.

Probably the most salient mechanism of stability for frames of reference is their own function and utility, which contribute to their recurrent use and therefore to their permanence. This means that individuals are not "obligated" to conform to existing frames of reference and could, in principle, adhere to new ones if they wished. However, they very rarely do so. They engage in *system justification* (Jost, 2019) to benefit from the *cognitive ease* and social advantages that the incumbent frame of reference provides. This constitutes strong positive feedback; the more frames of reference are used, the more useful they are, so the more they are used. As Jost (2019, p. 263) points out: "Engaging in system justification serves the palliative function of increasing satisfaction with the status quo and addresses underlying epistemic, existential, and relational needs to reduce uncertainty, threat, and social discord."

Further salient mechanisms of inertia for frames of reference include epistemic fallacy, sunk costs, and intertwinement with the regulatory system. As suggested above, epistemic fallacy is a natural part of frames of reference. This bias leads the epistemic community to confuse the model with reality, and therefore to confuse their assumptions, beliefs and values with objective truth. This is a powerful mechanism of stability for frames of reference, as we instinctively and genuinely refuse to negate the "truth".

Even if the observer suspects that their frame of reference is limiting, or inadequate to provide satisfactory solutions, reframing might involve a series of sunk costs that could be too high to accept. These costs involve, for instance, breaking the coherence with past actions (simply put, to admit that one was wrong); the cognitive stress of not having a settled frame of reference; the required work to recompose a new constellation of assumptions that make sense (a new structure of meaning); to risk collaboration arrangements with other individuals; and generally speaking, to unleash larger uncertainty.

Finally, perhaps the most important mechanism of obduracy for frames of reference is to be anchored in the real, well-established, and mutually supportive elements of UWSs which reflect the dominant paradigm (Feenberg, 1991). These include policies, rules, contracts, methods, tools, and perhaps most importantly, infrastructures. Reifications of a new frame of reference will hardly be able to penetrate the UWSs because they do not "fit" with the other existing elements. See, for example, the case study of Sofoulis (2015), where the dominant frame of reference of the urban water sector hindered the adoption of rainwater tanks.

The literature on urban water also suggests various theories to account for the lock-in of traditional UWSs which do not explicitly refer to tenacious frames of reference. When we look closer at these explanations, however, it is not difficult to conclude that they reveal a fixed link between an abstract frame of reference and its tangible expressions (the regulatory systems that it shapes). These theories include, for example, the status of water services as natural monopolies (Bakker, 2010; Lieberherr & Fuenfschilling, 2016), sunk economic costs of traditional infrastructures (Bakker, 2010; Kiparsky et al., 2013; Truffer et al., 2010), technological path dependency (Brown & Farrelly, 2009; Hiessl et al., 2001), institutional fragmentation (Brown & Farrelly, 2009), and general aversion to change due to concerns about innovations putting well-functioning basic water services at risk (Hering et al., 2013).

Despite all the natural mechanisms of inertia for frames of reference, and the specific obstacles exhibited by the water sector, paradigm shifts are unavoidable. The gap between reality and the rigid picture of reality portrayed by a paradigm will always grow wider and, at a certain point, become untenable. According to Kuhn's theory (1962), in a period of *normality* the gap continuously expands until the eventual emergence in the real world of an event (an unknown unknown) that does not fit into the interpretive structure of the frame of reference. Kuhn calls this event an *anomaly*. In the case of UWSs, it could take the form of a terrorist attack, a natural disaster, a financial crisis, a pandemic, a new pollutant, a new disruptive technology, or a new social need. This anomaly will turn out to have such decisive consequences for the functioning of the system that it cannot be ignored.

What Kuhn refers to as anomalies have several other names. In paper 4, anomalies are referred to as *disruptions* when they relate to facts, objective events in external reality, and as *selections pressures* (as in the field of socio-technical transitions (Berkhout et al., 2004; Geels & Schot, 2007; Smith et al., 2005) when used in a more specific sense, or when they are subjectively articulated within a frame of reference.

Another, similar concept is the idea of *reverse salient* (Hughes, 1993). Although this concept has a narrower meaning than *anomaly* or *disruption*, it may be of particular interest for the study of STES transitions, and reframing in UWSs. This is because a reverse salient is a disruption provoked by the internal evolution of the system, a kind of embedded mechanism of *creative destruction*[15]. This revolution "from inside" happens due to over-complexifications of the system which result in emergent, unintended and unwanted effects that can bring the whole incumbent system to a halt. At this point, the dominant frame of reference is ineffective, unable to give a response to the critical problem that the frame of reference itself has contributed to creating, despite investing significant effort and resources into finding a solution. This situation opens a window of opportunity for a reframing.

The original example of a *reverse salient* was given by Hughes (1993), for the electricity supply system. Growing demand for electricity over longer distances required increasingly high voltages for transmission in direct current (DC), which ultimately resulted in greater electricity loss. This reverse salient was solved by the revolutionary invention of alternating current (AC) at the end of the 19th century, which brought with it a whole new way of thinking about electricity. Reverse salients can also be found in the historic transformation of UWSs. In the mid-19th century, for example, open systems of wastewater management in urban areas polluted drinking water sources, provoking widespread epidemics of waterborne diseases such as typhus or cholera. This situation triggered a sanitary movement (Ringen, 1979), from which the modern-hydraulic paradigm of UWSs emerged.

[15] What Schumpeter (1942) calls a "gale of creative destruction".

When an *anomaly* emerges, the strong negative feedbacks that locked-in the old frame of reference (the old *normal*) grow weaker. At this point, fierce debate escalates among the critics and advocates of the old frame of reference, with its advocates desperately trying to patch its deficiencies to confront the anomaly. Alternative frames of reference take advantage of this window of opportunity to emerge, develop, and create positive feedback loops that provoke a non-linear change of the regulatory system. This is what Kuhn calls a *revolutionary period* that ends in a *paradigm shift*.

Although the paradigm shift described by Kuhn suggests a wholesale change in the frame of reference (and the regulatory systems that it shapes), the transformation should actually be considered an evolution rather than a substitution, as only some aspects of the model are changed, and these changes are often not as profound as reporters ardently claim. As shown in the Copenhagen case study (paper 4), as well as other case studies such as Saurí and Palau-Rof's (2017) analysis of Barcelona, new frames of reference which emerge after a disruption tend to combine both old and new perspectives.

This transformation dynamic of reframing, and the systemic change described in Kuhn's theory, are similar to alternative theories derived from the discipline of systems thinking. Such theories include the *S-curve* (Rotmans et al., 2001), which is typically referred to in socio-technical and sustainability transitions, or the *adaptive cycle* proposed by ecological sciences (Holling & Gunderson, 2002).

In the water sector, examples of anomalies that have recently triggered new frames of reference and transformations of UWSs are the millennium drought in Australia (B. C. Ferguson et al., 2013; Grant et al., 2013) and the 2011 cloudburst in Copenhagen (paper 4). More generally, a timely example of an anomaly is the COVID-19 pandemic, which triggered the adoption of new frames of reference in multiple sectors, such as the education system, the economy, healthcare, and the labour market.

Purposive reframing

The transition of UWSs through the "natural" reframing described by Kuhn (1962) is not a desirable way to conduct reframing. When the frame of reference is locked-in, and has entrenched the UWS in an unsustainable configuration for a long period of time, an anomaly usually manifests as an abrupt and violent change, involving a period of chaos and significant costs. Moreover, the new configuration of the UWS becomes highly influenced by the type of anomaly that has triggered the transformation. A more desirable situation would be a transition to the new frame of reference that is smoother (where the period of unsustainability is reduced), less violent, and possible to orient towards the most sustainable configuration possible. The present thesis represents a contribution to this underdeveloped field of research by improving our understanding of frames of reference, and suggesting strategies for oriented change (paper 4).

Chapter 3: Research design

3.1 Qualitative research

> *Pay attention to what is important, not just what is quantifiable*
>
> Donatella H. Meadows
>
> *Dancing with systems, 2001*

Most studies within the field of urban water are quantitative, responding to the fact that, traditionally, water management has been regarded as a purely technical issue. The sector usually focuses on technical problem-solving (engineering) within a physics-like vision of the world. It follows the so-called Newtonian principles; a realist, positivist, reductionist and monodisciplinary approach that is inclined towards the use of quantitative research methods to reveal universal truths. In contrast, this thesis belongs to an emergent body of research and practice that does not deny the centrality of the technical issue, but sees technical problems as interdependent on issues arising in the social sphere of reality. Unfortunately, quantitative approaches are often insufficient for the study of social problems with diffuse definitions, a complex character, and non-definitive solutions (when problems are wicked). As a result, qualitative approaches are being introduced into the field with a growing frequency, particularly those that are constructionist, integratory/holistic and multidisciplinary. This thesis is a perfect example of this trend, as it follows an exclusively qualitative approach.

There is no doubt that quantitative approaches are, and will continue to be, crucial in establishing concrete cause-effect relationships, and in predicting certain phenomena related to urban water services (primarily of a physical and technical character). However, the understanding of governance and frames of reference (the central themes of this thesis) belong to an abstract and complex level of social reality. This reality can hardly be reduced to numbers, should not be detached from its context, should not be reduced to isolated and independent parts, and should not be studied objectively by neglecting human biases, values and meaning. Qualitative approaches, meanwhile, provide a wider perspective, going beyond the apparently deterministic statistical correlations that rule certain outcomes. Qualitative research is suitable for exploration and profound understanding of complex social phenomena that may lead to these outcomes. It is underpinned by a holistic perspective that takes into account human nature (including biases, assumptions, beliefs and values) and social context, without ignoring the technical sphere.

More specifically, and in contrast with quantitative research, qualitative research is often characterized by the following attributes (Creswell & Poth, 2018):

- the involvement of the researcher as a key “instrument” that creates meaning.
- the use of multiple methods (documents, interviews, observations, etc).
- a complex reasoning that mixes induction (from observations to theory) and deduction (from theory to observations).
- an emergent design of research (the design is modified in parallel to the emergence of meaning).
- the reflexivity of the researcher, who is open about their motivations, intentions and perspectives.
- the complexity of their descriptions. There is no intention to reveal a cause-effect relationship that can be extrapolated to other settings (*statistical generalization*, according to Yin (2018)). Instead, qualitative research seeks to produce a comprehensive description of a concrete phenomenon that can help make sense of similar phenomena without claiming statistical representativeness (transferability, or *analytical generalization*, according to Yin (2018)).

3.2 Interpretive framework

Even if the researcher is unaware of it (as often happens in quantitative studies), any research practice is unavoidably underpinned by a frame of reference. In the case of qualitative research, the frame of reference that underpins a piece of research is often referred as an *interpretive framework* (Burrell & Morgan, 2016; Creswell & Poth, 2018).

An *interpretive framework*[16] can be defined as a coherent system of philosophical assumptions about the nature of reality (ontology), how we can gain knowledge about that reality (epistemology), the values that guide the pursuit of that knowledge (axiology), and the methods used (methodology) (Dezin & Lincoln, 2018). The interpretive framework emphasizes some aspects of reality and hides others, while conveying a methodological rationale that determines which research questions are posed, how the research strategy is designed, which methods are used to collect data, how to analyse and interpret the data, and how the validity of the results is evaluated.

Despite the relevance of interpretive frameworks for multiple aspects of research design, they are rarely described by researchers. This is either because they are unaware of them, as they use the "default" interpretive framework of their discipline and assume that it is unnecessary to describe it, or because they are reticent to subscribe to a tight philosophical approach that they know they do not fully observe. However, the identification of the interpretive framework is always useful, for both the reader and the author, who get to know which philosophical assumptions underpin the logic of the interpretations.

If it is this reticence to adhere to a single interpretive framework that keeps researchers from explicitly acknowledging which framework they are following, it is worth noting that they do not strictly need to adhere to just one interpretive framework. Indeed, they can actually use several in combination, as heuristics to approach the problem at hand. They must, however, keep in mind that their philosophical foundations must not be entirely contradictory, as would be the case, for example, if constructivism and positivism were used in combination (Dezin & Lincoln, 2018).

Using a mix of "standard" interpretive frameworks is becoming a popular approach in qualitative research. Interpretive frameworks are increasingly understood as ad-hoc combinations of philosophies, a kind of bricolage where "the bricoleur spontaneously

[16] These interpretive frameworks are commonly referred to as *research paradigms* of qualitative inquiry or social research (e.g. Dezin & Lincoln, 2018; Maxwell, 2012), but the term *paradigm* is avoided here as it is used with a broader significance throughout the present work.

adapts to the situation, creatively employing the available tools and materials to come up with unique solutions to a problem" (Maxwell, 2012, pp. 42–43). This allows an "emancipation from seeing the world in one color" (Dezin & Lincoln, 2018, p. 218). However, I see this mix of interpretive frameworks not just as a choice of research design, but to a certain extent, a requirement. The "standard" interpretive frameworks described in the qualitative research literature contain rigid and exaggerated philosophical positions that attempt to highlight differences among frameworks and create easily differentiable categories. They can therefore be understood as *ideal types*[17] to which, in practice, it is impossible to faithfully comply. "Real world" researchers adopt some of their tenets, but not all of them. This also means that, in practice, the interpretive frameworks are not isolated compartments, as it might seem from their theoretical description. Instead, they create a continuous space where they overlap, with the most radical positions at the extremes (*positivism* and *constructivism*), and a spectrum of philosophies in between.

In the following section, I briefly describe some relevant interpretive frameworks that have guided this thesis, and two further "extreme" interpretive frameworks (*positivism* and *constructivism*), that will be used as reference points of extremity. These descriptions are, I acknowledge, undeniably general, and purposefully ignore the differences among their multiple variations that can be found in the literature[18]. This description is justified by the character of the present thesis, where the interpretative framework has great significance for the understanding of frames of reference.

Positivism

Positivism departs from the ontological assumption that reality has a granular and mechanical nature, where discrete elements hold relationships governed by constant and

[17] For a definition of *ideal types*, see glossary and section 3.5

[18] The superficial description of these interpretive frameworks is an undisputed issue in qualitative research theory, and therefore will not be accompanied by selected references. More complete descriptions of these interpretive frameworks can be found in Creswell & Poth (2018); Crotty (1998); Dezin & Lincoln (2018); Given (2008).

linear cause-effect relationships (universal physical laws) which are context-independent. This idea renders a world that is simple, ordered, and deterministic, where all phenomena are determined by previously existing causes. With enough information about the present, and knowledge of the natural laws that govern reality, the future is predictable. The aim of the positivist researcher, then, is to unveil the *Truth* (the universal laws of nature) to define how the world works.

Positivism exhibits a realist philosophy, assuming that the real world exists as we perceive it, independently of our interpretations of it. This implies that all humans can experience reality in the same objective way, and that all phenomena allow only one possible interpretation. The *Truth*, therefore, is independent of the observer, there is only one way to understand a problem, and there is only one optimal solution.

From these assumptions, it may seem obvious that within positivism the ideas of second-order cybernetics and frames of reference turn out to be irrelevant. Frames of reference are often overlooked and uncontested here, as they are confused with "underlying reality".

In order to see the *Truth* and nothing else, positivism rejects all personal assumptions, beliefs and values that can "contaminate" observations and reason. Anything which is not observable, measurable, testable, verifiable and statistically generalisable is not considered knowledge, and is not considered to be meaningful or real. Researchers become faceless investigators, nothing more than "disinterested" and objective contributors to decision-making. Positivism aims to describe a world devoid of values, meaning and purpose.

The positivist methodology in qualitative studies attempts to adapt the methods of natural sciences. In its pursuit of objectivity and certainty, research questions must be as narrow as possible, and the object of research must be isolated from its context. To eliminate the influence of the context, the researcher can either manipulate the settings (create "lab conditions") or use large sets of data to minimize the influence of "extraneous" factors. Rigorous protocols of positivist research allow researchers to minimize the "contamination" of subjectivity, verify the research process, and repeat it to arrive to the same conclusions.

The positivist approach coincides with the popular understanding of science. When people claim that “science says…” or that something is “scientifically demonstrated”, they have in mind a positivist interpretive framework. However, in the academic world, the positivist approach has been debunked. As some have pointed out (e.g. Paley, 2008), this description of positivism is just a caricature that was popularized by postmodernists, and serves to juxtapose and explain other types of qualitative research that have a more constructivist character.

Although positivism in qualitative research has never encompassed all the above-mentioned radical claims at once, this interpretive framework has permeated industrialized societies, and their technological developments, for centuries. Positivism is still alive in the professional practice of many disciplines, particularly in natural sciences and technical disciplines, including the old urban water paradigm described in paper 1. Naturally, this interpretive framework has also shaped the education of water managers, who are prone to physics-type language and explanations. It should be noted however, that while positivism has undeniable value when the aim is to study isolated technical systems, like the hydraulic capacity of a pipe or the lifting power of a pump, it is useless as an approach to framing urban water services.

Post-positivism

Post-positivism comprises a group of philosophies that retain many of the tenets of positivism while introducing some of the most fundamental criticisms of its most radical assumptions.

Like positivism, post-positivism believes in the existence of an absolute reality, independent of the observer. It also represents a scientific approach to research, and copies, to a significant degree, the structure and language of qualitative research in natural sciences. For example, qualitative post-positivist research can often be found following the structure of quantitative research (introduction, questions, hypothesis, methodology, results, conclusions).

Unlike positivism, however, post-positivism believes that a perfect knowledge of reality is inaccessible, maintaining that it cannot be grasped, merely approached. Post-positivism assumes that it is impossible to verify anything empirically, and humans must instead resort to socially constructed models of reality to make sense of the world. Unlike in positivism, humans are not seen as having direct access to the absolute *Truth*. Instead, post-positivism acts "as-if" it was possible to find the *Truth*, and temporarily regards theories that could not be falsified as laws.

Furthermore, post-positivism fully acknowledges the subjectivity of the researcher, although it is seen as undesirable. As there is still a pursuit of objectivity, the researcher must keep as much distance as possible from the object of study. Like positivism, post-positivism is reductionist, logical, empirical, oriented towards cause and effect, and deterministic, with acontextual experimentation as the main method. It follows rigorous methodologies of data collection and analysis, allowing for reproducibility and validation of results. Post-positivism, however, is more open than positivism to multiple perspectives (both quantitative and qualitative approaches), which through interpolations have the potential to bring us closer to the truth.

When qualitative research emerges in fields of study with a strong tradition in quantitative research (as is the case for urban water research), the interpretive framework is usually post-positivist. This is either because the researchers in the field have been trained to see the world through the positivist lens, or because this approach benefits from greater legitimacy among peers and funding agents (Creswell & Poth, 2018). The advantage of post-positivism compared with positivism in urban water research is the recognition of subjectivity, which opens the door to reflexive approaches such as Kuhn's (1962) paradigm theory.

Critical realism

Critical realism is defined by some as a particular type of post-positivism that has strong ties with complexity theory and systems theory (Given, 2008). It occupies a middle ground between positivism and constructivism, utilizing (in rough terms) the ontology of the former (ontological realism) and the epistemology of the latter (epistemological relativism).

Like positivism, critical realism assumes the existence of an absolute reality, independent of the human mind. However, this reality is much more complex, and stratified into levels with increasing inaccessibility to the human mind. What we observe and measure (*the empirical*) are just interpretations of the superficial manifestations (*the actual*) of absolute reality (*the real*), which is inaccessible. The world, therefore, cannot possibly be described objectively, only interpreted. To give an example, concepts in critical realism are seen as social inventions (not discoveries), but are understood to reflect something that exists in the real world.

Rather than focusing on exposing the fundamental "laws of nature" in order to predict outcomes—as is the case in positivism and post-positivism—critical realism focuses on the understanding of phenomena and their underlying causes in complex environments. It assumes that complexity cannot be reduced to simplicity, and that it cannot be decontextualized and generalized. Instead, it must be embraced, and efforts should be made to understand it in all its richness in its real context, because knowledge is dependent on location, is historically and culturally dependent, and is intersubjectively created. Consequently, the typical research design of critical realism is based on combining as many perspectives as possible to approach a complex reality from different angles. It can resort to qualitative and quantitative approaches, a mix of various methods, and situated historical analysis, to produce deep and rigorous descriptions and conceptualizations. Critical realism is therefore an appropriate approach for the development of meta-synthesis[19] and explanatory frameworks[20].

While (post-)positivism and critical realism coincide in that elements of subjectivity (assumptions, beliefs, values, etc) should be reduced to a minimum, in critical realism they are not seen as a "contamination". Instead, they are observed and taken into serious consideration. They are believed to inform behaviours and function as determinant objects of investigation in our understanding of what happens in the social world. This

[19] For a definition, see glossary and section 3.4

[20] For a definition, see glossary and section 3.5

means that social structures are of particular interest to critical realism, producing reflexive approaches where researchers may analyse their own frames of reference.

Pragmatism

Pragmatism focuses on ontology, rather than epistemology, because it seeks to define what *truth* actually is, rather than how to attain it. Pragmatism is not knowledge-oriented, then, as it does not endeavour to find theoretical explanations, or discuss issues of rigour and validity. Instead, it is solution-oriented, because the only thing that matters is the practical effects achieved by research.

Pragmatic ontology differs significantly from the ontologies of the other interpretive frameworks. For pragmatism, there is an absolute reality, or what other interpretive frameworks call the objective *Truth*, but it is deemed inconsequential. Instead, pragmatism believes something to be "true" if it is useful and has meaning to inform behaviour. The pragmatic *truth* does not exist alone, but is "made" in the here and now by human beings and reality in cooperation. That which we cannot experience, or which has no effect on us, is not "true"; it is irrelevant, and does not exist.

The dichotomy of objective/subjective epistemology is also inconsequential for pragmatism. The pragmatic *truth* is co-created through a collective experience, and social structures such as frames of reference are therefore true by definition. Instead of being a nuisance, assumptions, beliefs and values are regarded as guides for research, as it is these that define what matters.

Pragmatism does not have a preferred methodology. Instead, it defines its goals, the problem at hand, and the research question, and then selects any method that can help to answer the question. The method is whatever "works" in each situation.

Constructivism

The fundamental assumption of constructivism is that there is no objective reality independent of the human mind. This assumption (*relativism*) does not negate the existence of a reality "out there", but simply denies that it has any structure or meaning prior to human interpretation. Realities, then, are constructed subjectively, and are unique to each individual and each situation. The object of study is not the "external world", but rather the subjective experience, and the observed phenomena are always unique and not statistically generalisable.

To interpret the realities that people construct, constructivism departs from vague research questions that do not constrain the range of possible explanations. To acquire a first-hand perspective of the issue, the researcher must embed herself in the reality that they want to interpret, employing methods such as participation in the phenomena under consideration, or direct observations and interviews. There is no attempt to abridge all these experiences into a condensed representation of an objective and generalisable reality, but rather to describe it in all its richness and complexity. The collected data is used to build comprehensive descriptions of the phenomena, from which unique patterns and meanings linked to the social context emerge. However, these explanations and theories are always temporal, because the experience is continuously transforming.

The validity of findings in constructivism is based on credibility and success. Credibility implies receiving the support of other informed and qualified researchers, and success implies that the findings provide a better understanding of the phenomenon.

The interpretive framework of this thesis

In recent years, (post-)positivist approaches in qualitative research have lost some of their popularity and legitimacy to non-positivist approaches (Lincoln et al., 2018). This tendency is reflected in the present thesis, which is informed by the critical realist interpretive framework, although it also includes elements of pragmatism and constructivism.

From critical realism, this study borrows the mix of realist ontology and relativist epistemology. The core ontological assumption is that there exists a reality "out there" that is independent of human understanding. There must be an objective world out there, because if not, there would be no need to improve it. However, it is also assumed that this reality cannot be grasped "as-it-is", because its complexity and dynamicity surpass our cognitive capacities. Focus, then, is placed on understanding the intersubjective and fluid creation of meaning that the stakeholders of the urban water sector engage in through frames of reference, and the effect that these social constructions have on real urban water services. Critical realism is therefore highly suited to the study of frames of reference that orient collective interpretation of reality (paper 1), the historical evolution of frames of reference in the context of social transformation (paper 2), socially constructed forms of organization such as governance (paper 3), and tools for cooperation across disparate frames of reference (paper 4).

In pragmatic terms, frames of reference are reality itself, because they are the truth we experience and the only truth that we will ever know. The idea is not to reveal an objective, universal Truth, but to suggest frameworks and theories with explanatory value.

Also in relation to pragmatics, these frames of reference are not just studied for the sake of expanding our theoretical knowledge. Frames of reference are studied for their contributions to solutions that could break the lock-in that is hindering the adaptation of the urban water sector to emerging problems. This is done through a reflexive approach to urban water services, providing researchers and practitioners with a new lens through which they can see and reflect on their thinking and behaviour, and have the freedom to change them.

The methodology employed in the study of frames of reference is both critical realist and pragmatist. This thesis incorporates multiple perspectives from diverse disciplines, none of which make any revelations about absolute reality, but which work together to create a richer and more credible description of the frames of reference that shape the real world. Rigid research protocols that are typical of (post-)positivism, and usually introduced for the sake of objectivity, repeatability, or statistical generalisability, are set aside in favour of subjective but credible conceptual frameworks that help to understand the social structures that shape UWSs.

Pragmatism is inclined towards the use of methods of direct observation, as it is through the senses that we can capture the pragmatic truth. However, first-hand empiricism is only a small part of the present work (appearing in the case study of paper 4). Instead, this thesis is mostly built on previous studies about frames of reference by other authors.

These studies are intended to reflect the values and philosophical beliefs that shape the perception of reality and the normative behaviour.

3.3 Conceptual framework

Metaphorically, Miles and Huberman (1984, p. 33, cited by Leshem & Trafford, 2007, p. 95) define a *conceptual framework* as “the current version of the researcher’s map of the territory being investigated”. In qualitative inquiry, a conceptual framework refers to a set of interconnected concepts and ideas employed by a researcher to orient research (help to define objectives and scope, pose questions, select methods, etc), make “sense” of observations, and contextualize findings within existing knowledge (Leshem & Trafford, 2007). Thus, conceptual frameworks are also a kind of frame of reference, and one which informs the research process in a more concrete manner than an interpretive framework. All serious research employs a conceptual framework, even if the researcher has not described it explicitly.

Established disciplines like sociology, psychology, economics, physics and biology have well-defined and settled conceptual frameworks, which build up a cohesive and highly specialized body of knowledge, but also limit the expansion of that knowledge. Interdisciplinary research, on the other hand, integrates ideas, concepts and theories from disparate disciplines. While these elements are more challenging to structure coherently, they are very useful for the interpretation of more complex real-world problems that cannot be approached from the lens of just one of these disciplines, creating new knowledge that transcends its constituent fields (Klein, 2017). As shown in chapter 2, this is the approach of the present thesis, where ideas from other disciplines like socio-technical transitions, political sciences, complexity theory, cybernetics, second-order cybernetics, policy research, philosophy, sociology and psychology are combined to frame complex ideas in relation to urban waters services.

The conceptual framework of this thesis was not designed at the outset. It emerged iteratively and reflexively from a large, non-systematic literature review that served to identify useful and coherent links among concepts from different disciplines. The “map of the terrain” was being drawn as the territory was “explored”. The conceptual framework is, therefore, both a scaffolding for research and an output of research. This approach is well-suited to exploratory studies where the questions are ill-defined.

Some of the links between disciplines have already been introduced into the study of urban water management (for example, the link between sustainability transitions and neo-institutional theory, e.g. Fuenfschilling & Truffer (2014); F. W. Geels (2005)), while others are novel ideas that, to the best of my knowledge, have recently been introduced for the first time (for example, the idea of metamodernism). Chapter 2 demonstrates the coherence among the concepts and theories employed, and provides the reader with the necessary knowledge to understand the content of the four papers, as well as their relation to each other.

3.4 Methods of data collection and interpretation

The lion's share of this thesis consisted of desk-based studies of secondary data, which through meta-synthesis resulted in various explanatory frameworks, descriptions of ideal types, a middle-range theory, and the conceptual framework presented in chapter 2.

The thesis also involved the collection of primary data (interviews), for the elaboration of an in-depth case study, which served to illustrate the applicability of the middle-range theory presented in paper 4.

Meta-synthesis

While literature reviews are commonly employed to identify a knowledge gap, to define effective research questions, or to academically contextualize a study, they can also be used as a method of data collection and interpretation. Where this is the case, literature reviews are often regarded as meta-analysis[21]. They gather studies of similar statistical populations (which are therefore usually quantitative) to strip them from their context,

[21] In this case, the prefix meta- refers to the reflexivity of the inquiry process, and a higher level of abstraction. In other words, it refers to the study of a set of studies, or the analysis of a set of analyses.

and average and produce a best estimate of a cause-effect relationship to enable prediction and control, usually in line with a (post-)positivist approach.

Unlike meta-analysis, a literature review carried out as a meta-synthesis aims at identifying, coherently interpreting, and integrating multiple partial accounts (often qualitative and non-statistical) of a complex and diffusely defined phenomenon, to gain a more comprehensive understanding of that phenomenon (Jensen & Allen, 1996; Walsh & Downe, 2005). These reviews do not produce straightforward answers to questions, but rather rich descriptions or a better understanding of a phenomenon.

Meta-syntheses are not just about lumping together multiple perspectives on one issue (they do not have an aggregative purpose). The objective is actually to produce a new level of understanding, or a holistic account of the phenomenon in the form of a new explanatory framework that reflects the perspectives it includes, as well as their relationship, dissonance and consensus. The process of interpretive synthesis is comprised of two aspects: the hermeneutic aspect, which regards the accurate interpretation of each source, and the dialectic aspect, which regards the process of comparing and contrasting the sources (Jensen & Allen, 1996).

From a critical realist perspective, meta-synthesis fits within realist ontology and interpretive epistemology. It combines multiple subjective interpretations of reality into a single, richer, more holistic and consensual interpretation. This new interpretation is assumed to be closer to the *truth* than any of the contributing perspectives, bearing in mind, as previously mentioned, that this is a pragmatic truth.

It possible to criticize meta-syntheses on the basis that they aim to integrate several interpretations of reality, which are acknowledged to be subjective and contextual, into what seems to be an objective and generalisable explanation. However, in this particular case, this criticism can be refuted by arguing that frames of reference are intersubjectively created by an epistemic community. It is precisely the integrated understanding of a reality which combines multiple subjective and contextualized perspectives that constitutes the answer to the research questions, as opposed to each of the individual accounts portrayed in the individual papers.

Case study

Paper 4 uses a case study of stormwater management in the municipality of Copenhagen (Denmark) to illustrate the BOIST (boundary objects in sustainability transitions) theoretical framework[22] (described here as a middle-range theory).

According to Yin (2018):

"A case study is an empirical method that investigates a contemporary phenomenon (the "case") in depth and within its real-world context, especially when the boundaries between phenomenon and context may not be clearly evident. […] A case study copes with the technically distinctive situation in which there will be many more variables of interest than data points, and as one result benefits from the prior development of theoretical propositions to guide design, data collection, and analysis, and as another result relies on multiple sources of evidence, with data needing to converge in a triangulating fashion."

This definition shows that case study is a well-suited research method for the critical realist interpretive framework employed in this thesis. It addresses a complex phenomenon embedded in its context, and assumes that multiple evidence sources are necessary to approach (triangulate) an objective reality. However, there is always the implicit acknowledgement that interpretations of the results are subjective.

The elaboration of paper 4 includes primary data from in-depth interviews with stakeholders of the urban water management regime, as well as document analyses. In addition, the case study "benefits from the prior development of theoretical propositions", which in paper 4 corresponds with the theoretical framework (middle-range theory) BOIST, providing guidance for data collection and interpretation.

[22] This framework is described below as an *explanatory framework*.

3.5 Results of research

The critical realism and pragmatic philosophies are well-suited to making sense of complex realities that encompass social and physical elements through system-wide descriptions. In this thesis, these descriptions are delivered in four different formats: conceptual frameworks[23], explanatory frameworks, ideal types, and middle range theories. The following section gives an explanation of the latter three formats:

Explanatory frameworks

In the present thesis, the term explanatory framework refers to an integrated description of a complex phenomenon that coherently combines existing concepts and ideas (usually from different disciplines). They function as “spectacles” that researchers and practitioners can use to make sense and (re-)frame issues of a complex reality within the water sector. Paper 1 presents an explanatory framework of paradigms of urban water, paper 2 an explanatory framework of evolving cultural frameworks that shape urban water paradigms in transition, and paper 3 an explanatory framework of governance.

Although explanatory frameworks and conceptual frameworks (chapter 2) are essentially the same thing, I assign them different roles. While conceptual frameworks constitute the theoretical foundations and structures required to contextualize, guide, and interpret research (Leshem & Trafford, 2007), explanatory frameworks are an output of this research. Furthermore, explanatory frameworks can also be used as conceptual frameworks in future research.

Ideal types

Some of the concepts that make up the explanatory frameworks and conceptual framework described in this thesis are *ideal types* (Doty & Glick, 1994). From the lens of critical realism, ideal types are frozen caricatures of an artificially delimited subsystem of a complex and fluid reality. They function as heuristic devices that help to interpret

[23] See section 3.3.

and approximate what is happening in the real world, but cannot be found in their "idealized" form in real life. Ideal types are useful to communicate an otherwise intangible idea.

All frames of reference described in this thesis are ideal types. For example, the institutional logics that may apply to the urban water sector of industrialized countries (hydraulic, market, and water sensitive logics) are ideal types, the "new paradigm" is an ideal type, and "metamodernism" is an ideal type.

Middle-range theories

Theories, like explanatory frameworks, serve as structures of meaning for observations, and connect them with previously existing knowledge. However, there are also some differences between theories and explanatory frameworks which merit discussion. In this thesis, the two are differentiated based on the assumption that explanatory frameworks have interpretive intentions (make "sense" of reality), while theories have both predictive and interpretive intentions. Examples of theories include the multi-level perspective of socio-technical transitions (Geels, 2002), and the institutional theory of organizational studies (Scott, 2014).

Merton (1968) suggests that there are three types of theories, with different scope and different levels of abstraction: long, middle and short-range theories. Long-range theories are usually described as theories of general domain, with the highest level of abstraction. In social sciences, they are generally all-embracing theories of society or social systems, or what others have called grand theories (Lyotard, 1984). Short-range theories describe situation-specific correlations between variables that "evolve in abundance during day-to-day research" (Merton, 1968, p. 39) and have the highest level of concretion, but are not generalisable. A middle-range theory, therefore, is located between these two extremes. These build bridges between theory and observations through the description of recurring phenomena in non-specific situations, providing a balance between the generalization but excessive abstraction of long-range theories, and the concretization but lack of generalization of short-range theories. In the present thesis, paper 4 describes a new theoretical framework in the form of a middle-range theory, which we called the BOIST framework.

3.6 Validation

The concept of *validity* has its roots in the positivist interpretive framework, where "to be valid" means that the results obtained through the research process correspond with the absolute *Truth*. This understanding of the term is linked to rigour in the application of a certain method that warrants the objectivity of the results and conclusions. However, this interpretation of validity is incongruent with the interpretivist epistemology of the present study. This thesis does not aim at providing a simplification of an objective *Truth*. Instead, it aims at providing tools that can conceptualize reality (in ways that are acknowledged to be subjective) in order to reflect and act upon it.

In qualitative research, *validity* has been widely disputed over the last three decades, and terms such as *rigour of interpretation*, *quality*, *trustworthiness*, and *authenticity*, have been suggested as a replacement for *validity*. All of these, however, have their own problematic definitions (Maxwell, 2012), but it is out of the scope of the present chapter to dwell further on this complex and unresolved debate. Instead, it is argued that *validity* can be substituted by *credibility* and *pragmatism*, two categories that summarize many other interpretations of validity in interpretive research.

Credibility (Creswell & Miller, 2000; Maxwell, 2012) means that the results are coherent with previous knowledge, accepted by peers (informed members of the academic community), and considered to have sufficient quality by merit of having overcome oriented criticism (Dezin & Lincoln, 2018). There is definitive proof of the credibility of this thesis in the fact that all papers have undergone a double-blind peer review in renowned international journals within the fields of water science and technology, environmental sciences and social sciences.

By *pragmatism,* it is meant that the results seem to have value in informing practice and improving the understanding of concepts and their interrelations, which may previously have been vague or ill-defined. This type of validation concurs with the interpretive framework of this thesis. In terms of critical realism, it ensures that new knowledge contributions bring us a step closer to the pragmatic *truth*. In pragmatic terms, it creates a truth that "works", by ascribing meaning to empirical observations of a complex phenomenon in the absence of other explanations that makes more sense.

3.7 Model of research

The research carried out for the elaboration of this thesis compromised the following elements:

- An initial research question that emerged from the author's previous knowledge, experiences and interests.
- Exploratory data collection.
- Definition of the conceptual framework.
- Selection of the interpretive framework.
- Definition of the following research questions, scope and objectives.
- Data collection (literature review, document review and interviews).
- Data interpretation (meta-synthesis and case study).
- Results (conceptual frameworks, explanatory frameworks, ideal types and a middle-range theory).
- Validation (peer-evaluation and publication).

In this thesis, there is a strong connection between the interpretive framework, the methodological approach, and the findings of the study. This means that, as expected, the lens used to look at the world, the questions asked, and the strategies used to collect and analyse information can be said to have determined the results (what is found). It also means that the results have determined which lens was used, which questions were asked, and which data was collected and analysed. This is possible because (unlike within the rigorous protocols of (post-)positivist research) the research design is not defined as a preconceived and fixed recipe, with linear and one-directional steps. The research design of this thesis was flexible, reflexive, and circular/iterative, and was continuously redefined or adapted to the creation of new explanations.

These constant revisions go in loops for every single step, for each of the individual papers, and for the whole thesis, dynamically adapting to the results while maintaining coherence across the whole thesis. This is what Maxwell (2012) calls an *integrated and interacting model of qualitative research*, or what Creswell and Poth (2018) call *emergent design*. This procedure is reflected in the present work by the fact that all the papers, as well as the extended introduction and conclusion, were developed in parallel and were able to influence each other. Furthermore, all were submitted for publication within a period of approximately one year.

3.8 A metamodern research design

The research design of this thesis also holds clear parallelism with the topic of study, adhering to the frames of reference that it aims to describe. The interpretive framework that combines ontological realism and epistemological relativism, the ad-hoc interdisciplinary conceptual framework, the emergent and iterative design, the various methods for data collection and analysis, and the type of validation, all reflect the philosophical foundations of the new urban water paradigm[24], and the core elements of the structure of feeling of metamodernism[25]. The combination of critical realism and pragmatism, for example, represents what is referred to in metamodernism as *informed naivety*. As in critical realism, informed naivety is the awareness of the existence of a deep, transient and complex reality that cannot be completely revealed. At the same time, this approach advocates for a pragmatic solution, consisting of relating solely to the superficial and apparent reality that influences us to the greatest extent, and acting "as if" it was the absolute *Truth*.

[24] Described in detail in paper 1.

[25] Described in detail in paper 2.

This parallelism, rather than being a meditated and a priori decision, has emerged naturally as a reflection of the results, while also benefitting from the lack of constraints that the research environment (supervisors, sponsors and colleagues) could have imposed.

Chapter 4: Results

This chapter offers a summary of the results obtained in the four papers included in this thesis, in light of the conceptual framework elaborated in chapter 2. The complete papers can be found in the appendix.

4.1 Paper 1

Franco-Torres, Manuel, Briony C. Rogers, and Robin Harder. "Articulating the new urban water paradigm." *Critical Reviews in Environmental Science and Technology* 51(23) (2021): 2777-2823.

Paper 1 addresses question 1 of the thesis: "What is an urban water paradigm?" and question 2: "What is the new urban water paradigm?"

This paper offers an explanatory framework that represents valuable advances in our understanding of what a paradigm actually is within the urban water sector. It describes how paradigms can be conceptualized as coherent structures comprised of philosophical foundations (ontological, epistemological and axiological elements), operational articulations (governance, management and infrastructures), and a methodology (a set of methodological principles that translate the philosophical foundations into operational articulations).

This explanatory framework is employed to concretize the new urban water paradigm and highlight the coherence between its different elements, a basic step for its recognition and adoption. Simultaneously, the framework is used to juxtapose the traditional (old) and emergent (new) urban water paradigms.

This paper also demonstrates how the old paradigm is at odds with contemporary reality in Western societies, promoting stability, homogeneity, fragmentation and hierarchical centralization in a context of complexity, fluidity and uncertainty. In other words, the old paradigm erroneously frames UWSs as simple technical systems instead of complex socio-technical-ecological systems. However, the meta-synthesis carried out for this study indicates that over the last two decades there has been a growing recognition of the complex and non-deterministic character of contemporary UWSs, triggering the gradual acceptance of subjectivity, uncertainty, the impossibility of universal solutions, and eventually, of the existence and necessity of reframing.

4.2 Paper 2

Franco-Torres, Manuel. "The path to the new urban water paradigm – from modernity to metamodernism" *Water Alternatives 14(3)* (2021): 820-840.

Paper 2 responds to question 3 of the thesis: "How are urban water paradigms shaped?"

This paper departs from the hypothesis that a society's values, beliefs and assumptions (its cultural framework), that are often inconspicuous and taken for granted, are the foundations of the paradigms that dominate each societal sector in a certain historical period. This idea suggests that the emergent paradigm of the urban water sector is a reflection of the deeper, slower transformation of a wider and subjacent frame of reference.

By combining knowledge from disciplines such as water management, geography, history, sociology, political ecology, philosophy and cultural criticism, paper 2 identifies four periods and three distinct cultural frameworks that have shaped UWSs in different ways over the last two centuries (Figure 6). These cultural frameworks succeed each other in what Schumpeter (1942) calls a "gale of creative destruction". The cultural frameworks, the societies that they create, and the UWSs that they shape are all continuously revolutionized from within, destroying the old model while creating a new one.

As has been recognized in previous studies, the modern episteme is the most influential of these cultural frameworks. This is the framework that has been underpinning the "old" urban water paradigm since the mid-19th century, and the one that has dominantly shaped UWSs until today. This frame of reference derives from a Newtonian perspective of reality, and the values and beliefs of the Enlightenment, reflecting the social transformations of modernity. In addition to embedding the old water paradigm within a technocratic logic, modernity affects many other aspects of society. There are numerous examples of this: modern architecture, Fordism as a style of production, public administration and the welfare state in public policy, old institutional theory, Keynesian economics, and positivist research, to name just a few. All of them convey an ordered and simple understanding of reality that can be objectively understood, predicted and rationally controlled.

In the second half of the 20th century, the modern episteme evolved into a differentiable cultural logic (*late modernity*), through a process that Beck et al. (2003) referred to as *reflexive modernization*, although many interpreted it as an expression of postmodernism. Late modernity can be related to market logic in urban water, the economics of neoliberalism, New Public Management in public policy, Taylorism (scientific management) as the dominant style of industrial production, the ecological movement, and scientific developments like cybernetics, fractal theory, or the popularization of the (deterministic) relativity theory. In this case, the cultural framework conveyed an ontology of (*restricted*) complexity (Morin, 2007), awareness of risk and uncertainty, a vision of a world that could be potentially understood and controlled, and goals of optimization and efficiency.

Finally, paper 2 describes how a new structure of feeling, which some have labelled *metamodernism* (Vermeulen & van den Akker, 2010), emerges in Western democracies at the beginning of the 21st century. The central claim of the paper is that the new urban water paradigm is imbued with this emerging and still diffuse cultural framework. Metamodernism is characterized by an oscillation between the postulates of postmodernism (nihilism, fragmentation, emotions, disengagement and scepticism) and the postulates of modernity (progress, order, homogeneity, enthusiasm, rationality, sincerity), emerging as a response to the widespread uncertainty and frequent "anomalies" of the 21st century.

Beyond the urban water sector, metamodernism is represented today by movements such as New Public Governance in public policy (network governance (Kickert et al., 1997), iterative governance (Torfing et al., 2012) or metagovernance (E. Sørensen & Torfing, 2016b)), the information society (Castells, 2010), behavioural economics (Thaler, 2016), second-order cybernetics (von Foerster, 2002a), generalized complexity (Morin, 2007), quantum (non-deterministic) physics, and even social media (Anderson, 2020). These movements are characterized by considering a complex and chaotic world where order emerges, where uncertainty is inherent to reality, and where there is no absolute truth, only perspectives.

Paper 2 suggests, then, that the understanding of metamodernism can provide some indications of the directions in which UWSs may transform in the following decades.

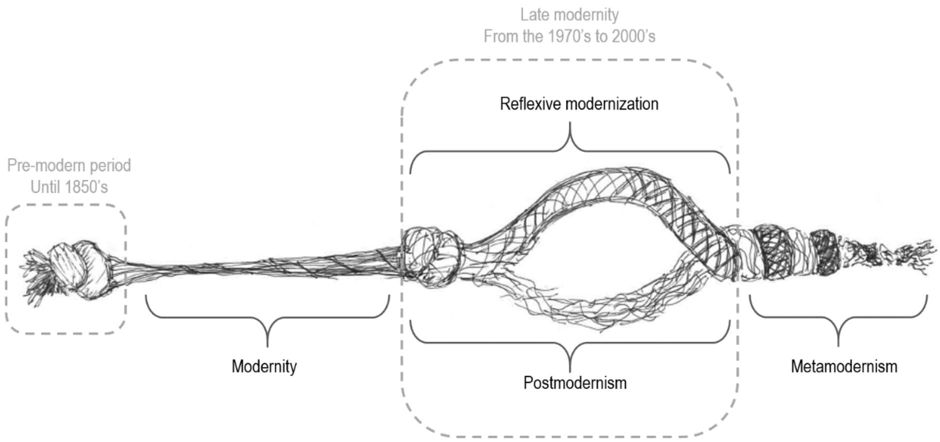

Figure 6. Evolution of the cultural frameworks in Western society that shaped the dominant urban water paradigm in four differentiated periods. First, it illustrates the pre-modern period as a knot, characterized by dogmatism, little hope and no sense of progress. This is followed by modernity, dominated by a trust in reason, order, technology and progress. This period gave rise to a series of social, economic and environmental crises during the 1960's and 70's (another knot), which opened the door to two contrasting perspectives in the late modernity period. Postmodernity, on the one hand, described a decomposition of the modern societal fabric, and a loss of faith in progress. Reflexive modernization, on the other hand, recognized complexity, but insisted on the tenets of modernity, advocating for more reason, order, technology and progress. The last period, from the beginning of the 21th century, is characterized by an emergent structure of feeling that oscillates between reflexive modernization and more postmodern approaches.

4.3 Paper 3

Franco-Torres, Manuel, Ragnhild Kvålshaugen, and Rita M. Ugarelli. "Understanding the governance of urban water services from an institutional logics perspective." *Utilities Policy* 68 (2021): 101159.

Paper 3 answers question 4 of the thesis: “What is urban water governance and how does it relate to urban water paradigms?” In the article, the concept of *urban water governance* is broadly defined as the “collaborative social practices, together with their supporting and resulting structures, that set the scene for management of water services”. Governance, therefore, is policy, polity, and largely, a political process (Gupta et al., 2015; Treib et al., 2007), where decisions are made in a context in which actors compete and negotiate for power and control.

In the last 150 years, water utilities have significantly increased the efficiency of their infrastructures and management, but little has been done to avoid conflicts and create synergies among their expanding number of constituent values, needs and perspectives. As was explained in chapter 1, the last two decades have seen gradual recognition for the idea that water crises are not exclusively crises of resources, technology or management, but rather crises of governance (Bucknall et al., 2006; OECD, 2011, 2016). Paper 3 hypothesizes that this shift in focus relates to the growing complexity of UWSs where, among other consequences, it has become increasingly challenging to balance the expanding number of values, needs and perspectives that relate to water in cities.

Traditionally, the study of governance has almost exclusively belonged to the fields of political sciences and public administration. In recent decades, however, it has acquired relevance in other disciplines as part of discussions on steering, control and management (Torfing et al., 2012). The study of governance has seeped into different fields, aiming to answer different questions, putting the focus on different aspects, and producing incompatible definitions that do not build on each other (Kersbergen & Waarden, 2004). The study of urban water governance was virtually non-existent before the 21st century, and the understanding of what governance involves in this sector, or how to govern governance, is still weak, a knowledge gap which undoubtedly impedes our ability to adequately approach contemporary water crises.

Paper 3 supports the idea that water crises may be understood as crises of governance. It does so by suggesting (1) that governance shaped by outdated frames of reference is ineffective, and (2) that governance shaped by conflicting or contradictory frames of reference may create incompatible processes and structures. The article provides an explanatory framework for water governance that combines, on the one hand, a taxonomy of the processes and structures that constitute water governance, and on the other, an illustration of these elements through the three distinct institutional logics (ideal types) that are expected to apply to all industrialized countries: the *hydraulic logic*, the *market logic* and the *water sensitive logic* (Fuenfschilling & Truffer, 2014).

The *hydraulic logic* is strong in the old paradigm of UWSs (defined in paper 1). It approaches the UWS as a technocratic and simple system, and is deeply rooted in the modern episteme of Western society (paper 2). The second institutional logic, the *market logic*, can be interpreted, from the perspective of paper 2, as the dominant frame of reference in late modernity, a manifestation of reflexive modernization. The emergence of this logic coincides with the growing interest in economic efficiency, optimization and risk reduction that accompanied the neoliberal reforms of the 1980's (most prominently the New Public Management). In this logic, the ontological, epistemological and methodological positions are those of complicated systems. The third institutional logic, the *water sensitive logic*, holds clear parallelism with the metamodern structure of feeling described in paper 2, and represents the core of the new paradigm described in paper 1. This frame of reference, which shares the philosophical underpinnings of the complex systems framework, incorporates transdisciplinary and participatory approaches in social networks that can provide a variety of viewpoints.

4.4 Paper 4

Franco-Torres, Manuel, Briony C. Rogers, and Rita M. Ugarelli. "A framework to explain the role of boundary objects in sustainability transitions." *Environmental Innovation and Societal Transitions* 36 (2020): 34-48.

The growing complexity of UWSs suggests that the number of institutional logics that influence governance may be on the rise. Problems in complex systems are wicked (unstructured, relentless, without a unique optimal solution), opening the door for multiple perspectives. The consequences of this growing variety may be twofold. On the one hand, the consequences may be positive, because a variety of frames of reference are necessary to adapt to a reality that is in constant change. On the other hand, they may be negative, because a growing number of frames of reference increases the likelihood of incoherencies, entrenched conflicts, and fragmentation. Consequently, paper 4 aims at answering question 5 of the thesis: "What can be done to balance variety and integration of frames of reference in urban water governance?"

A prominent approach to this fundamental challenge has been the study of boundary work, "the constructive effort to support communication and coordination across the fences that separate [epistemic] communities" (Keulartz, 2009, p. 266) in the "ambiguous" space that separates them (*a boundary* (Star, 2010)). Derived concepts include *boundary organizations* (Guston, 2001; O'Mahony & Bechky, 2008), *boundary spanners* (A. W. Richter et al., 2006), *boundary bridging* (Koehrsen, 2017), and *boundary objects* (Star, 2010; Star & Griesemer, 1989; Trompette & Vinck, 2009).

The concept of *boundary object* is employed in paper 4 as a solution to combine the variety and integration of frames of reference. Boundary objects are artefacts (such as physical objects, tools, narratives, concepts, prototypes, reports, computer models, etc.) that are attractive enough to capture the attention of multiple frames of reference. At the same time, they have sufficient *interpretive flexibility* to allow their concrete translation within each of these frames of reference, in coherence with existing interests, values, assumptions and beliefs. Boundary objects can be concrete, well-defined and coherent within a frame of reference, and at the same time benefit from their ambiguity and vagueness, in the "terra nullius" among the frames of reference. There, they function as shared points of reference, coalescing agents or even shared visions that are indispensable for communication, negotiation, collaboration and alignment of otherwise conflicting logics. Contemporary examples of boundary objects include ideas like sustainable development goals, resilience, smart cities, circular economy, nexus water-food-energy, liveability, the green economy, and the IPCC report. All are attractive, with vague significance in general parlance, and their own respective concrete meaning inside different institutional logics.

Paper 4 contributes to the bourgeoning field of sustainability transitions by suggesting a middle-range theory of boundary objects. This theory describes their function, their life-cycle, and how they can be purposefully employed to orient and accelerate a transition towards sustainability in UWSs. The proposed theory provides several important lessons, not only on the prescriptive use of boundary objects for orientation and acceleration of sustainability transitions, but more generally on the coexistence and interplay of frames of reference when anomalies emerge. The paper shows how certain actors of change (*champions*, *institutional entrepreneurs* or *boundary spanners*) must have the capacity to reflect on their own and others' frames of reference (their assumptions, beliefs, motivations, needs, vocabularies, etc.) and the political ability to accommodate them into a shared vision (what Battilana et al. (2009) and Fligstein (1997) call *aggregating interests*, or what Schön and Rein (1995) call *double vision*) in order to avoid conflicts, and the entrenchment of an unsuitable/unsustainable paradigm.

This middle-range theory of boundary objects in sustainability transitions is illustrated by the detailed case study of the municipality of Copenhagen, where a devastating cloudburst happened in the summer of 2011 (the "anomaly"). In this case, the concept of *climate change adaptation* was actively promoted as a boundary object to coalesce the efforts of the hydraulic, market and water sensitive logics, and reconfigure local UWSs under the dominant influence of the water sensitive logic.

Moreover, the life-cycle for boundary objects that is proposed in this paper has the potential to become a tool for the study of sustainability transitions, with significant explanatory value. This idea should, in principle, be applicable to transitions in other societal systems.

Chapter 5: General conclusion

The main conclusion of this thesis is that frames of reference matter, and their importance for the development of UWSs is largely unrecognized. They determine how actors provide meaning to the world, how they behave, which goals are worth pursuing, what problems need to be solved, and, most palpably, how infrastructure, management and governance should be conducted.

Thanks to their inherent rigidity and inertia, frames of reference provide certainty, stability and social cohesion, but at the same time, can hinder adaptation and become an obstacle for sustainable development. When reality changes, old frames of reference become obsolete, and can only provide recipes for cognition or behaviour that do not fit the new context or the new needs. Throughout most of human history, this has seldom been a problem, since reality changed at a very slow pace, matching the pace of change of frames of reference. With the exception of abrupt changes in frames of reference forced by punctuated “anomalies”—such as scientific discoveries, technological breakthroughs, natural disasters, pandemics, wars or social revolutions—individuals were born and died within the same frame of reference. Reframing was generally unnecessary, and when it was necessary, it was unavoidable (and catastrophic) in the short term.

However, the particularity of our present day and age is that the timescale of change in the “real world” is shrinking, and becoming shorter than the natural timescale of change of our frames of reference. Our reality is about to become too complex, with too much variety, too much interdependence between the elements that comprise it, more non-linear effects, and more wicked problems that cannot be rationally and permanently solved. The fixed assumptions, beliefs, or values that we use to organize our world and fulfil our needs will inevitably become outdated. This is, ultimately, a result of the maladaptation of manmade social and physical structures to the “reality” of their context. As complexity grows, there is a need for new, more sophisticated and abstract frames of reference, in order to adapt to a larger variety of situations.

This certainly applies to UWSs, where governance, management and infrastructures dedicated to fulfilling our water-related needs are shaped by an outdated, overly simplistic paradigm, which belongs only to the past.

5.1 Water crises as crises of framing

> *"What gets us into trouble is not what we don't know. It's what we know for sure that just ain't so"*
>
> Anonymous

As was stated in paper 2, water crises have, over time, been chronologically understood as crises of resources (too much or too little water); technology (issues of infrastructures to tame nature); management (mainly related to finances, risk, performance and, more generally, decision-making under complexity); and now, at the beginning of the new millennium, as governance problems (mainly problems of goal setting, policy-making, rules, conflicts, and cooperation). The research carried out for this thesis, however, supports the idea that crises of water should instead be conceptualized as problems of framing. An unfit and entrenched frame of reference, or even just conflicts among incompatible frames of reference, will ultimately result in infrastructure, management and governance arrangements that lack the ability to sustainably deliver urban water services in a context of accelerating change. Ultimately, it is not infrastructure, management, or governance that should receive the lion's share of our attention, but rather the frames of reference that justify them. Once we transcend an old frame of reference, governance, management and infrastructures will unfold consequentially.

However, reframing is more than the deepest leverage point for systemic transitions. Reframing is also a requisite for sustainable systems, because frames of reference of sustainable systems must be continuously updated to accommodate a transient reality. Ideally, the frame of reference should be as dynamic as reality itself, in order to avoid the entrenchment of (regulatory) systems that have severe reactions to (ever more frequent) anomalies. This, however, seems to be at odds with the nature of frames of reference, whose function is to create stability, certainty and continuity. According to Kuhn's theory (1962), when a new paradigm emerges (typically after an anomaly), it will go through a process of maturation where it co-evolves with the regulatory system that it shapes. Ironically, when the frame of reference and the regulatory system that it shapes are adapted to the anomaly that triggered them, when they are stable and mature ("normal"), they will also be outdated for their current reality. Frames of reference will always lag behind the reality they purport to model.

Of course, frames of reference cannot be updated dynamically, following the pace of an accelerating reality. However, actors can be aware of their frames of reference, can reflect on their own existence, importance and impact, and acknowledge their differences with others' frames of reference. The idea here is that once this is achieved, it will facilitate the conscious integration of a multiplicity of imperfect, rigid and outdated, but self-aware frames of reference in a dynamic and holistic *meta-frame of reference* that resides in nobody's head, but in the collective imagination. Compared with their constituent frames of reference, this meta-frame of reference would have an improved capacity to adapt to a fluid reality.

The following section suggests a normative approach that may lead to a meta-frame of reference that supports adaptive and sustainable regulatory systems in a transient reality. This configuration is based on lessons taken from all the papers included in this thesis, and is structured according to the *four methodological principles* described in paper 1, namely *learning*, *variety*, *integration* and *rebundling/distribution*.

5.2 Building principles of a meta-frame of reference

Learning

Intuitively, it can be argued that the *learning* methodological principle applied to a meta-frame of reference just means continuous reframing or, at least, frame reflection.

Primarily, learning oriented towards continuous reframing would consist of actively seeking to identify potential anomalies/incoherencies between the model and reality. This could be done, for example, by carrying out continuous experiments that break the established order dictated by the dominant paradigm. Experiments can provoke pockets of instability, and a certain degree of chaos that reveals incoherencies, creates opportunities for more advanced understanding, or simply provokes serendipitous configurations which eventually solidify into repatterned ways of thinking and doing.

However, as mentioned above, the idea of learning as constant reframing is at odds with some of the main functions of frames of reference, which are to provide stability, certainty and continuity. In addition, reframing as *learning* is implicitly negated by Kuhn's theory (1962), where reframing happens in a punctuated fashion forced by external events, and never in an internal, reflexive way. For Kuhn, a new paradigm is not "learned", it is just violently forced by a crude reality.

I suggest that a more appropriate and less radical understanding of *learning* to construct a meta-frame of reference should be limited to that of *frame reflection*, or awareness about our own and others' frames of reference (Schön & Rein, 1995). The concept is also comparable to the idea of *learning level III*, which Hawkins (1991, p. 177) defines as a "temporary access to a higher logical level of awareness, where we have the space to become free enough of our normal perspectives and paradigm constraints to see through them rather than with them, and thus create the space to change them". To put it metaphorically, frame reflection is like taking a rocket to space in order to gain a new perspective of the Earth.

Still, awareness and constant frame reflection come at a high cost. The cognitive strain of a continuous state of vigilance and scepticism (Kahneman, 2011), the lack of ontological security (Giddens, 1991), and the loss of the cognitive support (confirmation bias (Nickerson, 1998)) and social support that the epistemic community provides, is "uncomfortable", to say the least. I argue, however, that even though frame reflection is rare, it is increasingly common, because the gap between frames of reference and reality is becoming progressively more unbearable. This very thesis, for example, represents an explicit frame reflection, or an incipient second-order cybernetics approach, within the water sector.

It would be sensible, then, to assume that societies develop tools to cope with the "discomfort" of frame reflection. Paper 2 suggests that metamodernism (the emerging cultural framework of the 21st century) has its own strategy to deal with this compromise, namely what Vermeulen and van den Akker (2010) call *informed naivety*. In this context of application, *informed naivety* can be interpreted as self-delusion about the veracity of frames of reference. This strategy would consist of behaving as-if a frame of reference was "true" in order to avoid all the negative effects of frame reflection, while nonetheless remaining aware that frames of reference are not actually "true".

In summary, the *learning* that would help to construct a meta-frame of reference might mean being increasingly aware of one's own and other peoples' frames of reference, promoting their co-existence and integration, and enjoying the cognitive ease and social support that known frames of reference provide.

Variety

Let a hundred flowers blossom

Mao Zedong
1957

The second methodological principle of a meta-frame of reference is *variety*. Paper 1 borrows the idea of variety from the field of cybernetics, where it is defined as the total number of states in which a system can be configurated. Ashby (1956, 1958) proposes the *law of requisite variety*, which postulates that the greater variety that a regulator can perform, the greater the variety of disturbances in the context ("anomalies") that the system will be able to successfully adapt to. This principle, translated to the definition of a meta-frame of reference, means that a world which becomes increasingly complex requires a larger variety of co-existing, complementary frames of reference. This idea, while simple, has a deep significance. It implies that there is not a single true perspective, and that not all knowledge has to be funnelled into a set of pre-accepted values and beliefs.

At the same time, greater variety also means that frames of reference become richer, incorporating multiple assumptions, beliefs, values, rules, and tools, and ultimately resulting in a wider range of modes of governance, management and infrastructure. This suggests that a sustainable UWS should be composed of a growing multiplicity of atomized, hyperspecialized, coexisting and overlapping elements in an indefinite number of categories. This may include a variety of policies, organizations, roles, rules, knowledge and disciplines, computer models, combinations of sectors (public, private, research, non-profit), business models, infrastructures, etc. These elements are expected to provide timely and locally adapted solutions that exploit emergent opportunities and solve emergent problems.

Among all the categories, the variety of language has particular relevance. Language provides the building blocks of frames of reference, and a rich vocabulary is essential to portray a complex reality, determining which aspects of reality are regarded or ignored. This idea is supported by Kant (1781), who claimed that the world can only acquire meaning through naming and categorization, and resonates with Ludwig Wittgenstein's (1922) famous quotation "The limits of my language mean the limits of my world". To give a further example, Fletcher et al. (2015) concluded that the growing diversity of terminology for stormwater management reflected a transition from a narrow technical management paradigm based on pipe networks, to a more multidisciplinary approach.

In addition to exhibiting greater variety, the new vocabulary is also increasingly abstract, which has the advantage of being more flexible in capturing reality and serving a larger variety of points of view. It was not so long ago that common vocabulary of today such as environment, risk, efficiency, feedback, sustainability, resilience, uncertainty, synergies, etc. were nothing more than abstract, niche concepts. Nowadays they are more mainstream, and undoubtedly valuable to our present understanding of UWSs. These concepts can be ideas coined within the field of study, such as "water sensitive cities"; incorporated from other disciplines, such as "boundary objects" or "frames of reference"; or can simply represent more precise subdivisions of ideas that already existed, such as the idea of "single-", "double-" and "triple-loop learning".

A meta-frame of reference must embrace a variety of vocabulary from different disciplines. This thesis contributes to diffusing and concretizing a wide range of concepts that are useful to contemporary UWSs, such as complexity, wicked problems, governance, frames of reference (paradigms, institutional logics, cultural frameworks), reframing, leverage points, boundary objects, rebundling, distributed systems, etc., all of which are useful in our pursuit of a deeper understanding of UWSs, and one that matches our new reality.

Integration

In many regards, the world has become much more varied in recent decades, particularly in the case of UWSs. However, this diversity has been dispersed and disconnected. Indeed, multiple voices in our discipline have claimed that one of the most pressing problems of water governance and management today is that of fragmentation (e.g. Brown & Farrelly, 2009). For this reason, all urban water management frameworks[26] that have emerged during recent decades highlight the need for integration of needs, values, interests, knowledge, disciplines, rules, roles, tools, solutions, computer models, infrastructures, water uses, and even integration with nature.

From the lens of a meta-frame of reference, *integration* has the particular meaning of the consideration, coordination and accommodation of disparate frames of reference. The idea of integrating variety without destroying it is an important topic that, to the best of my knowledge, has thus far received little attention (cf. Bijker, 2009). Consequently, this matter was addressed as question number 4 in the present thesis, and approached in paper 4. From that paper, the most important lesson to be learned is that boundary objects can be used as coalescing elements for the support and integration of a variety of frames of reference. The paper argues that boundary objects can be any type of artefact, including ideas, narratives, physical objects, prototypes and computer models. To add to the

[26] Examples of these frameworks include water sensitive cities, integrated urban water management (IUWM), and sustainable urban water management (SUWM).

conclusions reached in that paper, I would like to add here the importance of utopias as boundary objects, in the meta-frame of reference that I describe.

Utopias can serve multiple functions (Levitas, 2010), such as decreasing system justification, serving as benchmarks for the criticism of the current reality, or constituting sources of motivation for system transformation. More specifically, utopias as boundary objects can orient transitions according to goals of collective regulation (Fernando et al., 2018), coalesce interests and worldviews, and mobilize actors by creating enthusiasm and optimism. The core function of utopias was well-articulated by Uruguayan writer Eduardo Galeano, when he said: “Utopia lies at the horizon. When I draw nearer by two steps, it retreats two steps. If I proceed ten steps forward, it swiftly slips ten steps ahead. No matter how far I go, I can never reach it. What, then, is the purpose of utopia? It is to cause us to advance” (Galeano, 1993).

There are plenty of examples in our current society of how abstract utopias can function as boundary objects in order to orient transitions. Among them, we find ideas like sustainability, resilience, the green shift, liveable cities, and water sensitive cities. While many scholars will argue that these concepts have a well-defined meaning, they will inevitably provide a highly concrete definition that it is by no means widely accepted. I addition to be attractive grand narratives, they can be translated as multiple, smaller narratives that are coherent within multiple disciplines or epistemic communities.

As the utopia is reified in concrete elements—which are inevitably not as attractive as the utopia itself—they anchor a new frame of reference in the real world. This was the case, for example, for the *environment*, which emerged as a boundary object during the 1970’s and 80’s.

“[T]he environment was once at the forefront of intellectual debate and new ideas on what the city could and should be like, but now, integrated into urban management practices, has become a serious but rather dull dimension of policy debate, at best a field of duty and responsibility rather than an inspirational source of urban change. […] this integration of the environment into our daily thinking about cities is a remarkable phenomenon which has gained rather than lost significance by having become sedimented into institutional practices and social sensibilities.” (Brandes et al., 2005, p. 60).

Utopias as boundary objects are not a new phenomenon in the water sector, and as acknowledged in paper 2, it should be noted that previous epochs had their own utopias. The modern episteme, for example, was based on the utopia of total dominance of nature, progress and endless supply development (cf. Moss, 2016). However, the new utopias of today seem to be becoming increasingly abstract, allowing for translations to a wider range of perspectives. They come in the form of ideal modes of governance (such as network governance or metagovernance), management frameworks (such as water sensitive cities or sustainable urban water management (SUWM)) and systems of infrastructures (such as sustainable urban drainage systems (SuDS)), which do not exist in their ideal form and Molle (2008, p. 128) sarcastically refers to these urban water utopias as *nirvana concepts*:

“concepts that embody an ideal image of what the world should tend to. They represent a vision of a 'horizon' that individuals and societies should strive to reach. Although, just as with nirvana, the likelihood that we may reach them is admittedly low, the mere possibility of achieving them and the sense of 'progress' attached to any shift in their direction suffice to make them an attractive and useful focal point”.

However, this enhanced interpretive flexibility puts the boundary concept at risk of remaining vague, losing legitimacy, and being unable to achieve its integratory goal. Indeed, several authors have pointed out that Integrated Water Management shared this unfortunate fate (Biswas, 2004; Jeffrey & Gearey, 2006; Molle, 2008).

Although there have been various attempts to reify these utopias, the necessary balance between concretion and sufficient abstraction to invite multiple perspectives seems difficult to achieve. To give an example, in recent years, the United Nations has been working towards the reification of the Sustainable Development Goals into a taxonomy, to demonstrate that sustainability can be understood in multiple different ways, by means of 17 goals and their corresponding sets of targets and indicators. This seems to suggest that, eventually, even the most abstract of utopias must be reified into a concrete set of tangible elements.

Rebundling and distribution

The fourth methodological principle of a meta-frame of reference is *rebundling*. In paper 2, I described the traditional approach to integration in UWSs as *centralization* or *bundling*, with the objective of constraining variety and making the systems predictable and controllable. Although this approach to integration seems to be unsustainable (violates the law of requisite variety), it is still part of the dominant UWSs paradigm in the form of hierarchical modes of governance, one-size-fits-all management, and large, centralized infrastructures. As a reaction to this, the idea of *unbundling* emerged in academic circles in the late 20th century, which in UWSs was reflected in the growing popularity of decentralized and varied systems (governance without government, multiple and disconnected management units, and decentralized infrastructures). However, this approach in UWSs lacked integration and resulted in too much variety and fragmentation, often leading to decreased quality in water service provision. To find a balance between total bundling (too much integration that kills variety), and total unbundling (too much variety that results in fragmentation), in the emerging cultural framework of the 21st century (metamodernism), there has been an emergence of a trend towards *rebundling* (cf. Hagel III & Singer, 1999) and distributed systems (cf. Baran, 1964).

I define rebundled, distributed systems (Figure 7) as ephemeral configurations of loosely connected clusters, composed of richly connected elements which provide pragmatic, timely and locally adapted solutions. Clusters are constituted by a locally adapted integration of heterogeneous elements (e.g. small-scale infrastructures, technologies, actors, guidelines), making the cluster an autonomous unit particularly fit for responding to local needs. At the same time, the cluster maintains loose connections with other clusters (to exchange resources and information) and become a node in a larger system, keeping the whole connected, redundant, flexible and adaptive (cf. Kovács & Juhász, 2020). This approach would be more resilient and sustainable than standard approaches based on large-scale centralized elements, or those based on a diversity of decentralized elements (Baran, 1964).

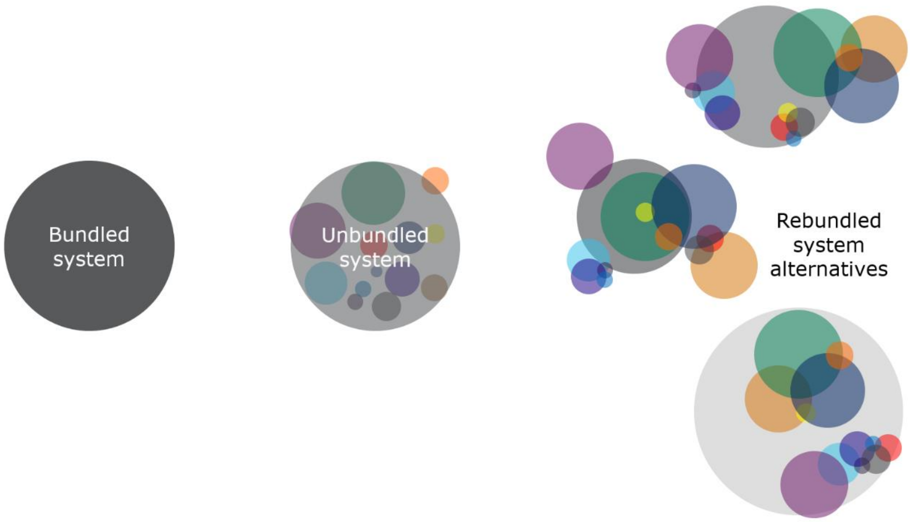

Figure 7. A bundled system, an unbundled system, and different rebundled system alternatives.

Interestingly, the rebundling of varied elements may result in new constructions such as hybrid governance configurations, complex interdisciplinary management models, and multifunctional infrastructures that function as new boundary objects (Gieryn, 1995). Heterogeneous infrastructures, management tools, and governance structures and practices can be shaped by, and translated to, multiple frames of reference, simultaneously and coherently. This rebundling can enable enhanced understanding, communication and cooperation, allowing for a balance between variety and integration within a meta-frame of reference.

Chapter 6: Practical advice

The present thesis is a theoretical piece of work consisting of an ecosystem of concepts and theories from different fields of knowledge. The primary aim of this framework is not to find solutions to concrete problems, or to perpetuate an agenda to improve the sustainability of urban water systems, but to create a lens that allows access to a layer of reality that is often ignored by the actors of the urban water sector. This is a layer of reality which, despite being rather abstract, has tangible effects on the provision of urban water services. The best advice to these actors would be to read the thesis with care and let it sink in slowly, enabling the content to provide meaning to the reader's context and experience, and hopefully inform action.

However, it must be acknowledged that reading this thesis may be challenging for the general public, and its practical uses may therefore remain unexplored. This concluding chapter, then, seeks to provide practical advice to all actors of the urban water sector, as well as some guidance addressed specifically to particular actors. These lessons do not claim to be comprehensive, but rather aim to serve as an illustrative translation of what the thesis may mean in practice.

6.1 General advice to all actors of the urban water sector

The advice elaborated below revolves around eight core ideas which have been adapted to the particularities of different actors.

Recognize UWSs as socio-technical-environmental systems

The first piece of advice is to recognize that UWSs are more than infrastructures. They are complex relationships of technical, environmental, economic, social and cultural elements that co-evolve. The technical sphere is just the most tangible part of the system, and ignoring the other spheres means turning a blind eye to a large part of the reality of urban water.

Reflect on the frames of reference

Second, actors should acquire the capacity to reflect on the frames of reference that underpin one's own and others' interpretations, goals and actions. In practice, this means delving deep into the underlying principles of thinking and behaviour, in order to establish the root logics or assumptions that make things as they are.

In addition, by recognizing frames of reference, actors will obtain the freedom to move away from the trodden paths of thinking and doing, becoming open to new perspectives. This realization may help actors to accept others' perspectives and facilitate communication, trust and collaboration. Actors should ultimately learn to navigate between the different frames of reference, learn their vocabularies, and recognize their codes and tokens.

Pay attention to language

The core lesson of this thesis is that frames of reference matter, and, to the same extent, that language matters. Language can be understood as the first-level reification of frames of reference, where ideas are packed, connected and transmitted. In the absence of the right vocabulary, ideas cannot be grasped or communicated, and some aspects of reality can not be appreciated.

Consequently, actors should pay attention to language and reflect on what ideas the words seek to convey, which values, needs and interests they transmit, and how they affect the transformation of reality. Actors should also reflect on the power of new vocabulary, and how words like risk, sustainability or resilience may have crucial impacts on outcomes.

Learn to play "the urban water game"

The fourth piece of advice is to pursue the understanding of urban water governance or, in other words, learn to play "the urban water game". In order to fulfil their needs and reach their goals, all actors of the urban water sector must interact with other actors within the formal and informal rules of governance. All actors will benefit from understanding what the rules are and which values, interests and assumptions they represent; how the rules are made and how the different actors can influence their transformation; what their role is in the game and where they have room to manoeuvre; and who the other players are and what they want. An urban water sector where all the players know and master the rules of governance will potentially result in a more effective and democratic provision of urban water services.

Recognize that reality is transient, complex, uncertain and uncontrollable

UWSs are systems in perpetual and unpredictable change, with the constant emergence of "black swans" or "unknown unknowns". Actors must recognize the impossibility of total predictability, and the futility of absolute control. Instead of seeking total predictability, they should dedicate large resources to continuously monitoring and evaluating change in order to learn and adapt. This means that, instead of building rigid or robust systems of control that cancel predictable change, actors should allow for certain slack in their relationship with the system in order to create flexibility and resilience. Rather than forcing the system into the desired results, actors would be better served to ally and co-evolve with the system. For example, instead of forcing natural processes to behave in the way we want, we should make use of the ecological services that nature provides us.

Bundle, unbundle and rebundle the system components

Bundling is a synonym of integration, a concept recurrently found in the recent literature of urban water management, which emerged in response to fragmentation problems in the sector. It represents the approach of considering UWSs as the complex whole that they are, rather than exclusively as separate, independent parts.

Unbundling means avoiding homogeneity and promoting variety. Urban water actors should strive to support a multiplicity of actors, perspectives, tools, knowledge, and solutions that match the inherent variety of a complex reality.

Rebundling consists of ad-hoc combinations (bundling) of heterogenous elements (those that were unbundled) to solve particular problems that cannot be adequately overcome with standard solutions.

Practice relentless "out of the lab" experimentation

"In the lab" experimentation can be defined as the planned alteration of one or a few parameters under otherwise controlled settings, which is often used with optimization objectives. "Out of the lab" experimentation, meanwhile, involves the relatively unplanned alteration of patterns (probing or testing), in a way that makes it safe to fail without putting the whole system at risk. This type of experimentation may be based on seemingly absurd hypotheses that do not necessarily make sense at the outset, or changes that simply aim to see "what happens if". This process has the potential to bring actors "out of the box" of pre-accepted knowledge, and is indispensable for a better understanding of UWSs in constant change. In addition, "out of the lab" experimentation unleashes a controlled amount of chaos that may reveal hidden dangers and innovative solutions.

Acquire a "metamodern" attitude

The "metamodern" attitude is characterized by an implacable enthusiasm, curiosity, trust, humbleness and acceptance of failure. It emerges from the realization that complexity and uncertainty make absolute control impossible. Nevertheless, it encourages the practice of never growing desperate and instead making the best of any possible situation.

6.2 Advice to urban water managers

Do not conceive management as system control but system orientation

The general conclusions drawn in the previous chapter suggest that sustainable UWSs must develop an ever-expanding complexity that seeks to match the equally ever-expanding complexity of reality. However, this is at odds with the nature of the human mind, which is permanently on the lookout for heuristics and ways to simplify reality in order to make it comprehensible and tractable (Kahneman, 2011). Undoubtedly, any effective strategy, policy, rule, standard, protocol, or theory must be as parsimonious as possible in order to be comprehensible and practicable. How can future UWSs be sustainably "managed" if we depend on simple solutions while the world grows to be increasingly complex?

The answer to this question resides, I believe, in how we interpret the concept of *management*. If we interpret *management* as rigid control, then management of future UWSs is a lost cause. On the other hand, if we interpret *management* as guidance or orientation, the simplicity of management is not necessarily contradicted by the complexity of the system. This can be justified on the basis that complex systems are living systems, and have a natural tendency to adapt to their environment, create order and self-reproduce[27] when they are not subjected to strong constrains. Management, in this case, would consist of expanding the range of action of the system and orienting the inherent self-adaptation properties of the system towards desired system configurations and results, and away from undesired system configurations and results. This may be done by means of bundling, unbundling and rebundling. In this way—to put it boldly—the internal complexity of the system will "take care of itself".

> *"We can't control systems or figure them out. But we can dance with them!"*
>
> Donatella H. Meadows
>
> *Dancing With Systems, 2001*

[27] This is what Maturana and Varela (1992) refer to as *autopoiesis.*

Your task is not to foresee the future, but to enable it.

Antoine de Saint-Exupéry
Citadelle, 1948

Relentlessly bundle, unbundle and rebundle the system components

Bundling, unbundling and rebundling may have multiple interpretations for urban water managers. “To bundle”, for example, can be interpreted as:

- To co-manage urban water with other urban services such as healthcare, food and energy production, communication systems, ecology, economic development, or urban life quality.
- To co-manage drinking water services, wastewater, stormwater, groundwater or water in rivers, lakes and sea.
- To integrate manmade structures (pipes, pumps, reservoirs) with natural elements (soil, vegetation, topography) that provide ecological services.
- To integrate knowledge and tools form multiple disciplines like hydraulics, hydrology, chemistry, biology, economics, information technology, urban planning, public administration, law and psychology.
- To design infrastructures that can integrate multiple functions, as in the case of stormwater management, where parks can be used for recreation and for detention of runoff.

“To unbundle” can be interpreted as:

- To create infrastructures with diverse elements that are nature-based, made of concrete, plastic or steel, that have large and small scales, that are under the ground, on the ground or on roofs, and that work towards multiple goals at the same time.

- To see water problems not as exclusively technical problems, but to frame them as problems of management, collaboration, regulation, economy or even social behaviour.
- To invite a variety of actors into idea generation and decision-making.

“To rebundle” can be interpreted as:

- To manage stormwater by combining trees, ponds, tanks, pipes and permeable surfaces, or by creating multifunctional infrastructures that serve multiple goals.
- To manage approaches that combine technological fixes, economic incentives and behavioural nudges, such as those aimed at reducing potable water consumption.
- To promote diverse forms of public-private-research partnerships which develop new technologies to fulfil concrete needs.
- To combine disparate interests and perspectives. One of the key lessons of this thesis is that this social rebundling can be done through boundary objects such as prototypes, benchmarks, new concepts, and most importantly, utopias.

Focus on interpretation, intent and governance, and not exclusively on technology

It is generally believed to have been organizational consultant Warren G. Bennis who uttered the following sarcastic statement: “The factory of the future will have only two employees, a man and a dog. The man will be there to feed the dog. The dog will be there to keep the man from touching the equipment”. I believe that this quotation also reflects the nature of management in future UWSs. The managers of the future will not need to focus on the technical aspects of urban water to the same degree that they have done so far, because the understanding and control of every single technical aspect of urban water systems will be done by hyperspecialized technicians. Instead, managers will need to focus on more abstract issues of interpretation, intent—the deep leverage points of the system—and governance.

This means that the importance of narratives, visions and utopias as powerful tools for urban water management must be recognized and exploited. The function of narratives is to give meaning to a complex reality, adapting it to the way humans think. Visions and utopias are particular types of narratives that serve as references to criticize the status quo, as benchmarks to orient change, and as persuading objects to unite actors with different values, interests and perspectives. Storytelling should be a core tool of urban water managers.

6.3 Advice to educational institutions

Incorporate a variety of frames of reference into the education of practitioners

For centuries, technical infrastructures (pipes, pumps, reservoirs, channels and water treatment plants) have been the core of UWSs. It is therefore not surprising that the provision of urban water services has been shaped by a technocratic frame of reference underpinned by a positivist and reductionist approach to knowledge. Our educational institutions lead our future urban water managers towards this monopolistic frame of reference, which exclusively venerates stationarity, homogeneity, fragmentation, centralization, predictability, certainty and control.

Many authors of the sources reviewed in the writing of this thesis vehemently reject this paradigm and its centrality in education. They point out that the positivistic/technocratic approach is unsuited to our current problems and needs, engenders side effects that it is not equipped to contend with (see Table 1 in chapter 1), and that it has a monopolistic character which prevents the introduction of new perspectives that might approach these problems in a sustainable way. The present curriculum for future urban water managers is therefore in stark contrast with the nature of the problems and needs that future urban water professionals will have to confront.

However, we should avoid throwing the baby out with the bathwater. This positivist, reductionist and technocratic frame of reference has underpinned unprecedented technical and social developments in Western countries, contributing to dramatic increases in life expectancy and improvements in urban life quality. This leads me to suggest that the technocratic paradigm is not the problem, but a necessary part of the solution. Above all, the technocratic frame of reference should abandon its monopolistic standpoint and open itself up to the introduction of new perspectives to urban water management.

This new educational agenda must move from acontextual fragmentation and analysis for prediction and control towards integration and holism for situated understanding and adaptation (Morin, 2007). Again, this does not mean that the traditional study of parts of the system in isolation should be entirely abandoned, because these are fundamental tools for the understanding of systems. Instead, they should always be combined with multiple methods, knowledge and perspectives, and even related to the dynamics of society as a whole, to create a richer picture of reality. A mixed approach should, among other things, pursue the incorporation of social sciences and qualitative methods to research and management, soft skills for effective communication and collaboration, the ability to read the context, and above all, the ability to simultaneously hold a concrete, technical and operational mindset and an abstract, utopic, and strategical mindset.

> *The test of a first-rate intelligence is the ability to hold two opposed ideas in the mind at the same time, and still retain the ability to function*
>
> Scott Fitzgerald
> *The Crack-Up (Esquire magazine), 1936*

Incorporate the idea of complexity

More concretely, the curriculum of future urban water managers should first develop its understanding that urban water is a complex system where technology, economy, environment, and society are tightly intertwined. Students should learn that the world, and UWSs in particular, are complex, non-linear, transitory, surprising, never entirely comprehensible, and not amenable to total control.

Educate multifaceted professionals

The above ideas aim to lead educational institutions away from the temptation to educate future urban water managers exclusively as hydraulic engineers. Instead, they should be educated as project managers, leaders, motivators, storytellers, researchers, educators, facilitators, negotiators and judges. Above all, they should "learn to play" the "urban water game" (to participate in "applied" urban water governance). The incorporation of all these necessary skills into a curriculum is not an easy task, as they do not fit with traditional educational methods. However, some of these skills can be learned by means of innovative teaching tools. Suitable examples of these include role-play and gaming simulation methods (e.g. Gomes et al., 2018; Hoekstra, 2012; Zhou et al., 2010).

6.4 Advice to scholars and research centres

Future directions of research

This thesis has an exploratory and reflexive character that opens the door to a wide range of questions. Therefore, the first advice to scholars addresses future directions of research.

A natural continuation of this thesis would be to find out if a profound paradigm shift is actually happening in practice, or whether the examples presented in this thesis are just niche changes with little or no effect on a system that is firmly dominated by the old paradigm.

If the new paradigm is becoming real in its entirety somewhere in the world, the next question would be why there, and what are the main drivers of change in that location? A collection of case studies that describe the application of the new paradigm in practice would be of interest to our understanding of how the paradigm shift can develop in practice.

In this thesis, I have also claimed that the new urban water paradigm is a reflection of a deeper societal transformation: the emergence of the metamodern cultural framework. It seems only logical, then, to ask whether the shift towards a new urban water paradigm is an unavoidable consequence of this cultural transformation. There is no doubt that an enhanced understanding of the modern cultural framework has enabled an enhanced understanding of the old urban water paradigm. We may assume, then, that a better understanding of the emergent cultural framework would help us not only to direct and accelerate the paradigm shift in the urban water sector, but also to foresee the inherent negative side effects that metamodernism might produce.

It is important to highlight that the scope of this thesis has been limited to Western democracies. Future studies should investigate whether frames of reference of UWSs outside these regions follow similar trajectories, or whether they have the possibility of leapfrogging some "unsustainable" stages of the Western transition and advancing more rapidly towards sustainability. Could rapidly expanding urban centres in Asia or Africa, for example, avoid rigid, large scale, linear and centralized infrastructures, and instead implement flexible, circular, distributed, rebundled, and nature-based infrastructures?

Although the scope of this thesis has also been limited to UWSs, the four constituent papers have shown—sometimes explicitly, others implicitly—that there has been parallel evolution in different realms, such as arts, science, public policy, environmental perspectives or economics, and ultimately, cultural frameworks. Although the similarities and parallelisms seem obvious now, they are surprisingly under-communicated, most likely due to the silo design of research. The findings of this thesis might be applied and expanded to other sectors such as health, education, transport, food production or energy, in order to frame their old and new paradigms, their use of boundary objects, and their modes of governance.

Produce more reflexive research

This thesis belongs to a kind of reflexive approach to urban water systems that has experienced exponential growth during the last two decades. In this approach, instead of trying to find new ways to more effectively control the environment, the researcher looks at how we create and use instruments of control. Instead of contemplating the effects of infrastructures, management and governance, it considers how infrastructure, management and governance come to be. This is, from my point of view, an under-researched approach that will be a requisite in achieving sustainable UWSs.

Produce more exploratory research

In recent decades, oriented research has gained legitimacy throughout Western societies. Research sponsors typically expect that scholars will produce concrete solutions to pressing problems, or new ideas that can be directly translated into specific improvements. Oriented research, meanwhile, is narrowed by perceived problems and needs, constrained to a paradigm's domain and developed in the realm of what we think is possible or beneficial. The objective of oriented research is to fill knowledge gaps, and to get to know what we knew that we did not know.

Conversely, exploratory research departs from an issue—not necessarily a problem—that is vaguely defined. It has the ability to transcend the limits of the frame of reference, explore the issue from other perspectives, and discover things that we did not know that we did not know. This thesis constitutes an example of this type of research.

It is my belief that too much focus on oriented research, and too little on exploratory research, will slow down the transition towards a new paradigm, limiting innovation and adaptability.

Produce research with society

Scholars and research centres have traditionally seen themselves as the primary producers of knowledge, and as separate from practitioners. However, the findings of this thesis suggest that researchers should produce knowledge in cooperation with other societal actors, and engage in active efforts to diffuse research results into society.

For example, researchers should actively seek alliances with water managers, to design prototypes and pilot projects; with private companies, to create new products and services; and with policy-makers, to design science-based policies. However, these collaborations should not be seen as one-directional transfers of knowledge, as all these actors have their own perspectives of reality, as well as tacit knowledge, which should be encompassed within the formal knowledge of research.

6.5 Advice to private actors

In this category, I include actors such as product developers, service providers, consultants, contractors, and property developers.

A particular characteristic of private actors is that they mostly adhere to a market logic, which is oriented towards profit maximization. However, their knowledge of how to navigate the market or maximize profits is often based on simplistic assumptions (neoclassical/rationalistic economics at best) and focuses on short and medium-term effects. An overreliance on profit maximization creates problems that, paradoxically, can actually reduce profits in the long run. On the one hand, this is because their rationalistic control strategy is at odds with complex systems. The harder they try to force the system in one direction, the harder it becomes to control it. On the other hand, the objective of profit maximization is often in conflict with the core values of other actors, creating entrenched disagreements and preventing collaboration.

Become an engaged societal player

The first specific advice to private actors is to become an engaged societal player, even when this does not obviously result in direct profit growth. In a complex society, private actors must attempt to build links and trust with all types of actors: public and civil organizations, educational institutions and students, research centres, other market actors, and even their competitors (*frienemies*). Unfortunately, humans, and private actors in particular, are biased to the belief that these interactions are zero-sum games, something that in complex systems is rarely the case. It is quite the opposite, in fact, as multiple interactions can open the door to synergic coalitions with other actors and allow access to networks for exchange of valuable information and business opportunities (Granovetter, 1973). In addition, intense societal engagement makes it easier to accommodate other actors' frames of reference in the business plans of private actors, building trust, supporting collaboration and preventing future conflicts.

As engaged societal players, private actors may also be invited to participate in governance, helping to orient the development of the sector and its design policy.

Fill and create emergent market niches

Another particularity of private actors is that their primary function is to provide the products and services that society demands, in a timely manner. Traditionally, there were only a few, well-defined urban water services, but during the last decades these needs have become more locally specific, diverse, and intertwined with other types of services. The urban water sector needs variety (unbundling) to fill emergent market niches. Private firms can innovate by combining (rebundling) technologies and tools, knowledge from disparate disciplines, or products and services that originally belonged to other sectors.

Be aware of social change

When needs are continuously evolving, and the context is complex and fluid, it is private actors, more than any other type of actor, that must be aware of change. This should be done at several levels. Private organizations follow change at the technical level, constantly looking for new technical problems and solutions in relation to which they can sell their services. Similarly, firms are also aware of economic change or regulatory change, where it affects their business. However, private actors are rarely aware of the underlying social environment, and particularly unaware of cultural frameworks and their evolution. It is widely accepted that many firms have failed because they did not follow the technical evolution (as in the case of Kodak, Nokia or Blackberry), although I would suggest the hypothesis that most firms fail because they do not adapt to the cultural framework of their times.

Actors are so embedded in their cultural framework that they often fail to recognize its existence and transformation. This is why private actors, as actors highly dependent on change, should learn to read the emergence of new language and narratives in the water sector. For example, bourgeoning ideas such as resilience, smart cities, green development and circular economies tell private actors in which direction the paradigm is changing.

6.6 Advice to policy makers

In the traditional urban water paradigm, politicians and regulators (the traditional government) have the monopoly of governance. Their function is to impose the right and impartial policies and rules of the “urban water game”. They assume control of management and infrastructures in a top-down fashion, and in doing so facilitate the optimization of urban water services. However, the acknowledgement of complexity implies that regulators cannot control the system, and what is worse, their attempts to control it often result in unintended consequences. In addition, their decisions are never objective. Instead, they are always shaped by a frame of reference. Policies and rules are inevitably permeated by a set of values, assumptions and prejudgments, representing the interests of certain groups.

Reflect on the frame of reference that underpins policy-making

The first advice to politicians and regulators is that, as democratic representatives, they should always reflect on the values, objectives, beliefs, and assumptions underpinning their decisions (their frame of reference), and expose these openly to the public. It should be a question of *what* they want to ultimately achieve, and *why*. This is an exercise that should be fundamental in democracy but that, strangely enough, is rarely practiced.

Embrace governance as a guided collaborative process

The second advice to politicians and regulators is to abandon the traditional idea of governance as an exclusive privilege of government. Governance should be a participatory process that involves all actors and includes both formal and informal rules. The formal government then becomes an integrator, a motivator, and an umpire. This facilitates the creation of networks with a variety of actors, suggests future directions, helps to create synergies, and avoids conflicts among groups with contrasting interests. Governance, then, is neither a top-down nor a bottom-up process, but both at the same time. All actors should be involved, and the policy-maker should be the core facilitator of the process.

Approach governance as relentless experimentation

The third advice to members of government is to practice relentless experimentation, where policies and rules "are really questions masquerading as answers" (Gunderson, 1999). Policy-making should be regarded as an iterative and endless process. There is no singular optimal policy in a complex and transient reality.

6.7 Advice to civil society organizations

By civil organizations, I mean communities that do not belong to the public or private sphere of society. What characterizes them is that they are built around special interests, and a shared perception of a need to reform a certain issue. They may be, for example, environmental associations, neighbourhood associations, or non-governmental organizations (NGOs), and constitute key actors in the top-down and bottom-up participatory character of the new (metamodern) paradigm.

Reflect on the frame of reference that binds the organization

The first advice to such organizations is to reflect on the frame of reference that binds the civil organization community; their values, goals, assumptions, language, narratives, etc. This analysis will primarily help them to understand who they are and what they want to achieve as a group.

Reflect on their role in governance

Another important reflexive exercise consists of analysing the "urban water game" (urban water governance) in which they must participate in order to achieve their goals. They must understand who is playing the game, what the rules are, and how the game is played in practice.

Gain legitimacy and adhere to the rules of the game

To achieve their goals in the "urban water game", civil organizations should develop a strategy focused on gaining legitimacy and mobilizing actors. Civil organizations are characterized by their opposition to certain aspects of the status quo and the paradigm that supports them. The dominant paradigm, however, is entrenched it its structures (those that make up the present configuration of the urban water system: laws, rules, contracts, roles, standards, codes, procedures, indicators, computer programs, infrastructures, etc), which provide rigidity and continuity. Typically, civil organizations attempt to radically alter these structures, and the associated paradigm, by confronting them head on, usually with rage and complaint. The rigid structures of the system will most likely suppress these attacks, and not only that, but the strategy will also most likely backfire, resulting in a loss of legitimacy for the civil organization.

Civil organizations will typically have a system of values, interests and goals that conflict with those of the incumbent system. Initially, the organizations should endeavour to shelter their interests and goals from the attacks of powerful actors who do not want the status quo to be altered. They should start by analysing the “urban water game” and playing according to the rules. Since the rules are made by humans to maintain order in an uncontrollable complex system, they are, by definition, imperfect. Consequently, they are susceptible to be interpreted or applied according to the interests and goals of the civil organization. In other words, the game has to be changed by following the rules of the game, and the system has to be changed from within the system.

Mobilize potential allies

The second focus point of civil organizations in the “urban water game” is mobilization. The strength of these organizations is that they are formed by activists, who have, on the one hand, the motivation and engagement that is lacking in public entities, and represent, on the other hand, community values that are lacking in private organizations. While private entities are strongly founded on an economic logic of profit maximization, which often creates conflicts of interests with other actors, civil organizations are founded on values that echo, or can exhibit synergy with, the interests of potential allies. However, it must be noted that a grassroots movement and enthusiastic activists are often not enough to mobilize a critical mass for change. The lessons learned in the present thesis suggest that civil organizations would benefit from joining/creating narratives, boundary objects and utopias that would fit their interests and grant them the collaboration and mobilization of other actors.

Benefit from anomalies

Finally, civil organizations are probably the actors with the most to gain from anomalies or disruptions (see section 2.5), which reveal that the dominant frame of reference is inadequate and that alternatives are therefore required. In this window of opportunity, these communities must be quick to deploy their perspective as a valid alternative. However, to exploit an anomaly and act within its window of opportunity is easier said than done. This strategy requires significant preparation, prior legitimization and mobilization work, and above all, a great deal of luck with timing.

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Appendix A: Publications

Paper 1

Articulating the new urban water paradigm

Franco-Torres, Manuel, Briony C. Rogers & Robin Harder, 2021

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Articulating the new urban water paradigm

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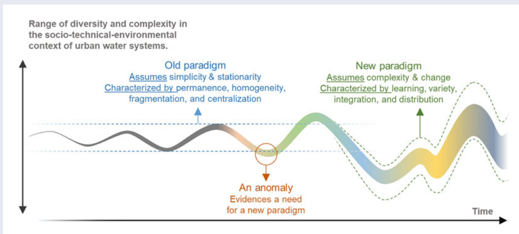
ABSTRACT

Urban water systems in industrialized countries have underpinned unprecedented improvements in urban living standards through effective drinking water supply, sanitation and drainage. However, conventional urban water systems are increasingly regarded as too rigid and not sufficiently resilient to confront growing social, technological and environmental complexity and uncertainty, manifested, for example, in the maladaptation to climate change, depletion of nonrenewable resources, and degrading urban livability. In response, a new urban water paradigm has emerged in the last two decades within the context of a broader societal change that promotes a more organic worldview over the classical mechanistic and technocratic understanding of reality. This article develops and applies an analytical framework to coherently describe the new paradigm and contrast it with the old urban water paradigm. The framework includes a philosophical foundation and set of methodological principles that shape the new paradigm's approach to governance, management, and infrastructure.



KEYWORDS Paradigm shift; new water paradigm; integrated urban water management; sustainable urban water management; water sensitive urban design; complexity

1. Introduction

The provision of water supply, sanitation and urban drainage services to households, businesses and communities has led to unprecedented improvements in life expectancy, economic growth, and quality of life in industrialized countries during the last 150 years. These services have relied on a system of social structures and material infrastructures—referred to in

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Supplemental data for this article can be accessed at publisher's website.

this paper as urban water systems (UWSs)—that have remained strikingly unchanged over the last century. In general terms society abstracts, cleans, transports, consumes and disposes water in the same ways it did at the end of the 19th century. However, the context in which these conventional UWSs operate has profoundly changed during recent decades. Western societies have grown increasingly complex due to accelerated technological development and faster exchange of information, where social, technical and biophysical elements have become more and more diversified and interdependent (Beck et al., 2003; Castells, 2010). This complexity has resulted in emerging problems—particularly climate change, rapid urbanization, and environmental degradation—and new societal needs, values and expectations—like social equity and urban livability—which conventional UWSs are poorly equipped to approach (Andoh et al., 2008; Bell, 2015; Daigger, 2009; Hering et al., 2013; Ludwig, 2001; Marlow et al., 2013; Pahl-Wostl et al., 2009). In other words, the ideas and assumptions that underpin our current UWSs are no longer fit for purpose.

A growing number of scholars have reported the gradual emergence of a new set of ideas and assumptions, a new mental framing or water paradigm (Gonzales & Ajami, 2017; Pahl-Wostl et al., 2011; Schoeman et al., 2014) that shapes new types of social structures and infrastructures capable of properly addressing current and anticipated needs and challenges. This new paradigm for UWSs can be seen as the local expression of a broader societal transformation that moves from a mechanistic to an organic worldview (Capra & Luisi, 2014; du Plessis & Brandon, 2015) which arguably started during the 1960s-70s (Franco-Torres, 2020) as an attempt to adapt to a more complex and dynamic reality. This broad paradigmatic transition had emerged in other sectors earlier (like urban planning (Jacobs, 1961), energy management (Lovins, 1976), or economic management (Schumacher, 1973)) and it is now increasingly recognizable in popular concepts like planetary boundaries (Rockström et al., 2009; Steffen et al., 2015) sustainability, resilience and green economy (UNEP, 2011), or the United Nations Sustainable Development Goals (UN, 2015).

While there is wide consensus about the existence of a new paradigm in the water sector, many authors have characterized the incumbent urban water paradigm as rigid and resistant to change, prone to continued operation under old beliefs and values despite evident problems of sustainability and increasingly complex societal needs (Brown & Farrelly, 2009; de Haan et al., 2015; Kiparsky et al., 2013; Roy et al., 2008). The incumbent paradigm has a distinct inertia as old ideas are entrenched within widespread technologies and infrastructures, management practices, rules, or organizational structures. This inertia is useful in providing stability and certainty, but also creates an impediment for adaptation to a changing reality. New ideas risk being discarded in favor of solutions that are firmly ingrained in the incumbent paradigm; they do not fit with established framings. See, for example, Sofoulis' (2015) description of the difficulty of introducing rainwater tanks—despite their obvious advantages—in the Australian water sector, Binz et al.'s (2016) report of problems to legitimize potable water reuse in California, or Coombes et al.'s (2016) analysis of engineering and economic assumptions belonging to the old paradigm impeding the adoption of governance policies toward water cycle management.

Despite this so-called *lock-in*, a growing number of scholars, policymakers and practitioners recognize the need for innovative approaches that derive from the new paradigm. Salient examples include Singapore's integration of the whole water cycle (Jensen & Nair, 2019; Lee & Tan, 2016), urban design responses that are sensitive to water environments in Melbourne (Australia) (Brown et al., 2013; Ferguson, Brown, Frantzeskaki, et al., 2013), the use of stormwater to enhance urban livability in Copenhagen (Denmark) (Franco-Torres et al., 2020; Ziersen et al., 2017), and collaborative planning processes in Rotterdam (The Netherlands) (de Graaf & van der Brugge, 2010; Dunn et al., 2017).

Thorough analysis of these successful case studies often point to key factors that supported the local adoption of new solutions, like the work of champions, the creation of communities of practice, the diffusion of narratives, or the creation of pilot projects. We argue, however, that a broader enactment of the new urban water paradigm could be accelerated with a better understanding of the paradigm itself, and an integrated definition of its constituent elements, which so far remain dispersed and fragmented in the literature. A plethora of normative water management frameworks that implicitly reflect the new paradigm (Table 1) has emerged (Esmail & Suleiman, 2020; Furlong et al., 2015; Schoeman et al., 2014), typically focusing on particular aspects of management, theories, and methods incorporated from other disciplines. These frameworks tend to be ambiguous (Biswas, 2004; Furlong et al., 2015; Molle, 2008) and "remain open to a multitude of interpretations which pose insurmountable obstacles in finding practical ways for their implementation" (Saurí & del Moral, 2001, p. 352). We argue that this coexistence of similar and ill-defined frameworks and terms means they tend to compete, hindering understanding and the development of the discipline and associated practices. The rampant diversity of partially overlapping terms used in the subfield of urban drainage management serves as a prime example of the reigning confusion (Chocat et al., 2001; Fletcher et al., 2015).

We therefore suggest that a transition to more sustainable and adaptive urban water management could be accelerated if scholars, policymakers and practitioners become conscious of their cognitive framings that may limit the consideration of alternative solutions, and of the existence of an

Table 1. Selection of management frameworks.

Framework	Focus	Framework
Integrated (Urban) Water (Resource) Management (IWM, IUWM or IWRM)	IWM seeks to combine multiple natural processes, scales, perspectives and needs in order to define holistic solutions.	(Biswas, 2004; GWP, 2000; GWP, 2012; Mitchell, 2006; Mukhtarov, 2008; Rahaman & Varis, 2005)
Adaptive Water (Resource) Management (AWM or AWRM)	UWSs are explicitly considered complex and dynamic systems that present a high degree of uncertainty. AWM proposes to understand and collaborate with the "natural" self-organizing processes of the social and natural systems through continuous experimentation, broad participation and learning, instead of forcing them toward certain predefined and narrowly defined outcomes.	(Georgakakos et al., 2012; Pahl-Wostl et al., 2007)
Sustainable (Urban) Water Management (SWM, SUWM)	SUWM builds on principles like adaptation, holistic decision making, broad stakeholder participation, decentralization, resource use efficiency, and community and environmental values, although these principles are not well linked in the framework.	(Hellström et al., 2000; Larsen & Gujer, 1997; Loucks, 2000; Marlow et al., 2013)
Water Sensitive Urban Design (WSUD)	WSUD is a multidisciplinary approach that highlights the link between urban design, land use, the efficient use of water, and the improvement of urban livability.	(Ashley et al., 2013; Mouritz, 1996; Wong, 2006; Wong & Brown, 2009)

alternative and coherent paradigm that can more effectively respond to present and future water-related needs (Abson et al., 2017; Meadows, 1999).

Certainly, there have been several insightful attempts to describe this new water paradigm (Capodaglio et al., 2016; Gleick, 2000; Grigg, 1998; Keath & Brown, 2009; Marlow et al., 2013; Ma et al., 2015; Mitchell, 2006; Novotny et al., 2010; Pahl-Wostl et al., 2011; Pinkham, 1999; Schoeman et al., 2014; Zandaryaa & Tejada-Guibert, 2009). However, these have not engaged with an in-depth explanation of what a paradigm is, tending to list characteristics that lack connection or a clear structure. They also tend to emphasize a particular water service—either drinking water provision, stormwater management, wastewater treatment, or water ecology—and have scarce reference to their common philosophical foundations.

This article therefore aims to describe a coherent framework that holistically connects the multiple ideas that underpin the new urban water paradigm and its derived social and technological structures in the water sector, across the different water services, and with particular attention to their shared philosophical foundations—the same foundations that underpin the broader social paradigm now emerging.

2. An analytical framework to describe urban water paradigms

Our paradigm framework encompasses three main categories: philosophical foundations, methodology, and operational articulations (Figure 1).

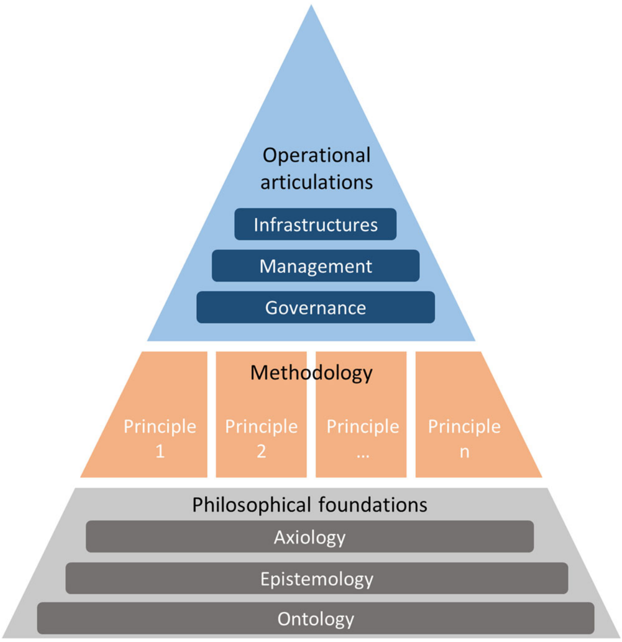


Figure 1. Urban water paradigm framework, encompassing three main categories and seven themes. Philosophical foundations (grey) provide the basis for methodological principles (orange), which further supports the operational articulations of UWSs (blue).

The first category, *philosophical foundations*, encompasses three themes that correspond with three nested branches of philosophy, which underpin both the broader social transformation and the sectorial transformation of the new urban water paradigm. These themes are rarely discussed explicitly in literature on UWSs. The first branch of philosophy, *ontology*, describes how the paradigm conceives the structure and nature of reality. The second, *epistemology*, expresses how knowledge about that reality is obtained. The third, *axiology*, describes the needs and values that guide actions. The description of these philosophical foundations builds on a theoretical argument that borrows elements from a wide range of disciplines, including science studies, philosophy, complexity studies, cybernetics or systems thinking.

The second category, *methodology,* encompasses a series of *methodological principles* that both reflect the paradigm's foundational philosophies and shape or orient the design of water governance, management, and infrastructures. These three elements are therefore referred to as *operational articulations* of an UWS.

The first operational articulation, *governance*, includes the social structures and practices that allow actors to work together in order to achieve common goals. The second, *management*, defines how interventions on the available resources are understood, planned, implemented, monitored and evaluated —within the rules and policies demarked by governance—in order to fulfill societal needs. And third, the design, construction, and operation of *infrastructure* mediates society with its natural environment and makes the management of resources possible. Infrastructure, at the top of the framework, represents the most tangible signature of an urban water paradigm, the tip of the iceberg, and serves as the mechanism for delivering urban water services.

In the following, we elaborate these different aspects of our framework, gradually moving from the abstract theory of ontology to the most practical examples of infrastructure of urban water systems. The sources that support the framework have been identified through a nonsystematic literature screening that included 148 key books and articles. The methodology of this search and the selected sources can be found in the supplemental material that accompanies this article.

In addition, the analysis and examples presented below juxtapose the old and the new urban water paradigm, making clear that both are holistic understandings of the world with their corresponding governance, management and infrastructure.

3. Philosophical foundations

3.1. Ontology

The understanding of reality that lies behind the old urban water paradigm—its ontology—is deeply influence by classical Newtonian physics (Dunn et al., 2016) and more concretely by its ontological reductionism (Biswas, 2004). This perspective describes the world as an orderly place where the similarities among elements are highlighted—and their dissimilarities neglected—in order to create a limited number of discrete and homogeneous categories. These elements are assumed to be poorly interconnected. Their relationships are linear—i.e. propagate change proportionally—and governed by few, simple, well-defined, deterministic, and immutable laws that provide simplicity and regularity, creating subsystems that are independent of their context and eternally oscillate within well-defined boundaries (Guba, 1990; Mazzocchi, 2016). All these characteristics suggest the metaphor of the world as a deterministic clockwork machine (Capra & Luisi, 2014; Heylighen et al., 2007; Human & Cilliers, 2013; Morin, 2007).

In contrast, the ontology of the new urban water paradigm is as a complex system (Coombes & Kuczera, 2002; Voulvoulis et al., 2017). This emphasizes the heterogeneity of elements and their strong interdependence, recognizing a holistic system behavior rather than focusing on the study of the individual elements in isolation (Ackoff, 1991). There is not a universally accepted definition of complex system (Mikulecky, 2001; M. Mitchell, 2009), but most agree they are profusely interconnected systems that can generate emergent behaviors. Individual component elements typically have multiple, short-ranged, and dynamic connections with neighboring elements (von Foerster, 2002). As a result, while the number of elements grows linearly, the number of links among elements grows exponentially (Cilliers, 1998; Heylighen, 1999). High interconnectivity also means complex systems are typically open, exhibiting rich interactions with its environment and making it difficult to delimit a boundary between the system and its context (M. Mitchell, 2009). This high interconnectivity renders in practice a dense and continuous reality that is constantly modulated, a space that is experienced as a continuous heterogeneity—what in physics is known as a *field*—with unique local properties. All these characteristics of complex systems facilitates the metaphor of the world as a *living organism* (Waldrop, 1993), rather than as a machine.

Despite the short range of interactions between neighboring elements, their rich connectivity allows the propagation, modulation and amplification of signals through long ranges, producing multiple circular causations and positive (reinforcing) feedback loops (von Bertalanffy, 1968). This provokes non-linear behaviors; very small signals can get amplified, resulting in unpredictable system-wide change (Kofman & Senge, 1993; Waldrop, 1993). Feedback signals can also be negative, providing temporal order and stability to the system by counteracting perturbations. However, this stability is superficial because complex systems are in a permanent dynamic state, which guarantees its survival: "Equilibrium is another word for death" (Cilliers, 1998, p. 4). Complex systems have a history and continuously evolve.

Interestingly then, complex systems are self-organizing; they lack a central controller (Prigogine & Stengers, 1997; Waldrop, 1993). They create new structures and behaviors at the macro level that could not be inferred from the local rules that govern the relationships of the entities and their individual properties. This phenomenon, characteristic of complex systems, is called emergence (Heylighen et al., 2007; Kauffman, 1995; Prigogine & Stengers, 1997) and can be easily recognized in systems like ant colonies, DNA, or markets. The human brain is also a good example: the study of individual neurons does not provide much information about the emergence of human consciousness.

This transformation of ontology permeates the water sector, which is today being widely understood as complex, non-stationary and susceptible to emergent behaviors at physical and social levels (Larson et al., 2015; Milly et al., 2008; OECD, 2015).

3.2. Epistemology

As for ontology, the quest for knowledge about the world in the old urban water paradigm is heavily influenced by the classical Newtonian physics, from which it inherits an *epistemological reductionism* (Morin, 2007). In the same way that one can disassemble a clockwork to understand its mechanisms, (epistemological) reductionism attempts to explain the functioning of a well-defined system by analyzing its constituent elements and their relationships. It involves the isolation of a subsystem from its context, its fragmentation in smaller parts, and their classification in homogenous categories. Then, it defines the relationship among parts to finally infer the "regular" behavior of the whole system, and predict its future state (Kofman & Senge, 1993; Mazzocchi, 2016). Relying on reductionism, the "apparent" complexity is never a hindrance for the acquisition of knowledge, as it is assumed that all systems can be reduced to simpler ones in order to be easily understood.

However, this reduction to simplicity does not eliminate complexity, it just makes it invisible by neglecting the particularities of the constituent parts, their rich and dynamic relationships, and their dependence on the context (Morin, 2007). Whereas reductionism may be an acceptable explanatory approach to well-defined and isolated problems (like basic water services), its utility to understand and predict complex, open, and dynamic systems (such as the urban water services demanded by industrialized societies today) is limited (Cilliers, 1998; Kofman & Senge, 1993).

Unfortunately, the distinction between simple and complex is not always straightforward (Andersson et al., 2014; Kurtz & Snowden, 2003). From the point of view of an observer embedded in a complex system, everything may appear simple: its own properties, the short-range relationships with its neighboring elements, and the extension of the system are known. However, this same observer is usually unaware about the dependence on its context, the feedback effects of its own actions, and the emergent phenomena at the system level. A complex system is, therefore, incompressible (Richardson & Cilliers, 2001); any model that perfectly mimics its behavior must be at least as complex as the systems themselves, easily surpassing the human capacity of understanding. Then uncertainty is not about external randomness, but rather about the observer's lack of knowledge (epistemic uncertainty) (di Baldassarre et al., 2016). This realization has influenced the epistemology of the new urban water paradigm, which has shifted from reductionism to holism, highlighting the contextual, dynamic, and always uncertain nature of knowledge.

In particular, the embracing of uncertainty is a key epistemological transformation. Relying on the power of reductionism and the deterministic nature of reality, the old paradigm is self-confident and predictive. It assumes that by carefully observing the past and accumulating knowledge about the mechanics of the system, it is possible to make accurate predictions and design optimal solutions, fostering the dream of a future without uncertainty. Contrarily, the new paradigm rejects simplicity, regularity, and the power attributed to reductionism. It focuses instead on open and dynamic systems, non-linear processes, emergent phenomena that are unpredictable, and the inability of the observer of acquiring the necessary knowledge (Allen et al., 2011; di Baldassarre et al., 2016; Heylighen et al., 2007; Morcol, 2001; Prigogine & Stengers, 1984).

Based on the perceived deterministic nature of reality and the power of reductionism, scientists and practitioners embedded in the old paradigm firmly believe they see the world "as it is"; that an objective reality exists "out there", to which they have direct access through careful observation, quantification, and reason. In this view, humans are external and objective observers that search for the unique truth awaiting to be unpacked (Morin, 1977; Zwarteveen & Boelens, 2014). As there is just one possible (rational) interpretation of reality, this has to be revealed by experts that apply supposedly rigorous and value-free scientific methods, yielding a context-independent knowledge that will unambiguously settle all disputes and orient policy design (Sarewitz, 2004).

Contrarily, the new paradigm recognizes that knowledge in a complex system is always imperfect and subjective because there are no fixed points of reference or external points of view. The observer is inexorably embedded in the observed system and any of her interpretations are inevitably situated and contextual (Cilliers, 1998; Prigogine & Stengers, 1984). For example, a complex system like the Internet cannot possibly be objectively and comprehensibly described by one user, who can only aim at providing a description of his use of the network and contextualized experience. Narratives, then, are effective ways to describe a certain aspect of a complex system, to provide structure and meaning under particular circumstances from a partial view, while still being coherent with the underlying objective reality (Lyotard, 1984).

Cilliers (1998) gives perhaps a better illustration of narrative knowledge by picturing a complex system as a dynamic network (Figure 2). A narrative forms one of multiple possible paths through the network that rest on the objective truth. These paths are just temporal framings, subjective interpretations of a connection between an input and an output, defined in terms of particular and temporal points of view, needs, and constraints.

The new paradigm recognizes the impossibility of finding the absolute truth and that strictly scientific knowledge built from the point of view of a single discipline has limited value. It focuses instead on "pragmatic" or "useful" truths (Pierce, 2011) that "work" in a certain context or situation.

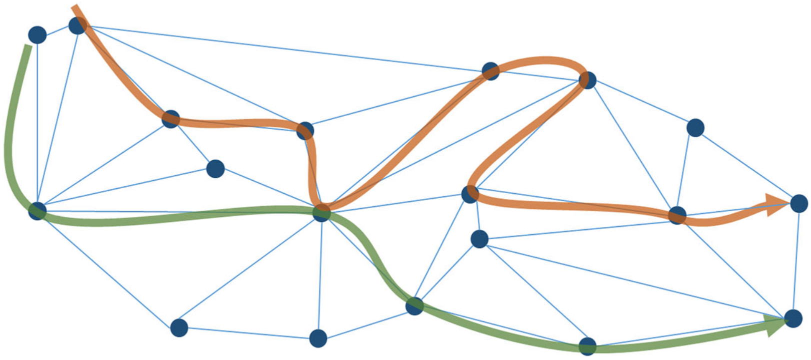


Figure 2. Alternative narratives (green and brown lines) provide situated explanations of a complex system (blue network) that do not necessarily contradict the underlying reality (the dots represent scientific "hard" facts). This figure is inspired by Cilliers (1998, p. 130).

They are *bricolage narratives* (Levi-Strauss, 1968) that integrate heterogeneous sources of information (Barbosa et al., 2012; Blanco-Gutiérrez et al., 2013; Croke et al., 2007) and have a practical relevance for concrete problems and needs. This "useful" truth is the only truth that will affect us, and the only truth that we may know (Bach et al., 2014; Gerlak, 2008; Harremoës, 2002).

The water management literature offers us multiple examples about the adoption of this new epistemology, advocating for participatory water management, multidisciplinary solutions, incorporation of uncertainty in planning, or continuous experimentation (Farrelly & Brown, 2011; Pan & Guo, 2019; Varady et al., 2016).

3.3. Axiology

In our review of ontology and epistemology we saw that the old urban water paradigm is essentially anthropocentric; the "external reality" is reduced to only those things that humans can observe or understand. Complexity and an ecological perspective are largely disregarded, largely due to the lack of the cognitive capacity (Simon, 1997) and analytical tools (Kellert, 1994) necessary to understand them. Unsurprisingly then, the fundamental values that steer behavior in the old paradigm (axiology) are also fundamentally anthropocentric; subsistence and (economic) growth. These are translated into a few universal, independent, and easily identifiable needs that typically include the provision of sufficient and safe drinking water, sanitation, and drainage (de Graaf et al., 2007; Gleick, 2000; Pahl-Wostl et al., 2011; Sofoulis, 2005), eclipsing any other "superfluous" needs.

This approach derives from an instrumental view of nature (Beck et al., 2003), which is regarded as a neutral context that lacks any intrinsic value. Nature is simultaneously seen as an unlimited source of resources, which generates a feeling of dominance for people, and as a constraining frame to fulfill human needs, which generates a feeling of fear related to the possibility of losing control of it (Wolfe & Brooks, 2017). The relationship with nature is, therefore, competitive. It is about nature's benefit or humans' benefit; a zero-sum game (Bernhardt et al., 2006). For example, there is a conflict between maintaining ecological flows of rivers and increasing abstractions of water to meet growing water demands.

The complex systems approach of the new urban water paradigm reveals that humans are not independent of their environmental context, but rather a part of it (Brooks & Brandes, 2011; Mebratu, 1998; Schmidt, 2013). Instead of competing with nature, humans must collaborate with it and design synergistic solutions that contribute to support human wellbeing (Bernhardt et al., 2006; Costanza & Daly, 1992; van Zeijl-Rozema et al., 2008; Zandaryaa & Tejada-Guibert, 2009). For example, during the last decade most industrialized countries have approved legislation that protect ecological flows in rivers in order to improve social welfare (EC, 2015; ICCATF, 2011). Therefore, the most salient values of the new paradigm are ecological sustainability and associated social welfare (sometimes referred as livability) (Garrote, 2017; Partzsch, 2009). This does not negate the importance of the values of the old paradigm, but expands them to include many others like physical and mental health, recreation, beauty, sense of community and social integration, equality, justice, or even cultural and spiritual values (de Haan et al., 2014; Ferguson, Brown, & Deletic, 2013; Marlow et al., 2013; Zwarteveen & Boelens, 2014).

The values considered in the new urban water paradigm are varied, ill-defined, subjective, interdependent (often conflicting) (Wong & Brown, 2009) and incommensurable. Therefore, it has become common praxis to lump them in the ambiguous concept of *sustainability*. This concept is not exclusive to the new paradigm; it has also been utilized in the old paradigm with a slightly different meaning. In line with the linear thinking of the old paradigm, sustainability has traditionally been understood as a static and objective goal or end-state, a point of optimal and static equilibrium in a perfect future where all needs are fulfilled in harmonic balance (Brown et al., 1987; Hardi, 1997). This is the so-called substantive sustainability (Truffer et al., 2010) and it is often reflected in sustainability indicators (UN, 2007; van der Steen & Howe, 2009; van Leeuwen, 2013) that provide a "deterministic single-criterion optimality" (Reed & Kasprzyk, 2009, p. 411).

In contrast, *procedural sustainability* (Truffer et al., 2010), which is more in line with the philosophical underpinnings of the new paradigm, acknowledges the dynamic nature of needs and values, and the complex system in general (e.g. Slocombe, 1990). In this interpretation, sustainability is an open-ended process—not a goal—that focuses on the available pathways to reach a moving target—a dynamic, socially constructed, unachievable ideal (Bagheri & Hjorth, 2007; Newman, 2005; Nonaka & Toyama, 2005; Voß & Kemp, 2006)—that must be constantly renegotiated within an evolving context (Robinson & Cole, 2015). Contrasting with the ambivalent feelings of dominance and fear that characterized the old paradigm, the new paradigm is associated with feelings of humbleness, hope and enthusiasm, guided by a utopic image of human welfare in perfect harmony with nature (Franco-Torres, 2020).

4. Methodology

Within a paradigm, a *problem* can be conceptualized as the factor that opens a gap between the present state and desired (optimal or sustainable) state where certain needs are effectively fulfilled. Building on the Merriam-Webster dictionary definition, this conceptualization leads to an understanding of *methodology* as "a body of methods, rules, and postulates employed by a discipline" to acquire knowledge or solve problems. Similarly, in the case of a paradigm, we interpret a methodology as a set of *(methodological) principles*, designed to modify or *regulate* the present state of things, solve concrete problems, and approximate to a desired state. These principles are shaped by the paradigm's philosophical foundations and used as a guide to define a *regulator*. From the point of view of cybernetics, regulators are sub-systems that locally constrain the variation of a wider system in which it is embedded (its sociotechnical-environmental context) within certain bounds in order to fulfill a certain set of needs (Ackoff, 1991; Ashby, 1956).

4.1. UWS as regulators of their context

An UWS can be conceptualized as a *regulator*. Urban water services like drinking water provision, sanitation or drainage require an UWS that regulates certain natural processes (basically to retain, convey, or treat water) with physical infrastructures (like dams, pipes, pumps and water treatment plants) and regulates certain social behaviors with social rules (like policies, guidelines, contracts, prices, technical standards and roles). To do so, the UWS, and more concretely its operational articulations (governance, management, and infrastructures), follow a set of characteristic methodological principles associated with each paradigm.

A core theorem of cybernetics, states that "*every good regulator of a system must be a model* [a replica] *of that system*" (Conant & Ashby, 1970, p. 89). Accordingly, the old urban water paradigm's methodology proposes an UWS that projects the stationarity and simplicity of its context and problems, while the new paradigm's methodology promotes an UWS that mimics the complexity and dynamism of its context and problems.

4.2. Tame problems vs wicked problems

In order to explain the methodological principles of each paradigm, it is convenient to describe first what problems they aim to solve, which clearly align with their respective ontologies.

For the old urban water paradigm, the simplicity of the world and the well-defined needs and values yield what Rittel and Webber (1973) call *tame problems*; simple, clearly structured, and static problems that are independent from other problems (Bagheri & Hjorth, 2007; Pahl-Wostl et al., 2011). Among several possible solutions there is always a unique optimal alternative—the "right solution"—an UWS configuration that has the capacity to solve the problem once and for all, which can be rationally inferred and that must be imposed as standard (R. R. Brown et al., 2006; Kreuter et al., 2004; Sarewitz, 2004).

The new paradigm focuses instead on *wicked problems*, which are complex, interdependent, unstructured, and pervasive (Rittel & Webber, 1973). There are infinite solutions to wicked problems but none of them are optimal or definitive—there are no silver bullets (Capodaglio et al., 2016; Ludwig et al., 1993). Whereas different solutions fulfill interlinked needs in variable degrees, being more or less attractive from different points of view (Kreuter et al., 2004), they also alter the system in a way that creates new problems elsewhere. Typical wicked problems in UWSs are the pervasive challenges that give rise to the need for a new paradigm, such as climate change, urbanization and non-point source pollution.

4.3. Methodological principles. From control to resilience

By focusing on a perceived existence of optimal and definitive solutions to tame problems, the old paradigm aims to build UWSs that function as rigid regulators based on prediction and control. These are able to withstand natural disruptions and change, keep homeostasis, and permanently fulfill a limited set of basic and independent needs in a de-contextualized environment (Capodaglio et al., 2016; de Bruijn et al., 2017; Pahl-Wostl, 2007).

From the perspective of the new paradigm this prediction and control approach is seen as a naïve delusion; it is considered not only ineffective, but also may result in unexpected and undesirable consequences (Holling & Meffe, 1996; Ludwig et al., 1993). For example, the straightening of rivers and construction of canals to facilitate urban development often results in greater flood risk (Castonguay, 2007; Wolsink, 2010). Instead, the new paradigm is inclined toward the development of *resilience* (Folke, 2006; Holling, 1973) as a regulative function to fulfill human and environmental needs.

Certainly, resilience has become a buzzword in academia and policy over the last decade, receiving varied—and sometimes contraposed—interpretations (Béné et al., 2014; Davoudi, 2012; Folke, 2006). For example, *engineering resilience* refers to the capacity of a system to quickly recover from a range of disturbances and maintain its ability to deliver its single intended function (de Bruijn et al., 2017; Holling & Meffe, 1996). This interpretation is more aligned with the old urban water paradigm, which aims to resist change by building up a threshold capacity to buffer contextual variations (Gleick, 2000), rigidly controlling the system and keeping it in homeostasis.

In contrast, the definition of resilience we attribute to the new paradigm, aligned with the concept of procedural sustainability, is the so-called *evolutionary resilience* (Davoudi, 2012). This resilience can be defined as the capacity of a regulatory system to continuously adapt to changes, identify synergies, and avoid conflicts with its environment in order to deliver a timely and convenient set of variable functions (Berkes et al., 2008; Simmie & Martin, 2010; Walker et al., 2004). This approach is radically opposed to the *control methodology* of the old paradigm and its engineering resilience, which seeks to force and dominate the environment to permanently yield a concrete output. Evolutionary resilience requires then relentless efforts of adjustment to ever changing values, knowledge and physical variables (Darnhofer et al., 2016; Takala, 2017), without losing fundamental structures that give continuity to the system (Herrfahrdt-Pahle & Pahl-Wostl, 2012). The design of flood-prone neighborhoods serves as a good illustrative example (Hale, 2016; Rode & Gralepois, 2017), where resilience is achieved through a range of measures (e.g. elevated buildings, flow-through neighborhoods, water storage, reduction of imperviousness) that reduce risks and simultaneous support new functions that improve urban livability.

We have identified four pairs of opposite principles that contrast the control methodology of the old paradigm and the resilience methodology of the new paradigm: stationarity vs learning, homogenization vs variety, fragmentation vs integration, and centralization vs distribution. Later we will explore how these four principles, shaped by the philosophical foundations of each paradigm, become reified as the operational articulations of the UWS.

4.3.1. Stationarity vs learning

To permanently dominate the environment and deliver a consistent service, the old urban water paradigm constrains the natural variability within

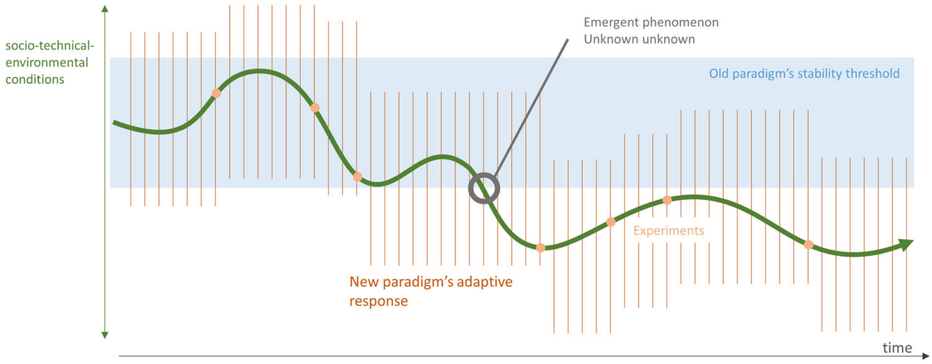


Figure 3. UWSs operate under non-stationary conditions (green line) (Milly et al., 2008). The old paradigm assumes stationarity; based on past behavior predicts that the conditions will remain within a certain range (blue stripe). Due to emergent phenomena (unknown unknowns (di Baldassarre et al., 2016)) the conditions unexpectedly move out of the predefined stability threshold. Contrarily, the new paradigm does not assume a fixed stability threshold, but continuously experiments (brown dots) to temporarily adjust to new conditions (brown vertical bars).

predetermined bounds, forcing it to be stationary (Gleick, 2000; Schoeman et al., 2014). This is done in practice by, for example, constructing large hydraulic infrastructures like reservoirs for water storage, desalination plants, or dikes for flood retention. In this conservative approach, the reliability of infrastructures stands out as the main issue since a loss of control is potentially catastrophic. There is an aversion to uncertainty and risk, relying on only well-known, standard, and fail-safe methods that stifle innovation and experimentation (Brown & Farrelly, 2009; Farrelly & Brown, 2011; Harremoës, 2002).

Contrarily, the new paradigm sees stationarity in UWSs as a problem rather than a solution, since it promotes a non-responsive regulation, neglecting the emergence of new needs and the evolving nature of context (Figure 3). Constant learning by doing—i.e. relentless experimentation (Allen et al., 2011; Farrelly & Brown, 2011; Kato & Ahern, 2008; Moberg & Galaz, 2005; Vreugdenhil et al., 2010)—is a preferred methodological principle that pragmatically reveals convenient ways to adapt to a dynamic and uncertain context. Small experiments purposefully create controlled instabilities and low-regret alternatives where it is safe to fail (Hashimoto et al., 1982; Holling, 1973), fostering innovation and anticipating emergent events, allowing the timely adaptation of an UWS to its environment (Conant & Ashby, 1970). However, learning not only requires proactive and persistent experimentation, but also the acceptance of uncertainty, tolerance of failure, constant monitoring, sensitivity to recognize change, trends and opportunities, reflexivity to continuously reconsider frames and goals, and the flexibility associated with the capacity to abandon old practices and structures and incorporate new ones (Burnham et al., 2016; Gunderson & Holling, 2002; Jiggins et al., 2007; Schelfaut et al., 2011; Wolsink, 2010).

In contrast to the predictive approach of the old paradigm, the new paradigm turns to other type of learning that could be called *abstract experimentation* (also referred as *possibilistic thinking* (Clarke, 2008), *what-if analysis* (Brown et al., 2015), or *counterfactual thought experiments* (Klotz & Horman, 2010)). This type of experimentation consists of creating a range of hypothetical future scenarios (Ingram & Lejano, 2007; Novotny et al., 2010; Schoonenboom, 1995), typically narratives of success (dream scenarios) or narratives of failure (nightmare scenarios) that project backwards to the present, providing guidance for action.

4.3.2. Homogeneity vs variety

In cybernetics, the term *variety* refers to the total number of states in which a system can exist (Ashby, 1956). The *law of requisite variety* (Ashby, 1956, 1958) postulates that the greater variety of responses a regulator can perform (like policies, rules, management solutions, or infrastructures), the greater variety of disturbances the system is able to successfully adapt to.

The old urban water paradigm assumes the context to be simple and regular, making a large variety of regulatory responses a burden rather than a solution. Conversely, the new paradigm confronts a complex context and therefore fosters a larger variety in its constituent elements (Aerts et al., 2008; Wong & Brown, 2008) in order to enhance its capacity for local adaptation and innovation, efficiency or redundancy (R. Biggs et al., 2012; Keath & Brown, 2009).

The new paradigm promotes a many-to-many relationship between needs and solutions. A combination of interdependent interventions of different nature and scale (Marsalek & Schreier, 2009; Pahl-Wostl, 2007) provide a suboptimal and temporary accommodation of multiple, diffuse, ever-changing, and interdependent needs (Capodaglio et al., 2016; Gonzales & Ajami, 2015; Werbeloff & Brown, 2011), which also are deeply embedded in their unique local context (Coombes & Kuczera, 2002; Dunn et al., 2016; Liu et al., 2007).

4.3.3. Fragmentation vs integration

The old paradigm rests on the underlying assumption that both the regulatory system (the UWS) and its regulated context can be divided in isolated subsystems that perform easily identifiable functions. These individual elements can be locally optimized and reassembled to produce universal optimal solutions (Schoeman et al., 2014; Wong & Brown, 2009). Accordingly, the *fragmentation principle* (*methodological reductionism*) becomes a prerequisite for prediction and control (Capra & Luisi, 2014; Turton & Meissner, 2002).

However, during the last two decades it has become widely accepted in the water sector that fragmentation in governance, management and infrastructures is a serious barrier to sustainability (Mukhtarov, 2008). Fragmentation represents the negation of the systemic nature of reality and implies an artificial rupture of connections, generating confrontations, interferences, inefficiencies, and risks (Brown & Farrelly, 2009; GWP, 2000; Ioris, 2008; OECD, 2016)

Integration, on the other hand, reinforces the systems ontology of the new urban water paradigm. Focusing attention on the dynamic relationships among parts and with their context (being context-sensitive), it produces a holistic view that is more likely to produce (evolutionary) resilient outcomes than a fragmented one (Gonzales & Ajami, 2015; Hardy et al., 2005; Varady et al., 2016; Wong & Brown, 2009). It can, for example, facilitate the development of coordination and synergies (R. Biggs et al., 2012), reduce tradeoffs and conflicts (Pahl-Wostl et al., 2008; Wolsink, 2006), suppress vulnerabilities (Gober, 2010; Pahl-Wostl et al., 2007), allow autoregulation, and foster serendipity (Darnhofer et al., 2016; Merton & Barber, 2011).

4.3.4. Centralization vs distribution

Despite its tendency toward fragmentation, the structures of the old paradigm are not completely disconnected. They exhibit centralized designs of control that excel at top-down integration where a central node concentrates resources. Still, centralized systems rely on fragmentation and homogenization. This is the typical scheme of networks of water distribution dependent on a single water treatment plant, or organizational schemes in hierarchical organizations dependent on a single leader.

Opposing centralization, many scholars argue that the new urban water paradigm supports *decentralization* (Daigger, 2009; Larsen et al., 2013; Leigh & Lee, 2019; Zhang et al., 2009), which implies that the whole system is not dependent on a central node, with the elements of the UWS geographically dispersed and often working in isolation. This claim is in line with the principle of variety, however, it opposes integration. Strictly speaking, decentralized sets of elements do not constitute a system because they may be disconnected—for example, a single household that exclusively relies on a private water well.

Instead, we argue that the varied and integrated regulatory systems of the new paradigm are actually *distributed* (Baran, 1964) (Figure 4). Distribution, as decentralization, implies that the elements of the system

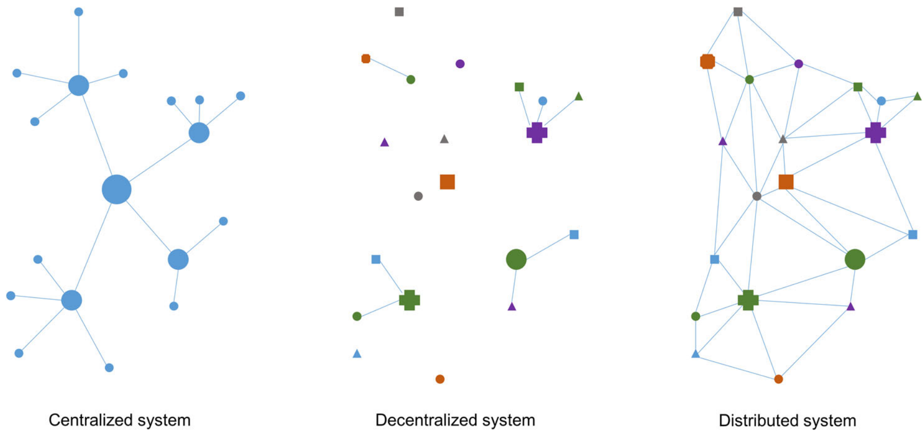


Figure 4. Types of system configurations. Adapted from (Baran, 1964). The points indicate units of production or consumption (differences in shape, size and color indicate their homogeneity), while the lines indicate their links to exchange resources and information.

are not exclusively dependent on a central node and that the nodes are geographically dispersed, but in addition it requires that the elements are connected to exchange resources and information to (ideally) all adjacent elements (Baran, 1964; Ryan, 2009). These "nodes" are semi-autonomous agents, meaning that they "work" at a range of scales; they both function autonomously, and they function as a part of a larger system generating emergent behaviors. Distributed systems are in general terms more resilient than both centralized and decentralized systems (C. Biggs et al., 2009; Chanan et al., 2009). They reduce risks, increase efficiency, and are more flexible and adaptable (Baran, 1964).

5. Operational articulations

Earlier, we conceptualized UWSs as regulators of their context that aim to solve water-related problems and fulfill water-related needs. They include aspects of governance, management, and infrastructures that reify some methodological principles, which in turn are shaped by the philosophical foundations of their corresponding paradigm.

In the old urban water paradigm, UWSs are meant to fulfill few, well-defined, immutable and non-contested needs (like drinking water provision, sanitation, and drainage) (Pahl-Wostl et al., 2011). This means that in order to achieve those well-defined goals, old management focuses on how to physically control nature and keep it within optimal bounds. The UWS of the old paradigm is therefore largely a material or technical issue (Saurí & del Moral, 2001; Swyngedouw, 1999).

In contrast, the new urban water paradigm sees water not only as a material issue, but also as a social issue (Zwarteveen & Boelens, 2014). It considers a variety of ill-defined and often conflicting needs in an ever-changing context that must be navigated and accommodated with help of good governance (Mguni et al., 2015). Indeed, recent literature widely acknowledges that water problems are mostly problems of governance (Bucknall et al., 2006; OECD, 2016; Pahl-Wostl, 2015; van Dijk, 2012).

5.1. Governance

The old paradigm assumes that it is possible to rationally design a simple and rigid institutional framework that provides guidance toward the optimal fulfillment of a few universal and undisputed water needs, including a small set of formal rules that keep human behavior in check—largely ignoring social or cultural variability (Bakker, 2010; Ioris, 2008; Pahl-Wostl, 2008).

The design of this rational system of rules and policies is the duty of a select group of actors with well-defined roles (the government) that are organized in rigid, centralized, hierarchical structures. The final decision-makers—usually politicians—are at the top, far from the resources that are being managed (Castonguay, 2007; Chandler, 2014), and carry the ultimate responsibility for water services (Turton & Meissner, 2002). They concentrate the authority, power, legitimacy, and information to rationally control the system by imposing formal coercive rules (Bakker, 2010). These decision-makers are supported by experts (Brown, 2005)—often engineers (Ingram & Schneider, 1998)—who have access to the "unique" truth. At the bottom of the hierarchy are the operators and consumers, whose participation in the policy design and rule-making is deemed as unnecessary or even detrimental (Bagheri & Hjorth, 2007; Schoeman et al., 2014; van Dijk, 2012), as the "right" technical decisions are already defined by experts: the beneficiaries of urban water services are mere rule-followers (Turton & Meissner, 2002).

However, when the old style of governance tries to engage with growing institutional complexity, where stakeholders have conflicting values, interests, agendas and horizons, sector-specific policies and rules become contradictory (Zandaryaa & Tejada-Guibert, 2009); governance becomes fragmented and multiple contestations and interferences emerge (Brown & Farrelly, 2009; Segrave et al., 2014). Governance problems become wicked.

The new paradigm fully recognizes that these problems transcend science and technology (Funtowicz & Ravetz, 1993; Weinberg, 1972) and cannot be optimally and permanently solved, fostering instead the coherence of local governance with its social context (Gonzales & Ajami, 2017; Neto, 2016; Wade, 2011) and the internal integration of policies and rules that affect the UWS. This integration requires wide participation of all actors

(Brandes & Kriwoken, 2006; Carr et al., 2012; Zandaryaa & Tejada-Guibert, 2009), with active engagement on the definition of problems and the design of coherent and synergistic policies and rules across sectors (Ananda & Proctor, 2013; Everard & McInnes, 2013; Mitchell, 2006). More concretely, participation is deemed essential to: gather diverse resources, skills, knowledge, values, interests and needs (Allon & Sofoulis, 2006; Arnold, 2013; Jameson & Baud, 2016; Rijke et al., 2013; van der Brugge, 2009; van Dijk, 2012); harness enthusiasm and commitment (Patterson et al., 2013; Sofoulis, 2015); provide transparency, trust, and equity (Dietz et al., 2003; Domènech et al., 2013; Hahn et al., 2006; Wolsink, 2010); and confer legitimacy on the selected alternatives (Hering et al., 2013; Sofoulis, 2015).

This *new governance* (Osborne, 2010) is distributed in clusters (also referred to as *network* or *polycentric governance*). These clusters create partnerships between diverse actors through interactions to find synergies and negotiate conflicting interests (Bos et al., 2015; Pahl-Wostl et al., 2008; Torfing et al., 2012). For example, between public agencies specializing in different sectors (not only for water provision, sanitation, or flood prevention, but also other sectors like transport, energy, urbanism and recreation), private actors (like technology providers, consultants or land developers), research actors (like universities and research centers) and civil society organizations (like NGOs and neighborhood associations). These interactions are conducted not only through formal relationships, but also through informal (shadow) networks (Bos et al., 2015).

At the same time, there is a shift from the few rigid roles in the old paradigm to a wide variety of overlapping and flexible roles. For example, government agencies like water utilities are not only *supply developers,* but also *resource custodians* and *information providers* (Brown et al., 2009; Pires, 2004; Prasad Pandey & Kazama, 2014). For distributed infrastructures, consumers also become producers (*prosumers*) (Novotny et al., 2010; Sofoulis, 2015) of their own water supply or wastewater, and private competitors also become collaborators to achieve synergistic solutions. All those actors are dependent on each other to fulfill their duties and goals. For example, public water utilities are often dependent on private contractors or consultants to deliver the desired water service.

Hence, governance in the new paradigm is not the exclusive function of the government (Gleick, 2000; van de Meene et al., 2011; van Dijk, 2012); it is the collaborative effort of a group of actors with access to power, legitimacy, information, and knowledge in varying degrees, which aim to carry out enterprises that often involve conflicting interests (Costa et al., 2012)—water services become everybody's responsibility (Turton & Meissner, 2002). The outcomes of this distributed governance are collaboratively created and emergent, instead of rationally planned by an elite (Bos & Brown, 2012). Therefore, pragmatic solutions arise from a learning approach that involves participation, continuous experimentation, monitoring, and revision of strategies, policies and rules (Bos & Brown, 2012; Hukka & Katko, 2015; Jameson & Baud, 2016; OECD, 2011). Policies are not fixed solutions, but instead "questions masquerading as answers" (Gunderson, 1999).

5.2. Management

The regulative function of management in the old urban water paradigm has a clear bias toward simplification and homogenization. For example, water is classified in binary: it is either fit or unfit for consumption, it is a resource or a waste (Bindra et al., 2003; Partzsch, 2009; Pinkham, 1999). Potable water, the highest water quality, is employed for all purposes (*one-size-fits-all*), including drinking, irrigation and toilet flushing. After its use, it is considered a waste and conveyed to the sewer, regardless of its quality or new characteristics. Compare this with the new urban water paradigm, which considers that all water is valuable, even when it is of low quality (Listowski et al., 2009; Wilcox et al., 2016). Here, water of the highest quality is used for human consumption, while lower quality water can be used for different non-consumptive purposes by matching it with their intended use (*fit-for-purpose*) (Gikas & Tchobanoglous, 2007; Lee & Tan, 2016; Makropoulos et al., 2018).

Another example is stormwater, which, in the old paradigm, is always considered a nuisance that must invariably be drained away by underground pipes—the only and standard structural solution. Conversely, in the new paradigm stormwater is seen as a valuable resource that contributes to improving urban amenity (Martin et al., 2007). Stormwater management tools are also manifold (Chocat et al., 2001; Hale, 2016; Marsalek & Schreier, 2009; Meinzen-Dick, 2007), including structural and technical solutions (like various green infrastructures or more traditional infrastructures), economic incentives and disincentives (like markets, insurances, innovative rate structures, taxes, rebates, or subsidies), or sociopolitical instruments (like benchmarking systems, educational and behavioral programs, water rights, changes in routines, or even organizational reforms).

The few, simple problems and solutions considered by the old paradigm are managed as if they were independent from other subsystems, while the new paradigm pays attention to the linkages between multiple problems and multiple solutions. For instance, while drinking water provision, sanitation, and urban drainage have traditionally been managed as independent subsystems in the water sector (Anderson & Iyaduri, 2003; Mukheibir et al., 2014), the new paradigm focuses on the coordinated management of these water services (Mitchell, 2006; Ross, 2018; Vairavamoorthy et al., 2015). Stormwater can be a source of drinking water (Campisano et al., 2017; Sharma et al., 2013; Sofoulis, 2015), leaky sewers can pose a pollution risk for water supply, and wastewater can be used to refill groundwater aquifers (Binz et al., 2016; Evans & Evans, 2012).

The fragmentation (methodological) principle of the old paradigm is also reflected operationally in other ways. For example, water management is usually approached through the individual lens offered by a particular discipline or functional silo (like hydraulics, hydrology, biology or economics) (Brown, 2005; Brown & Farrelly, 2009; Garrote, 2017; Saraswat et al., 2017). These predict the behavior of a few environmental variables and describe clear, linear paths of action to accomplish their objectives independently of other goals or constraints (Deng et al., 2013; Loorbach, 2014). Another example of fragmentation in management is the separation of UWSs from natural processes (its context), which must be understood, predicted, and tightly controlled. In practice, this means that natural processes not directly benefitting human interest must be disrupted or constrained, and substituted by rationally designed linear processes that permanently fulfill a fixed set of human needs (Bagheri & Hjorth, 2007; Brandes et al., 2005). For example, the natural water cycle is disrupted and converted to an artificial one-path-flow process (Daigger, 2009): raw water (the input) is abstracted from far locations where it is easily accessible (the "external" context), transported through long distances (often by interbasin transfers) (Domènech et al., 2013; Gleick, 2000; Saurí & del Moral, 2001), treated and distributed, consumed and polluted (the output), and discarded as waste back to nature (the "external" context) (Bindra et al., 2003; Everard & McInnes, 2013; Rojas et al., 2015; Takala, 2017). This linear flow creates an illusion of resource abundance (Stuart, 2007), in which higher demand urges increased raw water abstraction from the environment (Gleick, 2003; Saurí & del Moral, 2001).

In contrast, the integration (methodological) principle of the new paradigm invites a style of management that is context-sensitive and mimics or allies synergistically with natural processes of cyclical character (Byrnes, 2013; Zandaryaa & Tejada-Guibert, 2009), rather than a parallel linear process of environmental control (Hering et al., 2013; Niemczynowicz, 1999). For instance, it mimics circular natural processes where water—together with its associated energy and nutrients—is recovered or recycled to remain part of the system, as there is not an "outside" where it can be infinitely extracted or disposed (Anderson, 2003; Gondhalekar & Ramsauer, 2017; Haase, 2015; Hoff, 2011; Pennisi, 2012; WWAP, 2017). Following this logic, the concepts of *waste* (for wastewater) or *nuisance* (for stormwater) become obsolete because any element is eventually recycled and should be rather seen as a potential resource

(Arden et al., 2019; Chocat et al., 2001; Grant et al., 2012; Ma et al., 2015; Novotny et al., 2010), use of which saves costs, prevents pollution and avoids the depletion of their sources (Chanan et al., 2013; Hemmes et al., 2011; van der Hoek et al., 2016; Wallace et al., 2017).

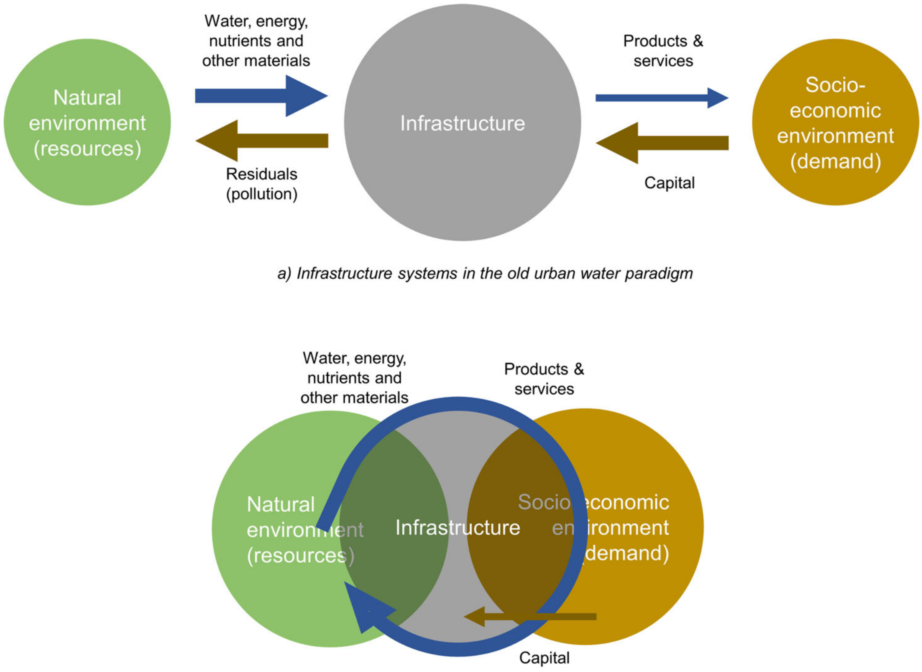
This type of management approaches also aligns with so-called nature-based ("green") solutions for water (WWAP, 2018), which utilize ecosystems that can potentially deliver any water-related service that humans might require (MEA, 2005; Schuch et al., 2017)—for example, flood risk management and natural drainage (Pappalardo et al., 2017), water purification (Everard & McInnes, 2013), urban cooling (Norton et al., 2015; Schmidt, 2010), support of biodiversity (Filazzola et al., 2019), or even enhancement of physical and psychological health (Tzoulas et al., 2007)—often with lower costs and higher efficiencies than those of the "grey" solutions. Context-sensitive management requires then a local management style that benefits from intimate knowledge of local characteristics (like ecology, geomorphology, infrastructures, urban form, demographics, rules, standards and cultural characteristics) seen from an integrated perspective (Ferguson, Brown, & Deletic, 2013; Marlow et al., 2013; Mitchell, 2006; Rygaard et al., 2014).

Finally, management planning clearly reflects an epistemological transformation in shifting from the old to the new urban water paradigm. The old paradigm relies on isolated mathematical models that are regarded as prediction machines to find optimal solutions that unambiguously point toward the "right" course of action. Contrast this with the management planning of the new paradigm, which aims at producing pragmatic illustrations of reality (Bach et al., 2014; Deletic et al., 2018; Schmitt & Huber, 2006) and does not dismiss predictive models but combines them in a process of iterative and situated bricolage. It integrates their results (Brouwer & van Ek, 2004; Croke et al., 2007; Zhou, 2014) to produce hypothetical scenarios and narratives that improve the understanding of complex UWSs and support—but never settle—the decision making process (Bagheri & Hjorth, 2007; Rygaard et al., 2014; Westley et al., 2011).

5.3. Infrastructures

Infrastructures are the physical manifestation of urban water paradigms, reflecting their understanding of reality, relationship with nature and most important needs and values.

Considering that the old paradigm aims at physically forcing natural processes into certain linear processes to fulfill human needs, it is not surprising that in this frame, UWSs becomes a mechanical and technocratic issue (Capodaglio et al., 2016; de Bruijn, 2004; Wolsink, 2010), with focus



a) Infrastructure systems in the old urban water paradigm

b) Infrastructure systems in the new urban water paradigm

Figure 5. (a) In the old paradigm, hard infrastructures are the dominant factor, the socioeconomic environment is perceived as simple, and the natural environment is reduced to a container for the resources that need controlling and as a sink for residuals. Linear production (one-way flow) results in the depletion of resources and the proportional creation of pollution. The products and services produced are few and the capital costs high. Adapted from Sahely et al. (2005). (b) In the new paradigm, infrastructures merge with the complex socioeconomic and natural environment, supporting circular flows of resources without residuals, and generating multiple products and services. The capital compromised is low as the system is more efficient and self-sustaining.

on the construction of robust infrastructures (normally built from concrete, plastic or metal materials) (Pinkham, 1999).

Conversely, in the new paradigm, the concept of infrastructure acquires a wider meaning, merging technical and environmental elements that build synergies with its social and environmental context (Fletcher et al., 2015; Goonetilleke et al., 2005; Masi et al., 2017; Novotny, 2009). For example, infrastructures benefit from ecosystem services (Carlson et al., 2015; Fletcher et al., 2015) and strengthen popular values in our contemporary society like livability and sustainability, shaping and supporting certain social identities and social behaviors (A. Amin, 2014; Bell, 2015) (Figure 5).

The old paradigm's infrastructures are large and robust constructions with definite and long lifespans (Sharma et al., 2010). They respond to the need to withstand and dominate nature, create optimal economies of scale, and support professional management by technical experts. They exhibit a limited repertoire of standard, independent, and discrete elements that perform only one function—generally of hydraulic character—and are linearly connected in centralized schemes (Ashley et al., 2015; Everard & McInnes, 2013; Partzsch, 2009; Pinkham, 1999). Typical examples are large water treatment plants, urban channels, or dams.

On the other hand, infrastructures of the new urban water paradigm are distributed (Fane, 2005): varied, decentralized, and integrated (Chanan et al., 2009; Chocat et al., 2007; Makropoulos & Butler, 2010; Mitchell, 2006; Sharma et al., 2010). They form richly connected networks that continuously exchange resources and information (Yuan et al., 2019). These networks encompass locally adapted and semi-autonomous elements (Novotny, 2009; Rygaard et al., 2011) that have multiple forms and sizes (Fryd et al., 2010; Novotny et al., 2010; Saurí & Palau-Rof, 2017), are made with natural and artificial materials, perform and contribute to circular processes, and continuously fulfill multiple functions at multiple scales (Fletcher et al., 2015; Gill et al., 2007; Novotny et al., 2010; Pappalardo et al., 2017; Semadeni-Davies et al., 2008; Sharma et al., 2013). They conform organic systems in constant adaptation that can be regarded as ephemeral infrastructures with indefinite lifespans (Capodaglio et al., 2016; Chanan et al., 2010; Vieira et al., 2014).

While the infrastructure of the old paradigm is comprised of independent elements, invisible to the public (often buried, like pipes, or in distant locations, like treatment plants), and detached from its context, the new paradigm exhibits ubiquitous networks firmly embedded in the city fabric and environment, intentionally visible and representing a vital part of the public life (Bernhardt et al., 2006; Brandes & Brooks, 2007; Gleick, 2003; Pahl-Wostl et al., 2011; Saurí & del Moral, 2001). For example, stormwater managed at a catchment scale with a distributed network of green roofs, swales, or urban creeks that support biodiversity, provide an esthetic value, trap pollutants, act as temperature regulators for the city, or diminish the peak runoff under a storm (Andoh et al., 2008; Berardi et al., 2014; Schuch et al., 2017; Wong & Brown, 2009).

Advocates of distributed infrastructures argue that they are more resilient than centralized systems for several reasons. First, because they make possible a locally tailored management approach with solutions that efficiently adapt to multiple contexts, purposes or types of resources (Chanan et al., 2013; Díaz et al., 2016; Keath & Brown, 2009; Leigh & Lee, 2019; Wolsink, 2006). Second, because their modular nature gives them a sensitivity and scalability that efficiently allow the system to adapt to changing circumstances (Amin & Han, 2007; Gikas & Tchobanoglous, 2007; Marlow et al., 2013). Third, because they work on the basis of redundancy and complementarity of other solutions at multiple scales, minimizing risk and providing alternative functions (Andoh et al., 2008; Gonzales & Ajami, 2017; Marlow et al., 2013; Werbeloff & Brown, 2011; Wong & Brown, 2009).

A disadvantage of distributed systems is that they develop slowly (Baran, 1964). Therefore, in practice, distributed water infrastructures are most often implemented as a supplement to existing centralized systems, which serve as the backbone that connects all nodes (Ferguson, Brown, Frantzeskaki, et al., 2013; Lee et al., 2013; Porse, 2013). However, it is expected that, with time, the local stations turn to be the main centers of production and consumption. This is the case of urban drainage systems, for example, where local infrastructures for stormwater management are built today to support the traditional centralized system, but eventually will manage most of the stormwater locally in a distributed fashion (Saurí & Palau-Rof, 2017).

6. Discussion and conclusion

In this paper, we articulate a coherent and holistic set of ideas, values and assumptions that are shaping urban water innovations that aim to respond adaptively to the non-stationary nature, uncertainty and emergent needs of our current society. This description is intended to equip water scholars, policymakers, and practitioners with a frame of reference to understand and embrace the benefits of novel styles of governance (like participative approaches), management (like circular use of resources) and infrastructures (like solutions based on ecosystem services). The articulation of the new paradigm that we provide may also offer concrete guidance for action and decision making to these actors when defining the types of governance arrangements, management systems, and infrastructures needed to improve the sustainability of UWSs in complex contexts; namely, promoting variety, integration, distribution and constant learning. For instance, scholars could be encouraged to consider problems from the lens of different disciplines; policymakers could open decision processes for participation by multiple stakeholders and the creation of intersectoral policies; and practitioners could continuously experiment with distributed infrastructures that simultaneously deliver multiple functions, complement each other, and build synergies with nature.

In developing the urban water paradigm framework, we have aimed to be coherent but not necessarily comprehensive, as the depth of the paradigm cannot be fully encapsulated in a single article. The characterization of the new paradigm that we present in this article should be regarded then as a heuristic tool or an ideal type (Doty & Glick, 1994); an idealized model that does not exist exactly as described anywere in the world, but that serves as a benchmark to recognize and create innovative approaches that help to address emerging challenges in the water sector. Therefore, future studies that analyze the degree of implementation of these new styles of governance, management, and infrastructure could provide valuable insight into the key enablers and strategies that have helped enact the key methodological principles in practice.

Finally, we reflect on the parallel shifts being experienced in other parts of society as part of a broader paradigm change. According to recent literature, most sectors—like energy (Geels et al., 2017; Verbong & Geels, 2010), health (Johansen & van den Bosch, 2017), and education (Yarime et al., 2012)—are experiencing similar transitions toward more sustainable modes of production and consumption (Loorbach et al., 2017). These transitions reflect the same underlying changes in society that drive the transformation of the water sector, and share multiple aspects with the new urban water paradigm—like promotion of diversity, learning approaches, distributed structures, or greater citizen participation. The construction of a more solid definition of the new urban water paradigm would benefit from a deeper analysis of the roots of this broader societal change through further research.

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Articulating the new urban water paradigm

Supplemental online material

Summary table

The table below synthesizes the key points for the old and new urban water paradigms for each of the seven themes of the paradigm framework.

Old urban water paradigm	New urban water paradigm
Ontology (nature and structure of reality)	
• The world is simple, ordered and regular • Tendency to homeostasis • Homogeneity of components and their individual characteristics • Dominance of linear relationship among elements • Subsystems can be isolated from context • Metaphor of clockwork machine	• The world is complex, chaotic and dynamic • Constant evolution • Heterogeneity of components, their rich interactions and holistic, emergent behavior • Dominance of non-linear relationship among elements • Subsystems are embedded and dependent on context • Metaphor of living organism
Epistemology (nature and methods of knowledge)	
• Knowledge is objective and universal • There is a single truth • Uncertainty comes from external randomness • Science-based and predictive • Fragmentation (reductionism) • Observation, quantification, probability and reason	• Knowledge is subjective and contextual • There are multiple truths (that do not necessarily contravene an underlying truth) • Uncertainty comes from the observer's lack of knowledge (epistemic uncertainty) • Narrative-based and embracing of uncertainty • Union (holism, integration) • Experimentation and pragmatism
Axiology (needs and values)	
• Anthropocentric • Fundamental values of subsistence and growth • Urban water needs are few, universal, permanent, well-defined, independent and non-contested • A competitive, instrumental relationship with nature: it is seen as lacking intrinsic value, and as a source of resources or constraining frame • Invokes ambivalent feelings of dominance and fear • Achieving sustainability is about optimal and fixed single-criterion goals	• Ecocentric • Fundamental values of ecological sustainability, livability, equity, and justice • Urban water needs are multiple, contextual, evolving, ill-defined, interdependent, and disputed • A collaborative, integrative relationship with nature: humans and nature are the same system • Invokes feelings of humbleness, hope, and enthusiasm • Achieving sustainability is an open-ended process to reach a moving target
Methodology (underlying principles of practice)	
• Tame problems (simple, structured, static, independent of other problems, and with a permanent solution) • Objective is a definitive optimal system state • Strategy is to predict and control to withstand and suppress change • Methodological principle 1: Stationarity • Methodological principle 2: Homogeneity • Methodological principle 3: Fragmentation • Methodological principle 3: Centralization	• Wicked problems (complex, unstructured, dynamic, interdependent with other problems, without a permanent solution) • Objective is to continuously adjust the system trajectory • Strategy is to create evolutionary resilience • Methodological principle 1: Learning • Methodological principle 2: Variety • Methodological principle 3: Integration • Methodological principle 3: Distribution

Governance (social structures and processes)	
• Principle 1 Stationarity: Goals, policies, rules and roles are rigid, settled and uncontested, objective and rationally designed for optimization • Principle 2 Homogeneity: Goals, policies, rules and roles are few, well-defined, and universal. Governance process are exclusively of the government. • Principle 3 Fragmentation: Goals, policies, rules and roles are independent and isolated • Principle 4 Centralization: Hierarchical governance (top-down). Collaboration is enforced through coercion	• Principle 1 Learning: Goals, policies, rules and roles are flexible, in permanent transformation and usually contested, emergent from experimentation and negotiation • Principle 2 Variety: Goals, policies, rules and roles are multiple, ill-defined, and context-dependent. • Principle 3 Integration: Goals, policies, rules and roles are interdependent and overlapping. • Principle 4 Distribution: Governance processes are open for wide participation and democracy (bottom-up). Collaboration is encouraged through trust, enthusiasm and synergies
Management (planning, design and delivery approaches)	
• Objective is to control the physical resource • Principle 1 Stationarity: Aims at perfect control; to keep the system into a range of optimality in perpetuity. Use of prediction models. Solutions are optimal and permanent • Principle 2 Homogeneity: Few types of problems approached with few types of standard solutions and sources of information to meet few needs (one-size-fits-all) • Principle 3 Fragmentation: UWSs have independent elements isolated from its context (standard management). They disrupt and constrain natural circular processes that are substituted by linear processes that extract resources and produce waste. Management solutions are independent. • Principle 4 Centralization: Management activities are concentrated in space and time	• Objective is to fulfil water-related needs • Principle 1 Learning: Aims at adjusting to the context to deliver a timely set of needs. Learns from experimentation, use of hypothetical scenarios, and constant readjustments. Solutions are pragmatic, suboptimal and temporary • Principle 2 Variety: Many types of problems approached with many types of solutions and sources of information to meet many needs (fit-for-purpose) • Principle 3 Integration: UWSs have interdependent elements embedded in its context (local management). They ally with and mimic natural circular processes where there is no waste (recycling). Management solutions are interdependent • Principle 4 Distribution. Management activities are distributed in space and time
Infrastructures (biophysical structures and mechanisms)	
• Mechanical, made of technical elements that are invisible (buried or in distant locations, ignored by the public) • Principle 1 Stationarity: Robust, permanent, nonreactive • Principle 2 Homogeneity: Few standard designs, large and robust, monofunctional (generally hydraulic) at single scale • Principle 3 Fragmentation: Discrete elements that are linearly connected, infrastructures mediate the dissociated socio-economic and natural environment • Principle 4 Centralization: Dependent on a central node with standard and isolated peripheral nodes.	• Organic, made of technical and natural elements that are visible (part of public life) • Principle 1 Learning: Flexible, ephemeral, adaptive • Principle 2 Variety: Multiple designs of all sizes and forms, multifunctional at multiple scales • Principle 3 Integration: Network of elements that support circular management, infrastructures merge with the socio-economic and natural environment • Principle 4 Distribution: Network of integrated elements that are locally tailored, scalable, and redundant.

Articulating the new urban water paradigm

Supplemental online material
Literature review of descriptions of the new urban water paradigm.
Selection of sources and coding

Our description of the new urban water paradigm was developed through an extensive literature review. The selection of sources started with a query in the scientific database *Scopus* to find articles containing the text strings "water paradigm" or "water management paradigm" in their title, abstract, or key words; this yielded 34 sources—*Scopus* was used as it allows the search to be limited to abstract, keywords and title, and certain thematic areas to be selected. The query included peer-reviewed articles in English language, published before 2018, and in the subject areas of environmental science, agricultural and biological sciences, social sciences, earth and planetary sciences, and engineering. Three of the 34 articles were not related to our topic and therefore discarded. In the remaining 31 articles—which were classified as *relevant sources*—the term *paradigm* was used with multiple different meanings, usually referring to particular aspects of water management—for example, the use of integrated management frameworks (Kibaroglu & Sumer, 2007; Mills-Novoa & Hermoza, 2017), or the revegetation of cities (Kohutiar & Kravcik, 2010; Lodemann et al., 2010; Schmidt, 2010)

The 31 *relevant sources* were further classified into two groups as *key sources* or *specific sources* (Figure 1). The *key sources* (initially three of 31) provided a broader description of the new urban water paradigm (Gleick, 2000; Gonzales & Ajami, 2017; Pahl-Wostl et al., 2011), and the *specific sources* (28 of 31) focused on specific aspects of the paradigm.

Further, two types of searches were made. One consisted of inspecting all *relevant sources* in search for references that could also be considered *relevant sources*—and later classified as *key* or *specific sources*. The other type of search aimed at identifying later publications that cited our *key sources* and could be potentially added to the group of *relevant sources*. This "cited by" search was carried out in the scientific database *Google Scholar* rather than *Scopus* as it provides a more comprehensive set of results (Harzing & Alakangas, 2016).

Both types of searches were iterated until the searches reached saturation point (Guest et al., 2006), resulting in 148 *key sources* and more than 200 *specific sources*.

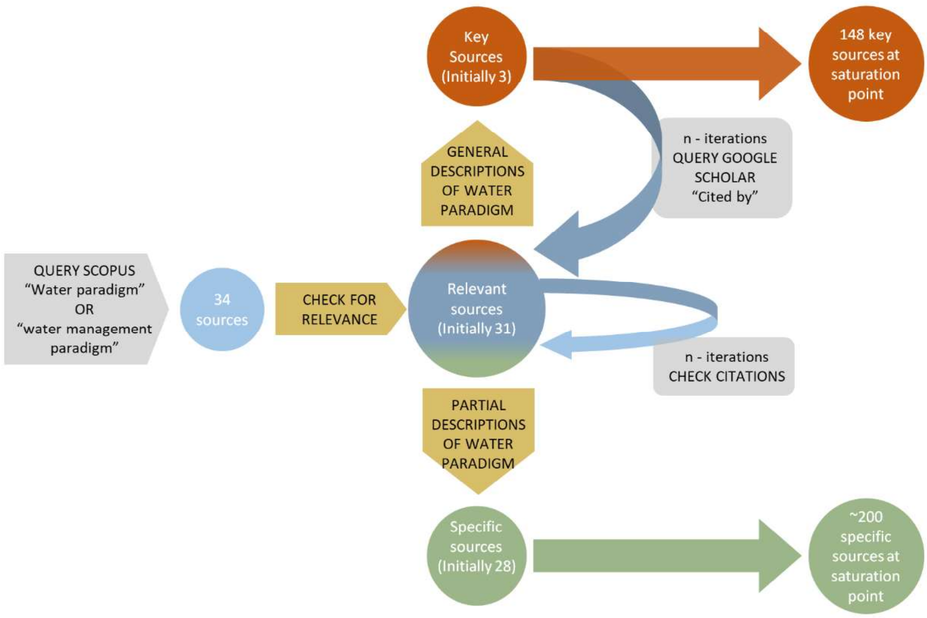

Figure 1. Protocol for source selection in the literature review.

While the literature review was protocol-driven, it was not *systematic* as it did not fulfill requirements like full repeatability and it was influenced by the researchers' judgement (Haddaway & Bilotta, 2016). However, strategies like citation tracking are powerful tools to identify key sources, and a non-systematic literature review may be well-suited to issues of complex and heterogeneous evidence (Greenhalgh & Peacock, 2005) (such as our task of defining a paradigm).

The process of analysis and synthesis of the selected articles ran parallel to the iterative selection of new sources, which lasted from January 2018 until March 2019. The advantage of this strategy was that the core tenets of the new paradigm became gradually clear through the analysis, facilitating the recognition of more *key references* in the reviewed articles.

Key sources and specific sources were analyzed, attributing relevant sections of text with codes that emerged as the analysis developed (for example, *multiplicity*, *small infrastructures*, or *circular processes*).

Synthesis within the framework

In a second phase of analysis, these codes were organized and synthesized into seven themes that inductively emerged through analytical iterations, defining a framework for describing paradigms and contrasting old with new.

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Paper 2

The path to the new urban water paradigm – from modernity to metamodernism

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The Path to the New Urban Water Paradigm – From Modernity to Metamodernism

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ABSTRACT: The urban water sector in industrialised countries is transitioning towards a new paradigm, usually characterised by participatory approaches to governance, integrated modes of management, circular economies, partnership with nature, and green and distributed infrastructure. However, change in a prevailing paradigm is rarely seen in connection with shifts in the underlying societal beliefs, assumptions, and values of an epoch (that is, the cultural framework). In this paper, I review the alterations that the dominant urban water paradigm has experienced over the past 150 years, analysing them in relation to evolving cultural frameworks. I start with industrial modernity (mid-19th century to mid-20th century), followed by descriptions of postmodernism and reflexive modernisation (late 20th century). Finally, I provide an innovative analysis of the new urban water paradigm as a reflection of metamodernism, an emergent cultural framework recently described in the field of cultural studies. I show that metamodernism can be used to explain coherently how urban water systems in industrialised countries are responding to growing complexity and uncertainty. They do so by oscillating between principles associated with modernity, such as order, technological optimism and utopian development, and postmodern principles, such as eclecticism, partial views of reality and participation.

KEYWORDS: Urban water management, new paradigm, modernity, reflexive modernisation, metamodernism

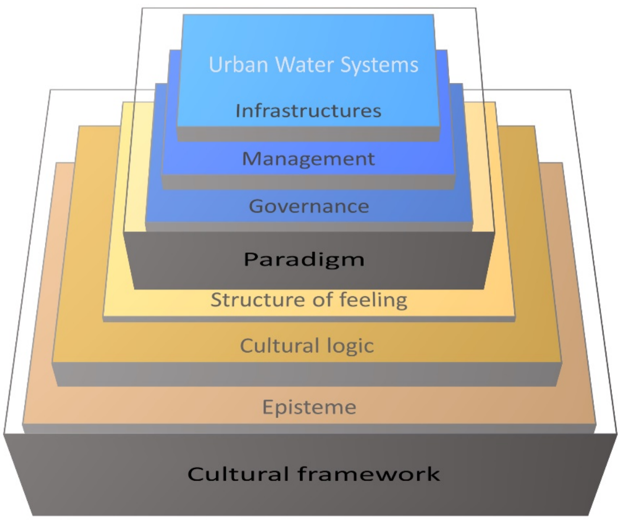
INTRODUCTION

Urban water services, such as drinking water provision, wastewater collection, and urban drainage, are possible thanks to urban water systems (UWSs). These encompass interdependent technologies and physical infrastructures (e.g. computer models, water reservoirs, pipe networks, water treatment plants), social structures (e.g. values, beliefs, guidelines, rules, laws, contracts) and biophysical elements and processes (e.g. soil, vegetation, microorganisms, topography, precipitation, evaporation). The conventional configuration of UWSs in industrialised countries has remained strikingly unchanged for more than 150 years (Novotny et al., 2010), and it has been undeniably effective in providing basic water services. However, the sustainability of UWSs is currently being questioned, owing to their lack of capacity to cope with emerging developments, such as climate change, new social needs, degradation of infrastructure, and the appearance of new pollutants. This mismatch has led to the recent emergence (mostly in academic arenas) of an alternative blueprint for UWS configurations, a 'UWS paradigm', that better tackles contemporary water challenges (Pahl-Wostl et al., 2011; Franco-Torres et al., 2020a).

Throughout history, cities in industrialised countries have continually adapted to new water-related needs and problems by following similar trajectories (Staddon et al., 2017). Such adaptation is usually interpreted from the lens of 'technological determinism', which refers to a predefined and inevitable improvement path of knowledge accumulation and technical development that eventually succeeds in satisfying all water needs (e.g. Brown et al., 2009; Novotny et al., 2010). However, this explanation fails to consider that UWSs are culturally embedded. It can be argued that UWSs are sectoral expressions of an 'underlying culture' that they help to create, a wide cultural background characterised by the fundamental, deeply entrenched, inconspicuous and taken-for-granted values, feelings, ideas, and assumptions of an epoch (Gandy, 1997; Swyngedouw, 1999). The transformation of paradigms is then a co-evolution of previously existing UWS configurations and a continuously changing underlying culture. This co-evolution influences certain technologies and infrastructures, social institutions, and types of relationship with the natural environment.

The underlying culture is also reflected in artistic expression, mass media, political discourses, science and technology, modes of social organisation, and paradigms of all societal services (Connor, 2004). It has been given many names, including *episteme* (Foucault, 1970), *cultural logic* (Jameson, 1991), and *structure of feeling* (Williams, 1961, 1977) (Figure 1). These three concepts do not refer to the same realities, and are categorically different, but are intimately related through being *cultural frameworks* with different degrees of maturity, pervasiveness, or reification. *Episteme*, the most rigid and structured of these concepts, refers to a distinct system of values, ideas, and assumptions that are deeply entrenched in a society and its artefacts. *Cultural logic* and *structure of feeling* refer instead to an emerging attitude, a zeitgeist or generalised sentiment towards reality that is not yet fully articulated and seldom reified.

Figure 1. Cultural frameworks (epistemes, cultural logics, structures of feeling) support and determine the configuration of the urban water system (UWS) paradigm, which can be analysed in terms of characteristic modes of governance, styles of management, and infrastructures.



Since the mid-19th century, traditional configurations of UWSs in industrialised countries – the traditional UWS paradigm – have resonated with an episteme called *modernity* (Swyngedouw, 1999; Kaika, 2005) that is still shaping modes of water governance, management, and infrastructures (Edwards, 2003). However, since the late 1960s, this episteme has been challenged in the urban water sector by a cultural logic called *postmodernism,* which acknowledges the existence of multiple – and potentially contrasting – values and needs (Allan, 2004), and suggests alternative arrangements to modern UWSs. To my knowledge, the contemporary structure of feeling currently shaping the emergent urban water paradigm, and challenging the still dominant modern paradigm, has not been described previously.

Following work by Allan (2004), I examine how the urban water paradigm was shaped by the modernity episteme during the 19th and 20th centuries, and how postmodernism and later variations of modernity brought new values and needs to the urban water sector in the late 20th century. I then apply *metamodernism* (Vermeulen and van den Akker, 2010), a structure of feeling that emerged at the turn of the millennium, to theorise about the evolution of contemporary UWSs.

This analysis does not aim to demonstrate a complete paradigm transformation in the urban water sector in the past 150 years or so, as the sector is still patently dominated by the episteme of modernity (Edwards, 2003), like contemporary life in general (Giddens, 1990). Citing Huyssen (1984: 8), the objective is rather to describe "(…) a noticeable shift in sensibility, practices and discourse formations which distinguishes a post-modern set of assumptions, experiences and propositions from that of a preceding period". The analysis centres on an emergent structure of feeling, metamodernism, which is tightly connected to the slow crystallisation of a new UWS paradigm. The latter can serve as a blueprint for alternative approaches to conventional – or 'modern' – urban water governance, management and infrastructures.

The analysis considers three periods with their characteristic, though not necessarily dominant, cultural frameworks: (i) (industrial) modernity (mid-19th to mid-20th century), characterised by the episteme of modernity; (ii) late modernity (mid- to late 20th century), demarcated by the emergence of, firstly, postmodernism as a juxtaposed cultural framework to modernity and, secondly, the process of *reflexive modernisation*; and (iii) the early 21st century, typified by the arrival of metamodernism. Following a description of each period and its characteristic cultural framework, I show how the cultural frameworks can be used as lenses through which we can understand the evolution of the urban water paradigm over the past 150 years.

MODERNITY

The basic social arrangements and physical structures that have made possible the UWSs enjoyed today in Western societies began to take shape in the mid-19th century, coinciding with *industrial modernity* (period) (Beck, 1992; Allan, 2004) and *high modernism* (cultural framework) (Scott, 1998). For simplicity, industrial modernity and high modernism are referred to hereafter as 'modernity'.

Modernity has its philosophical roots in the Enlightenment, an intellectual movement of Western culture that peaked during the 18th century. The Enlightenment often caricatured its predecessor, the Middle Ages, as a period of mysticism, superstition, ignorance and dogmatic faith in God, in order to present itself as the opposite (Kant, 1784). Before the Enlightenment, nature was considered wild and feminine, a source of life, wonder and danger, expressing the almightiness of God and punishing mankind's disobedience with droughts or floods (Merchant, 2003; Kaika, 2005).

According to Lechner (1989), the end of the pre-modern period meant a transition from a divinely imposed order to a humanly produced one, which would allow the establishment of a definitive system of social organisation and the domination of nature in order to fulfil all human needs. Natural scientists of modernity saw the world as an orderly place governed by the simple laws of physics described by Newton; a clockwork that spoke the language of mathematics and that could be understood, predicted, and controlled by a human (certainly masculine) operator.

These principles of the Enlightenment, and other closely associated ideas (reason, objective truth, mastery of nature, freedom, capitalism), became anchored in Western societies during the 18th century, and they were seen as contributing to the exponential scientific and technological improvements of the Industrial Revolution. These advances dramatically improved the quality of life in industrialised countries (Pinker, 2018), endowing modernity with assertive, optimistic and enthusiastic features; there was a belief that humanity was on the road to continuous and linear progress, leading to a utopian future of order, welfare, and happiness.

Modernity imbued all aspects of society (politics, economics, technology, urbanism, arts) with simplicity, order, certainty, control, and efficiency. Modern society, satirised by Huxley (1932) in the dystopian futuristic novel *Brave New World*, became obsessed with rational homogenisation, technological knowledge, straight lines, pure forms, standardisation, and isolated categories (Scott, 1998). All these tropes are easily recognisable in the early 20th century architecture of American and many European metropolises, with skyscrapers and social housing, respectively, being the most iconic examples. For all their differences, both are functional, simple and minimalistic constructions that lack superficial ornamentation, and project an image of order and stability with defined volumes and straight lines (Marmot, 1981).

On the political plane, modernity was urged to respond to the social unrest deriving from impoverished living conditions in industrialised cities, and it did so through strong centralised governments that sought to impose a rigid social order (Foucault, 1975) and to promote growth. These governments controlled regulation, the allocation of resources, and the development of large welfare programmes. The latter required high public spending, and involved clear roles, mechanical functions, and neat hierarchical organisations based on rational planning (Osborne, 2010).

Despite its ubiquity in industrialised countries, modernity had many critics. These included in particular the followers of *romanticism*, a European cultural movement that peaked in the 19th century. Romanticism served as a counterpoint to the Enlightenment, Industrial Revolution and modernity. For example, it worshipped emotion instead of reason; sublimity, beauty and freedom of nature instead of the power of technology and the machine to dominate nature; and feelings of nostalgia, devotion to the past and tradition instead of enthusiasm and hope for the future and progress. Linked to the romanticism movement, in German-speaking countries the so-called 'life reform' (*Lebensreform*) movement appeared at the end of the 19th century. It encouraged humans to live in harmony with nature, instead of subduing and exploiting it, and promoted the creation of alternative communities that prioritised values such as sharing, equity, and justice (Repussard, 2017).

PRE-MODERN UWS

The modern UWS paradigm that has been hegemonic in industrialised countries from the mid-19th century is perhaps better understood when compared with the urban water sector in pre-modern times. In the early 19th century, the crowded, polluted cities of the Industrial Revolution grew chaotically, without clear planning for essential services and with weak or non-existent institutional arrangements. People managed their water needs individually, with ad hoc solutions consisting of local, small-scale, decentralised infrastructures that were labour-intensive (Wolfe, 1999). City dwellers had modest water consumption (15-20 litres per day), and drinking water was obtained from local wells, rainwater tanks, or nearby ponds and streams (Tarr et al., 1984). Wastewater from washing, cooking and cleaning was disposed of in cesspools, in backyards or directly on the streets, while human waste was deposited in privy vaults or cesspools located in cellars or nearby houses. These were periodically emptied, and their contents were dumped in watercourses close by or used as fertiliser on farms. Improvised drainage gutters and pipes provided a degree of protection against stormwater, and were occasionally used to convey waste (ibid).

THE MODERN UWS PARADIGM

The migration of workers from the countryside to the city accelerated in the mid-19th century, but contrary to urban expansion in the early 19th century, it was now 'ordered' according to the central tenets of modernity. Regarding potable water, modern cities engaged in the 'hydraulic mission' (Swyngedouw, 1999). A continuous water supply into cities became a prerequisite for public health, food security, economic growth, and general progress. New infrastructures – such as dams, pumps, and piping systems – were installed to meet exponential growth in water demand due to industrial production, firefighting and household consumption, particularly following the introduction of the flush toilet. This supply-driven logic, a vicious circle of continuous socioeconomic and industrial growth, led to incessant expansion in water demand, water supply, resource exploitation and water infrastructures (cf. Moss, 2016). At the core of this logic was an assumption that water was an unlimited resource to be subjected to human reason, technology, and needs (Gleick, 2000; Allan, 2004).

The exponential increase in water use in modern cities rendered the pre-modern wastewater management approach unsustainable (Tarr et al., 1984). Existing privy vaults and cesspools became overloaded, flowing directly to nearby streams or filling alleys with faecal waste until rainfall washed it away. Paved surfaces were extended across the modern city to improve transport and to facilitate construction, but they also had the unintended effects of impeding rainfall infiltration and altering natural drainage patterns. In wet weather, water flowed quickly over the smooth urban surfaces, generating higher volumes of runoff and causing floods and material damage. Lack of infiltration also impeded groundwater recharge. As a consequence, baseflow to nearby streams decreased and in dry weather, these streams mainly carried waste from households and industries, producing odours and sanitary concerns.

Open management of wastewater and industrial pollution made industrialised cities barely habitable. Cross-contamination of drinking water sources with wastewater caused multiple outbreaks of diseases, such as typhoid fever or cholera, that killed tens of thousands in Europe and America (Harremoës, 1999; Wolfe, 1999). In the early to mid-19th century, the dominant theory was that these diseases were transmitted through *miasma* – the pestilent odours that emanated from waste or dead bodies, and that inundated the industrialised city. In the 1840s-1850s, this belief triggered the *sanitary movement*, a new urge for 'cleanliness' that linked waste with sickness (Tarr et al., 1984). The sanitary movement – and the modern ideals of order, progress, national development, welfare, public health, and willingness for large public spending – resulted in the construction of vast sewerage network systems that conveyed waste to streams, rivers, or the sea. This technology quickly spread through Europe and North America in the late 19th century, propelled by the assumption that cities with sewerage networks would grow faster by attracting industry, workers, and investment (ibid).

During this period, hydraulic engineers gained a leading role in the design and management of water infrastructure. These professionals exalted the scientific interpretation of reality, observation, objectivity and reason, and believed that problems should be approached mathematically, quantitatively and through application of predictive models that could provide absolute certainty (Forman 2007). Imbued with this discourse, engineers and urban planners advocated the development of grandiose, rational, and city-wide plans for progress. Ironically, hydraulics and hydrology were (and mostly still are) eminently experimental disciplines that resort to trial-and-error methods, heuristics, and approximation. These methods certainly provided solutions with pragmatic validity, but were distant from the ideals of scientific inquiry (ibid).

The colossal sewage networks of the early 20th century deviated greatly from the perfect or definitive design solutions they were intended to represent. It became common practice to divert polluted streams into large, buried pipes in order to hide waste and odours from people, and to level the terrain to facilitate construction and mobility, effectively creating combined sewers that conveyed wastewater and stormwater. During the modern period, most urban streams disappeared (Novotny et al., 2010) and waste accumulated in harbours, which became endemic points of pollution, or in rivers, contaminating the water source for other cities downstream and triggering new disease outbreaks (Tarr et al., 1984; Okun, 2000). In addition, the urge for 'cleanliness' introduced new technologies, cultural norms and habits that greatly increased use of water for personal hygiene and comfort, with e.g. bathing and laundering displaying a five-fold increase compared with the pre-modern period (Shove, 2003).

As local sources of drinking water became exhausted or polluted, new infrastructures were created to transport pristine water from more distant sources, and many coastal cities built submerged sewage outlets to convey the waste farther away. However, in the early 20th century people were still dying of typhoid fever and cholera, leading to a focus not only on the quantity, but also the quality, of drinking water (Barraqué, 2003). The first drinking water treatments and new public health policies appeared; large-scale chlorination was applied (markedly increasing life expectancy in the Western world); and the first wastewater treatment plants were constructed, notably improving the status of harbours, rivers, and lakes. Once again, however, solutions were never optimal and, up to the mid-20th century, modern cities experienced new types of waterborne diseases and eutrophication of lakes and rivers (Okun, 1996; Wolfe, 1999).

The above illustrates how modern solutions that aimed at controlling nature were not as ordered, rational, and effective as intended. This was partly because increasingly complex systems were not amenable to rigid control strategies and were in practice managed by trial-and-error (Petroski, 1996), and partly because modern solutions had unintended and increasingly complex consequences. However, the dominant narrative persisted, demanding redoubled efforts to reach higher levels of understanding, prediction, and control. This self-reinforcing pattern, whereby modernity is both the problem and also the solution, not only persists but is gaining ground (Beck et al., 2003).

The UWSs of modernity were primarily regarded as a mechanical issue, reflecting the mechanical nature of reality and confidence in technical progress. Large dams, interbasin canals, major reservoirs, and centralised pipe networks and treatment plants formed ubiquitous and homogeneous infrastructural grids, a megamachine supplying a one-size-fits-all product (one quality of drinking water, one type of wastewater) in a linear metabolism of extraction, consumption, and disposal (Kaika, 2005; Sofoulis, 2005; Tarr et al., 1984). This large-scale, capital-intensive and centralised infrastructure was both the driver and the consequence of modernity (Tarr and Dupuy, 1988; Scott, 1998). It reinforced modern values and beliefs, such as the need for centralisation in government and management; bureaucracy; professionalisation; scientific knowledge; and rational planning to control nature and society.

Regarding governance and financing, in the late 19th century Western cities experimented with different forms of public and private UWSs. Initially, water supply was offered by private companies, and they limited their activities to rich neighbourhoods since poor households lacked the capacity to pay for this service (Bakker, 2010). However, the generalisation of water supply services soon started to be seen as a prerequisite for urban progress and, following a public service ethos, municipalities were increasingly expected to ensure service provision (Kellett, 1978; Tarr et al., 1984; Bakker, 2010). Economic elites had an interest in promoting city-wide water supply services ensured by the public sector rather than private companies; such services would benefit industrial development, firefighting, and the health of workers. These elites made use of their political influence and urged municipalities to take responsibility for this expensive infrastructural development in a monopolistic fashion (Hassan, 1985). The shift from private to public service provision was also compatible with the underlying assumption of modernity, inherited from the Enlightenment, that water services were the right of all citizens. In addition, the government had democratic authority, regulatory power, and the capacity to gather the necessary knowledge, thereby contributing to the professionalisation of the service (Bakker, 2010). Finally, the assumption that needs and solutions were well-defined and undisputed (Pahl-Wostl et al., 2011) facilitated the concentration of decision making in a central agent that could rationally determine the 'right' actions to achieve the 'right' outcomes.

Turton and Meissner (2002) claim that modern governance of UWSs is based on a *Hobbesian hydrosocial contract*, as it shares many similarities with the broader social contract proposed by Thomas Hobbes in his book *Leviathan* (1651). According to the Hobbes doctrine, citizens renounce their rights and empower a central authority – a strong, bureaucratic, paternalistic government – to impose morality, truth and social order, and through strict regulation, to enforce the social collaboration that large collective projects require. In the modern water paradigm "the individual looked to government to provide for their basic needs such as water supply and sanitation, so the government responded accordingly" (Turton and Ohlsson, 1999: 19). A good example of this is the British Public Health Act of 1848, which made the government responsible for safeguarding the health of the general population, underpinning in practice the universal and public provision of water supply and sewerage services (Okun, 1996).

Citizens were seen by the government and the water managers simply as unknowledgeable and passive clients, dissociated from the technological system and the natural context. The buried water infrastructures became inconspicuous ('out of sight, out of mind'), while the urban population was under the illusion that water supply was endless. Waste disappeared automatically ('flush and forget'); cities appeared to be fully protected against floods; seasonal fluctuations were rendered imperceptible; and there seemed to be an absence of environmental externalities (Sofoulis, 2005; Stuart, 2007).

LATE MODERNITY

In Western societies, the intense development of science and technology during the early 20th century helped to reduce natural risks, fuelled the economy and improved living standards through cheaper food, energy, building materials and water, in the process reinforcing the narratives of the power of reason, progress and mastery of nature. Despite these undeniable advances, in the 1960s there was a sense of the end of an era and the emergence of a new cultural framework, a structure of feeling that is often referred to as postmodernism (Lyotard, 1984; Jameson, 1991).

In the 1970s-1980s, postmodernism gained much popularity in academic circles, despite its multiple (and often contradictory and confusing) uses in fields like philosophy, history, arts, linguistics and sociology. However, all these uses represented a rejection of modernity's accounts of progress, and a more or less radical rupture with the core postulates of modernity and the Enlightenment (Best and Kellner, 1997).

Today, postmodernism is commonly associated with the growing social dissatisfaction and feeling of social decay in the 1960s-1970s, exemplified by social movements against war; racial, class, and gender discrimination; the AIDS pandemic; the oil crisis; the economic recession; the environmental crisis and nuclear power; or simply general disenchantment with capitalism, consumerism and the traditional institutions of modernity (Jameson, 1991). Postmodernism emerged from the major problems generated by modernity; a prevailing feeling of uncertainty, risk, absence of opportunities, injustice and, generally, decline instead of progress. Multiple social critics, feminists in particular (e.g. Haraway, 1988, 1991; Harding, 1992), claimed that the core of the problem was that, behind the ideas of emancipation, freedom, welfare and progress of modernity, there lay an elitist, white, masculine, controlling, oppressing and techno-optimist (meta)narrative of rationality, order and simplicity that endowed a ruling class with the power to impose *its* reductionist and 'objective' vision of reality through rules, norms and certain types of knowledge. Inevitably, this biased narrative – legitimated by rationality, science, and technology – produced interest-based accounts of reality, and negative consequences for the environment and marginalised groups.

While modernity promoted simple, standard and context-independent, all-embracing narratives that (arguably) formed one single objective truth, postmodernity promoted complex, contextual and situated knowledge ('small narratives'; Lyotard, 1984) that allowed for the existence of multiple perspectives about that truth. Postmodernism thus embraced a plethora of practices, logics, values, and needs that were all equally valid. It advocated heterogeneity, deconstruction and diversity, as well as the inclusion of scientific and non-scientific views, and it was preoccupied with issues of values, power and justice. In practice, postmodernism was associated with a tendency for flexibility in industrial production, labour, and the economy; such flexibility was required for innovation and adaptation to a context in constant change, and superseded the rigidity and standardisation of modernity (Harvey, 1989).

Despite the popularity of postmodernism in the late 20th century, there is a lack of consensus among scholars about when modernity ended. Indeed, scholars do not agree on whether it has ended at all. According to some sociologists, like Ulrich Beck, Anthony Giddens and Scott Lash (1994), we still live in (late) modernity, as today's Western society is still deeply embedded in this episteme's characteristic 'ordering status'. We roughly preserve the modern systems of production and consumption, the same ways to acquire knowledge (deduction, logic, and the scientific method), and similar systems to organise time, space and social life, while other radically different systems are very difficult to imagine. Giddens (1990) argues that postmodernity does not exist in practice (i.e. there is not a *postmodern* UWS) and that it is at most an 'aesthetic reflection' of the generalised sense of disorientation resulting from the unintended consequences of modernity. In other words, for Giddens, postmodernism is just a structure of feeling and not an episteme, because modernity still is *the* episteme.

This idea of continuity with modernity has been described by Beck et al. (2003) as 'reflexive modernisation'. This refers to the radicalisation and saturation of modernity in the late 20th century, an 'abuse' of the postulates of modernity (too much order, reason, science, technology, progress, capitalism, and production) that attempts to restrict the emerging complexity using the same tools that provoked it in the first place. The multiplication of technologies, advances in communication, emergence of the information society, and growth in international trade during modernity and late modernity have made the world an increasingly diverse, interconnected, and dynamic place (Giddens, 1990; Castells, 2010), where small changes often have disproportionate and unintended effects. These include 'manufactured risks' (Giddens, 1999) and new social, environmental, and technological problems (Beck, 1992) – such as global wars, environmental catastrophes, depletion of resources, financial crises, and social and economic inequalities – that form the basis of the postmodern feeling.

The rigid and isolated categories of modernity, which sought to impose simplicity and order, eventually became ineffective for classifying, understanding and controlling the growing diversity of actors, values, needs, relationships, forms of knowledge, and technologies (Bauman, 2000). While the postmodern framework regards this growing diversity as a manifestation of the deconstruction of a modern world on the verge of collapse, the reflexive modernisation framework sees fragmentation and micro-categorisation as an unavoidable solution to the continued production of (increasingly unmanageable) order and the elimination of (ever-growing) uncertainty.

Reflexive modernisation is underpinned by a philosophy that shows some similarities to, yet differs in some critical points from, the fundamentals of modernity. In terms of similarities, both reflexive modernisation and modernity exhibit a realist ontology, which is the belief that the external world exists independently of the human mind; they assume an objective truth 'out there' that can be judged from a detached and disinterested perspective. In modernity, this realism was 'naïve', and assumed that the use of observation and reason would be sufficient to obtain a complete understanding of the (simple) world exactly 'as is'. Reflexive modernisation applies a critical realist philosophy (Bhaskar, 1975), which assumes that perfect knowledge of reality is unattainable because the complexity of this external reality is such that our empirical methods, cultural predisposition, and limited cognitive capacities will never allow us to completely understand it (Simon, 1997). We are condemned to create biased versions of reality.

Unlike naïve realism, critical realism – and by extension, reflexive modernisation – does not maintain a defence of observation and rationality. It argues that accumulation of knowledge and triangulation among multiple commensurable methods and perspectives (from multiple sciences or points of view) can bring us very close to a perfect understanding without ever attaining it (Bhaskar, 1975). One of the obsessions of reflexive modernisation is to minimise uncertainty, to cancel the risks that modernity itself has created, and to bring back certainty and control. As in modernism, reflexive modernisation is optimistic for a future of prosperity and continued growth despite limits, risks and uncertainties, but at the same time, there is a rising fear of losing the advances made so far (Giddens and Pierson, 1998).

THE LATE-MODERN UWS PARADIGM

Despite the unprecedented technological development that industrialised countries experienced during the 20th century, their urban water infrastructures did not undergo substantial intrinsic transformations over this period. Nonetheless, the reliability of these infrastructures did improve and they showed solid expansion, markedly contributing to increased life expectancy and improved life quality. This expansion also gave rise to a diversity of interdependent actors, forms of knowledge, values, needs, services, and 'unintended consequences'. Complexity in the water sector manifested itself as new types of problems that were "multi-dimensional, multi-sectoral, and multi-regional and filled with multi-interests, multi-agendas, and multi-causes" (Biswas, 2004: 249).

The most notorious 'unintended consequences' of modernity are: the emergence of new contaminants; the depletion of water sources; environmental degradation; urban floods; the decay of infrastructures; and financial problems caused by diminishing willingness for public spending (Barraqué, 2003; Bakker, 2010; Novotny et al., 2010). These challenges did not emerge simultaneously in all Western countries; different regions were affected by their particular problems and pressures, but in general Western countries responded to the growing complexity, and the 'side-effects' of modernity, with a discursive shift from certainty to uncertainty (Allan, 2005), and an ambivalent attitude, combining modern enthusiasm and postmodern pessimism. There is, thus, an insistence (especially among practitioners) on the most fundamental modern principles – i.e. more reason and technology to control nature, top-down approaches to water management based on 'expert knowledge', and the goal of a fixed utopian future of total satisfaction of needs. There is also a feeling (especially in academic circles) of pessimism, crisis, and vulnerability that reflects the postmodern ethos. This latter view rejects standardised and all-embracing rational narratives of science, technology and universal knowledge, and instead embraces uncertainty, variety, individuality, and bottom-up approaches to water management (Franco-Torres et al., 2020a).

In the context of this ambivalence, the 'progress' of modernity mutated into the concept of '(substantive) sustainability' (Truffer et al., 2010). This refers to an optimal state of the system where consumption of natural resources equals their rate of recovery in a mechanical fashion, with flows and stocks. It still follows the linear path of modernity towards a utopian future, though this time one of optimal efficiency, null uncertainty, and elimination of risks (Hollick, 1993). It also introduced a multi-perspective vision of reality where various environmental, economic, and social needs are fulfilled once-and-for-all. This meant, for instance, that hydraulic engineering lost its absolute hegemony in favour of other disciplines, such as chemistry, biology, planning, ecology, and economics.

In the late 20th century, two of these disciplines, namely ecology and economics, gained a prominent role in the pursuit of sustainability. During the 1970s, ecological values were incorporated into water policy in most Western countries (Hajer, 1995; Gleick, 2000). From the postmodern perspective, these values represent biocentrism or ecocentrism, and challenge the modern perception of water and nature as expendable commodities (Brand and Thomas, 2013). From the perspective of reflexive modernisation, the introduction of ecological values indicates a shift from concerns about how nature can harm humans to concerns about how humans have harmed nature, triggering negative consequences for human welfare (Giddens, 2013) and motivating an even higher level of intervention and dominance of nature.

After the fever of maximisation and eternal growth that characterised the modern period, the economic sustainability of late modernity became tightly linked to the idea of efficiency, whereby limited resources should be optimised and allocated for maximal utility, in order to decouple (sustainable) growth from resources exploitation and environmental degradation (OECD, 2001). During the 1980s, the neoliberal economic logic became increasingly popular in most Western countries, where the modern style of rational resources allocation was blamed for most problems affecting the water sector, i.e. water scarcity, pollution, lack of maintenance and, generally, low performance and low economic efficiency (Bakker, 2010). The underlying argument was that the expanding complexity of UWSs exceeded the capacity of governments for rational prediction and top-down control, while the free market (the 'invisible hand' of capitalism) was a better regulatory mechanism that could automatically create an optimal order through pricing of water and water services (Chandler, 2014). Countries such as the USA, Australia and the UK adopted a New Public Management approach that resulted in widespread privatisation of water services. Other Western countries did not opt for full privatisation but this style of management nonetheless influenced their public utilities, which followed the management model of private companies by introducing full cost pricing, property rights, economic incentives, cost-benefit analysis, decentralisation of management into independent specialist agencies (in silos), and outsourcing contracts (Bakker, 2010).

Although neoliberalism in the water sector created efficiency gains and greater interest in service provision among competing private actors, in extreme cases it also resulted in fragmentation of governance, management and infrastructure systems, eroding the (modern, Hobbesian) hydrosocial contract. It splintered the modern political consensus on large-scale strategic planning, and deprived central government of its monopolistic capacity to organise, finance and provide extended services to the entire population, eventually resulting in higher levels of inequality, service inefficiencies, conflicts of interests, and risks (Graham and Marvin, 2001).

The neoliberal approach was also disputed by other elements of the sustainability concept that exhibited a postmodern disposition. Civil groups and environmental organisations plainly rejected the neoliberal mantra of water as an economic good (cf. UN, 1992a; The World Bank, 1993), claiming instead that water is a human right and heritage with natural and cultural value. They argued that social sustainability should consider the ethical dimension, particularly the unequal distribution of social and environmental costs of new water infrastructures, which was not encompassed by market approaches or cost-benefit analysis. This postmodern approach also rejected the standard, rationally designed technical solutions, suggesting instead contextualised solutions, qualitative methods, participatory policy making, and iterative practice (Jeffrey and Gearey, 2006; Postel and Richter, 2012). For example, these principles are central to Agenda 21 (UN, 1992b), the Dublin principles for sustainable development (UN, 1992a) and the IWRM framework (GWP, 2000a).

The postmodern disposition also provoked scepticism about many other modern management tools, such as comprehensive city-wide plans, which were deemed unrealistic, inflexible, and unable to meet local and varied problems and needs (Graham and Marvin, 2001). In the previous period of modernity, there was a focus on capital-intensive solutions to support fulfilment of rational, grandiose and standardised plans, while in late modernity the focus is on knowledge-intensive solutions to tackle unique local problems through multi-perspective approaches. This is done in practice through a plethora of quantitative tools for analysis and optimisation (Hellström et al., 2000), e.g. modelling tools, cost-benefit analysis, risk assessment and key performance indicators.

Regarding infrastructure, the sustainability problems of the late 20th century are addressed in late modernity by improving efficiency, adapting to stricter environmental requirements and reducing natural risks through more advanced technological fixes, without abandoning the essence of modern infrastructures. Late-modern infrastructures are still rigid, and do not respond adaptively to complexity and uncertainty, as the latter are 'cancelled' by the certainty provided by the increasingly enhanced management tools. For example, the (economic) risk of urban floods is minimised by construction of optimised underground stormwater reservoirs; end-of-pipe pollution is brought within regulatory thresholds with the help of enhanced methods of phosphorus removal in wastewater plants; and energy-intensive desalinisation plants are constructed to compensate for exhaustion of conventional water sources and to cancel out climate variability. These solutions remain on the technological path of modernity in that they retain the large, linear (one-through-flows) centralised constructions, and the technocratic, standardised, deterministic design that seeks to tame nature.

However, in late modernity a postmodern opposition to this type of infrastructure has emerged in the form of 'nonconventional' alternatives (e.g. EPA, 1977). They often suggest small, decentralised, flexible, eclectic and context-dependent constructions that allegedly improve efficiency by providing locally adapted solutions that are more democratic, have lower environmental effects, and do not involve sunk costs (Pinkham, 1999; Hiessl et al., 2001; Gleick, 2003). However, their implementation has so far been merely anecdotal, in small and dispersed demonstration projects, that rarely achieve their intended results (Larsen et al., 2016).

METAMODERNISM

While modernity as a social and cultural phenomenon is relatively well-defined and undisputed by most social theorists, postmodernism as a cultural logic still prompts widespread debates about its degree of influence, and its very existence. It is even more difficult to find any general agreement about our contemporary cultural framework. Nonetheless, in recent decades, fundamental changes in discourses about governance, management and production of infrastructures – a UWSs paradigm – have emerged from the academic arena; these changes can be traced back to an emergent structure of feeling in the 21st century.

Vermeulen and van den Akker (2010) found that the attitudes, feelings and perspectives in the arts and Western culture, which emerged at the turn of the 21st century, did not fit the mainstream characterisations of modernity or postmodernism. They suggested instead that these patterns corresponded to a new, distinct and coherent structure of feeling born in response to several tumultuous events in the new millennium, e.g. terrorism on a global scale (such as 9/11), climate change, and the 2008 financial crisis. The accelerated complexity of late modernity is yet again being manifested as unpredictable phenomena – the side-effects of reflexive modernisation. These are 'wicked' problems (Rittel and Webber, 1973), ones that are unstructured, interdependent and pervasive, in permanent transformation, and without an optimal or definitive solution. Such disruptive and unexpected events herald a new generalised perception of a dynamic and complex reality governed by "unknown unknowns" (Steffen et al., 2011), where: "[N]ot only are risks not known with certainty, but the degree of uncertainty is itself highly uncertain" (Dietz et al., 2002: 332). It could be said that the principles of modernity are once again being radicalised in such an extreme way that what they are, and what they claim to be, result in two completely opposing themes. There is renewed enthusiasm for reason, order, progress, capitalism, science and technology, but the factual reality shows such an extreme degree of fracture, complexity and dynamism that it forces any ordering system to shatter into minuscule pieces (Bauman, 2000), resulting in a society that in practice better fits a postmodernist description than modernity patterns. This ongoing fragmentation and volatility, which in the late 20th century was seen in postmodern terms as a sign of uncertainty, risk, unrest, chaos, and decline, is accepted as a natural part of life and a motivating challenge in the 21th century.

In accordance with this narrative, Vermeulen and van den Akker (2010) discerned a new structure of feeling that aims to make the growing diversity, complexity and uncertainty more manageable, while providing a new sense of ontological purpose. They called this cultural framework *metamodernism* and described it as a permanent oscillation between modernity and postmodernity. This does not mean that its predecessors have ceased to exist, but rather that metamodernism embodies continuous negotiation between these two 'contradictory' positions.

The term metamodernism has been used previously with a different meaning. In the meaning adopted by Vermeulen and van den Akkern (2010), 'meta' denotes 'temporally beyond' the modern period and at the same time 'in-between' modernity and postmodernism perspectives. Similar descriptions of this metamodern structure of feeling were suggested in the late 20th century by other scholars, but they identified metamodernism as a late transformation of either modernity or postmodernism, as in the case of 'moderate postmodernism' (Best and Kellner, 1997), 'liquid modernity' (Bauman, 2000) and, most recently, the very last transformation of reflexive modernisation (Beck et al., 2003). The present analysis is based on the metamodernism described by Vermeulen and van den Akker (2010), as their idea of oscillating or interspersing between modernity and postmodernity seems to offer a coherent cultural framework for shaping the emerging paradigm of UWSs.

Metamodernism recognises that the growing complexity and uncertainty evidenced in late modernity cannot be reduced to a simpler system, objectively understood or universally optimised through reason. At the same time, it also does not suggest abandoning reason entirely. For example, in an attempt to describe a milder, more reconstructive postmodernism (here understood as metamodernism), Umberto Eco argued that the goal is "not to kill reason, but to render bad reason harmless, and to dissociate the notion of reason from that of [absolute] truth" (Eco, 1986: 126). This can be seen as an invitation to use reason pragmatically (Pierce, 2011), with the aim of revealing 'useful truths' that provisionally 'work' under certain circumstances and for certain intentions. This practical truth is the only reality that humans experience or will ever get to know.

The pragmatism of metamodernism is reflected in a new mutation of the idea of progress, modernity’s core value. From being a straight line leading to (substantive) sustainability in late modernity, i.e. the point in optimal human development where all present and future needs are fulfilled, it transforms into a continuous pursuit of an elusive future, a moving target or utopia that is constantly reconfigured and ambiguously defined. In this new '(procedural) sustainability' (Kemp and Martens, 2007; Truffer et al., 2010), the process is what really matters. Practical knowledge and satisfactory solutions are discovered by means of relentless experimentation (learning by doing), while recognising that attempts to reach truth or optimality are futile.

This new interpretation supersedes the reductionist approach to sustainability, seen during late modernity, which involved optimisation of the economy, society and the environment as isolated categories, and instead focuses on hedonism and better quality of life. This might seem an anthropocentric (that is to say, modern) view of reality, but it reveals a postmodernist and complex understanding of reality where quality of life unavoidably involves the welfare of the environment in which humans are embedded. For example, a Danish environmental entrepreneur described work towards a green energy utopia in the following way: "We have small objectives all the time. We erect 11 windmills, and we have a party and drink beer. Then we build a system for district heating, and we drink beer. The small objectives are what is interesting. Not the final goal, because we will never be done" (Lie, 2019: 27).

Procedural sustainability moves back and forth between postmodernism and modernity. Postmodernism provides an awareness of ubiquitous complexity, uncertainty, ephemerality, fragmentation and dispersion. It is deconstructive, experiments continuously and triggers a certain amount of chaos, from which variety can flourish in the form of multiple categories of governance, management and infrastructures. Modernity then intervenes to 'prevent' excessive fragmentation and dispersal, integrate the diversity, and provide certainty, order, continuity, and purpose. Modernity brings the elusive future, the utopia, which gives meaning, a sense of direction, a source of enthusiasm, and becomes a social binding agent, combined with an assertive and constructive attitude (Constanza, 2000). This type of sustainability is a metamodern reconstruction that continuously creates new ad hoc objectives and categories to integrate the chaotic multiplicity. It relentlessly observes, evaluates, negotiates, experiments, transforms, and learns to fulfil an "impossible possibility". Metamodernism "seeks forever for a truth that it never expects to find" (Vermeulen and van den Akker, 2010).

THE METAMODERN UWS PARADIGM

In recent decades, there has been a progressive reduction in natural risks, improvements in efficiency, and minimisation of the most obvious environmental impacts. However, in the same way that modernity did not manage to maintain perpetual linear progress, late modernity has never achieved the perfect sustainable equilibrium. Development has triggered even more uncertainty, "manufactured risks" (Giddens, 1999), institutional fragmentation and social confrontation (Milly et al., 2008; Brown and Farrelly, 2009; Barnett and O’Neill, 2010). New problems faced by the urban water sector in the 21st century include constrained sources of financing; conflicts among regulatory policies; climate change;

depletion of water sources; a growing number of water pollutants; and the security threats of digitisation and bioterrorism.

The polarisation and ambiguity between modern and postmodern attitudes that emerged in late modernity seem to have expanded recently. The urban water literature shows dissatisfaction with the status quo, and a clear tendency to dismiss modern UWSs as completely outdated, unsustainable, and unable to meet the water challenges of the new century (e.g. Andoh et al., 2008; Hering et al., 2013; Marlow et al., 2013). However, practitioners (mostly engineers) display strong confidence in modern pathways and future technical advancements to solve all water problems. This can be read as an entrenched confrontation between, on the one hand, postmodern gloom, uncertainty, change and a commitment to diversity and flexibility, and on the other hand, modern progress, enthusiasm, technological solutionism and a commitment to robustness, continuity and optimization. Some observers (e.g. Sedlack, 2014) claim that the present situation is untenable, and that the water sector faces a bifurcation and must choose between modern continuity and postmodern disruption.

Metamodernism offers a new approach to this dilemma: oscillation between the modern and the postmodern. The contemporary (metamodern) discourse of the water sector seems not to reject modern social structures in their totality, but rather promotes their coexistence and hybridisation with postmodern alternatives (Ferguson et al., 2013; Coutard and Rutherford, 2015). Moreover, the sector seems to perform adequately in its fusion of pessimism and enthusiasm.

The metamodern approach, which with careful analysis can be observed at multiple levels of UWSs, acknowledges the uniqueness and heterogeneity of individual elements of the system, and also their integrated behaviour. In modernity, the focus was on *bundling* water services, actors, processes, rules, knowledge, technologies, infrastructures and flows according to predefined standard categories. In late modernity the categories multiplied, became fragmented, confronted, and *unbundled*. Now, metamodernism promotes *rebundling* those (still independent and continuously multiplying) pieces in a myriad of possible customisations that pragmatically fit particular circumstances and needs (Figure 2).

In late modernity, the number of public, private and civil actors multiplied in the urban water sector, and they became increasingly interdependent. This trend continues today, and it is increasingly difficult to achieve satisfactory institutional arrangements. Therefore, in the 21st century, it is often claimed that water crises are mainly crises of governance (GWP, 2000b; UN, 2003; OECD, 2011), requiring collaboration-intensive approaches that fairly integrate multiple needs, values, beliefs, and worldviews. Metamodern governance of UWSs responds to institutional fragmentation by 'oscillating' between the vertical/hierarchical structures of modernity, the horizontal/network/participatory modes of postmodernism, and the market logic of late modernity, producing a new kind of UWS governance called 'hybrid governance' (van de Meene et al., 2011; Gupta et al., 2015) or 'polycentric governance' (Ostrom, 2010). In this approach to governance, formal government does not disappear, and the sector does not become completely privatized. Rather, the public/private dichotomy becomes less distinct, new actors continuously emerge, and formal government acquires a softer role, becoming a supervisor, an umpire, a gatekeeper, a motivator, or an integrator of a diversified network of rebundled actors. This institutional arrangement corresponds to what Turton and Meissner call the *Lockean hydrosocial contract*, where "the rulers are merely the trustees of people" (2002: 18) and participatory processes guarantee the fulfilment of their water rights.

Figure 2. In modernity, UWSs were bundled as a homogeneous and simple whole. In late modernity, UWSs were unbundled into a variety of elements that competed with the traditional modern configuration (large grey circle). Metamodernism suggests rebundling elements in an infinite number of possible cluster configurations that hybridise with more traditional modern structures to adapt to particular circumstances and needs.

Formal government acquires an integrative role that involves facilitating the creation of collaborative governance networks, offering direction, and providing certainty by establishing clear institutional frameworks. For example, re-municipalisation of water utilities is a growing trend (Kishimoto et al., 2015; McDonald, 2018), underpinned by the integrative need, and emerging aspirations to social and environmental justice that compete with, and often eclipse, the logic of cost minimisation (Lobina, 2017). The 'ambiguous utopias' of metamodernism – such as sustainability, resilience, liveability, climate change adaptation or even the water-sensitive city – are further rebundling elements of these governance networks; they provide compatible meanings to complex problems and coalesce disparate interests, needs and values (Franco-Torres et al., 2020b).

Metamodern management acknowledges a diversity of needs and the complexity, fluidity, and uncertainty of reality. It seeks no 'silver bullets' or 'right' answers, but searches instead for pragmatic solutions that are 'satisfactory' under particular circumstances. These solutions are identified by experimentation and learning in partnership with multiple social actors and with nature, and involve rebundling multiple sources of knowledge (multiple disciplines, mixed inquiry methods, objective and subjective knowledge, explicit and tacit knowledge), disparate models and decision-making tools (predictive and non-predictive, quantitative and qualitative), and multiple partial measures (technical, educational, economic, regulatory).

Metamodernism does not completely reject the approaches to risk and optimisation held in late modernity, such as probabilistic risk evaluations, life-cycle analysis or cost-benefit analysis, but neither does it view them as 'machines of truth'. Instead, metamodernism considers these approaches as admittedly unreal constructions treated 'as-if they were real', "a kind of informed naivety, a pragmatic idealism" (Vermeulen and van den Akker, 2010). They function as heuristic devices that help shape the problem at hand, design testable solutions, take decisions, and keep moving forward towards utopia.

Metamodern management exhibits a clear systemic approach that builds internal coherence and reinforces the integration of UWSs with their contexts. It combines the isolated solutions of modernity that extract resources and deliver waste in a linear fashion with local solutions of circular management, and promotes the reuse, recycling and upcycling of water, nutrients and energy. Metamodern management emphasises integration with the natural environment through the concept of 'ecosystem services' (MEA, 2005), and the adaptation of UWSs to natural processes and structures, instead of aiming to control them. Integration with the social environment is emphasised through maintaining awareness of water in all urban development, e.g. stormwater is viewed as a valuable social, economic and ecological element, instead of a waste that must be quickly removed.

The metamodern infrastructure of UWSs is also a rebundling of standard modern infrastructures and an emerging multiplicity of alternatives. There are still large, conventional centralised infrastructures like pipe networks, reservoirs and large water treatment plants, which provide robustness, stability, and integration. These are combined with diverse, small, decentralised infrastructures like rainwater tanks, infiltrating pavements and user-scale water treatment plants, which provide local adaptability and multiple functions (e.g. Saurí and Palau-Rof, 2017; Tortajada et al., 2017). Thus hard/grey elements made from metal and concrete co-exist with natural/green elements that benefit from ecosystem services, like swales, infiltration ponds, or small streams.

While the individual infrastructure elements are locally adapted, they are also part of a large ecosystem of infrastructures that effectively covers the cityscape and works as a living system. This ecosystem involves a wide range of modular solutions at multiple scales that complement and compete with each other; provide several levels of redundancy and risk protection; are flexible enough to adapt to continuous change; and contribute simultaneously to a range of tailored functions. These modular solutions manage water volumes, purify water, regulate the urban temperature, support biodiversity, and create attractive recreational spaces. They form a network that is in constant transformation and renewal, simultaneously ephemeral and eternal, relentlessly experimenting and adapting to new technologies, new needs, and continual disruptions. It is a living part of the city, unashamedly visible (Mitchell and Campbell, 2004), that blends synergistically with its environment and all other societal services.

DISCUSSION AND CONCLUSIONS

This paper describes how the UWS paradigm, with their characteristic modes of governance, styles of management and types of infrastructures, has evolved in Western countries during the past two centuries, and how it reflects different underlying cultural frameworks that exist on a wider social scale.

Identification of UWS paradigms and societal cultural frameworks is not new; e.g. Swyngedouw (1999), Kaika (2005) and Bakker (2010) have formulated clear descriptions of modern water management, while Allan (2004) has described an evolution through modernity and late modernity. However, the influence of postmodernism in the UWS paradigm is only barely mentioned by authors like Sofoulis (2015), Pahl-Wostl et al. (2011) and Jeffrey and Gearey (2006), and to my knowledge, no previous study has provided a sound and coherent description of the emerging water paradigm as a reflection of a nascent cultural framework – here called metamodernism. I argue that this new cultural framework is represented in UWSs as an oscillation between the order, simplicity and assertiveness of modernity and the eclecticism, fluidity and uncertainty of postmodernism, opening the way for innovative methodological approaches like pragmatism, flexibility, distribution, and experimentation in UWSs.

Viewing transformations in UWSs (or any other societal service) in relation to underlying beliefs, values and feelings of an epoch can serve as a critical reflection exercise for practitioners. Understanding how framings of reality determine choices and, ultimately, have tangible effects on reality – or recognising that an inherited paradigm may be outdated for dealing with emerging challenges – should be part of basic professional education, prompting practitioners to select alternative solutions.

At a systemic level, cultivating awareness of cultural frameworks and paradigms may serve to accelerate transition towards more sustainable futures, and also create the very possibility of their existence, because 'natural/unconscious' evolution into a future better than modernity should not be taken for granted. UWSs are still eminently modern and metamodernism is merely a structure of feeling; that is, an emerging way of thinking that continuously challenges the hegemonic late-modern paradigm, becoming visible in ambivalent or contradictory infrastructures and social structures that often drift away from sustainability, instead of approaching it. Therefore, instead of following a predetermined path to sustainability, there is a risk of the late-modern UWS paradigm becoming entrenched or deteriorating.

Even if the metamodern UWS presented in this paper eventually becomes the dominant paradigm, it is important to avoid the trap of regarding metamodernism as the ultimate cultural framework bringing us to the climax of social development (cf. Fukuyama, 1992). Metamodernism is inherently maladapted to future development because it is emerging as a response to past and present problems, not future problems. Yet another cultural framework will emerge to correct the problems that metamodernism will generate, but that we are currently unable to perceive. Meanwhile, it may be useful to continue exploring and understanding metamodernism in order to orient its capabilities towards more sustainable UWSs.

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Paper 3

Understanding the governance of urban water services from an institutional logics perspective

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Understanding the governance of urban water services from an institutional logics perspective

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ABSTRACT

In recent decades, the urban water sector has experienced accelerating social complexity that derives from conflicting goals and beliefs, making the sustainability of the sector primarily a governance issue. However, existing governance models do not reflect the new reality. There is thus an urgent need to develop an urban water governance model reflecting this increasing complexity, to support sustainable governance. We integrate concepts from sociology, institutional theory and sustainability transitions to build a governance framework that includes interactions of social structures, and practices, shaped by different institutional logics and categorised at strategic, tactic, operational, and reflexive level.

1. Introduction

Water is a core element of numerous societal functions in urban areas, including the delivery of potable water to households, business and industries, disposal of waste, drainage and flood control, fire-fighting, provision of aesthetic values in public spaces and support of biodiversity, among many others. All these functions are referred to as *urban water services*. Until the late 20th century, these services were few, well-defined and uncontested (Pahl-Wostl et al., 2011), effectively supporting rapid economic growth and rising living standards in industrialised countries. Centralised and hierarchically organised government was then strictly occupied in applying well-known solutions of a technical character.

However, in recent decades we have witnessed ever-growing complexity and uncertainty (Bauman, 2000; Beck et al., 2003; Castells, 2010), simultaneously triggering the emergence of new technical, social, economic and environmental issues. Examples are climate change adaptation, maintenance of infrastructures under financial constraints, prevention of terrorism and cyber-security risks, provision of aesthetic and recreational services, and maintenance of healthy ecosystems. These needs are diverse and ill-defined, and often reflect conflicting values, beliefs and goals that cannot be solved with simplistic technical solutions or effectively handled by a centralised government in isolation. There is a growing recognition that sustainable development of the water sector is generally not hindered by technical problems, lack of knowledge or resources, or financial constraints, but rather by socio-institutional challenges (Brown and Farrelly, 2009; van Dijk, 2012). The Global Water Partnership (GWP, 2000, p. 17) has even claimed that "the water crisis is mainly a crisis of governance", a proposition often echoed by leading international organisations such as the UN, World Bank and OECD.

Research on governance has burgeoned in diverse fields (including political science, public administration, economics, sociology and geography) during the past two decades, addressing disparate issues and producing diverging interpretations (Kemp et al., 2005; Kersbergen and van Waarden, 2004; Kjær, 2004; Kooiman, 2003). This growing interest is also reflected on the study of urban water governance (Neto, 2016), which usually departs from a definition of governance constrained to a "narrowly technical decision-making process" (Bakker, 2010, p. 8). The different conceptualisations of governance suggested for the urban water sector are often supplemented by non-coherent incorporation of ideas from these diverse fields, preventing understanding and consensus about what *governance of urban water services* actually means (van de Meene et al., 2011; van Dijk, 2012) and impeding successful design of sustainable governance configurations (OECD, 2011).

To address this issue, Loorbach (2010) devised a governance framework for managing sustainability transitions in Western democracies. This framework is simultaneously analytic and normative.

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Analytically, it recognises four different governance levels (strategic, tactical, operational and reflexive), advancing understanding of what governance actually means in different applied sectors, including the urban water sector. Normatively, the model may be used in the purposeful design of governance instruments that orient transitions in certain societal sectors (such as transportation, health or water) toward more sustainable configurations. Although Loorbach's research is widely cited for its innovative approach to "transition management" (orienting transitions), it does not take into consideration the cultural-cognitive background of governance, i.e., the co-existence of diverse structures of values, beliefs and goals (here referred to as institutional logics) that are a source of conflicts and fragmentation, often hampering sustainable development (Besharov and Smith, 2014). Loorbach (2010, p. 169) notes that "governance activities" are dependent on the "'culture' of the societal (sub-)system", but offers no further explanation. We include this cultural-cognitive aspect in the governance framework with the support of the institutional logics perspective (Friedland and Alford, 1991; Thornton et al., 2012). Instead of creating a framework that merely facilitates "implementation of governance strategies and instruments" (as Loorbach aimed to do), we argue that awareness of an underlying cultural-cognitive structure (institutional logics), and how it shapes the instruments and operational outcomes of governance, has significant potential to orient and accelerate sustainability transitions (Abson et al., 2017; Meadows, 1999).

Specific objectives of this study were to: (i) provide a better understanding of the governance of urban water services and its components in Western democracies; and (ii) illustrate how governance can be simultaneously shaped by multiple (sometimes contradictory) cultural backgrounds. The framework developed by Loorbach (2010) was extended to include an institutional logics perspective borrowed from the field of institutional theory (Friedland and Alford, 1991; Thornton et al., 2012) to achieve these objectives.

The contribution of this extended framework is twofold. First, it serves as a basis for developing theory on urban water governance and provides the congruence that this sub-field of research currently lacks. Second, it raises awareness among urban water practitioners, policymakers and decision-makers about the meaning and content of *governance*, and the need to consider the interplay between contested values, beliefs and goals, when seeking to produce sustainable solutions for urban water services.

2. Methodology

Based on a theoretical review, we extended an existing classification of governance practices and structures (2010) developed in the field of sustainability transitions with elements borrowed from sociology, with emphasis on institutional theory.

As described by Fuenfschilling (2019), in recent years researchers in the novel area of sustainability transitions have resorted with growing frequency to the field of institutional theory to extract concepts and ideas that help explain how socio-technical regimes are structured and their dynamics of transformation. Prominent examples are the seminal paper by Geels (2004), and other recent publications by Smink et al. (2015), Jolly and Raven (2016) and Franco-Torres et al. (2020a). In these studies, the idea of *institutional logics* is central. It is useful in understanding how institutional structures in socio-technical regimes contradict and relate to each other and influence the cognition and behaviour of actors to support or prevent sustainability transitions.

The outcome of this study is an innovative and encompassing governance framework of a 'neutral' character that serves to analyse all styles of governance shaped by different institutional logics. We illustrate this framework by applying it to the governance of urban water services, which involves three differentiated *ideal types* of institutional logics defined by Fuenfschilling and Truffer (2014). Ideal types are tools for empirical analysis of abstract, rich and generalisable static models designed to classify observations (Doty and Glick, 1994). In the present case, they are ideal and thus exaggerated visions of institutional logics, inferred from empirical analysis, that are not found in the real world but are useful to illustrate the co-existence and conflict of governance logics that hinder sustainable development.

The remainder of this article is structured as follows. We first present a short definition of governance of urban water services, followed by a description of the theoretical building blocks of our governance framework, including concepts such as social *structures* and *practices* (Giddens, 1984), *social institutions* (Scott, 2014) and *institutional logics* (Friedland and Alford, 1991; Thornton et al., 2012). We then present three concrete (institutional) logics identified in the urban water sector and apply these when describing the governance framework and illustrating its elements. The analysis ends with a short discussion and some conclusions.

3. Governance of urban water services

Until recently, in sectors where political influence has traditionally been low, such as the water sector, the term governance has rarely been used. According to the Scopus scientific database, the term "water governance" was only used in one article (considering title, abstract or keywords) before the year 2000. However, since then there has been exponential growth in the frequency of use of this term, which appeared in 81 articles published in 2009, in 254 articles in 2017 and in a total of 2235 documents by October 2020.

Over the past two decades, *governance* has become increasingly identified with participatory, bottom-up, network or multi-stakeholder policymaking, and gradually detached from its traditional meaning as the exclusive responsibility and duty of central government (Kooiman, 2003; Osborne, 2010). Participatory governance was thus adopted as the dominant understanding of *governance* in the water sector from the beginning. However, this is a narrow use of the concept that neglects other existing governance modes, such as market-based governance or hierarchical governance (Windhoff-Héritier, 2002).

Consequently, we broadly define the *governance of urban water services* as the collaborative social practices, together with their supporting and resulting structures, that set the scene for management of water services. It is important to note that although *water governance* and *water management* are sometimes used interchangeably, they refer to two closely interrelated but distinct processes. According to Pahl-Wostl (2009), *management* refers to activities that directly involve control of resources, e.g., monitoring, analysis, planning, design, construction, operation or maintenance, and the assets used to control these (technical, financial or human). In contrast, *governance* provides socially constructed elements such as goals, rules or roles that constrain and support management activities.

The definition above implies that *governance* simultaneously comprises social structures and social practices. Social structures are patterns of behaviour and cognition that guide and limit social practice, leading to cooperation. For example, Young (2013, p. 88) defines *governance* as practices "centered on steering human groups toward desired outcomes and away from undesirable outcomes", while he defines *governance system* as "an ensemble of elements [structures] performing the function of governance in a given setting". The structure determines practice, but practice also determines the structure, because structures are social patterns that are continuously created, carried, maintained and reproduced through repeated action (Giddens, 1984). We extend Loorbach's (2010) framework, which recognises four types of "governance activities", by suggesting that these activities can be viewed as four types of governance structures and related agency shaped by a cultural-cognitive background (institutional logics).

4. The building blocks of the governance framework

4.1. Social institutions

The concepts of *structures* and *practices* are made more tangible in the context of governance when identified with *social institutions* (Barley and Tolbert, 1997), which in this study are understood as established law or practice. Social institutions "comprise regulative, normative and cultural-cognitive elements that, together with associated activities and resources, provide stability and meaning to social life" (Scott, 2014, p. 56). They "give rise to social practices, assign roles to the participants in these practices, and guide interactions among the participants" (Young, 2013, p. 89).

Scott (2014) identifies three *pillars of institutions*: regulative, normative and cultural-cognitive. They can be placed along a spectrum, with the regulative pillar (formal rules that are conscious and legally enforced) on one extreme, and the cultural-cognitive pillar (beliefs and assumptions that are unconscious and taken for granted) on the other extreme. The normative pillar—norms and values—is in an intermediate position. *Regulative* institutions constrain and regularise behaviour through rule-setting, monitoring and sanctioning activities (Scott, 2014), i.e., they set the "the rules of the game" according to North (1990, p. 4). These formal rules, which were the only object of study of early institutional theorists, assume that individuals are rational decision-makers who optimally evaluate the convenience of compliance with the rules to achieve their objectives. *Normative* institutions are a collection of values, viewed as legitimised ends, norms and means (Scott, 2014). In other words, normative institutions represent the actions and objectives of individuals that are accepted by society. In this view, actors are not rational instrumentalists, but rather have behaviours that are oriented by moral guides, relying on feelings of shame or honour. *Cultural-cognitive* institutions serve as "the software of the mind" (Hofstede et al., 2010). These shared symbols guide the selection of information (deciding what gets our attention), interpretation of the information and construction of meaning. Cultural-cognitive institutions do not suggest recipes for action, but set the stage where the action is played out (Schneider, 1976, pp. 202–203 in Scott, 2014). Actors are often unaware of the limiting and supporting context that these cultural-cognitive institutions provide, and mimetically follow socially accepted prescriptions in a taken-for-granted manner, since other behaviours are not conceivable. Cultural-cognitive institutions are legitimised when they are comprehensible, recognisable and culturally supported. These structures are instrumental in complex and uncertain situations, providing ready-made solutions that are not necessarily optimal, while compliance protects actors from confusion and anxiety.

A central concept within institutional theory is the institutional field, which comprises "clusters of organisations and occupations whose boundaries, identities, and interactions are defined and stabilized by shared institutional logics" (Greenwood and Suddaby, 2006, p. 28). The urban water sector fits well into the institutional field concept, as it involves a network of diverse organisations (e.g., water utilities, regulatory agencies, formal authorities, constructors, consultants, suppliers, researchers, landowners, non-government organisations, service consumers) convened around the provision of water services. These organisations share a common understanding of the services, the means they use, the rules they follow and the needs they fulfil, all shaped by customised institutional logics (Scott, 2014). An institutional field like the urban water sector does not exclusively rely on one pillar of institutions, but instead incorporates all three pillars, which tend to more or less converge around various *institutional logics*. Next, we explain what the concept of institutional logics means, with particular focus on urban water services.

4.2. Institutional logics

Friedland and Alford (1991) introduced the concept of *institutional logics* as a set of cultural elements that shape practices and structures (institutions) at all social levels. Thornton and Ocasio (1999, p. 804) went on to define these as "the socially constructed, historical patterns of material practices, assumptions, values, beliefs, and rules by which individuals produce and reproduce their material subsistence, organise time and space, and provide meaning to their social reality".

Thornton and Ocasio (1999) also describe in detail how institutional logics constrain and facilitate action and help to make sense of reality. In a complex world full of uncertainty that exceeds the human capacity to analyse all possible interpretations of reality, options of action and their consequences, the societal landscape provides actors with ready-made institutional logics, i.e., rationalities of behaviour that can be adapted for particular settings in the form of specialist structures and practices. Institutional logics support actors to create vocabularies and understand the world, and give meaning to action by focusing attention on some aspects of reality, while obscuring others. Selection and adhesion to these rationalities provides legitimacy, effective responses, feeling of order and ontological security (Giddens, 1984; Thornton and Ocasio, 2008).

Institutional logics thus reflect broader societal discourses that permeate the regime, influencing the vocabulary of discursive hotspots and becoming established in institutions, to which they provide content and meaning (Lawrence and Suddaby, 2006). At the agency level, individuals and organisations can borrow and combine institutions that represent different logics to create identity, expose their interests and needs, and shape corresponding behaviours (Friedland and Alford, 1991).

In Friedland and Alford's (1991) perspective, the macro scale of society is an *inter-institutional system*, a complex system of mixed cultural material that serves as a foundation for constructing more sector-specific institutional logics. This varied content can be classified into different *institutional orders*, which represent cultural subsystems governing different areas of life, each one with its own organising principles, cultural symbols and rationalities. Thornton et al. (2012) extended this insight by describing seven institutional orders, i.e., *family*, *community*, *religion*, *state*, *market*, *profession* and *corporation.* They provide a detailed typology of each order with its respective elemental categories consisting of root metaphors; sources of legitimacy, authority and identity; basis of norms, attention, and strategy; control mechanisms; and economic systems (see Thornton et al., 2012, p. 56 for a detailed description).

4.3. Urban water services sector logics

Fuenfschilling and Truffer (2014) identified three distinct ideal types of institutional logics that may apply to every water sector in industrialised countries: *hydraulic logic*, *market logic* and *water sensitive logic*. The *hydraulic logic* has been the dominant rationality in most industrialised countries during the past 150 years, corresponding to what some scholars call the *old water paradigm* (Franco-Torres et al., 2020b). This approach focuses on meeting basic water-related needs through a command-and-control strategy. However, the hydraulic logic has been challenged since the 1970–80s by the market and water sensitive logics. The *market logic* appeared during the 1980s with the introduction of New Public Management reforms advocating reduced influence of central government and greater market influence (Bakker, 2010). This logic focuses on optimisation and efficiency in the use of resources through adoption in the public sector of market tools and modes of management proper of private corporations. The *water sensitive* logic derives from the environmentalist movement of the 1970s. It emphasises the limited nature of natural resources and their intrinsic value, as well as their connection with renewed appreciation of community values and social equity. In this logic, the urban water sector is seen as a complex system that requires integrated and participatory management to achieve sustainability.

According to neo-institutionalism, organisations (e.g., water utilities) belonging to the same regime or institutional field (i.e., the urban water services sector) have similar practices and structures (are isomorphic), because they are exposed to the same environment and seek the same sources of legitimacy (Meyer and Rowan, 1977). Therefore, we argue that these organisations tend to follow the same institutional logics, which define the content and meaning of institutions and limit the behaviour of actors, leading to homogeneity. However, Meyer and Rowan (1977, p. 356) also recognised that "organisations in search of external support and stability incorporate all sorts of incompatible structural elements". A regime may then be heterogeneous and semi-coherent, with contradictory elements of governance at all levels (Howlett and Rayner, 2007). Thornton et al. (2012) explain this apparent contradiction by suggesting that several institutional logics coexist in the institutional field, cooperating or competing, reinforcing each other or producing incoherences—a view supported by Besharov and Smith (2014). We argue that in order to understand and handle the complexity in urban water services provision, it is necessary to understand and manage the multiple institutional logics (hydraulic, market, water sensitive) that shape the governance of these services. Next, we present a theoretical governance framework for urban water services that takes institutional logics into consideration.

5. The governance framework

Inspired by the work of Loorbach (2010), our water governance framework (Fig. 1) separates governance structures and practices into four levels: strategic, tactic, operational and reflexive.

The strategic, tactical and operational levels move from the abstract to the concrete in three different dimensions: social, temporal and spatial (Table 1). Strategic governance broadly affects the cultural structure of the institutional field (the urban water sector), with a temporal scale of approximately 30 years. Tactical governance is more specific, affecting concrete areas of the institutional field that deal with specific types of challenges, with a time scale that varies between five and 15 years. Operational governance has an application to concrete behaviours in defined cases or projects, and its time scale is that of projects, usually under five years.

Institutional logics are the foundation of this governance framework, moulding all structures and associated practices. This influence also operates in the opposite direction, as practices create and reinforce certain structures and rationalities through use (Greenwood and Suddaby, 2006; Maitlis and Christianson, 2014). This process of transformation or redefinition is explicitly captured in our framework by the fourth level of governance, the reflexive level.

Table 1
Representation of the strategic, tactical and operational levels of governance.

	Structure	Practice	Location	Time horizon
Strategic level	Policy goals	Policy design	The institutional field	30 years
Tactical level	Policy tools	Institutional work	Concrete areas of the regime	5–15 years
Operational level	Identities, goals and schemas	Sense-making, decision-making and mobilisation	Projects	0–5 years

5.1. Strategic level of governance

The strategic level of governance (Table 2) focuses on developing a vision, defining priorities and setting objectives in a long-term perspective. At this level we ask "Where do we want to go and why?" in its broadest form, providing responses that are firmly attached to the field logics, borrowing their meaning, values and mission, and setting the direction of the regime. In our governance framework, these structures and practices are represented by policy goals and policy design, respectively.

In reality, policy design is sometimes carried out in a thoughtful and meaningful way, while at other times, it is contingent and irrational, resulting from informal political negotiation (Howlett, 2014). Loorbach (2010) argues that discussion of long-term goals resembles the latter, as it usually lacks a formal arena (goals are not institutionalised) due to the mid-term range of political cycles, individual interests and public pressure. Nevertheless, institutional logics always guide policy design.

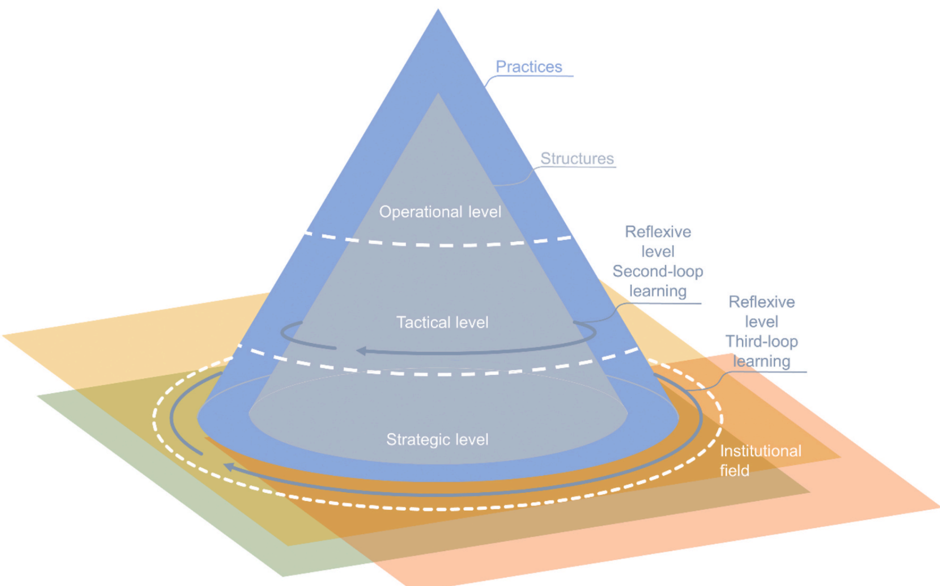

Fig. 1. The urban water governance framework. Governance is composed of structures (grey cone) and practices (blue cone), built on one or several institutional logics (superposed tiles of different colours) within an institutional field (largest white-dotted circle). Governance also involves four levels: operational (tip of the cones), tactical (middle of the cones), strategic (base of the cones) and reflexive (the two circular arrows that renew the structure and the institutional logics).

Table 2
Illustration of strategic governance structures and practices through the lens of hydraulic logic, market logic and water sensitive logic.

	Hydraulic Logic	Market Logic	Water Sensitive Logic
Structures: Policy goals	- Public welfare. National development. Paternalistic - Provision of basic needs - Water as a public good	- Make the most of available resources - Rationalisation and optimisation - Water as an economic good	- Protection of the environment - Quality of life - Water as a heritage and an essential element for liveability
Practices: Policy design	- Hierarchical - Technocratic	- Multi-centric - Corporatist	- Heterarchical - Participative, transdisciplinary

5.1.1. *The strategic level of the hydraulic logic*

The hydraulic logic is grounded in the *state* and *profession* institutional orders. From the state, it takes the strategy of providing public welfare and national development, while from the profession it takes notions of personal expertise and reputation, as particularly represented by the engineering profession. In this logic, water is a public good related to basic needs, e.g., provision of drinking water of sufficient quality and quantity, removal of hazardous waste, or control of flooding. Central government behaves paternalistically and makes itself responsible for these needs. This rationality corresponds with the command-and-control paradigm that dominated the urban water institutional field during the past 150 years. The approach envisages a relatively simple system where water-related problems are pressing, but few and simple, and the solutions straightforward and consensual, involving the control of nature through physical, technical and centralised solutions like dams and pipes (Franco-Torres et al., 2020b).

In the hydraulic logic, strategic activities are carried out according to the most classical (Weberian) understanding of governance and public administration, with clear divisions between actors and the hegemony of the public sector. Public authorities govern in a hierarchical mode and are exclusively in charge of policy definition. The hydraulic logic involves strong agreement on objectives, resulting in clear policies focusing more on technical aspects (e.g., how infrastructure can achieve the objectives) and usually ignoring the social sphere (Hurlbert and Gupta, 2015).

5.1.2. *The strategic level of the market logic*

The market logic is based on the institutional order of the *market* and the *corporation* and regards water as an economic good. Thus, unlike the hydraulic logic, it does not provide water services at any price, but to an economically rational extent, focusing on efficiency and optimisation of available resources. This optimal point is achieved through market mechanisms, where actors, promoting their own interests, balance out supply and demand for services. Policy design is more open to participation, with economists, consultants and market agents having high relevance. Public authorities and engineers have a secondary role, subject to market forces and the rationality of economic efficiency.

5.1.3. *The strategic level of the water sensitive logic*

The ideal type of water sensitive logic is based on the *community* and *professional* institutional orders. The environmental sphere is considered an actor in its own right, but at the same time highly relevant for human quality of life. In this logic, water is essential for liveability, not only for survival, and its policies guide toward conservation of natural resources, equity of access, and connections between nature and human wellbeing, aiming at environmental and social sustainability. The urban water sector is viewed as a complex system, where problems such as non-sustainability, poor resource management or climate change are highly unstructured, the needs are diverse, changing and interconnected, and the goals can be conflicting, with disagreement on science and values (Hurlbert and Gupta, 2015). Therefore, policy design is ideally self-organised in a network mode, where transdisciplinary and participatory processes are used to incorporate a variety of views and the needs of all (including public, civil and private actors) to achieve balanced public service delivery. In this mode of strategic governance, which Osborne (2010) calls "New Public Governance", the policymaking process aims at reaching agreement among actors, but also other valuable outcomes like increased social and political capital, learning, innovation and flexibility (Connick and Innes, 2003). All actors of the regime show commitment, with community goals acquiring status and relevance, but professionals such as natural and social scientists, NGOs and civil organisations play a prominent role.

5.2. *Tactical level of governance*

At the strategic level (Table 3), we ask "Where do we want to go and why?" and at the tactical level we ask "What tools are needed to get there?" The tools are *policy instruments*, i.e., institutions that serve to influence the regime toward the achievement of policy goals (de Bruijn and Hufen, 1998). Policy instruments have a shorter time horizon than policy goals (5–15 instead of 30 years), and are narrower in scope, focusing on concrete challenges while neglecting general development of the institutional field (Loorbach, 2010).

A functionalist approach to policy instruments views these as technical, rational and objective tools that government chooses to reflect its policy goals accurately. However, in the interpretative approach, these instruments are viewed not as neutral, but as conveying additional meanings and assumptions (Majoor and Schwartz, 2015). Our governance framework recognises that policy instruments are non-neutral elements that reflect the values, beliefs or assumptions of the regime's logic(s). Thus, they are not only formal, visible instruments such as laws and regulations exclusively created by the government, but also norms, values or cognitive elements that are consciously and unconsciously created and followed by the members of the institutional field.

In our framework, tactical practices correspond to what Lawrence and Suddaby (2006, p. 215) call *institutional work*: "the purposive action of individuals and organisations aimed at creating, maintaining and disrupting institutions", these activities being carried out by "institutional entrepreneurs", i.e., certain actors that have the vision, motivation and ability to affect institutions (DiMaggio, 1988).

Political scientists have produced several classifications of governance policy instruments (Majoor and Schwartz, 2015). The most popular taxonomy is probably that by Hood and Margetts (2007). They apply a more government-centered, "intentional design" approach that distinguishes four types of resources that governments can use to achieve changes in behaviour to accomplish policy goals. The first, *nodality*, refers to the position of government as a node in an information network. The second, *authority*, concerns regulatory and coercive instruments. The third, *treasure*, denotes the economic assets and capabilities that are at the disposal of the government. The fourth, *organisation*, refers to the organisational structures that provide the capacity to control action. For a broader understanding of governance (Osborne, 2010) this classification is still useful, as actors other than government, e.g., private and civil actors, can create instruments based on the same types of resources. For example, some policy instruments do not involve government actors at all, e.g., codes of conduct, eco-labels, benchmarking, best practices, co-regulation or voluntary agreements (Zito et al., 2003), which some call *New Governance Arrangements* (NGA) (Howlett and Rayner, 2007).

In practice, most regimes have developed a varied range of policy instruments that belong to all three pillars of institutions and adapt to specific problems through coexisting top-down and bottom-up

Table 3
Illustration of tactical governance structures and practices through the lens of hydraulic logic, market logic and water sensitive logic.

	Hydraulic Logic	Market Logic	Water Sensitive Logic
Structures: Policy tools	- Authority and organisation resources - Institutions as formal rules - Formal and well-defined - E.g., laws and technical guidelines	- Organisation and treasure resources - Institutions as norms and values - Formal/informal - E.g., corporatisation of water utilities, full cost recovery and cost-benefit analysis	- Nodal resources - Institutions as norms, values and cognitive elements - Informal and ill-defined - E.g., education, labels, standards and benchmarking
Practices: Institutional work	- Done by public authorities - Purposeful design	- Done by public/private actors - Purposeful/emergent design	- Done by public/private/civil actors - Emergent design

governance modes (Jordan et al., 2013). They often include formal institutions that are purposefully designed by public authorities and more emergent institutions, usually norms, values or cognitive elements, which arise from the interaction of non-government actors that are more or less aligned with each other and with certain (institutional) logics (Howlett, 2014; Howlett and Rayner, 2007).

5.2.1. The tactical level of the hydraulic logic

Since the hydraulic logic focuses on basic water needs that are fulfilled using well-known solutions, there is little room for debate, assuming that there is just one right way to do things. This logic encourages the imposition of *the* "right solution" through the adoption of rigid hierarchical schemes of social organisation underpinned by authority and organisation resources. Most policy instruments are then formal rules from the regulative pillar (such as laws, regulations and formal guidelines) that employ coercion to force cooperation. These institutions are purposefully and explicitly conceived by the central government, mostly in concrete technical terms, drawing on the knowledge of engineers. They are designed by different government agencies in isolation, based on a narrow and monodisciplinary understanding of the problem, and ignoring other needs or policy tools. These agencies usually have the capacity to monitor and sanction contravention of their rules, often generating conflicts with other rules created by other agencies. For example, government agencies may impose contradictory procedures for dealing with heavy rainstorms: The road administration may require removal of stormwater from roads to a nearby stream network as quickly as possible, to avoid disturbance to traffic; the planning administration may require some roads to be used as floodways, to prevent damage to buildings; and the environmental administration may require runoff from roads to be prevented from entering streams, as it may be polluted and could damage sensitive ecosystems.

5.2.2. The tactical level of the market logic

The market logic considers that conventional governance based on rational prediction and control is ineffective when water problems are too complicated. Bureaucratic means are too rigid and do not respond effectively to the problem of limited resources. Instead, market logic regards the provision of urban water services as an economic issue where market tools can provide optimal solutions (Chandler, 2014). As most basic urban water services are natural monopolies, the introduction of private actors aims at increasing competition and improving efficiency. Their policy of optimisation is translated into regulative market instruments and public sector reforms. The treasury-based instruments include rules for full cost recovery and consumer funding, pricing regulation and subsidies. The organisational resources can consist of an amalgamation of small local water utilities and their corporatisation (so that they become profit-oriented), outsourcing of services, and fragmentation and devolvement of hierarchical governance to independent agencies. Despite these measures, in reality, the total privatisation (asset transfers) of urban water services is rare. Public authorities usually remain central but highly dependent on many private actors (Bakker, 2010).

5.2.3. The tactical level of the water sensitive logic

In the water sensitive logic, urban water services are regarded as complex systems with intertwined needs that require adaptive policy tools, instead of rigid instruments or economic optimisation. This logic resorts mainly to network-based institutions (norms, values and cultural-cognitive beliefs) that function as mimetic mechanisms and nodal resources seeking to achieve voluntary changes in behaviour and self-organisation. Many of these instruments are well-known in the urban water sector, i.e., normative institutions such as accreditation, benchmarking, and certification provide status and legitimacy to complying actors. The fostering of transdisciplinary networks and information and education campaigns are cultural-cognitive institutions that result in taken-for-granted behaviours. In the most extreme version of this ideal type, these network policy instruments have an emergent character, i.e., they are not exclusively or purposefully designed by public authorities, but are instead the result of interactions among different actors. They are valued for their flexible, participatory, and democratic character, but also criticised for a weak focus and lack of monitoring and accountability measures (Jordan et al., 2013). A less extreme understanding of the water sensitive logic is that public authorities still have the exclusive capacity to create regulative institutions, which can include organisation and authority mechanisms. The former usually aim at creating connections between administrative bodies for vertical and horizontal coordination, to achieve integrated management of water services, while the latter usually define high environmental standards.

5.3. Operational level of governance

The operational level of governance (Table 4) includes the micro-practices resulting from situated interpretation and application of governmental policy goals and instruments. At this level we ask "What is our role, what do we want, what is the problem we face, and how can we cooperate to solve it?".

In our framework, the structures of operational governance correspond to methods individuals use for categorisation and cognition, which are culturally embedded in the incumbent institutional logics. Thornton et al. (2012) refer to these as the *micro-foundations of institutional logics*, which include *identities*, *schemas* and *goals*. These elements provide individuals with guidance to interpret the environment in interaction with others in specific situations, resulting in behaviours appropriate to their institutional context.

Of particular relevance for governance are the *roles* (a type of *identity* that informs actors how to make sense of situations, which *goals* to prioritise and how to make decisions) and *scripts* (a type of *schema* that describes recurrent activities and patterns of interaction in well-known situations) (Thornton et al., 2012). Goals at the operational level are subject to the role of the individual and the limitations of policy tools. Shared logics between individuals result in shared attention, coherent constellations of identities and schemas and shared goals, promoting

Table 4
Illustration of operational governance structures and practices through the lens of hydraulic logic, market logic and water sensitive logic.

		Hydraulic Logic	Market Logic	Water Sensitive Logic
Structures	*Roles*	- Well-defined - Dominance of politicians and engineers - Considers users as citizens	- Ill-/well-defined - Dominance of utility managers, economists and consultants - Considers users as customers	- Ill-defined, mixed roles - Dominance of researchers, facilitators, and champions - Considers users as participants
	Goals	- Few - Isolated - Well-defined. Basic goals - E.g., reduce leakages in pipe networks	- Multiple - Isolated/interconnected - Well-defined, economically ranked - E.g., reduce energy costs in water treatment	- Multiple - Interconnected - Ill-defined, incommensurable - E.g., create multipurpose infrastructures like stream daylighting
	Schemas	- Imposed routines, rigid technical procedures	- Economic, supply-demand adjustment	- Social and environmental, flexible, adaptive
Practices	*Sense-making & Decision-making*	- Based on technical knowledge - Quantitative technical analysis - Focus on outputs	- Based on self-interest - Quantitative economic analysis - Focus on costs and benefits	- Participatory, based on consensus - Quantitative/qualitative analysis - Focus on diverse meanings and values
	Mobilisation	- Coercion, command and control, and professional reputation	- Self-interest, negotiation and accommodation	- Trust and reciprocity, cooperation and alliance formation, and professional reputation

collaboration, whereas differing or contradictory logics among individuals result in divided attention, roles and goals, incoherent scripts and conflicts, struggles for power and barriers to cooperation (Besharov and Smith, 2014; Thornton et al., 2012).

Operational structures underpin operational practices of governance, which refer to day-to-day governing under specific circumstances, aiming at solving time- and space-bounded issues. They involve *sense-making*, *decision-making* and *collective mobilisation*, practices shaped by the context and activation of identities, goals and schemas, and implementation or adherence to policy tools.

Sense-making creates meaning out of a novel, unexpected, confusing, or ambiguous circumstances (Maitlis and Christianson, 2014). It translates the new understanding into language and serves as a basis for action, although shaped by the constraints of existing institutions (Barley and Tolbert, 1997), in our framework policy instruments. Sense-making underpins *decision making* and *mobilisation*, which refer to the collection of symbols and material resources and motivation of actors to accomplish collective goals or policies.

5.3.1. *The operational level of the hydraulic logic*

In the hydraulic logic of urban water services, identities, goals, and schemas are often formal elements that fit into the regulative pillar of institutions. The roles are standardised and unambiguous, mainly political or technical, where water utility engineers are central. Scripts are rigid, well-defined and based on regulative institutions, such as the processes used to plan and design infrastructure. The goals are uncontested and related to the solution of technical problems, e.g., reducing leakages or designing water treatment plants. Regarding practices, sense-making and decision-making are dominated by the workers of state-owned utilities, presenting a marked technocratic character. Mobilisation is based on expedience, and formal power is used to impose coercion, command and control (Kersbergen and van Waarden, 2004). All these elements have a rigid character that constrains the freedom of actors but enables social acceptance and coordination.

5.3.2. *The operational level of the market logic*

The market logic encompasses a mixture of well-defined and undefined roles. Managers of corporatised water utilities, economists and consultants have a highlighted position, while final users are identified as customers. The managers' goals are related to cost reduction and improvements in efficiency, through, for example, energy savings or lower construction and maintenance costs, whereas private firms aim at maximising profits. Scripts are not strictly defined, since sense-making and decision-making are based on ad-hoc cost-benefit analysis and supply-demand calculations. Mobilisation is based on negotiation and accommodation practices (Kersbergen and van Waarden, 2004), heavily influenced by actor self-interest in gaining control of resources.

5.3.3. *The operational level of the water sensitive logic*

The water sensitive logic encompasses a large variety of roles that are mostly flexible and ill-defined. Typically, actors are informal, like facilitators, champions or grassroots activists. The division of power among roles is no longer clear, which introduces challenges with accountability. NGOs and researchers are important actors in this logic but are not held responsible for any decision. The collaboration networks involve a mix of public, private and civil actors, with a continuous flow of participants that are integrated in terms of their commitment to strategic (policy) goals. However, operational goals are often fuzzy because they deal with multiple needs, as in projects on construction of green roofs or daylighting of streams. The scripts of action are also ill-defined, providing room for flexibility and innovation. Sense-making and decision-making follow participatory pathways and mobilisation relies on practices such as persuasion, concerted effort, cooperation and alliance formation (Kersbergen and van Waarden, 2004).

5.4. *Reflexive level*

Reflexive activities involve the continuous processes of transformation and adaptation of governance structures (and derived practices) to context. Loorbach (2010, p. 170) states that "reflexive activities relate to monitoring, assessments and evaluation of ongoing policies, and ongoing societal change". We argue that reflexive activities should instead be described as a multi-level societal learning process (Pahl-Wostl, 2009), which actually implies changes in governance and implicitly includes the analysis activities described by Loorbach (2010).

Although the social learning process described by Pahl-Wostl (2009) has, in principle, three levels (*single*, *double*, and *triple-loop learning*), we believe that the concept of governance only encompasses the latter two. *Single-loop learning* falls outside the concept of governance because it exclusively involves quantitative regulation of existing management practices (Argyris, 1999; Argyris and Schön, 1978). For example, in the context of water scarcity, single-loop learning refers to further extraction of underground water or digging new wells.

The first reflexive process of the governance framework is thus *double-loop learning* (Argyris, 1999; Argyris and Schön, 1978), involving redefinition of governance structures within the same logic or from other logics at any level (strategic, tactic, operational). Following the previous example, double-loop learning may involve the imposition of new policies and rules that prohibit the use of potable water for landscaping or car-washing. This transformation may follow the hydraulic logic, which restricts the use of a scarce resource to satisfy basic human needs, or a water sensitive logic, which aims to avoid adverse effects on the environment of greater water abstraction. In the market logic, *double-loop learning* could mean, e.g., higher water prices to incentivise users to reduce consumption, while maintaining revenues.

The second reflexive process of governance is *triple-loop learning* (Hawkins, 1991; Swieringa and Wierdsma, 1992), which we identify as adhesion to new institutional logics or abandonment of old logics, corresponding to a change in fundamental beliefs and values. Triple-loop learning could mean a change from hydraulic logic, where water is considered a human right and everybody is entitled to use it, to market logic, where water is an economic good, and only those who pay for it are entitled to use it.

6. Discussion and conclusions

In recent decades, the field of urban water management has outgrown its technocratic foundations. Rising evidence of its growing social, technical and environmental complexity has prompted research on how actors organise to achieve common and conflicting goals in complex environments or, in other words, how governance may be improved. However, what governance means in the urban water sector remains unclear. In practice, governance in this sector has traditionally been interpreted narrowly, as "decision-making" (Bakker, 2010). However, scholars have adapted ideas from disparate fields of knowledge and modified the concept to fit their particular visions of reality. The result is divergent, partial or incoherent descriptions of urban water governance, hampering theoretical development and design of practical solutions. Examples are the application of a narrow political science focus to formal policy tools or a psychological approach focusing on individualistic models of behaviour.

We present a coherent framework to organise what we consider the most critical elements of urban water governance. We also highlight some key aspects of urban water governance that have previously been overlooked. One such aspect is the dual character of governance. Previous descriptions have focused either on the structures of governance or governance practices carried out by certain actors, whereas our framework focuses on both simultaneously, as they are interdependent and mutually supportive (Giddens, 1984). Another aspect is the multi-level nature of governance (strategic, tactic, operational and reflexive), inspired by the work of Loorbach (2010). We extended this framework by including two other key aspects of governance: (i) the recognition of a cultural background (expressed in the coexistence of different institutional logics) that shapes the practices and structures of governance; and (ii) a more detailed description of the reflexive level of governance, involving double-loop (Argyris, 1999; Argyris and Schön, 1978) and triple-loop learning (Hawkins, 1991; Swieringa and Wierdsma, 1992). In particular, the recognition of the existence of multiple institutional logics (the cultural background) provides our governance framework with the ability to conceptualise some of the most acute urban water problems, i.e., a growing number of conflicts due to divergent values, beliefs and goals that often lead to institutional fragmentation and stagnation in the transition to sustainability.

Our analysis is richly illustrated by three ideal types of institutional logics previously observed in the urban water sector, namely hydraulic, market and water sensitive logics (Fuenfschilling and Truffer, 2014), demonstrating how different logics can result in entirely different governance components that often interact and compete to create incongruences and conflicts. The use of ideal types facilitates visualisation of paradoxes of understanding and performing (Smith and Lewis, 2011) and makes it possible to design strategies that accommodate conflicting values, world views or interests in order to create innovative solutions to complex problems (Jay, 2013). Application of this idea is exemplified in the case study in Franco-Torres et al. (2020a), which provides empirical evidence of how certain actors in the municipality of Copenhagen gained awareness of the conflict among logics regarding stormwater management. Equipped with a new understanding, those actors managed to create strategies that accommodated the hydraulic, market and water sensitive logics, making possible the collaborative work required to advance the design of more sustainable management.

At a more abstract, but perhaps more powerful, level is the idea that awareness of institutional logics and their effect on cognition and behaviour provides an essential platform for transitions to sustainability. Abson et al. (2017) and Fischer and Riechers (2019) (both inspired by Meadows, 1999) differentiate between tangible/practical interventions such as adjustment of *feedbacks* and *parameters* (i.e., structures of governance like policy tools or roles), which produce minor advances toward sustainability, and abstract interventions, such as changes in *intent* or *design* (i.e., awareness about institutional logics and the ability to transcend them), which have considerable potential to move a sector toward sustainability. Similar ideas to this change in *intent* or *design* are the concept of *frame reflection* or *reframing* found in the work of Schön and Rein (1994) in the field of policy analysis, and the concept of *triple-loop learning* (Hawkins, 1991; Swieringa and Wierdsma, 1992) in the field of organisational science.

We hope that future studies use the governance framework presented in this article as a starting point for designing strategies to identify and align conflicting institutional logics, and thus overcome governance barriers that impede the transition to more sustainable futures.

Declaration of competing interest

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

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Paper 4

A framework to explain the role of boundary objects in sustainability transitions

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Original research paper

A framework to explain the role of boundary objects in sustainability transitions

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ABSTRACT

Our modern society is characterized by increasing diversity and complexity, leading to overwhelming challenges like climate change or environmental degradation. These problems are posing impracticable ethical dilemmas and conflicts of interest among an expanding range of institutional logics. While this cognitive, ideological, scientific, and political diversity can represent a major barrier for the collaborative work that sustainability transitions require, it is also a necessary resource for innovation and adaptation. It is then natural to wonder how diversity and collaboration among institutional logics can be accommodated and balanced. In this article, we develop a framework to explain the role of *boundary objects in sustainability transitions* (BOIST framework), which describes how ambiguous artefacts (boundary objects) can be deliberately employed by actors to drive transitions through bridging conflicting logics without constraining their diversity. The applicability of the framework is demonstrated with an in-depth case study of the Copenhagen municipality's transition to more sustainable stormwater management.

1. Introduction

Our modern society is characterized by a relentless growth of diversity, complexity and uncertainty (Beck et al., 2003; Milly et al., 2008) that leads to interdependent, unstructured, and pervasive problems—what in social policy is called wicked problems (Rittel and Webber, 1973; Weber and Khademian, 2008). These problems are overwhelming societal challenges like climate change, environmental degradation and loss of biodiversity, bioengineering, artificial intelligence, or mass surveillance. They typically create ethical dilemmas and conflicts among actors with different worldviews (sets of values, beliefs, interests and goals). These major societal challenges, and the large socio-institutional transformation that they can lead to, are the object of study of the interdisciplinary field often called sustainability transitions (Loorbach et al., 2017; Markard et al., 2012). This field aims at finding ways to understand, promote, accelerate, and orient socio-technical regimes towards more sustainable social configurations.

Overarching social problems have traditionally been addressed in a rigid top-down style, by a strong government that imposes a solution based on a defined set of values, beliefs or goals in order to generate unity, collaboration and eliminate uncertainty (Hobbes, 1960). In the best of cases, the enforced worldview builds on scientific evidence to determine a (supposedly) optimal solution,

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constrain diversity, enforce collaboration and settle the debate once and for all (Sarewitz, 2004; Stirling, 2010). While in the past, this approach was successful to confront simple and undisputed societal challenges (e.g. Pahl-Wostl et al., 2011), it becomes increasingly clear that our current social reality, with complex and non-linear behaviours, refutes the existence of these simple, universal and objective solutions for wicked problems (Funtowicz and Ravetz, 1993; Prigogine and Stengers, 1984)—and therefore also refutes the utility of the rigid top-down approach. This suggests instead that diversity is essential for understanding, innovation, flexibility and adaptation to complex and uncertain problems (Biggs et al., 2012; Page, 2010; Stirling, 2010), with governance being distributed among a growing number of actors with contrasting worldviews (Kooiman, 2003; Sørensen and Torfing, 2016). But from this arises the dilemma of how to build up the wide social collaboration required to create sustainable solutions to complex social challenges (Leck and Simon, 2012), without imposing unity or restricting the expanding cognitive, ideological, scientific and political diversity (Keulartz, 2009).

While this tension is central in sustainability transitions, it has rarely been explicitly addressed (cf. Stirling, 2011) and has not yet received attention in existing frameworks of transition governance. For example, in the framework built by Smith et al. (2005) (sustainability) transitions are dependent on two main factors: the existence of selection pressures (and their effective articulation), and the adaptation capacity available. In turn, this adaptation capacity has two sub-dimensions: the presence (and diversity, we claim) of resources—like knowledge, funding, or legitimacy—and the capacity for coordination among regime members for the effective exploitation of these resources. However, Smith et al. do not elaborate on how to build coordination among a local community actors that exhibit different worldviews, without restricting their diversity. Keulartz (2009, p. 266) claims that the answer to this question can be found in the concept of *boundary work*—a term with origins in science and technology studies (Gieryn, 1983)—that refers to “the constructive effort to support communication and coordination across the fences that separate communities”. We argue, more concretely, that a particular tool of boundary work, namely *boundary objects* (Star, 2010; Star and Griesemer, 1989), has the ability to simultaneously support coordination and diversity. Furthermore, we claim that boundary objects may be the answer to two additional questions that arise from Smith et al.’s framework: What does *articulation of selection pressures* mean in practice? How are available resources concentrated to make the transition possible?

Boundary objects are artefacts (things, concepts, discourses, processes, etc.) that have the ability to simultaneously project disparate interpretations—they have interpretive flexibility—while constituting a solid nexus for communication and collaboration among disparate worldviews (Star, 2010; Star and Griesemer, 1989). The concept, originally from the field of science studies, has had a prolific life in a wide range of disciplines during the last 30 years (Trompette and Vinck, 2009), and also has occasionally been borrowed in the field of sustainability transitions as an accessory element (Augenstein and Palzkill, 2016; Klerkx et al., 2010; Pel, 2016; van der Jagt et al., 2019; Wittmayer et al., 2017). However, during the last few years, some studies have begun to explore its potential for expanding the theoretical base of the field. For example, Stirling (2011) refers to boundary objects as a tool to simultaneously encourage “pluralistic tolerance” and foster the collaboration among diverse views that sustainability transitions require, while more recently Koehrsen (2017) has investigated how boundary concepts can help to enable cooperation among worldviews without consensus. More examples include the empirical work of Hauber and Ruppert-Winkel (2012) and Harlow et al. (2018), who describe how boundary objects are able to align conflicting interest and guide a transition in the energy and transport sector.

Building on these studies, in this article we develop a framework to explain the role of *boundary objects in sustainability transitions* (the *BOIST* framework), which focuses on three proposed capabilities of boundary objects: (1) to build cooperation among conflicting worldviews without constraining diversity, (2) to articulate selection pressures, and (3) to concentrate resources in order to make transition possible. This analysis is done simultaneously at two levels: the *system level* and the *actor level*. The system level describes how boundary objects affect the transformation of the socio-technical system, while the actor level describes how certain actors [*boundary spanners* (Klerkx et al., 2010; Richter et al., 2006; Smink et al., 2015; Williams, 2002)] embedded in those systems deliberately employ boundary objects to drive change [conduct *boundary work* (Gieryn, 1983; Guston, 2001; Richter et al., 2006; Williams, 2002; Zietsma and Lawrence, 2010)]. Attention to boundary work resonates with the growing interest in an agency perspective in sustainability transitions (Avelino and Wittmayer, 2016; Barnes et al., 2018; Farla et al., 2012; Fischer and Newig, 2016; Wittmayer et al., 2017), contrasting with the more common analysis of transitions that focus on systemic changes (e.g. de Haan and Rotmans, 2011; Geels, 2004, 2002). This agency approach is useful to analyse the governance of transitions (e.g. Frantzeskaki et al., 2012; Turnheim et al., 2015), and more specifically transition management (Brown et al., 2013; Loorbach and Rotmans, 2010; Rotmans and Loorbach, 2009) or strategic niche management (Raven et al., 2016; Schot and Geels, 2008). Following this vein, our framework provides an agency approach to boundary objects from which they can be seen as tools for transition management.

This article is structured as follows. First, we expand on the two building blocks of our framework: institutional logics and boundary objects. Next, the theoretical development of the framework is presented, which is structured following the life cycle of a boundary object (Star, 2010; Steger et al., 2018) in a particular community of practice in a particular place, offering a simultaneous system and agency perspective. Then, we apply the framework to analyse the case study of stormwater management in Copenhagen (Denmark), where the concept of climate change adaptation (CCA, the boundary object) was used to (1) articulate a selection pressure, (2) build cooperation across conflicting worldviews and (3) concentrate the necessary resources to drive the transition towards more sustainable modes of stormwater management.

2. Conceptual development of the framework

2.1. Theoretical building blocks

From the outside, socio-technical regimes may seem heterogeneous with incoherent sets of social structures. However, there is usually a finite number of interacting worldviews, with their characteristic systems of values, beliefs, interests and goals that support and constrain thinking and action in a particular direction. These worldviews, which the boundary object literature calls *social worlds* (Star and Griesemer, 1989), have recently been introduced in sustainable transitions as institutional logics (Brodnik et al., 2017; Fuenfschilling and Truffer, 2014; Smink et al., 2015)—a concept with roots in institutional theory (Friedland and Alford, 1991; Thornton et al., 2012; Thornton and Ocasio, 2008). These institutional logics (hereafter referred to simply as logics) may cooperate or compete with each other, resulting in incoherencies across the regime (Besharov and Smith, 2014; Goodrick and Reay, 2011; Smink et al., 2015). In general terms, a transition in a socio-technical system can be conceptualized as a transformation of the relative influence of its constituent logics (Brodnik and Brown, 2017).

Some logics are inherent and essential to the functioning of a socio-technical system—as we will see later for the hydraulic logic in the modern stormwater management regime. Other logics, however, emerge in the regime as niche innovations (Brodnik et al., 2017; Smink et al., 2015) reflecting deeper changes in underlying societal structures (changes at the landscape level)—for example, the market logic spread over many socio-technical systems when neoliberal politics became popular in western countries during the 1980s. If disparate logics are strongly represented and offer contradictory prescriptions (for instance, health services may be regarded as a human right or as a profit-making business; mass surveillance may be seen as an issue of public protection or of citizen control), extensive and intractable conflicts can arise, threatening the durability of the socio-technical regime (Besharov and Smith, 2014).

In our transitions framework, we conceptualize boundary objects as elements that enable the articulation of selection pressures and the interaction, communication, alignment of interest and cooperation among logics without a need for consensus (Bartel and Garud, 2008; Bressers and Lulofs, 2010; Cash et al., 2006; Cash and Moser, 2000; Koehrsen, 2017; Star and Griesemer, 1989) (see Fig. 1). A clear explanation of the idea of boundary objects can be offered based insights from semiotics. In this field, a *sign* (e.g. a word) is composed of two elements: a *signifier* (what we can perceive with our senses, e.g. a word's sound or written form) and a *signified* (its meaning) (Saussure, 1959). A boundary object is a signifier (not necessarily a word, for example it could be a physical artefact or a process) characterized by its large interpretive flexibility (Star and Griesemer, 1989). It has the capacity to adopt concrete signifieds inside different logics—called *translations* in science and technology studies (Callon, 1984)—while remaining ambiguous enough to support collaboration across logics without forcing actors to abandon their initial standpoints (Carlile, 2004; Star and Griesemer, 1989). Indeed, the word *boundary* refers to the shared space between institutional logics, and the word *object* does not refer to a physical entity, but to the shared aim of action (Star and Griesemer, 1989). Some examples of boundary objects include computer models (Larson et al., 2015), the IPCC report (Cash and Moser, 2000), ecosystem services (Abson et al., 2014), innovation

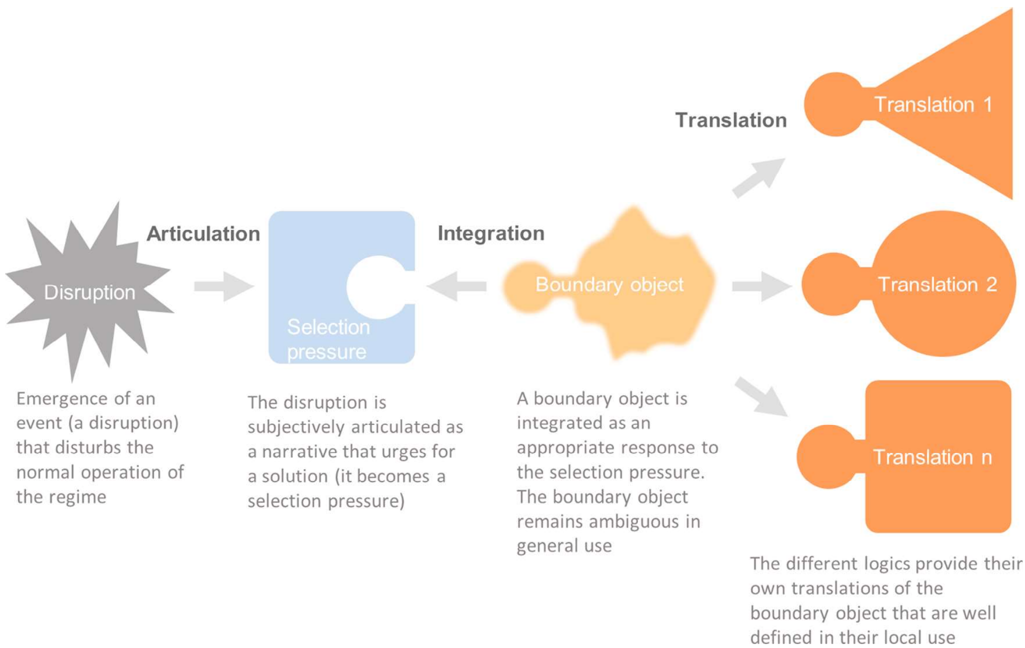

Fig. 1. A boundary object serves to simultaneously articulate a selection pressure, provide an undisputed solution and support multiple translations influenced by different institutional logics.

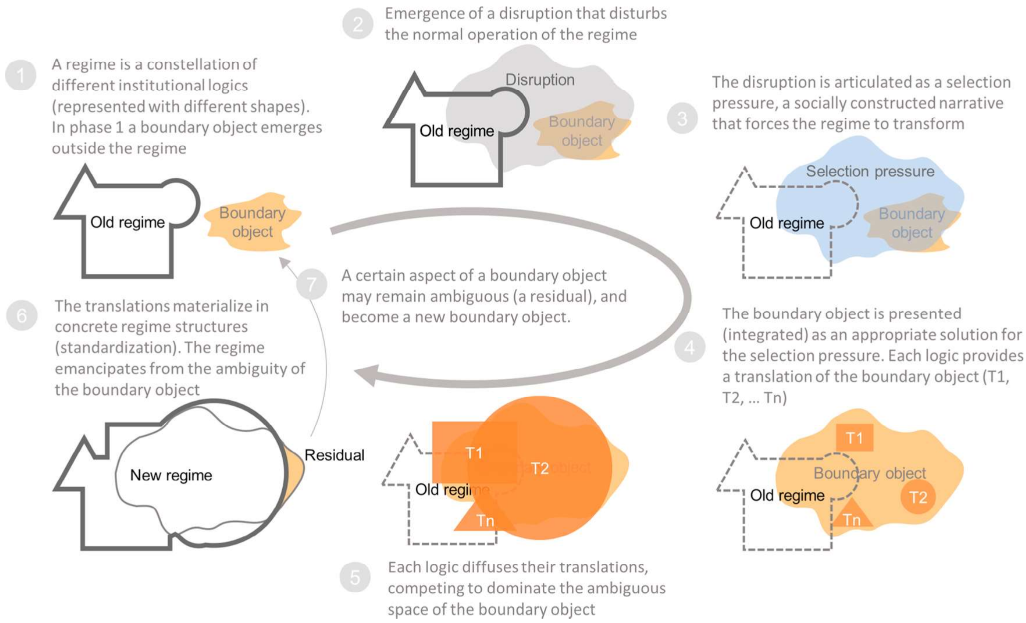

Fig. 2. The BOIST framework describes seven phases in the lifecycle of a boundary object during a transition.

narratives (Bartel and Garud, 2008), frameworks like the Integrated Water Resource Management (Molle, 2008), many other ill-defined ideas like resilience (Brand and Jax, 2007), or even the concept of sustainability transitions itself (Loorbach et al., 2017).

2.2. *Introducing the seven phases of boundary objects*

In this section, we present a description of the seven phases of the transition framework, which are introduced according to the circular life of a boundary object, inspired by the work of Star (2010) and Steger et al. (2018). Fig. 2 provides a visual representation of each these phases, with brief explanatory text. These seven phases can be understood as both systemic developments and actor strategies.

2.2.1. *Phase 1: Emergence of a boundary object*

A boundary object usually emerges outside the regime and can be later introduced into the regime by advocates of an institutional logic that, early on, intuit a (representative or communicative) value on it. Sometimes, new, ill-defined boundary objects grow from previously existing boundary objects that have lost their ambiguity. This is what Star (2010) calls *residual categories*—or just *residuals*.

2.2.2. *Phase 2: Emergence of a disruption*

A disruption can emerge independently of the boundary object. The Oxford English Dictionary defines *disruption* as a “disturbance or problem which interrupts an event, activity, or process”, which, in this framework, corresponds with a disturbance of the normal operation of a stabilized socio-technical system. Typical examples of disruptions include rapid demographic changes, natural disasters, new legislation or revolutionary technical innovations.

2.2.3. *Phase 3: Articulation of a selection pressure*

While some authors in sustainability transitions have referred to what we call disruptions as *selection pressures* (e.g. Berkhout et al., 2004; Smith et al., 2005), we introduce a clear distinction between the two terms. Selection pressures are disruptions that have been *articulated*. Without this articulation, disruptions are neutral events that lack social significance—they have not received attention or meaning from the members of the regime. Regimes are social constructions (Geels, 2011) that require an *articulation* of the causes and consequences of disruptions that happen in the “real world”. Without this articulation, a disruption goes ignored and does not exist from a social perspective (Beck, 1992; Snow and Benford, 1988).

More specifically, we consider a selection pressure the shared realization that a certain disruption calls into question the capacity of the current socio-technical system to fulfil its intended function, requiring urgent efforts for adaptation—or for suppression of the disruption. A selection pressure instigates action; *something must be done.*

Transitions literature often assumes that sudden or violent disruptions are essential to open a window of opportunity and force the transformation of the regime (Geels, 2011; Smith et al., 2005; Smith and Stirling, 2010). Conversely, we argue that what is indispensable is the social construction of an effective selection pressure, which can also be developed in response to minor or gradual disruptions—which are ubiquitous in modern societies (Berkhout et al., 2004). The articulation is often an arbitrary process, but it can also be purposeful, enabling regime actors to trigger and shape a transition.

2.2.4. Phase 4: Integration of the boundary object and emergence of multiple translations

We argue that boundary objects can function as appropriate responses to selection pressures because they can be simultaneously attractive and vague ideas—what Molle (2008) calls a *nirvana* concept. On the one hand, they may be an appealing signifier that is widely accepted, representing a suitable solution for the selection pressure from any perspective. On the other hand, they are so plastic and ambiguous that any logic can create their own signified (translation). Using a boundary object as a reference point, it is possible to achieve an incipient cooperation to approach the selection pressure prior to consensus among the different logics (Koehrsen, 2017; Star, 2010).

In the same way that selection pressures could be intentionally articulated, advocates of a certain logic can promote what we call the *integration* of a certain boundary object into a selection pressure (Fig. 1). After the link is established, advocates of the different logics start elaborating their *translations* in tune with their values and worldviews, including a concrete solution for the problem and the motivational reasons to support it (Snow and Benford, 1988). Accordingly, the dominant logic of the incumbent regime makes a translation of the new boundary object that supports the existing regime structures, while "divergent" logic(s) that aim at triggering a transition normally promote some solutions that question the status quo.

2.2.5. Phase 5: Dominance of the ambiguous space

The existence of a selection pressure is a stressful situation for governance actors who are compelled to respond quickly and adapt the regime to the new development—or, instead, they try to lock the regime in the old configuration and withstand or neutralize the selection pressure. Consequently, these decision-makers are willing to provide resources (like financial support, political support or administrative expedition) and legitimacy to those actors that represent the most accepted translation of the already integrated boundary concept. At this point, the motivated advocates of different logics strive to put forward their translations in the incipient discursive arenas, where the boundary object is still ill-defined (what we call the *ambiguous space*) to gain access to the resources and be granted the legitimacy to act.

We identify four actor strategies that may be employed to conquer the ambiguous space, which correspond with growing degrees of diffusion and fixation of a boundary object in the regime.

The first is the *ownership* of the boundary object. Actors that introduce the boundary object into the regime create an early translation that fit their own logic. Even if this translation is not fully understood or accepted by other actors, the primary logic may be publicly associated with, and credited as, the "owner" of the boundary object.

The second strategy, *storytelling*, involves the definition and dissemination of a compelling narrative (a translation) that can persuade other actors through diverse means, including networks, research, education, conferences and the media, which expands the body of supporters. Storytelling is a well-known strategy in organizational research as a tool of resource acquisition (Lounsbury and Glynn, 2001; Martens et al., 2007). The success of this diffusion is strongly dependent on how compelling the story is, as well as the skill, power and social capital of the communicator. A good story creates a series of positive feedback loops, as other actors appropriate the narrative and diffuse it with their actions and within their networks.

The third strategy, *accommodation of other logics*, involves the partial merging of translations in areas where they become compatible and mutually supportive, as long as the union does not disturb the internal coherence of their original translations (Besharov and Smith, 2014). This idea has been repeatedly studied in the field of institutional theory, and it is often referred as *aggregating interests* (Fligstein, 1997). In this process, the translation gains support and legitimacy from a wider body of actors and, at the same time, incorporates useful elements from other rationalities "in a way that resonates with the interests, values, and problems of potential allies" (Battilana et al., 2009, p. 80). Others, like Schön and Rein (1994, p. 207) in policy analysis, call this strategy *double vision*, and define it as "the ability to act from a frame [a logic] while cultivating awareness of alternative frames". In practice, the application of this strategy can unfold in multiple ways. For instance, it can involve the exploration of synergies with other logics through networking, the engagement with the overarching political agenda to benefit from the momentum of politically goals already legitimated, or the development of interdisciplinary predictive models.

The fourth actor strategy is the *construction of obligatory passage points*—borrowed from science and technology studies (Callon, 1984). The agents of an institutional logic that get control over an ambiguous space become central nodes in a network of collaboration made together with the accommodated logics. As a sort of gatekeeper, they acquire the legitimacy and capacity to define the new regime's structures that all actors must follow in order to engage in collaborative work.

2.2.6. Phase 6: Standardization and emancipation

After the ambiguous space is significantly reduced, consensus starts to emerge across the different institutional logics and the boundary object is materialized in the form of *standards* (Star and Griesemer, 1989)—agreed-upon definitions, classification, and rules—which makes the boundary object less vague and constrain the range of action of the members of the regime in a certain direction. Apart from standards, the dominant logic can reify a boundary object in the shape of demonstration projects (Farrelly and Brown, 2011; Vreugdenhil et al., 2010). For instance, new infrastructures or interdisciplinary prediction models not only make the boundary object an unambiguous instantiation of a certain translation, but can also support further diffusion of the translation, become a reference point for future projects and develop a sense of ownership from multiple disciplines towards the new infrastructures and/or practices being demonstrated.

The new hybrid translation that solidifies reflects to a large degree the dominant logic, while incorporating elements of other competing logics that had been accommodated. These structures are now so embedded in the regime that they eventually become taken-for-granted and invisible (Star and Bowker, 2006; Star and Ruhleder, 1996). At this point the boundary object loses its ambiguity, and therefore, it is not a bridge, but a merged area of institutional logics. By definition, it ceases to be a boundary object and loses relevance for future transformations of the regime. In our own words, the regime *emancipates* from the boundary object's influence.

2.2.7. Phase 7: Emergence of residuals

So far, we have seen how the boundary object slowly transforms from ambiguous to concrete. However, some aspects of the boundary object resist the standardization—no logic manages to make them concrete. These remaining regions of ambiguous space are marginalized and become newborn, independent boundary objects, or what Star (2010) calls *residual categories*, which are available to trigger a new transition.

3. Empirical application of the framework

3.1. Data collection and analysis

The sustainability transition selected for empirical application of our framework is the transformation of the stormwater management regime of the municipality of Copenhagen (Denmark) from approximately the year 2007–2019. During this period, the regime experienced a significant change in its policies and practices, reflecting a new configuration of logics. This case study shows how the transition was accelerated and oriented through the instrumental use of a boundary object—*climate change adaptation* (CCA).

The case study compromised collection and analysis of secondary and primary data, construction of a chronological narrative of the case's key developments including actor perspectives and strategies and, finally, analysis of this narrative using the boundary objects in sustainability transitions framework developed in Section 2.

The secondary data included a desktop review of existing academic literature related to our case, newspaper articles, videos of conference presentations, legislation, industry reports and municipal agencies' planning documents. Especially relevant were the transcripts of four interviews conducted by Steffensen (2013) in 2012 that made it possible to contrast old and new narratives, providing evidence of the regime transition. All this information was analysed with the software NVIVO 11 (Bazeley and Jackson, 2013). The content of the data was first coded to identify individual elements (like *hydraulic logic* or *storytelling*), the codes were then grouped into the framework's descriptive categories (like *institutional logics* or *actor strategies*), and finally, classified into themes (corresponding with the framework's seven phases). Primary data included eight semi-structured interviews conducted in December 2018 and January 2019 with actors that had an active role in the stormwater sector of Copenhagen during the period 2008 – 2018. The participants were selected via the snowball method, which particularly addressed key gaps in the narrative constructed from the other data sources (Table 2). When all the chronological gaps were filled and the analysis reached saturation point (Guest et al., 2006) the data collection and interviewing process concluded. These new interviews were transcribed and coded in the same fashion as the secondary data. Finally, the interpretation of the case study was validated by the interviewees, who had the opportunity to read a draft of the article and provided feedback.

3.2. Defining the case and its institutional logics

To categorize the diversity of institutional logics that were present in the stormwater management regime during the period of study, we have focused on the classification of institutional logics created by Fuenfschilling and Truffer (2014) for urban water management systems in industrialized countries, which includes: the *hydraulic logic*, the *water sensitive logic* and the *market logic*. These are ideal types, meaning they are caricatures of existing logics—simplistic and generalizable static models—that serve as heuristic tools for empirical analysis (Doty and Glick, 1994). The reality is, of course, much more nuanced. Within Copenhagen's stormwater sector, actors had values and worldviews that do not perfectly fit within those three logics, but there is a general alignment.

This socio-technical transitions occurring in urban water have been previously described (Brown et al., 2009; de Haan et al., 2015), suggesting that urban water regimes are evolving from technocratic regimes focused on large-scale infrastructures and rigid institutions—which can be identified by the dominance of a hydraulic logic—towards adaptive, reflexive and resilient regimes that focus on distributed and integrated infrastructures and institutions—which can be identified by the dominance of a water sensitive logic.

The hydraulic logic has a public welfare orientation based on the protection of people and goods from damages inflicted by stormwater, which is considered a nuisance. To fulfil its mission, this logic takes an eminently mechanistic approach to control nature; stormwater must be conveyed, pumped, or stored with large, centralized and robust infrastructures that, being mainly buried underground, are invisible to citizens. The most direct representative of the hydraulic logic in the municipality of Copenhagen has traditionally been the water utility. This organization stands out for technical competence for design and management of the infrastructure and their members are mostly engineers. Their mission is simple and well-defined. In the words of a utility staff member interviewed in 2012: "Actually, our only objective it to guarantee that all the water is conveyed away" (interview #3).

The water sensitive logic is closely related to a still ill-defined stormwater paradigm that has been emerging during the last two decades (see e.g. Novotny and Brown, 2014; Pahl-Wostl et al., 2011, 2006; Pinkham, 1999). This logic has a clear orientation towards environmentalism, sustainability, adaptation, resilience, and ultimately, enhanced livability. To fulfil that goal, the logic is

Table 1
List of interviews.

Source	Interviewee and role
Secondary data (Steffensen, 2013)	#1 Manager in the technical and environmental department of the municipality of Copenhagen (hereafter simply referred as the environmental department)
	#2 Project leader in the economic department of the municipality
	#3 Project leader in the water utility
	#4 Project leader in urban development department of the municipality
Primary data (2018−2019)	#5 Manager in the environmental department of the municipality
	#6 Researcher from Aalborg University with focus on CCA in Copenhagen
	#7 Manager in the environmental department of the municipality
	#8 Manager of the water utility
	#9 Leader of a neighbour's association
	#10 Project leader in the environmental department of the municipality
	#11 Researcher from Aalborg University with focus on CCA in Copenhagen
	#12 Manager in the environmental department of the municipality

underpinned by a complex and systemic understanding of reality that considers a wide range of confronting and synergistic needs that must be integrated. Contrasting with the hydraulic logic, the water sensitive logic does not see stormwater as a nuisance, but rather as a resource that can deliver recreational, aesthetic, environmental or even health benefits to the city. The water sensitive logic suggests an experimental and integrative approach that adapts to nature, mixing traditional and low-technology infrastructures—both under and above the ground, both grey and green—that provide a multiplicity of services. The most salient advocates of the water sensitive logic in Copenhagen belong to a small group of champions from the *technical and environmental administration of the municipality* (hereafter simply referred as the *environmental department*). From an agency perspective, this case study describes how these actors purposefully use the idea of CCA (the boundary object) to accelerate and orient the regime transition towards a configuration that clearly reflects the water sensitive logic.

Finally, market logic has played an important role in Copenhagen's transition. In this logic, the municipality is understood as a corporation, whose objective is to maximize the benefits (socioeconomic optimality) of their shareholders (the citizens). Here, stormwater is an economic issue, primarily focusing on the costs of its management and the potential economic damages of flood. The market logic is especially popular at the political level of the municipality as it provides a widely accepted framing for decision-making.

3.3. CCA and Copenhagen's transition to the water sensitive logic

We now present the chronology of how Copenhagen's stormwater management transition unfolded, organized and interpreted through the seven phases of the boundary object's life cycle (Fig. 2). Table 3 (located at the end of section 3) presents a summary of this analysis, as well as key definitions of the concepts involved. Table 1 (also located at the end of section 3) summarizes the most relevant actions carried out to use boundary objects instrumentally in the transition.

3.3.1. Phase 1: Emergence of climate change adaptation (CCA) as a boundary object

Before the 2000s, it was a widespread belief that developed countries would be marginally affected by climate change, thanks to their low vulnerability and adaptive capacity (Moser and Ekstrom, 2010). However, the publication of the IPCC (2007) report was a critical moment that marked the emergence of climate change adaptation (CCA) as a global agenda. In 2008—when CCA was non-existent in the Copenhagen municipality's plans, and narrowly defined as an issue of flood prevention in the water utility plans—two managers of the environmental department represented the City of Copenhagen at an international climate change conference, where they became inspired by the adaptation plans of other cities like London, Rotterdam or New York. Back in Copenhagen, these two managers championed the adaptation agenda, trying to convince the local government to start working on a CCA plan, and indirectly using it as "leverage for greening the city" (interview #10). However, the idea was rejected with the argument that the municipality should focus instead on mitigating climate change. In Copenhagen's 2009 Climate Plan (CM, 2009), mitigation was indeed the main issue, but CCA was timidly introduced for the first time in the municipality plans as a small subchapter, although no concrete measures were described. The environmental department champions opted then for the strategy of building interest and legitimacy for CCA by inviting representatives from the aforementioned cities to present their work, and from there, politicians gave commitment to start working on Copenhagen's CCA plan, which was finished during the first half of 2011. At that point CCA was effectively introduced in the municipality plans, forming a boundary object.

3.3.2. Phase 2: Emergence of a cloudburst as a disruption

On 2 July 2011, the most intense cloudburst ever recorded in Copenhagen hit the city centre, with 135 mm (one quarter of the average yearly rainfall) measured in only 2 h (Beredskabsstyrelsen, 2012), causing significant damage to public and private infrastructures. Insurance companies reported that more than one third of the building owners in the municipality filed insurance claims, exceeding a total of EUR 800 million (Arnbjerg-Nielsen et al., 2015).

Table 2
The framework's main theoretical concepts and their associated case study interpretations.

Phase	Key concept	Theoretical description	Case study interpretations
#1. Emergence of a boundary object	Regime	A more or less stable amalgam of different institutional logics that yield a semi-coherent set of rules	The stormwater management regime of Copenhagen
	Institutional logics (or simply *logics*)	Distinguishable rationalities, with their characteristics system of interests, values and worldviews that support and constrain action in a particular direction	Hydraulic logic, market logic, water sensitive logic (adapted from Fuenfschilling and Truffer, 2014)
	Dominant logic	The logic that imbues the majority of the regime's structures	Before the cloudburst, the rules of the regime were strongly influenced by the hydraulic logic
	Boundary object	A signifier (e.g. a word or physical artefact) with interpretive flexibility, susceptible to accept multiple signifieds (meanings or translations)	CCA emerges outside the regime. Initially, there is little agreement across logics about what it means in practice.
	Actors	Individuals or organizations that belong to a regime and draw on one or several institutional logics	For example, the environmental department of the municipality, the economic department, the water utility, local politicians, and neighbour associations
#2. Emergence of a disruption	Disruption	An event that disturbs the normal operation of the socio-technical system	The cloudburst event of 2 July 2011
#3. Articulation of a selection pressure	Selection pressure	The shared realization that a disruption calls into question the capacity of the current socio-technical system to carry out its function	The City of Copenhagen is suddenly perceived as highly vulnerable to climate change (which manifests as cloudbursts)
#4. Integration of a boundary object and emergence of multiple translations	Integration	The boundary object is presented as the right response to the selection pressure (it is integrated) even though its meaning is still ambiguous	CCA is identified as the right response to avoid catastrophic effects of another cloudburst; however, there is not general agreement on what CCA involves
	Translation (T_1, T_2, T_n)	Signifieds for the boundary object, i.e. concrete meaning to the boundary object according to each institutional logic	The hydraulic logic translates CCA as a hydraulic solution. The water sensitive logic translates CCA as an opportunity to improve the city's amenity. The market logic translates CCA as an economic solution and opportunity
#5. Dominance of the ambiguous space	Ambiguous space	The use of a boundary object without being attached to any concrete or well-defined signified (meaning)	The earliest use of climate change adaptation did not have a concrete meaning
#6. Standardization and emancipation	Standards	New elements of the socio-technical system that constrain the range of action by actors. They are instantiations of one institutional logic's translation	CCA materializes in the form of new rules and infrastructures that mostly instantiate the water sensitive logic (e.g. green, visible and multifunctional infrastructures)
	Emancipation	Disconnection of the new regime from the transformative influence of the boundary object	New standards are taken for granted and not seen in direct connection with CCA anymore
#7. Emergence of residuals	Residual	Remaining regions of the ambiguous space that no logic manage to concretize, becoming new boundary objects	The link between economic growth and environmental objectives is not described by the CCA narrative; the *green shift* boundary object gives a response to this need

3.3.3. Phase 3: Articulation of the cloudburst as a selection pressure

The day after the cloudburst, members of the Danish Meteorological Institute hurried to announce that the cloudburst could not be linked with certainty to climate change; however, they confirmed, this kind of event could be more common in the future (DMI, 2011). Despite this announcement and probably compelled by the need for a plausible explanation for what had just happened, the media, municipality staff and the government immediately accepted that the cloudburst was a confirmation and direct consequence of climate change, implying that a new cloudburst would happen again in the near future.

The cloudburst, an isolated disruptive event, was socially articulated as a newly discovered risk; in other words, a selection pressure that required an urgent response. Brown et al. (2011, p. 4044) call this a situation of political risk: "Politicians, state agencies and large corporations considered they had no other option than to 'take action', that external pressures led them to a position where they had to be seen to be doing something and quickly". According to a manager of the water utility (2018) "both [the mayor of the environmental department and the municipality mayor] took turns on getting on TV and promising the people 'here we are doing something'" (interview #8). Another member of the environmental department confessed in 2019 that some municipality workers referred to the cloudburst of 2011 as the "fundraising rain" (interview #12).

From being an almost irrelevant concept prior to the cloudburst, CCA became an extremely popular issue in Copenhagen. It was a recurrent topic in the media and the number of reports from a variety of institutions about climate change, floods and greening of the city exploded in 2012 (Krawack and Madsen, 2013). As a staff member of the environmental department put it in 2012 "Climate change adaptation is the talk of the town" (interview #2). It might seem self-evident that the cloudburst would become attached to CCA and transform into a selection pressure. However, in reality, this is far from inevitable; Lyons et al. (2018) found that the

Table 3
Summary of agents' strategic use of boundary objects to accelerate and orient sustainability transitions.

Phase	Theoretical description of agency	Agency in the case study
#1. Emergence of a boundary object	*Introduction of a boundary object in the regime* and building up its legitimacy	Some actors of the environmental department championed the idea of CCA (the boundary object) in the municipality plans, supported by actors from other major cities
#2. Emergence of a disruption	The emergence of a disruption is rarely something that is under the influence of the regime actors	The occurrence of the cloudburst was not an event that could be controlled by actors
#3. Articulation of a selection pressure	*Creation of a narrative* in which the disruption becomes a selection pressure that forces decision-makers to act	Creation of the narrative where the cloudburst is a direct effect of climate change, which becomes an emerging threat to a vulnerable city; something must be done
	Promotion of the boundary object as a solution for the new selection pressure that is appealing and ill-defined in general use	Promotion of CCA as a solution for the problem of vulnerability of the City of Copenhagen
	Creation of multiple translations of the boundary object that are well-defined inside an institutional logic	The hydraulic, the market and the water sensitive logics each create their translations of climate change adaptation
	Claiming "ownership" of the boundary object	The environmental department actively contributed to build and strong association between itself, CCA, and the water sensitive logic translation
	Storytelling. Diffusion and promotion of a translation	Advocates of the water sensitive logic carried out *communication tasks* to publicize their translation of CCA as a positive message of common interest, innovation, and sustainability, which motivated political power to support them with resources
	Accommodation of other logics	Advocates of the water sensitive logic fitted their translation to the interests of hydraulic and market logics
	Creation of obligatory passage points. Create new regime's structures that all actors must follow in order to engage in collaborative work	The environmental department gained responsibility for coordinating the cloudburst management plan, becoming in practice an obligatory passage point
#6. Standardization and emancipation	*Creation of standards*, which unambiguously define the meaning of the boundary object	The environmental department had responsibility for defining the characteristics of the new stormwater infrastructures
	Creation demonstration projects	Demonstration projects like the Climate Neighbourhood (Klimakvarter) became a reification of CCA
#7. Emergence of residuals	The emergence of residuals is an unintended effect that under certain circumstances could be exploited to create a new boundary object	The link between economic growth and environmental objectives is not described by CCA; the *green shift* boundary object gives a response to this need

association of extreme weather events with climate beliefs heavily depends on the previously existing logics.

In the case of Copenhagen, CCA functioned well as a boundary object for several reasons. First, because it provided a sensible and useful narrative that everybody could agree with in a moment of confusion and urgency—nobody could be against CCA, it was a *nirvana* concept (Molle, 2008). Second, it was accommodated in the current international and scientific landscape, which gave it legitimacy. And third, it provided interpretive flexibility for different logics.

Advocates of the water sensitive logic quickly recognized the cloudburst and the sudden interest for CCA as a window of opportunity to drive their agenda: "We ride on a wave and suddenly it disappears if we do not make some radical changes" (interview #4 in 2012).

3.3.4. Phase 4: Integration of the boundary object (CCA) and emergence of multiple translations

Advocates of the hydraulic logic translated CCA as a matter of coping with increasing volumes of stormwater by systematically increasing the size of the buried pipes. However, already in 2008, Copenhagen's water utility showed some features of the water sensitive logic, acknowledging that the traditional hydraulic logic approach was not fully sustainable. For instance, the municipal master plan for wastewater (CM, 2008) proposed to limit the amount of stormwater entering the combined pipes, mainly to protect the sanitary service by preventing the overflow of combined volumes of stormwater and wastewater. The plan recommended that as much stormwater as possible should be managed locally by infiltration, retained on surface where it caused little damage or redirected on surface to nearby lakes or streams.

The water sensitive logic translation of CCA was inspired by what the environmental department champions learned in the international conference in 2008. They recognized there that CCA could be seen as an opportunity to make changes in the urban space and improve the liveability. The following paragraph from the Copenhagen's CCA Plan of 2011 summarizes the approach:

> The work on climate adaptation offers us a unique opportunity to develop Copenhagen to continue to be one of the world's best cities to live in. By choosing solutions that improve the city's physical environment and create attractive urban spaces in relation to residence, transport and experiences, we can use climate adaptation efforts to raise the quality of life of the people of Copenhagen (CM, 2011a, p. 57).

At that time, this positive approach was innovative, but has become more widely acknowledged in academic literature and in practice over the last decade (Aylett, 2015; Shaw et al., 2014). However, in 2011 the conversion of this CCA understanding into practical measures was still unclear. At this point, "the interpretation space for what the new concept of stormwater management, namely climate adaptation, actually covers, is still open for negotiation" (Steffensen, 2013, p. 12).

The environmental department champions also pointed out in their 2012 interviews that in the period just after the cloudburst, it was important to manage the urgency and panic because the regime did not automatically turn away from the hydraulic logic and initially resorted to the construction of large pipes. This backlash—which has been widely documented in other case studies (see e.g. Rogers et al., 2015)—is illustrated in an appendix (CM, 2011b) to the wastewater master plan (CM, 2008). This document was released as an emergency response to the cloudburst, aiming to implement urgent adaptation measures before the next "cloudburst season" (CM, 2011b, p. 7), expected in summer 2012. This appendix is of strictly hydraulic character, proposing new pipes to directly convey stormwater to the sea, reopening and creating new wastewater overflows to the harbour, and using parks and small lakes to store stormwater until the capacity of the wastewater system recovered from the storm.

At the same time, strong political pressure resulted in the rapid creation of a cloudburst management plan (CM, 2012), which provided greater concretization to the water sensitive translation. This document mostly promoted local management of stormwater at the surface: creation of green boulevards, redesign of recreational areas and daylighting of streams. The objective was not to completely substitute the old underground system, which would be unrealistic, but instead to develop a whole new system of integrated surface solutions. These solutions should be able to handle cloudbursts and also provide multiple functions when it is not raining—like recreational and aesthetic value, enhanced biodiversity, or improved physical and psychological health of the citizens—while, at the same time, deferring the augmentation of the underground pipe network. From the perspective of the water sensitive logic this type of management was an opportunity to revitalize the city and make it greener.

However, this translation was not unproblematic. During the last century stormwater was managed underground, where it was invisible and isolated from other urban services. Bringing stormwater to the surface meant that its management would overlap with multiple societal functions that compete and collaborate in a shared urban space, making the situation much more complex and potentially conflicted. For instance, residential developers complained about the space taken by infrastructures inspired by the water sensitive logic—like raingardens and swales—and car owners were concerned that these infrastructures would reduce the space dedicated to parking or that the use of roads as floodways would create new risks and disturb the traffic during the storms. Another group that viewed the surface solutions with distrust was the municipal department in charge of water quality of the city's water bodies. They considered that the road's runoff under light rainfall was too polluted to be diverted to the lakes and streams and they advocated for the use of the traditional underground system that conveyed stormwater to wastewater treatment plants.

While the water utility became gradually receptive to the introduction of surface management of stormwater—they saw it as an inevitable measure to maintain the hydraulic efficiency of the sewers—the approach's complexity motivated them to occasionally turn back to old, well-known and simpler solutions: "if things are too complicated on the ground, the natural response, so the backbone response of the [water] utility can be very often to say: 'ok, let's put a pipe underground'" (interview #6).

The third logic, the market logic, was in principle closer to the hydraulic logic, as the reduction of flood damages by traditional underground infrastructures was seen as an economic priority; however, the water sensitive logic interpretation of CCA as an opportunity quickly captured its attention. The core market logic narrative was that a new surface-based approach to stormwater management would ultimately serve as a tool for economic growth. The ambition was that innovative green infrastructures would make Copenhagen an international leader in sustainability; an attractive city for investment, tourism and specialized workers that would, in turn, contribute to economic development. Additionally, the new stormwater management would make the city a showroom for export of Danish technology and design (CM, 2015, p. 14).

3.3.5. *Phase 5: Dominance of the ambiguous space*

The framework's four actor strategies for asserting dominance over the ambiguous space were at play in the Copenhagen case. As described earlier, the environmental department champions lobbied for the introduction of CCA into the municipal plans because they recognized that it was a useful tool to boost their water sensitive logic agenda, while it did not receive great attention from other logics. "[At the conference] we grasped that it was a really interesting task and there was nobody that would take it" (interview #1). The environmental department became the unofficial *owner* of CCA; they actively contributed to fix the association between the concept, the environmental department, and the water sensitive translation across the regime.

It certainly was a stroke of luck that the cloudburst hit exactly when the CCA Plan (CM, 2011a)—guided by the environmental department—was about to be released. Before that, the city planners estimated that it would take some years to gather the necessary political and economic support for the plan to be implemented. Instead, it immediately jumped to the top of the political agenda.

Right after the cloudburst, advocates of the water sensitive logic intensively publicized their translation of CCA at municipal, national and international arenas as a positive message of common interest, innovation and sustainability. The environmental department internally referred to this labour as *communication tasks* (Steffensen, 2013), which were mainly carried out by champions through their already established networks. An environmental department manager recognized in 2019 that "doing the storytelling about what adaptation could bring, also of positive things to the city, was a reason why it was easy… not easy, but it was possible for us to get to a political decision" (interview #12). Even though other frontrunner cities like New York or Rotterdam also worked very hard to impose the water sensitive translation of CCA—even taking into account that New York also had a great disruptive event (Hurricane Sandy in 2012)—this interviewee claimed that Copenhagen made a faster transition because they may have been better at "telling the story".

Another environmental department staff member refers to the storytelling strategy of his colleague: "She told the tale that we are going to green the city, that we are going to make exports, that we are going to help building the roads new […] she hyped this very much […] she also went onto the international scheme, or in the international discussions on this, and used the success that she had already gained to hype it even more". Internationally, the environmental department staff members participated in many conferences and events where they presented their CCA plans as a case of success. As they drew international attention towards Copenhagen, these champions tapped into the positive self-image of local decision-makers. Several interviewees remark that politicians were proud of their projected identity, and they were pressed to meet the expectations created in those adaptation plans through generous support and resourcing.

At the same time, the water sensitive logic champions tried to build synergies with other logics and with the overarching political agenda of the municipality. In the words of an environmental department manager in 2012: “It is really a matter of trying to understand and get into those you talk to [...], why are they here [...] and try to understand how this [our translation of CCA] can support any issue of their agenda” (interview #1). The *accommodation* of the hydraulic logic and market logic into the water sensitive logic translation were two essential processes in the transition. The narrative provided by the water sensitive logic was not fanatic, had an inclusive character, and constantly referred to the CCA as both a hydraulic and economic issue. From a hydraulic logic perspective, the water utility assumed that surface management of stormwater was necessary to cope with increasing stormwater volumes and reduce the load of the sewers to protect its sanitary function. Meanwhile, the accommodation of the market logic was based on two narratives: one, that surface management was cheaper than traditional underground infrastructures, and two, that CCA would bring net economic gains for the city through additional benefits like pollution removal, rises in property values, tourism or increased employment (CM, 2014). It could be said that part of the success consisted in making other logics join the path marked by the water sensitive logic without obliging them to abandon their original identity. For instance, a manager of the environmental department reflected on the logic of the water utility in 2019: “Well, they [the water utility] are still thinking very much hydraulic, that is their goal, because that is what they need to do. They are just thinking about hydraulic issues in a different way” (interview #12).

Regarding other competing interests, water sensitive logic advocates always insisted on finding synergistic solutions. For example, even though the traffic department was, in principle, sceptical of the use of roads as floodways, the environmental department champions convinced them that CCA was actually an opportunity to renew and improve the roads network. Another environmental department staff member (2019) commented on the accommodation labour of one of his colleagues: “she was good to work the system in many angles and make of this a story were we all benefited” (interview #5). Evidence of the successful integration of translations is the immediate approval of the cloudburst management plan (CM, 2012) in the city parliament, without debate and with unanimous support.

This accommodation of other logics was not an easy process and should not be taken for granted. For example, previous environmental plans in Copenhagen, like the development of Agenda 21, were carried out exclusively by the environmental department, with very little interest in involving other municipal agencies. This department was viewed with mistrust by other agencies, which labelled their members as narrow-minded, as they put environmental concerns above any other problem (technical or economic), inhibiting collaboration and ultimately resulting in limited success (Jensen et al., 2013).

All the previous work converted the water sensitive logic advocates into *obligatory passage points*, gatekeepers of a sort, which funnelled and guided the collaboration network. For example, the environmental department was granted responsibility for the subsequent cloudburst plans (CM, 2012), which will shape the transformation of the city over the following 20 years.

3.3.6. Phase 6: Standardization and emancipation

An important part of the concretization work led by the environmental department was to define *standard parameters* for future infrastructures that were imbued with the water sensitive logic (see e.g. CM, 2013). For example, it was required that new infrastructure should be as green, visible, and multifunctional as possible. In addition, projects should provide a net socioeconomic benefit for the whole community and create synergies with other projects or municipal plans.

Soon after the cloudburst, the water sensitive logic advocates recognized that their translation needed to be materialized into *demonstration projects* to give some tangible support to their narrative. Some interdisciplinary predictive models were developed to represent the solutions being promoted (Fryd et al., 2012), but the most publicized demonstration project was Skt. Kjelds neighbourhood, renamed as the Climate Neighbourhood (Klimakvarter), which was selected to be a frontrunner in the city's CCA. It was devised as a symbolic project that encompassed all the characteristics of the water sensitive logic, served as a platform for interdisciplinary experimentation and learning, and it was presented internationally as a showroom of exportable innovations (CM, 2016). The idea of the Climate Neighbourhood attracted international attention and has already been exported to other cities like New York and Beijing.

The ultimate concretization of the water sensitive logic translation was the political approval for implementing the cloudburst management plan for the next 20 years, which includes 300 stormwater management projects with a budget of EUR 1.3 billion (Ziersen et al., 2017).

An environmental department manager interviewed in 2019 believes that planning processes guided by the water sensitive logic have become rooted in the municipality and are increasingly being taken for granted, but the corresponding design and implementation of infrastructures are still maturing. Nonetheless, she recognizes that this assimilation will eventually occur, as it has for Copenhagen's bicycle infrastructure:

> In the beginning, when you started building bicycle lanes: ‘oh, where are the cars going to be?’ and so on. And now, nobody questions [...] that you need to have a bicycle infrastructure in place almost before anything. When it is snowing in Copenhagen you clean the bicycle lanes before you clean the street [...] So it is really, really embedded in the DNA, both in the management and in the construction that is going on in the city. [Climate change] Adaptation is so new that we are still, I mean, starting walking. A bit insecure, and sometimes stumbles (interview #12).

However, at a certain point it is likely that the new social structures will become so firmly rooted in the regime that they will *emancipate* from the boundary object. Unfortunately, the timeframe of our case study does not allow us to empirically confirm this hypothesis, but it could be argued that previous boundary objects used in Copenhagen's stormwater sector have been emancipated. For example, *ecosystem protection* (a previous boundary object) was firmly materialized as a formal requirement for phosphorus removal and reduction of sewer overflows (Sørensen et al., 2006), which are now taken for granted and have a limited presence in today's public debate.

3.3.7. Phase 7: Emergence of residuals

Looking back, we could argue that CCA was a residual of climate change mitigation, and climate change mitigation was a residual of sustainability, both of which encompassed the region of ambiguousness that its predecessor could not materialize. We suggest that in the case of CCA, the residual ambiguity might be the link between green infrastructures, quality of life and economic growth, which is difficult to concretize. However, this ambiguity is valuable, as the different logics can cooperate without giving up their own interests and assumptions. The "green shift" or "green economy" (grønn omstilling) (Floater et al., 2014) is a new boundary object that has arisen in Copenhagen in the last years, functioning as an excellent nirvana concept and a renewed expression of the ecological modernization philosophy (Jensen et al., 2013).

4. Discussion and conclusion

In this article, we have presented the Copenhagen case study as an empirical and comprehensive application of a new framework for explaining the role of boundary objects in sustainability transitions (BOIST) (Table 3). The framework supports a narrative that describes how the concept of CCA (a boundary object) was introduced by advocates of the water sensitive logic as leverage to slowly transform Copenhagen into a greener city. However, the occurrence of a catastrophic cloudburst (a disruption) led to a sudden emergence of fear for climate change and urgency for adaptation of the stormwater system (a selection pressure). CCA rapidly gained public salience and the different logics started to shape their particular interpretations (translations). Advocates of the water sensitive logic effectively diffused their translation of the concept, promoting their story, accommodating values and interests from other logics, and carrying out demonstration projects that concretize the regime transformation, imposing the vision of livability over the narrower vision of hydraulic efficiency.

The framework provides two simultaneous levels of analysis for this case study. First, at the systemic level, where a socio-technical transition is understood as a reconfiguration of the regime's institutional logics, triggered by a boundary object; a transition from the absolute dominance of the hydraulic logic to a more balanced configuration of logics. The second is an analysis at the agency level, showing how actors purposefully use boundary objects to (1) articulate a selection pressure, (2) concentrate the necessary resources to make effective a socio-technical transition, and, most importantly, (3) build cooperation across conflicting logics. The framework demonstrates how a boundary object behaves as coalescent element in sustainability transitions, serving as a point of agreement and cooperation for disparate institutional logics without constraining their valuable diversity. The environmental, livability, hydraulic and economic perspectives are each able to develop their disparate translations of CCA, while still engaging in collaborative work.

Our case study has been selected to empirically demonstrate the deductively constructed framework, and in other practical applications some elements may not be as easily identifiable. Most notably, our case study happens to portray a sudden and well-defined disruption, the cloudburst, which is well suited for our demonstration purposes. However, the framework does not exclude the possibility that also minor or very gradual changes (minor disruptions) can be hyped by boundary spanners, articulating them as selection pressures that require urgent action. For example, before the cloudburst, climate change was articulated in Copenhagen as a very gradual selection pressure that demanded a reduction in greenhouse gas emissions. To address this need, the environmental department created the Copenhagen's Bicycle Strategy 2011–2025, which focused on the boundary object "World's best bicycle city" (CM, 2011c). This ambiguous vision managed to coalesce the interests of not only the environmental logic, but also that of mobility, public health, economic, political, and not least, the livability logic. From 2010 to 2018 the percentage of citizens using bike transportation increased from 36 to 62 % (CM, 2019) and Copenhagen has repeatedly ranked between the most livable cities of the world, partly thanks to its bicycle culture (Nikel, 2019).

Therefore, we argue that the proposed framework may improve the understanding of highly placed-based transitions—as, we assume, boundary objects are involved in many of them. At the same time, it may help to identify actor strategies or policies to drive these transitions in a certain direction, for example through introducing useful boundary objects, translating them, diffusing them or using them to accommodate conflicting logics. In more academic terms, we believe that our framework is a solid starting point for a new range of studies that focus on the role of boundary objects in transition management, both contributing to the growing application of institutional theory (Fuenfschilling, 2019) and the emerging focus on agency perspectives (e.g. Fischer and Newig, 2016; Wittmayer et al., 2017) in the field of sustainability transitions.

However, it is also important to recognize that transitions are complex phenomena that cannot be completely explained by a simple framework of reduced scope like ours (Holtz, 2011). Our research—both for explanatory and policy design purposes—may be integrated into larger simulation models that attempt to reproduce possible pathways in which a transition can unfold (de Haan et al., 2011; de Haan and Rogers, 2019; de Haan and Rotmans, 2011), or even be combined with models from other disciplines to inform strategic planning (Rauch et al., 2015), constituting a promising idea for future research.

Our globalized society is relentlessly increasing its diversity and complexity, generating interdependent, unstructured, and pervasive problems that create new conflicts among an expanding number of logics. While in the past—with limited diversity and complexity—the definition of problems and selection of solutions used to be undisputed, already today and more intensely in the future, the difficult accommodation of disparate goals, values and worldviews may pose a serious barrier for sustainability transitions. Therefore, we anticipate that boundary objects will become increasingly relevant, and hope that our framework becomes a valuable conceptual element in the toolkit of sustainability transitions.

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Appendix B: Co-author statements

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DECLARATION OF CO-AUTHORSHIP

Manuel Franco Torres apply for the evaluation of the following thesis:

Framing urban water

*)The declaration should describe the work process and division of labor, **specifically identifying the candidate's contribution**, as well as give consent to the article being included in the thesis.

Declaration of co-authorship on the following article:

Franco-Torres, Manuel, Briony C. Rogers, and Robin Harder. "Articulating the new urban water paradigm." *Critical Reviews in Environmental Science and Technology* (2020): 1-47.

Manuel Franco-Torres was the main author of article. Franco-Torres conceived the idea of describing the new urban water paradigm in contrast with the old paradigm and the design of the explanatory framework for paradigm analysis. Franco-Torres selected the methodology, carried out the meta-synthesis and wrote the paper. Franco-Torres also produced all figures and tables.

Briony Rogers provided concrete feedback (comments and edits), particularly contributing to the structure of the paper and conclusions. Rogers also made language editing.

Robin Harder provided concrete and continuous feedback (comments and edits), particularly contributing to refining the analytical framework, the structure of the paper, and provision of additional sources for the meta-synthesis.

I hereby declare that this article can form part of the named thesis by the PhD. Candidate Manuel Franco-Torres

…Melbourne, 10/11/2021…..
Place, date

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Signature co-author
Briony C. Rogers

Declaration of co-authorship on the following article:

Franco-Torres, Manuel, Briony C. Rogers, and Rita M. Ugarelli. "A framework to explain the role of boundary objects in sustainability transitions." *Environmental Innovation and Societal Transitions* 36 (2020): 34-48.

Manuel Franco-Torres was the main author of the article. Franco-Torres identified the compromise between variety of logics and cooperation needs among logics in the urban water sector, conceived the idea of a theory of how boundary objects could help to overcome this challenge, and completed the case study of Copenhagen. Franco-Torres selected the methodology, carried out the literature review and interviews, and wrote the article. Franco-Torres also produced all figures and tables.

Briony C. Rogers contributed with valuable discussions that helped to identify the knowledge gap. Rogers provided concrete feedback for all the versions of the article, commented and edited the article and suggested changes in its structure. Rogers also made language editing.

Rita M. Ugarelli provided comments to the article.

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Uppsala, 8 November 2021	R Harder
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Place, date	Signature co-author Robin Harder

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Ragnhild Kvålshaugen commented and edited the article, and contributed with changes in its structure.

Rita M. Ugarelli contributed with the identification of the knowledge gap and provided comments during the writing process.

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