


Review

Urban Adaptation to Climate Change State of the Art: Evaluating the Role of Adaptation Assessment Frameworks through a Systematic and Bibliometric Analysis

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Abstract: Urban adaptation and resilience are essential aspects of climate change. The latest IPCC reports of 2022 recall the importance of taking concrete actions, especially through the implementation of actions able to make cities more resilient. However, the current scientific discourse predominantly revolves around policies, theoretical aspects and specific case studies. This study aims to provide an updated analysis of the existing scientific literature, with an additional focus on the role of assessment and monitoring frameworks in urban adaptation. By employing qualitative and quantitative methodologies, supported by VOSviewer for co-occurrence network analysis, this paper reveals novel clusters and thematic groupings within the ongoing debate. Results include the identification of new clusters and thematic grouping and the identification of potential future trends.

Keywords: urban climate adaptation; adaptation monitoring; adaptation assessment; bibliometric review; systematic review



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1. Introduction

Urban adaptation is a key aspect of climate change studies and actions. According to the European Climate Adapt program (<https://climate-adapt.eea.europa.eu/>, accessed on 20 June 2023), urban adaptation can be defined as “the process of adjustment to the actual or expected climate and climate hazards, seeking to reduce the negative impacts or exploit beneficial opportunities”. This definition doesn’t differ from the more general Climate Adaptation concept, which is defined by the 2014’s IPCC report [1] and recalled in the 2020’s EEA Report [2] as “the process of adjusting to actual or expected changes in the climate and its effects. In human systems (e.g., urban areas), adaptation seeks to moderate or avoid harm or exploit beneficial opportunities”.

Urban adaptation can be understood as the specific application of the broader concept of climate adaptation to the urban context. Urban adaptation and climate adaptation share similarities, both emphasizing the need for adjusting to altered circumstances. Crucially, urban adaptation recognizes the necessity for cities to undertake a process of adjustment in response to changes, aiming to restore or achieve a desired state.

Moreover, both urban adaptation and climate adaptation definitions seem to overlap with the concepts of urban resilience and climate resilience. According to Meerow et al. and many other researchers [3–6], the concept of urban resilience arises from the socio-ecological domain as a strategy to provide operative support for solving sustainable management issues on complex systems. It has been considered useful for its application to the complexity of urban contexts [7,8] and transposed into urban studies as a key aspect of cities’ response to climate change. The review performed by Meerow et al. [3] can be considered a key contribution to the conceptualization of the topic. They also provide a new definition of urban resilience which takes into consideration six key conceptual aspects:

- The first one is the concept of equilibrium, which is recurrent in post-disaster contributions and disaster management topics. According to this science, there are different

types of equilibrium: single-state, multiple-state and dynamic non-equilibrium. According to the authors, urban resilience scholarship is tending to assume the multi or non-equilibrium concepts, evidencing that many states of equilibrium can exist in cities and communities simultaneously (as claimed also by [9]). Others even affirm that cities are constantly changing, thus there isn't a real state of equilibrium to be considered [5,10].

- The second point is the idea that resilience is a positive concept. The authors refer to the existence of a debate about the positiveness of the resilience concept, especially in consideration of the return of the urban context to a previous condition that might not be desirable. Even if the debate is present, it is generally assumed that resilience is desirable and contributes to cities' sustainability.
- The third critical aspect is the inclusion of the three more common pathways to a resilient state (persistence, transition and transformation) in the urban resilience concept, meaning that urban resilience can produce a return to a previous urban condition or a change in the urban structure. Some contributions on this topic are provided by [4,11–15].
- The concepts of adaptation and adaptability including considerations of short-term adaptation and long-term or general adaptability.
- The timescale of actions, referring to the rapidity of recovery.
- The specificities of the urban dimension, which are complex, interrelated and dynamic systems.

The definition proposed by Meerow et al. is the following: "Urban resilience refers to the ability of an urban system and all its constituent socio-ecological and socio-technical networks across temporal and spatial scales to maintain or rapidly return to desired functions in the face of a disturbance, to adapt to change, and to quickly transform systems that limit current or future adaptive capacity" [3]. Two additional key interesting aspects:

- This definition highlights the fundamental "ability" that urban systems must possess to respond to changes, encompassing the entire urban context and its socio-ecological and socio-technical networks. This ability is the starting point for all definitions of urban adaptation and resilience; however, it is not clear how cities can truly acquire it. Some reflections and strategies are present (e.g., in [16–20]) to support cities in finding this starting point, but there is no consensus on what exactly frames it.
- The second aspect highlighted is the ability cities should have to be resilient, which is commonly recognized in the fast return to a previous situation (recovery) or the implementation of a change in the systems to adapt to the new condition. This second part of the definition is more agreed upon in the international debate as it characterizes adaptation and resilience strategies.

These aspects are further emphasized in one of the last reports on adaptation produced by IPCC [21], which links together not only climate and all ecosystems (including biodiversity and urban areas) but also human society. The report confirms the central role that cities played in climate change and, specifically, in adaptation, recalling how, in urban contexts, climate change produces impacts on human health, livelihood and infrastructures and focusing on some of the main cited phenomena such as heatwaves and air pollution. The need of maintaining the surface average temperature lower than 1.5 °C is set in the report together with the assessment of the current mitigation pathway. As it is written under the point SPM.C.1, adaptation measures have been put in place unfairly around the globe and not considering the long-term impacts. Indeed, the commitment around adaptation is more linked to policies (with the spread also of decision support tools) than to the implementation of concrete actions and it is usually directed at solving immediate or short-term climate problems [21,22]. There is a need to spread adaptation strategies taking into account medium and long-term changes, especially in the form of operative roadmaps and through pilot interventions. To support the action, it is crucial to provide and define a shared assessment and monitoring framework. According to Brown et al. [23], much

academic and grey literature is present in the context of monitoring and evaluation of urban climate resilience and adaptation initiatives, but no common approach is still present.

In this broad context, the paper aims to investigate the current debate around urban climate adaptation with a look at the role that assessment and monitoring frameworks have. It is structured in five sections. The first one investigates the urban adaptation scientific literature through a qualitative approach, to identify the research questions. The second one describes the methodology used to conduct the quantitative analysis, the Section 3 provides the results of both the systematic literature review and the co-occurrence network analysis in VOSviewer. The fourth and last sections provide a discussion and a conclusion of the contribution.

In this study, urban adaptation and urban resilience are used almost as synonyms, adopting the previously cited definitions of IPCC and Meerow et al. However, the study recognizes the broader nature of the urban adaptation concept, which is linked with global sustainability and climate change, and the more specific one of the resilience concept, linked with local urban systems. Resilience seems to be very strongly associated with concepts such as specific shocks, stresses, vulnerabilities, etc. [24,25].

2. Qualitative Literature Review and Research Questions

Urban adaptation and resilience have been key topics in the scientific debate about climate change since the beginning of the new century. According to Einecker and Kirby [26], the climate change discourse has included in itself both a general scientific production and a specific one about mitigation, adaptation and resilience since around 2010. The climate change general production sees slow and constant growth since the 1990s, with preliminary appearances and with acceleration after 2006–2008, while the three topics of mitigation, adaptation and resilience seem present in the debate mostly from 2006.

According to several authors [26–31], the scientific discourse on climate change can be traced back to the second half of the previous century. Early contributions, primarily from a climatological perspective, began to discuss global warming and greenhouse gas emissions. Notably, Wang et al. [32] made significant contributions in the 1970s. In 1965, scientists from the US President's Science Advisory Committee published a report titled "Restoring the Quality of Our Environment", which highlighted concerns about rising atmospheric temperatures and established an initial link to CO₂ concentration. In 1972, the Club of Rome commissioned the report "The Limit of Growth", which reported insights into the availability of resources on the planet. The same year the Stockholm conference adopted a declaration stating the need to protect natural resources. In 1987, the Brundlant Report "Our common future" defined Sustainable Development as a balance among economy, ecology and equity. From these preliminary and quite well-known moments of recognition of the climate change discourse, many additional scientific contributions can be traced. A very interesting one is provided by Jeremy Leggett [33] in his viewpoint published in Energy Policy in 1991. The author answered to the first IPCC report which was stating the global warming problem and was providing projections for the future. Leggett supported the report also providing some mind maps about the potential future policies that mankind would have taken to answer this challenge. Another important prescient contribution, this time on the topic of adaptation, has been provided by Mark Meo [34], who discussed from a policy perspective the impacts of climate change in the Tennessee Valley Authority reservoir system and Apalachicola Bay. According to [26], the adaptation debate has been slower at the beginning compared to the mitigation one, also due to contrasting opinions claiming that adaptation was less scientific and efficient, being just an illusory and late response to climate changes (see, for example, the opinion of Al Gore [35] contained in his book "Earth in the Balance: Ecology and the Human Spirit"). It is in 2007, that Pielke and colleagues started to claim, through a publication in Nature, that adaptation was part of the climate change response and not just a late attempt to solve climate issues [26,36].

Since then, the growth of climate change scientific production and its distinction in mitigation and adaptation discourses has been constant, with an acceleration around

2009–2010. Even if with differences, the three specific topics seem growing together at a slightly higher speed than the general climate change one. Still the study of [26] reports also the number of publications derived from the Web of Science database under the period 1991–2019 divided into the three topics of adaptation, mitigation and resilience. According to them, the adaptation discourse in the period seems bigger than the others (27,318 results compared with the 15,275 of mitigation, and 10,311 of resilience). However, the attention given to the adaptation discourse seems to be consistent in a more recent period. This is also the point stated by many other researchers such as [37,38]. Similarly, the resilience concept seems to be the most recent one, maybe appearing as a consequence of the Katrina impact in the USA in 2005 [26,36,39].

Going further into the adaptation and resilience discourse from a thematic point of view, it is possible to trace a multiplicity of elements that have been included in this debate. Many authors tried to divide the topics of resilience and adaptation into sub-topics. According to Yang et al. [39], for example, the resilience contributions applied to the urban dimension cover mainly the following aspects: system characteristics (see for example [40–42]), construction [10,43,44], evaluation index system, and, finally, policies [45]. Also Guo et al. [46] identified some clustering, providing ten more precise sub-topics for urban resilience, namely: urban floods, urban ecosystem services, urban landscapes, trauma, agency, conceptual models, transition, common property systems, urban regeneration, and wildland-urban interface. Although this analysis is accurate, there is a mix of typologies of themes: the authors mixed for example methodological approaches with adaptation themes.

In this paper, a refinement of this subdivision is provided acknowledging that urban adaptation studies have many sub-topics and that these can be divided into different aspects. An interesting perspective is provided by the number of studies deepening assessment frameworks and evaluation aspects of adaptation and resilience. Since urban adaptation has been identified as a crucial aspect to be considered, many studies emerged on the topic of assessment and measurement [47–49]. Although these studies seem to be less abundant than the theoretical ones, it is possible to see that there is a growing debate on them. A deep analysis of the state of the art, together with a deep evaluation of policies and actions is crucial to support cities in defining their priorities. Indeed, according to Chen et al., “Prioritization [...] helps leverage resources to address relevant climate risks” [50]. This point is also raised by [47] in the framework of the H2020 project RESCCUE (RESilience to cope with Climate Change in Urban arEas).

There are many typologies of adaptation assessment frameworks. Generally, they are composed of a step-by-step approach (or at least by some guidelines or procedures) and they include indicators or indices. According to [49], current existing frameworks propose several typologies of indicators, namely: indicators of climate exposure, vulnerability, risk or resilience (this is probably the most used ones), context-specific indicators of adaptation interventions (used for measuring specific actions or policies), standard adaptation indicators of portfolios (for example global or national frameworks), comparative global indices (usually used for ranking countries). Another subdivision is provided by [47]. The authors acknowledge the presence of four main adaptation assessment methods: the cost-effectiveness analysis (CEA) linking together impacts and investments; multi-criteria analysis (MCA) which is used for scoring systems and for determining the potential accomplishment of an objective policy or action; risks reduction assessment which, as the name recall, are useful for assessing risks in its triangular declination of hazard, vulnerability and exposure; cost-benefit analysis (CBA) which also links impacts and investments but in a comparative way. Of course, to perform these types of analyses data are needed. As posited by [51], the availability and collection of locally based data is one of the main challenges to meeting the objectives of climate adaptation.

Inside this topic, an innovative perspective is provided by subjective measures. According to [52], subjective analysis can provide a deeper understanding of resilience. Common assessment instruments tend to deconstruct the topic in many sub-domains and then re-

compose them in indices. Conversely, subjective analysis takes into account perceptions, opinions, preferences or self-assessments of individuals, supporting a more holistic analysis of the phenomenon.

The synthetic background literature review presented here demonstrates the diversity of approaches in both the general concept of urban adaptation and its specific assessments. Bibliometric analyses of the debate are present but not very recent and do not cover recent years. They don't seem to cover the role and weight of assessment literature in the whole urban adaptation debate. Additionally, the common subdivision of the scientific production on urban adaptation includes many aspects of the discipline, mixing results, assumptions and methods. Therefore, this paper seeks to address some of the existing gaps by providing a bibliometric review of the urban adaptation topic, focusing on its connection with two key elements:

- an updated understanding of the urban adaptation topic inside the scientific production and through the identification of sub-themes divided per typology;
- the weight that assessment and monitoring frameworks are currently having in the general urban adaptation debate.

The objective of the paper is to review the literature on urban adaptation, including the most recent one, and provide reflections for the prosecution of the research on the topic.

Hence, the research questions (RQs) that form the basis of this review paper are as follows:

- RQ1: How is the current urban adaptation debate framed and what are the main aspects covered?
- RQ2: What is the role of assessment and monitoring frameworks inside the broader context of urban adaptation studies?

3. Materials and Methods

Following the methodology recalled by Zheng et al. [53] and many authors [54–56], hybrid techniques were used to perform the analysis, mixing both qualitative and quantitative approaches. This review paper provides a mixed approach, using qualitative and quantitative methods. The qualitative one has been used to produce the background literature review described in Section 2 and it was aimed at identifying the research questions. For this part, relevant papers have been selected from the main scientific databases, namely Scopus, Web of Science and Google Scholar. In particular, bibliometric and review studies have been selected at first and these led to other publications.

To support the investigation around the research questions a more quantitative approach has been used. In particular, two methods have been adopted: a systematic review and a bibliometric analysis. The systematic review has been performed in a limited database of 202 publications, with the support of Zotero and the Nested Knowledge web tool; while the bibliometric research has been performed within four additional and larger queries providing collections of scientific production and the use of the VOS viewer tool (Table 1).

Table 1. Detail of the literature search on Scopus for the bibliometric analysis.

Query Wording	Details	N° of Papers
"Urban" AND "Climate" AND "adaptation"	In Title, Abstract, Keywords	3021 (after refining)
"Urban" AND "Climate adaptation"	In Title, Abstract, Keywords	659 (after refining)
"Urban" AND "Adaptation" AND "monitoring"	In Title, Abstract, Keywords	1711 (after refining)
"Urban" AND "Adaptation" AND "assessment"	In Title, Abstract, Keywords	2635 (after refining)

Scopus was selected as the main source for both methodologies, primarily due to its reputation for indexing high-quality and peer-reviewed papers, as well as its extensive coverage of the urban adaptation topic. Scopus was selected as the main source for both

methodologies, primarily due to its reputation for indexing high-quality and peer-reviewed papers, as well as its extensive coverage of the urban adaptation topic. It is worth noting that in future publications, the inclusion of other databases, such as Web of Science, will be considered, as mentioned in the Section 6.

3.1. Systematic Review with Zotero and NESTED Knowledge

The systematic literature review has been performed to answer to the first research questions and, thus, to evidence the current state of the art of the urban adaptation scientific production. After some iterations, the selected query to the Scopus database has been “urban adaptation” in title, abstract and keywords. The query provided a database of 323 contributions. After a preliminary refinement in the platform, a .csv and .ris database of 202 articles has been considered. The refinement in Scopus consisted in selecting only English contributions and excluding scientific fields not relevant to this study (namely all medical, genetic, and chemistry fields). The database has then been imported into the Nested Knowledge online platform (<https://nested-knowledge.com/>, accessed on 20 June 2023). This platform allows a smoother process while performing systematic literature reviews. Although its functionalities can go quite deep, only screening, tagging and qualitative analysis have been used. In particular, the database composed of 202 articles has been uploaded into the platform; exclusion criteria have been defined (see Table 2 as well as a hierarchy of tags. According to these, all articles have been manually screened and either excluded or assigned to one or more tags. This preliminary phase allowed the refinement of the database into 140 papers that have been deeper read and analysed. The tags hierarchy has been iteratively updated until the final ones, as reported in Appendix A.

Table 2. Exclusion criteria and the number of papers excluded.

Exclusion Criteria	N° of Papers
Out-of-topic contributions for scientific field reasons: medical or historical or agricultural or animal related studies	9
Out-of-topic contributions for focus/paper aims reasons: papers not related to the urban dimension and/or not related to climate adaptation	39
Not enough information (absence of the abstract)	12
Entire proceedings or special issues	2
Total	62

Therefore, all 202 articles were screened and selected by manually reading their title, abstract and keywords. Table 2 records the exclusion criteria and the number of papers excluded. At the end of the first analysis, 140 papers were left for tagging and deeper reading. Among these 140 papers, the most cited 10 and the most recent 10 have been extensively reported in the paper (Tables 5 and 6). In the next sections, those selections are further presented and discussed.

3.2. Bibliometric Methodology

To answer the second research question and verify the findings of the systematic review, a bibliometric approach has been followed. Different queries have been identified and performed, as reported in Table 2. This literature search was conducted between January and April 2023, with a final check for new papers on the 9 June 2023.

Different trials and phases occurred during the literature search. The first two were general searches including “urban” and “climate adaptation” in the title, abstract and keywords. This was important to understand the general response of the database and to check the big picture of the topic, also in relation to the systematic literature review performed before. After this general search, which produced the first bibliometric insights, more precise queries were performed including different types of wording, namely adding

“monitoring” and “assessment” to the general query. Table 2 reports the different search phases with the related numbers, after the refinement inside the Scopus platform. The refinement consisted in selecting only English contributions and excluding scientific fields not relevant to this study (namely all medical, genetic, and chemistry fields).

According to many authors [57,58], a bibliometric analysis is a research method that involves the systematic examination of publication data to gain valuable insights into patterns, trends, and relationships within the scholarly literature. By utilizing statistical analysis, bibliometric studies provide quantitative assessments of various aspects, such as citation counts, authorship patterns, and journal impact factors. Within this methodology, this paper only focuses on the co-occurrence of keywords to trace trends and domains. The aspects related to co-authorship networks, journal impact factors, recurrent journals and their networks have been left outside this study and will be presented in a future publication.

To perform the bibliometric analysis (consisting in this case mainly of the co-occurrence of keywords) the VOS viewer tool was used. VOSviewer [59] is an open-source software, freely available and downloadable for all operating systems (<https://www.vosviewer.com/>, accessed on 13 May 2023). Many papers were published recently with the use of VOSviewer in many fields of research [60–63].

The software allows for correlating terms referred to in the literature such as terms included in titles and abstracts but also authors and journals. The software can also perform a cleaning process by adding Thesaurus files. This file was created for each of the analyses performed and was added to the tool to avoid duplications, double counting, normalized abbreviations, etc. After having obtained the first results, clusterization parameters were changed in order to obtain a relevant number of clusters and, thus, more relevant maps. Unless otherwise specified, all analyses conducted using VOSviewer aimed to generate maps illustrating the co-occurrence of terms in titles, abstracts, and author keywords. The input files utilized were bibliographic database files downloaded from Scopus. Binary counting was chosen to prevent duplicate counting of terms within the same paper.

4. Results

In this section, a comprehensive yet concise overview of the key findings from the analysis is provided. The section is organized into subsections, each presenting the results obtained from a specific query.

4.1. Systematic Analysis of the Urban Adaptation General Query (140 Papers)

The systematic analysis performed in the database of 140 refinement papers evidenced the presence of multiple aspects composing the urban adaptation topic. The papers were clustered through a personalized tagging hierarchy. The tags were refined iteratively during this phase (see Figure A1 in Appendix A). What emerges from this analysis is the presence of a multi-layered and complex debate about the topic. Indeed, the articles appear to be divided into multiple levels of themes and topics.

The first stage of distinction sees four macro-levels (Table 3):

- a thematic distinction of the main focus of the contributions;
- a distinction based on specific interventions or actions proposed by the studies;
- different types of results provided;
- the presence of specific case studies and frameworks of the studies.

Table 3. The first grouping of the 140 papers. Note that each paper can be inserted into more than one group.

Grouping (Macro-Level)	N° of Papers	% on the Total
Thematic level	88	62.9%
Innovation Typologies Level	42	30%
Results Typologies Level	140	100%
Implementation Level	97	69.3%

The first group, from now called the Thematic Level, collects the different focus themes of each contribution. Inside this macro-group, there are papers focusing on specific adaptation aspects (such as specific risks) but also on themes such as land cover, social equity and policies.

The second group, from now called the Innovation Typologies Level, collects papers that describe and provide analysis of specific strategies, pilot technologies, and roadmaps as the core part of the study.

The third group, from now called the Results Typologies Level, classifies and collects the different typologies of results that the studies propose.

Finally, the fourth group, from now called the Implementation Level, includes all the papers that referred to specific case studies and/or specific projects (e.g., European projects).

Table 3 shows the number of studies included in each of the groups. Of course, each contribution can be clusterized into multiple groups.

The initial grouping of papers reveals some key aspects:

- The majority of papers (62.9%) focus on a specific theme. A deeper analysis of the cluster is necessary to understand the main themes emerging from this analysis. Papers excluded from this cluster were mainly comparative studies, included in the Implementation Level (e.g., papers comparing case studies on multiple themes).
- A smaller yet noteworthy portion of papers (30%) is dedicated to exploring highly specific strategies, such as particular technologies or architectural aspects, showcasing the focused nature of these studies.
- The majority of papers (69.3%) feature a case study or a selection of case studies, indicating that most papers in the selected database describe or analyze the implementation of specific actions and approaches in real-world contexts.
- Finally, as studies display various forms of results, papers have also been classified according to the type of yielded result (see Section 4.1.3).

The following paragraphs will deepen each cluster, providing more details.

4.1.1. Thematic Level

The majority of papers have been categorized into specific thematic groups, revealing five prominent themes. These include:

- Adaptation-related studies, comprising the largest cluster, centered around specific adaptation practices. Sub-themes within this cluster explore topics such as land cover, health and climate adaptation, adaptation policies and planning, and specific aspects of urban systems resilience (including studies on risks, uncertainties, heatwaves, heat islands, extreme events, water management, floods, droughts, and coastal areas).
- Urban and social equity-related studies, which also encompass investigations of people's perceptions of climate adaptation.
- Studies examining the correlation between mitigation and adaptation, offering reflections on the interplay between these two aspects.
- Studies focusing on finance and funding mechanisms for adaptation strategies, shedding light on the financial considerations and mechanisms associated with implementing adaptation measures.

- Studies providing insights into data and knowledge creation for climate adaptation, exploring the generation and utilization of knowledge in the context of climate adaptation. For a detailed breakdown of these themes and their respective sub-clusters, see Table 4.

Table 4. Details on group 1, Thematic Group, and its sub-groups.

Thematic Group Subdivision	Sub-Groups	N° of Papers	% on the Total
Adaptation related studies (total of 63 papers, 45%)	Land cover	3	2.1%
	Health	3	2.1%
	Adaptation policies and planning	28	20%
	Specific aspects of urban systems' resilience (including both risks and specific studies on heatwaves, heat islands, heat stresses, extreme events, water management, floods and droughts, and issues related to coastal areas)	38	27.1%
Urban and social equity-related studies (total of 28 papers, 30%)	Urban equity/social equity and justice	23	16.4%
	People's perception on climate adaptation	5	3.6%
Correlation between mitigation and adaptation	No sub-groups	3	2.1%
Finance and funding	No sub-groups	3	2.1%
Data and knowledge creation	No sub-groups	1	0.7%

As it is possible to see in the table, the majority of papers are part of the specific resilient sub-group, which provide general insights on risk, uncertainty and vulnerability concepts [50,64] and specific expressions of adaptation and resilience. It is, for example, the case of Larson et al. [65], who discusses the complexities and uncertainties of water resource sustainability in urban areas facing climate change and also provides insights on a decision support tool, or Aroua [66], who highlights the potential vulnerability of urban ecosystems due to inadequate management and social interventions, specifically related to sub-aerial exposure, water-related hazards, sensitivity, and adaptation ability. Other interesting studies included in the groups focus on heat events and extreme heat events [67–71]; precipitation and floodings [72–77]; sea level rise and coastal areas issues [78–80].

The contributions about finance and funding mechanisms are also quite interesting, even if small in number, as this is perceived as an important topic for the concrete implementation of actions [81,82].

Finally, it is also interesting to note that even though there is only one publication focusing mainly on data and knowledge, this is also a key topic. The paper of Torres et al. [83] focusing on the case of São Paulo, identifies data and knowledge gaps that hinder implementation and emphasizes the need for a change in the status quo through planning, governance processes, social learning, and justice to effectively address climate change.

4.1.2. Innovation Typologies Level

Within this group, numerous noteworthy contributions propose and evaluate strategies and methods to enhance urban adaptation. The group is divided into two subgroups, namely:

- Participative practices and multi-level governance: This subgroup consists of 24 contributions that highlight the significance of participation in improving the climate adaptation of communities and cities. These studies emphasize the involvement of both citizens and stakeholders [17,20,69,84–87]. Klein et al. provide an interesting approach by examining the role of the private sector [20].
- Physical interventions and technologies: This sub-group includes 19 contributions that focus on specific strategies for climate change adaptation. These strategies encompass

various aspects such as cool roofs [71], green infrastructures [88–91], transport [92] and urban architecture and urban form [88,93–95].

The extensive array of research within these subgroups yields valuable insights into the significance of active engagement, effective governance, and tangible interventions for bolstering urban adaptation to climate change.

4.1.3. Results Typologies Level

This group examines the typologies of results provided by the contributions and is further divided into six subgroups:

- **Conceptual frameworks:** This subgroup represents 54% of the total papers and focuses on advancing the topic from a conceptual and theoretical standpoint. These contributions may question social equity, and participation, or provide new perspectives on risks and vulnerability [96–101].
- **Assessment and monitoring frameworks:** Accounting for 12% of the papers, this subgroup proposes frameworks for assessment and monitoring. For instance, Savic et al. [102], conducted an assessment of outdoor thermal comfort, da Silva et al. [77] developed a methodology for sensitive analysis and incorporated Monte Carlo Simulation into a multicriteria decision model, and Shi et al. [103], introduced a composite index applied to China.
- **Roadmaps:** Comprising 8% of the papers, this subgroup focuses on the development of roadmaps that outline pathways and strategies for urban climate adaptation.
- **Scenario creation and simulations:** Representing 5% of the papers, this subgroup explores the creation and utilization of scenarios and simulations to understand potential future outcomes and inform decision-making processes.
- **Modelling and decision support frameworks:** Accounting for 9% of the papers, this subgroup centers on the development of models and frameworks that facilitate decision-making in the context of urban climate adaptation.
- **Comparative studies:** Making up 12% of the papers, this subgroup conducts comparative analyses of case studies, examining similarities and differences across multiple contexts to derive valuable insights and lessons for urban climate adaptation.

By categorizing the contributions into these subgroups, a comprehensive understanding of the range of approaches and focus areas within the field of urban climate adaptation can be achieved.

4.1.4. Implementation Level

The collection of identified papers on urban climate adaptation reveals a diverse array of research, concerning case studies. Within this context, the papers can be broadly categorized into four distinct sub-groups.

The first sub-group encompasses papers that propose strategies and interventions specifically tailored to European Union (EU) cities, constituting 18% of the overall body of literature. These contributions are quite spread across Europe, having representations of UK, Portugal, Bosnia and Herzegovina, Spain, Italy, Austria, Germany, Poland, the Netherlands and the Czech Republic. A compelling example is showcased by Hoeben et al. [104] and Yang et al. [105], present a comparative analysis involving multiple cities.

The second sub-group focuses on case studies from cities outside the EU, representing a significant proportion of 41% of the papers. These studies explore various non-EU urban contexts, presenting valuable insights into the strategies, policies, and practices employed to address climate change impacts and build resilience. Also in this case, there is a spread of cases in Africa (7%), Asia (13.12%), Australia and Oceania (4.1%), North America (10.66%), and South America (8.2%). It is interesting to note that some contributions generally refer to the Global South (4.92%).

The third sub-group contains papers related to European-funded projects, constituting 4% of the studies. These papers often examine the outcomes and lessons learned from specific projects funded by European initiatives or research programs, which con-

tribute to advancing knowledge and understanding of urban climate adaptation within the European context.

Lastly, the fourth sub-group, comprising 3% of the papers, encompasses comparative studies of case studies within transnational networks. These studies investigate the experiences and practices of cities that are part of transnational networks such as the C40 cities or the Covenant of Mayors [106–110].

It is worth noting that while these four sub-groups represent a significant portion of the literature, approximately 34% of the papers do not focus on specific case studies. Instead, they may explore broader theoretical frameworks, methodological approaches, policy analyses, or conceptual discussions that contribute to the overall understanding and advancement of urban climate adaptation as a field of study.

In summary, the range of papers analyzed demonstrates a rich tapestry of research on urban climate adaptation, encompassing EU and non-EU case studies, European-funded projects, transnational networks, and broader thematic explorations.

4.1.5. Analysis of the Most Cited Papers and the Most Recent Ones

This paragraph provides a summary of the 10 most cited papers included in this database (Table 5) and of the 10 most recent ones.

Table 5. List of the 10 most cited papers.

Paper Citation	Year	N° of Citations
Carter, J. G., G. Cavan, A. Connelly, S. Guy, J. Handley, and A. Kazmierczak. 2015. "Climate Change and the City: Building Capacity for Urban Adaptation". <i>Progress in Planning</i> 95: 1–66. [111]	2015	377
Anguelovski, I., L. Shi, E. Chu, D. Gallagher, K. Goh, Z. Lamb, K. Reeve, and H. Teicher. 2016. "Equity Impacts of Urban Land use Planning for Climate Adaptation: Critical Perspectives from the Global North and South". <i>Journal of Planning Education and Research</i> 36(3): 333–348. [112]	2016	289
Birkmann, J., M. Garschagen, F. Kraas, and N. Quang. 2010. "Adaptive Urban Governance: New Challenges for the Second Generation of Urban Adaptation Strategies to Climate Change". <i>Sustainability Science</i> 5 (2): 185–206. [113]	2010	225
Wamsler, C., E. Brink, and C. Rivera. 2013. "Planning for Climate Change in Urban Areas: From Theory to Practice". <i>Journal of Cleaner Production</i> 50: 68–81. [114]	2013	194
Araos, M., L. Berrang-Ford, J. D. Ford, S. E. Austin, R. Biesbroek, and A. Lesnikowski. 2016. "Climate Change Adaptation Planning in Large Cities: A Systematic Global Assessment". <i>Environmental Science and Policy</i> 66: 375–382. [18]	2016	183
Hunter, A. M., N. S. G. Williams, J. P. Rayner, L. Aye, D. Hes, and S. J. Livesley. 2014. "Quantifying the Thermal Performance of Green Façades: A Critical Review". <i>Ecological Engineering</i> 63: 102–113. [115]	2014	160
Archer, D., F. Almansi, M. DiGregorio, D. Roberts, D. Sharma, and D. Syam. 2014. "Moving Towards Inclusive Urban Adaptation: Approaches to Integrating Community-Based Adaptation to Climate Change at City and National Scale". <i>Climate and Development</i> 6 (4): 345–356. [116]	2014	101
Cuce, E. 2017. "Thermal Regulation Impact of Green Walls: An Experimental and Numerical Investigation". <i>Applied Energy</i> 194: 247–254. [117]	2017	100
Mauree, D., E. Naboni, S. Coccolo, A. T. D. Perera, V. M. Nik, and J. -L. Scartezzini. 2019. "A Review of Assessment Methods for the Urban Environment and its Energy Sustainability to Guarantee Climate Adaptation of Future Cities". <i>Renewable and Sustainable Energy Reviews</i> 112: 733–746. [118]	2019	98
Fratini, C. F., G. D. Geldof, J. Kluck, and P. S. Mikkelsen. 2012. "Three Points Approach (3PA) for Urban Flood Risk Management: A Tool to Support Climate Change Adaptation through Transdisciplinarity and Multifunctionality". <i>Urban Water Journal</i> 9 (5): 317–331. [73]	2012	97

The most cited study is by Carter et al. and is from 2015 [111]. It discusses the building of capacity for urban adaptation in the face of climate change, emphasizing the importance of collective action and knowledge sharing among stakeholders. Anguelovski et al. [112], in 2016, provide insights into the equity impacts of urban land use planning for climate adaptation, highlighting the need for inclusive approaches in both the Global North and South. Birkmann et al. [113] focused, in 2010, on the challenges of adaptive urban governance and the development of second-generation adaptation strategies. Wamsler et al. [114], in 2013, explored the practical implementation of climate change planning in urban areas, emphasizing the translation of theory into practice. Araos et al. (2016) [18] conducted a systematic global assessment of climate change adaptation planning in large cities, underscoring the need for context-specific strategies. Their contribution is particularly relevant because it highlights the diversity of approaches taken by cities in response to climate change, including the development of dedicated adaptation plans, integration of adaptation into existing policies, and engagement with stakeholders. It also identifies common challenges such as limited financial resources, governance complexities, and uncertainties associated with future climate projections and it concludes by emphasizing the importance of knowledge sharing and learning across cities to enhance effective adaptation planning. Hunter et al. [115], in 2014, critically reviewed the thermal performance of green facades, providing valuable insights into their role in climate adaptation. This contribution is the only one with Cuce et al. [117] in the selection focusing on a specific strategy, in this case, green façades. Conversely, Archer et al. (2014) [116] examined approaches to integrating community-based adaptation at the city and national scale, recognizing the importance of local participation. As anticipated, Cuce investigated in 2017 the thermal regulation impact of green walls [117]. Mauree et al. [118] conducted in 2019 a comprehensive review of assessment methods for urban energy sustainability and climate adaptation. Finally, the 2012 paper of Fratini et al. [73] proposed a tool, the Three Points Approach (3PA), for urban flood risk management, emphasizing transdisciplinarity and multi-functionality.

Even considering that citations grow over time, it is interesting to notice that the most recent contribution is from 2019 and it concerns assessment methods. The paper from Mauree et al. [118] takes into consideration different assessment methods, including energy modelling, life cycle assessment, carbon footprint analysis, and environmental impact assessment.

Analysing the 10 most recent ones (Table 6), it is evident how the publications offer a diverse range of approaches and contextualizations in the field of urban adaptation even in the past few months. According to Scopus analytics, 62 papers have already been published in 2023, and 131 were published in 2022. While each work addresses a specific aspect (e.g., local based planning approaches [119], tools integration [120,121], prioritization and planning aspects [122], analytical frameworks [123], equity and justice aspects [124–127], nature-based solutions [125–127]) they collectively underscore the importance of adopting comprehensive and long-term based approaches as well as making informed decisions grounded in evidence.

In particular, Liu and Fan [119] explore the factors contributing to local-level institutional adaptation to climate change, focusing on China's Sponge City Program. The study adopts a configurational approach, which examines how different combinations of factors interact to produce specific outcomes. The authors identify key factors that facilitate or hinder institutional adaptation by analyzing empirical evidence from the Sponge City Program. They investigate the interactions between elements such as governance structures, policy instruments, financial resources, and stakeholder engagement. The findings support the role of local governments as institutional entrepreneurs in climate change adaptation, while also highlighting the need to consider institutional capacity, financial resources, incentives, and knowledge as core aspects influencing local adaptation.

Table 6. List of the 10 most recent papers.

Paper Citation	Year	N° of Cit.
Liu, J., Fan, B. 2023. What contributes to local-level institutional adaptation under climate change? A configurational approach based on evidence from China's Sponge City Program, <i>Journal of Environmental Management</i> , 342: 118292. [119]	2023	0
Allard Hans Roest, Gerd Weitkamp, Margo van den Brink, Floris Boogaard, 2023, Mapping spatial opportunities for urban climate adaptation measures in public and private spaces using a GIS-based Decision Support Model, <i>Sustainable Cities and Society</i> , 96: 104651. [120]	2023	0
Waller J. 2023, Stormwater Capital Improvement Planning: A framework for project identification and prioritization for pluvial flood mitigation, <i>Journal of Critical Infrastructure Policy</i> , 3(2), 93–115. [122]	2023	0
Sarah Kehler, S. Jeff Birchall, 2023, Climate change adaptation: How short-term political priorities trample public well-being, <i>Environmental Science & Policy</i> , 146: 144.150. [22]	2023	1
Jinxuan Wang, Karen Foley, 2023, Promoting climate-resilient cities: Developing an attitudinal analytical framework for understanding the relationship between humans and blue-green infrastructure, <i>Environmental Science & Policy</i> , 146, 133–143. [123]	2023	0
Jaekyoung Kim, Junsuk Kang, 2023, AI based temperature reduction effect model of fog cooling for human thermal comfort: Climate adaptation technology, <i>Sustainable Cities and Society</i> , 95: 104574. [121]	2023	0
Ifedotun Victor Aina, Djiby Racine Thiam, Ariel Dinar, 2023, Economics of household preferences for water-saving technologies in urban South Africa, <i>Journal of Environmental Management</i> , 339: 117953 [124]	2023	0
Erich Wolff, Hanna A. Rauf, Perrine Hamel, 2023, Nature-based solutions in informal settlements: A systematic review of projects in Southeast Asian and Pacific countries, <i>Environmental Science & Policy</i> , 145: 275–285. [125]	2023	0
Mahir Yazar, Abigail York, 2023, Nature-based solutions through collective actions for spatial justice in urban green commons, <i>Environmental Science & Policy</i> , 145: 228–237. [126]	2023	0
Robbert P.H. Snep, Judith Klostermann, Mathias Lehner, Ineke Weppelman, 2023, Social housing as focus area for Nature-based Solutions to strengthen urban resilience and justice: Lessons from practice in the Netherlands, <i>Environmental Science & Policy</i> , 145: 164–174. [127]	2023	0

Roest et al. [120] present a GIS-based Decision Support Model for mapping spatial opportunities for urban climate adaptation measures in both public and private spaces. The authors recognize the need for effective strategies to address climate change impacts in urban areas and propose a framework to identify suitable locations for adaptation interventions. The research utilizes geographic information systems (GIS) and incorporates various spatial data sets to assess the potential for implementing climate adaptation measures. The new Decision Support Model provided in the study takes into account factors such as land use, vulnerability, exposure, and accessibility to determine areas with the highest potential for interventions. The study highlights the spatial opportunities available for implementing climate adaptation measures, by identifying suitable locations and by focusing on the importance of data quality. Through the proposed model, decision-makers and urban designers can collaborate and prioritize interventions that maximize their effectiveness and contribute to building more climate-resilient cities.

Waller [122] presents a framework for Stormwater Capital Improvement Planning (SCIP) to address pluvial flood mitigation through a systematic approach for identifying and prioritizing projects to mitigate the impacts of pluvial flooding. The author proposes a multi-criteria decision-making process that considers factors such as flood vulnerability, infrastructure condition, and cost-effectiveness. The framework enables decision-makers to evaluate and compare various flood mitigation projects and prioritize investments based on their potential impact and resource requirements.

Kehler and Birchall [22] investigate the challenges that arise when short-term political priorities overshadow the long-term goal of climate change adaptation, ultimately affecting public well-being. The publication highlights the importance of considering the long-term consequences of policy decisions related to climate change and emphasizes the need for greater integration of sustainability principles into political decision-making processes. By examining case studies and analyzing the impacts of short-term thinking on climate change adaptation efforts, the authors provide insights into the potential risks and consequences

of prioritizing immediate gains over long-term resilience. This contribution is significant in the theoretical aspects of the urban climate adaptation topic.

Wang and Foley [123] focus on the promotion of climate-resilient cities by developing an attitudinal analytical framework that explores the relationship between humans and blue-green infrastructure. The publication emphasizes the importance of understanding public attitudes and perceptions towards nature-based solutions to climate change, such as green spaces, urban forests, and water bodies. By analyzing survey data and conducting qualitative interviews, the authors provide insights into the factors influencing public acceptance, engagement, and behaviour towards blue-green infrastructure.

Kim and Kang [121] focus on urban heat islands and propose an AI-based temperature reduction effect model for fog cooling as a climate adaptation technology to enhance human thermal comfort in urban areas. The publication highlights the increasing need for innovative solutions to mitigate the adverse impacts of rising temperatures in cities. The authors develop a model that utilizes artificial intelligence algorithms to simulate the temperature reduction effects of fog cooling systems, by analyzing the potential cooling benefits and evaluating the energy efficiency of fog cooling technologies.

Using sociological and economic points of view, Aina, Thiam, and Dinar [124] delve into household preferences for water-saving technologies in urban South Africa. The publication investigates the factors influencing households' adoption and willingness to pay for water-saving technologies. This study supports the development of policy interventions able to decrease drought vulnerability in South Africa, especially in urban contexts.

Wolff, Rauf, and Hamel [125] conduct a systematic review of nature-based projects (including community gardens, waterfront revegetation, green open spaces, and wetlands) implemented in informal settlements in Southeast Asian and Pacific countries. The publication highlights the potential but also the challenges of these solutions, which can be funded by very different bodies such as multilateral banks and international agents, as well as born as grassroots initiatives.

Yazar and York [126] delve into the concept of nature-based solutions (NBS) implemented through collective actions to promote spatial justice in urban green commons. The publication highlights the significance of equitable access to and benefits from urban green spaces. By examining case studies and drawing on theoretical frameworks, the authors explore how collective actions, involving collaboration between diverse stakeholders, can enhance spatial justice in the context of nature-based solutions.

Finally, Snep et al. [127] examine the role of social housing as a focal area for implementing nature-based solutions to strengthen urban resilience and justice. The publication specifically focuses on lessons derived from practical experiences in the Netherlands. By analyzing case studies and drawing on insights from stakeholders involved in social housing projects, the authors explore how these solutions can address social and environmental challenges in urban areas, particularly in the context of providing affordable and sustainable housing. In particular, it identifies which solutions best match social housing practices.

From these publications, some trends can be identified: (1) the use of innovative tools (such as GIS and AI) to provide data-based and evidence-based solutions also useful to prioritize urban adaptation interventions; (2) the growing importance of social justice and equity in the implementation of those measures, especially nature-based solutions in vulnerable contexts such as social housing (also in European contexts) and the Global South; (3) the continuous birth of new decision model frameworks and tools aiming to support decisions and showing the lack of a common approach.

4.2. Co-Occurrence Analysis of Urban Adaptation, Monitoring and Assessment

This analysis aimed to provide an updated understanding of the urban adaptation topic and to support both the qualitative and systematic reviews. The VOSviewer software (version 1.6.18) was utilized for this analysis, with each query's papers entered separately in an appropriate format. The analysis focused on word co-occurrence in titles, abstracts, and keywords. Binary counting was applied, with a minimum requirement of five-term co-

occurrences for inclusion in the map. The normalization process employed the association strength method. To enhance the accuracy of the analysis, a cleaning phase was conducted, which involved reviewing all considered words and incorporating a thesaurus file. This step helped eliminate irrelevant terms, including singular and plural words and prevented double counting, such as with abbreviations. Further optimizations were made to determine the optimal number of clusters, with each cluster containing a minimum of 130 words. The results are shown in Figures 1–4. Figures 1 and 2 shows the co-occurrence network maps for the general queries of “urban” AND “adaptation” AND “climate “ (3021 results) and “urban” AND “climate adaptation” (659 results) while Figure 3 shows the query including the word “monitoring” and Figure 4 the query including the word “assessment”.

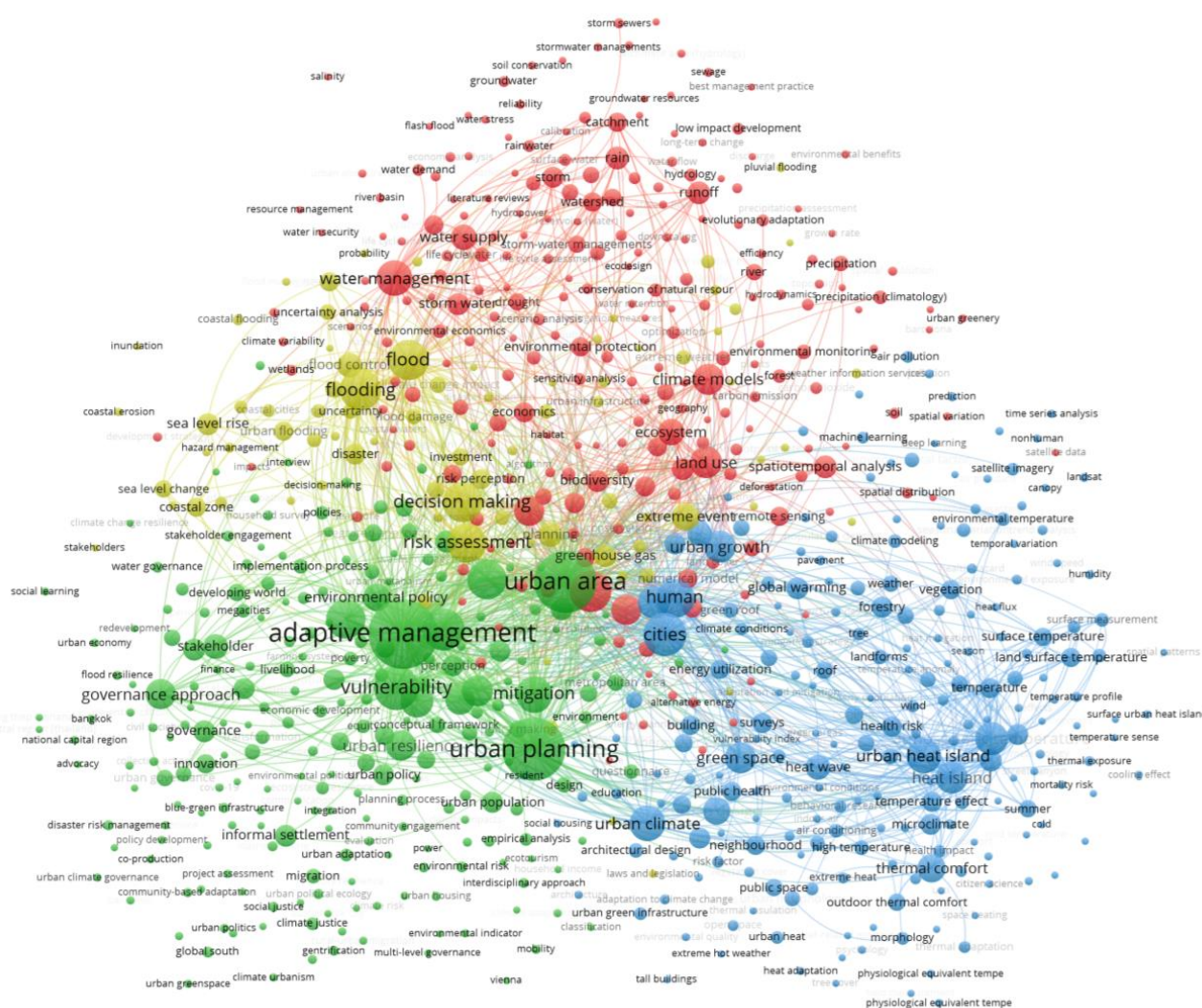


Figure 1. The output of the term co-occurrence analysis for the urban AND climate AND adaptation query, performed in VOSviewer. Network visualization. The figure shows the physical distance among keywords present in titles, abstracts and author keywords, providing clusters of networks of co-occurring terms. Red: land use and water management cluster; green: urban adaptation theories; blue: heat islands; yellow: risk management.

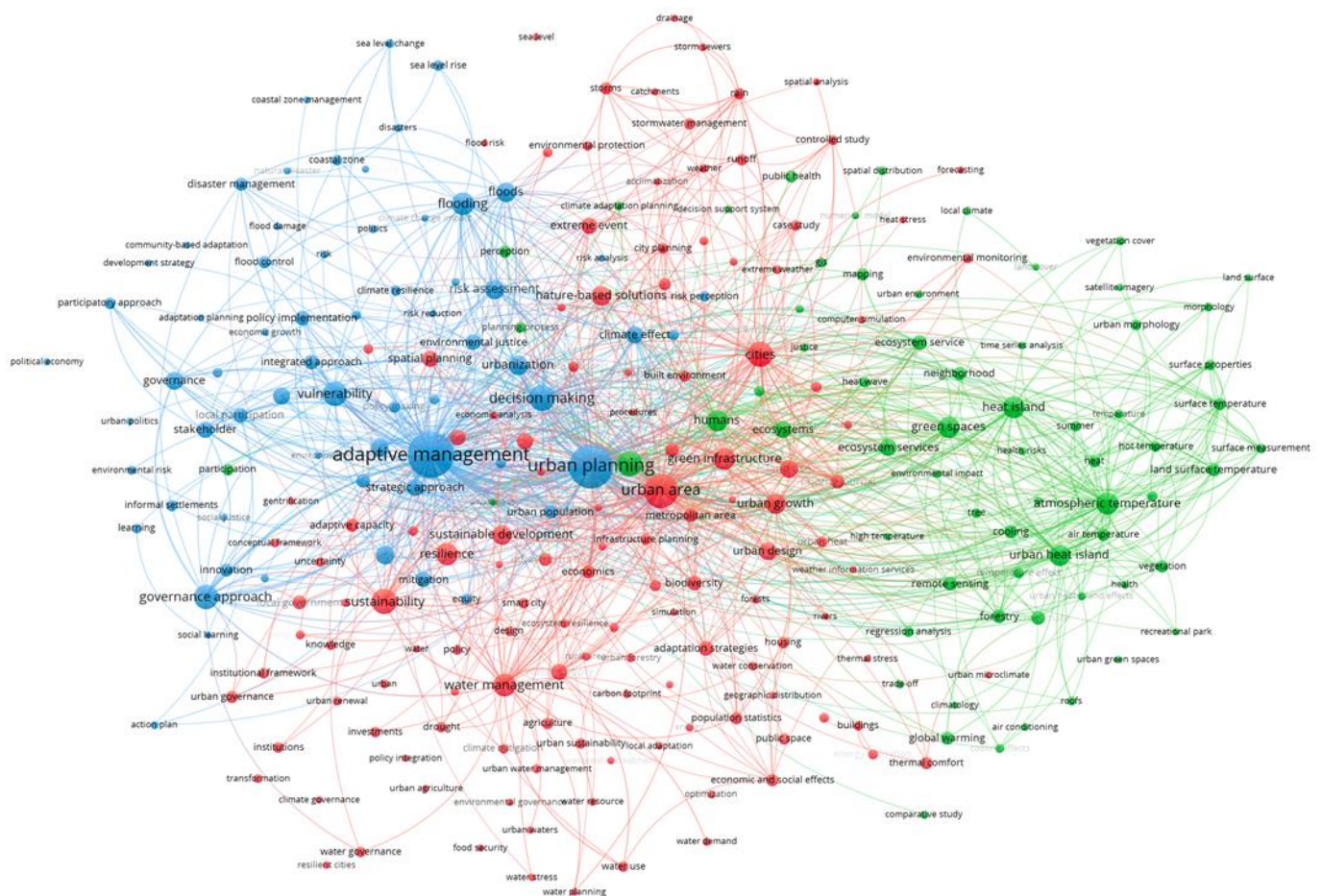


Figure 2. The output of the term co-occurrence analysis for the urban AND climate adaptation query, performed in VOSviewer. Network visualization. The figure shows the physical distance among keywords present in titles, abstracts and author keywords, providing clusters of networks of co-occurring terms. Blue: urban adaptation theories; green: heat islands; red: extreme events.

4.2.1. General Queries of Urban Climate Adaptation

Figures 1 and 2 show the two network maps for the more general queries. These queries have been useful to understand the big picture of the domain and to identify the major clusters. It has been also useful to validate the systematic literature review.

The network presented in Figure 1 reveals the existence of four distinct clusters, each representing specific aspects of the urban adaptation field. The first cluster (232 items—represented in red) encompasses keywords related to water, water management, climate models, and remote sensing. Within this cluster, various water stresses and shocks, such as floods and drainage, are interconnected with elements of climate modelling, including indicators like “carbon dioxide”, “carbon emission”, and “carbon footprint”. The second cluster (228 items—represented in green) focuses on the structural elements of urban adaptation theory. It encompasses keywords like urban planning, mitigation, smart cities, and places a significant emphasis on urban resilience, vulnerability, and governance approaches. It is interesting to note the dimension of some of the terms, such as adaptive management, urban planning and vulnerability. If the words urban planning and vulnerability, but also mitigation and governance, are clearer concerning the topic, the words “adaptive management” deserves attention. Indeed, the concept of adaptive management is key in the environmental and resource conservation field, and it can be dated back to the late 1970s. It has been developed by C.S. Holling and Carl Walters respectively with publications in 1978 [128] and 1986 [129]. According to them, adaptive management involves a deliberate and explicit approach to natural resource management, aiming to enhance knowledge and

minimize uncertainty. According to Rist et al. [130], the concept is still well present in the adaptation debate and this seems to be confirmed by the results of the present study. The third cluster (213 items—represented in blue) primarily contains keywords related to heat, heat islands, temperature, and thermal comfort, with additional indicators relevant to microclimate analysis, such as humidity. This cluster is predominantly associated with urban and human factors. Lastly, the fourth cluster (79 items—represented in yellow) acts as a bridge between the water-related cluster and the theoretical cluster. It includes words related to risks, risk management, floods, and flooding. Overall, this analysis highlights the division of the urban adaptation topic into macro-themes, which aligns with findings from the systematic literature review. These macro aspects encompass theoretical studies, urban microclimate and planning, urban heat island and thermal comfort, climate modelling and analysis, as well as water management and floods.

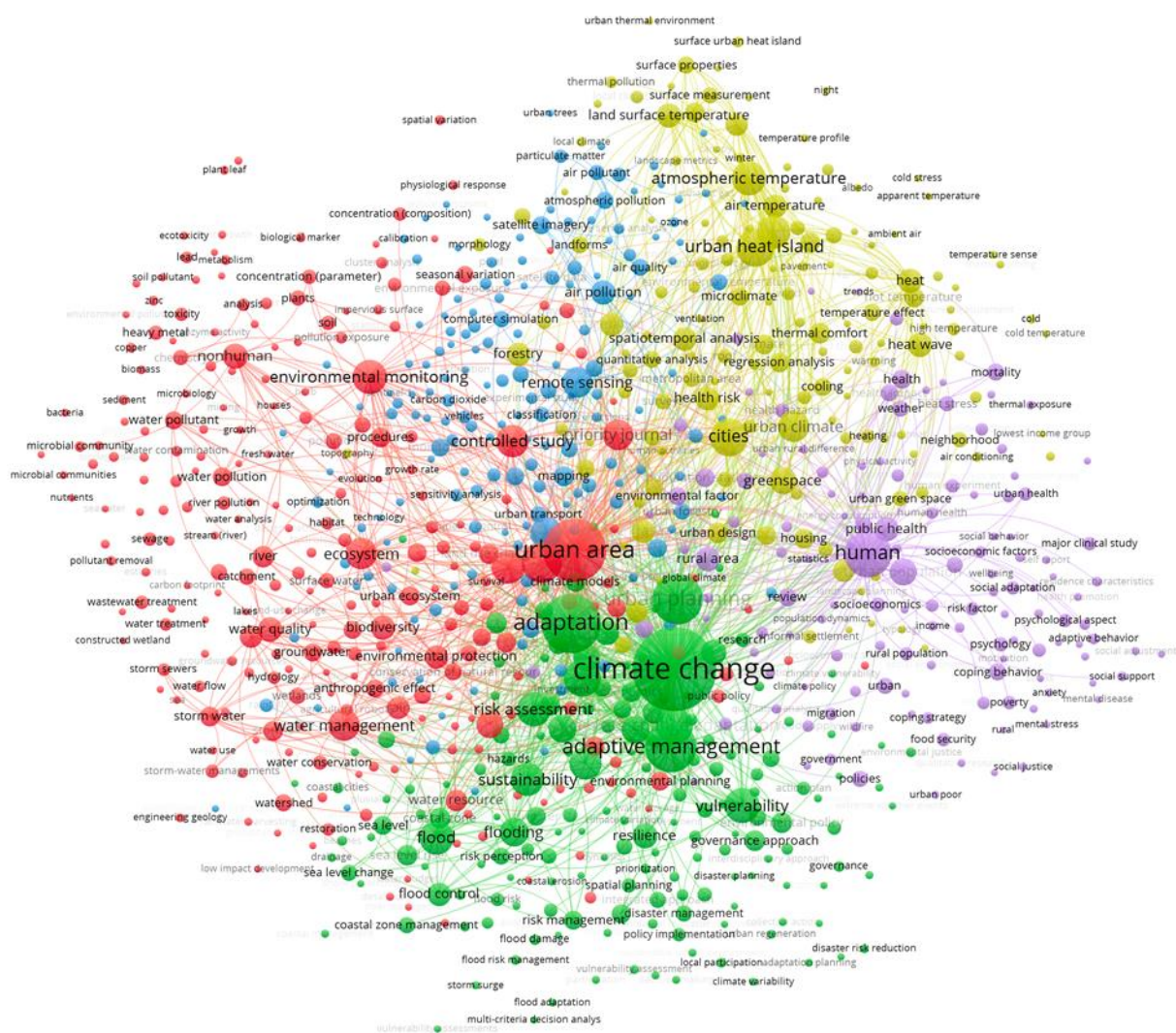


Figure 3. The output of the term co-occurrence analysis for the urban adaptation monitoring query, performed in VOSviewer. Network visualization. The figure shows the physical distance among keywords present in titles, abstracts and author keywords, providing clusters of networks of co-occurring terms. Red: environmental monitoring and water management; green: urban adaptation theories; blue: data, sensing; yellow: heat islands; violet: human and health dimensions.

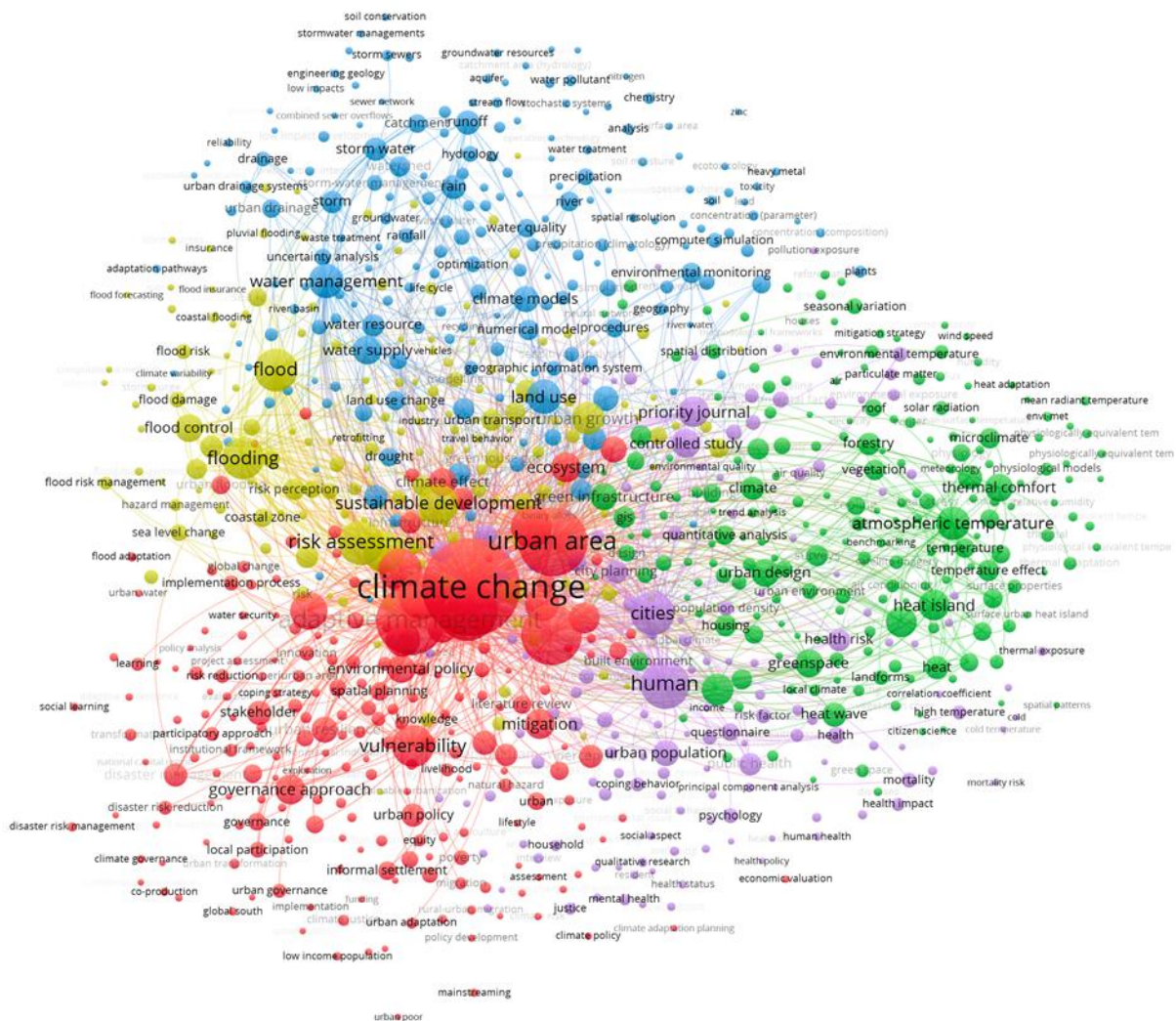


Figure 4. The output of the term co-occurrence analysis for the urban adaptation assessment query, was performed in VOSviewer. Network visualization. The figure shows the physical distance among keywords present in titles, abstracts and author keywords, providing clusters of networks of co-occurring terms. Red: urban adaptation theories; green: microclimate analysis; blue: water management; yellow: floods management; violet: humans and health.

Figure 2 further confirms and supports the previous analysis, revealing the presence of three clusters. The first cluster (130 items—represented in blue) primarily encompasses the theoretical aspects of the field. The second cluster (67 items—represented in green) consists of words related to heat islands, microclimate, urban aspects, and planning. Lastly, the third cluster (64 items—represented in red) is closely tied to specific stresses, shocks, and vulnerabilities associated with extreme events, water management, storms, and related factors.

4.2.2. Specific Queries of Urban Climate Adaptation Monitoring and Assessment

Similarly, Figure 3 depicts the landscape with five distinct clusters. The first cluster (246 items—represented in red) encompasses keywords associated with environmental monitoring and various aspects of water management. The second cluster (169 items—represented in green) revolves around adaptation theory, including terms like “vulnerability”, “risk assessment”, “flood”, “flooding”, and “disaster management”. Moving on, the third cluster (167 items—represented in blue) incorporates words related to sensing, data, simulations, and mapping. The fourth cluster (145 items—represented in yellow) centers around heat stress, temperature issues, and heat events. Notably, this cluster includes “cities” alongside

“urban design” and green infrastructure. Lastly, the fifth cluster (132 items—represented in violet) gathers words related to the human dimension and health, encompassing terms such as “urban” and “policies”.

Similarly, Figure 4 illustrates a comparable distribution of clusters with a total of 5 clusters. The first cluster (212 items—represented in red) revolves around the theory of adaptation and resilience, encompassing keywords such as “risk”, “vulnerability”, “stakeholders”, “environmental policies”, and “urban policies”. The second cluster (202 items—represented in green) pertains to microclimate analysis, temperature, heat-related aspects, and green elements. It’s worth noting that, unlike the previous analysis, the prevalence of terms like “heat” and “heat islands” is relatively lower, suggesting a less dominant focus in publications. The third cluster (192 items—represented in blue) encompasses keywords related to water management. The fourth cluster (165 items—represented in yellow), though relatively smaller, features prominently displayed words like “flood”, “flooding”, and “risk assessment”, which are interconnected with various other terms. This cluster was not present in the previous analysis but was part of the water management cluster. Finally, the fifth cluster (145 items—represented in violet) compiles words associated with humans, health, and population. Once again, this cluster also includes the term “cities”.

In the next section, a discussion of the results is provided.

5. Discussion

This paper aimed to address two research questions related to the concept of urban adaptation: RQ1: How is the current urban adaptation debate framed and what are the main aspects covered? and RQ2: What is the role of assessment and monitoring frameworks within the broader context of urban adaptation studies?

To achieve these research objectives, a qualitative analysis of the literature, along with a systematic review, was conducted. Additionally, bibliometric co-occurrence methodologies were employed to examine clustering within the field. Specifically, the terms ‘assessment’ and ‘monitoring’ were queried in association with ‘urban adaptation’ using the Scopus database. The analysis involved both qualitative and bibliometric approaches, utilizing tools such as VOSviewer.

The results of the study shed light on the framing of the urban adaptation debate and its main aspects. With regard to the first research question, several points can be discussed and highlighted, as follows.

- (1) The analysis revealed a broad range of topics receiving significant attention, without any predominant aspect dominating the discourse. However, several trends were identified. Firstly, there was an emergence of operative roadmaps, particularly applied to specific case studies. Local-based approaches seem to be favored over generalization when proposing pathways and roadmaps, aligning with the recent IPCC reports’ [21,131,132] emphasis on this aspect. This trend indicates a potential direction for future research.
- (2) The theoretical aspects underlying urban adaptation demonstrated continued relevance, with notable contributions, such as the work by Martín et al. [67] who proposes advancements in the domains of risk, vulnerability, and uncertainty. The recent work of Kehler and Birchall [22] is also significant in highlighting the failures of short-term-based political measures against long-term ones. Theories around urban adaptation don’t seem to be exhausted and much remains to be defined and organized. Contributions from various scientific fields reveal the cross-cutting nature of the topic.
- (3) Although many themes emerge, such as water-related strategies, flooding, artificial intelligence, sensors and data, it is crucial to categorize them according to a preliminary classification, to provide a more organized and precise structure to the domain. This study identified different key macro-groups with which the analysed literature seems to align (Appendix A). These are: (a) thematic focus, (b) innovations, (c) results, and (d) specific applications to case studies.

The first group is strictly related to the core themes of publications on urban adaptation, perceived by scientists as the most important and urgent aspects, including specific resilience strategies, physical elements and impacts, urban and social equity, causal relationships between mitigation and adaptation strategies, finance and funding, and data and shared knowledge creation.

The second group reveals the presence of a very interesting macro-level within urban adaptation studies that is entirely focused on innovation and innovative strategies. However, it is quite interesting to note that this section is mainly divided into two core parts: the first one being related to participation and participatory approach as ways to support the transformation of urban contexts. This is not surprising as in many other contexts related to climate change this is also a crucial aspect (for example in the context of smart city and energy transition grassroots initiatives are very important innovative ways to perform urban transformation as described in [133]). The second part is composed of the implementation of specific strategies linked to a particular theme or new technologies, as well as physical interventions related to urban form and nature-based solutions.

The third macro-level is probably the most interesting and innovative one as it highlights not only the core themes assessed in urban transition but also the methods, innovations, and results proposed to advance the discipline and the transition itself. It includes pathways and implementation roadmaps, scenarios and simulations, modelling and decision support tools, assessment and monitoring frameworks, and theoretical and conceptual contributions.

The last macro-level identified focuses on implementation, collecting contributions devoted to describing, proposing, and analyzing specific contexts. Contributions come from around the world, with concentrations in both non-European and European cases.

- (4) The debate is still divided into three main groups: water and flood management which seems to be the predominant risk present in the literature together with heat islands and thermal-related shocks, which constitute also the second group of attention. The last one seems to be human and health-related impacts. It is also interesting to note that monitoring aspects are growing, especially linked to the use of technologies.

Regarding RQ2, the role of assessment and monitoring frameworks within the broader context of urban adaptation studies was found to be significant. These aspects were suggested by 2022's IPCC report [21] and highlighted in numerous publications as crucial tools for supporting cities in prioritizing actions. However, the analysis did not indicate a clear convergence toward a single system. The current trends in the field appear to be diverse and widely spread across the research field. Indexes and composite indexes are a growing topic in the debate. They are perceived by many authors as ways to structure the complexity of the topic and to simplify an approach to monitoring that would be too complex without those types of instruments [134,135]. It is worth noting in addition that monitoring frameworks are intended both as supporting tools for impact analyses but also as guiding principles to identify actions and select options. A good example of this last case is the framework proposed by the European Climate Adapt program with the Urban Adaptation Support Tool (<https://climate-adapt.eea.europa.eu/>, accessed on 20 June 2023) aiming to assist cities in all the phases of their transition.

Within the assessment and monitoring literature, certain clusters exhibited a degree of convergence. The theoretical cluster still emerges as particularly relevant also in these specific queries, appearing as the largest in the assessment query and the second largest in the monitoring query. The second key theme is centered around water management, encompassing risks related to floods and flooding and including all aspects related to flooding monitoring and impacts. Another important cluster pertained to temperature, heatwaves, and heat islands, closely tied to the urban dimension and urban design, confirming its significance in the context of urban areas. The fourth notable theme within this discipline relates to people's health and well-being as a main impact of climate adaptation, highlighting the strong connection between adaptation strategies, climate risks, shocks, and individual welfare. Finally, the last significant aspect revolves around data acquisition

and utilization in specific monitoring analyses, such as micro-climate and GIS applications, which is a growing trend in various monitoring contexts [136–138].

6. Conclusions, Limitations and Further Works

In conclusion, this review has highlighted some interesting aspects of the urban adaptation concept and has drafted potential new lines of research. The methodology employed has been threefold, providing: (1) a qualitative background literature review of recent contributions on the topic; (2) a systematic literature review within a refined database of Scopus scientific contributions containing 140 articles; and (3) a bibliometric co-occurrence analysis within the VOSviewer tool. The review has raised questions that can guide future investigations. The main aspects addressed are as follows:

1. Firstly, the framing of the urban adaptation debate reveals a diverse range of topics without a singular dominant aspect. Notable trends include the emergence of operative roadmaps, local-based approaches, and advancements in the theoretical understanding of risk, vulnerability, and uncertainty. Moreover, there is a prevalence of reflections and strategies applied to non-EU cities and countries. Transnational networks play a significant role, and papers comparing multiple cities worldwide offer interesting approaches.
2. Secondly, the importance of assessment and monitoring frameworks is emphasized, recognizing their role in supporting prioritization of actions by cities. However, a unified system has not yet emerged, indicating a wide range of approaches in the field.
3. Lastly, the clustering and grouping of research provide insights into organizing the field, considering thematic focus, methodology, results, and application to local cases.

The present study contributes by updating the understanding of the multifaceted and holistic nature of urban adaptation. It sheds light on current trends and provides clustering of different aspects within the field. These findings have significant implications for further research, policy, and practice in urban adaptation. It is important to note that the study's scope is limited to a single database, which calls for future investigations incorporating additional sources such as the Web of Science to ensure a comprehensive analysis. Furthermore, future research could explore monitoring frameworks within the grey literature of urban adaptation through qualitative-quantitative analysis, thereby uncovering additional insights. Additionally, the same database of articles could be used for other bibliometric analyses, including co-authorship networks, journal networks, and similar analyses.

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Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available in this article.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

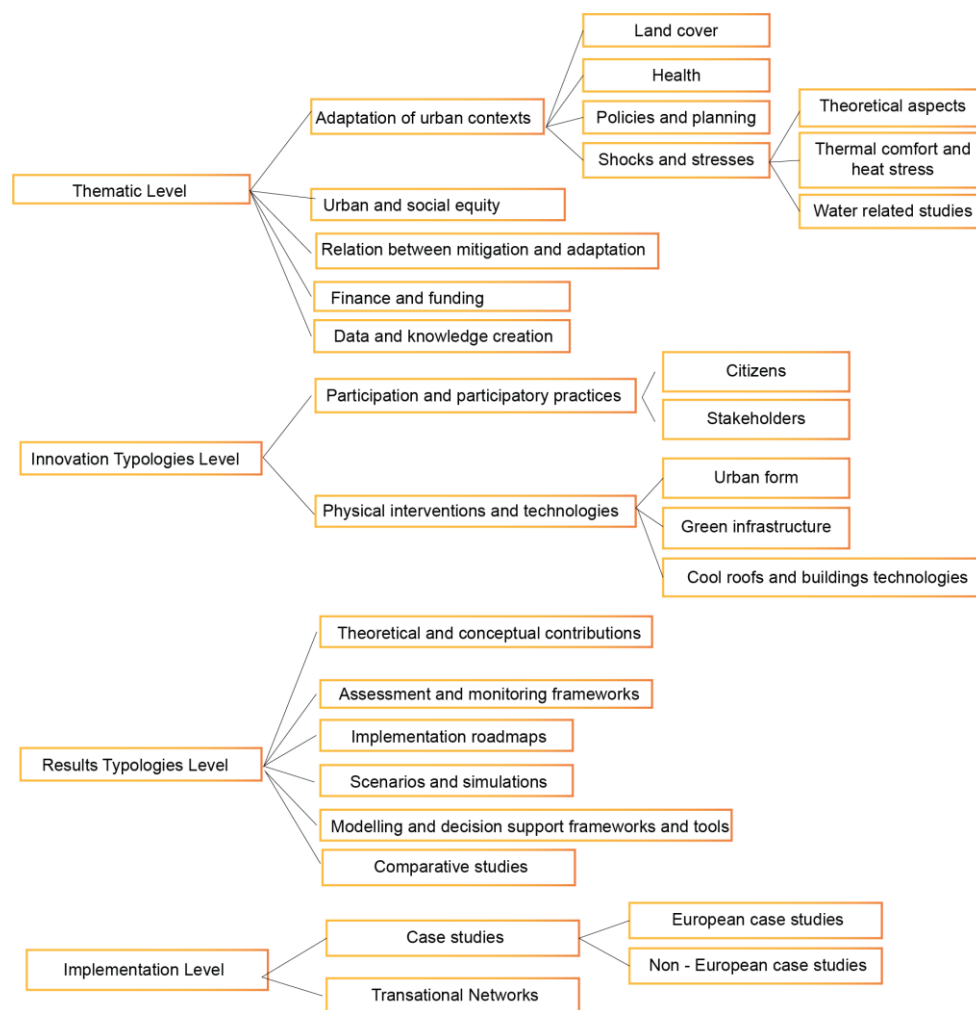


Figure A1. This figure shows a representation of the systematic literature review result clustering. It puts in evidence the different identified levels.

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