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Do we know how urban heritage is being endangered by climate change? A systematic and critical review

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A R T I C L E I N F O

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A B S T R A C T

It is worldwide accepted that climate change is affecting cities and that the conservation of the cultural heritage contributes to sustainable development. However, despite the high level of interest and research in climate-change risks on socioeconomic, urban and natural systems, studies that assess climate change impacts on urban cultural heritage and contribute to a holistic understanding on the subject present noticeable gaps in knowledge.

A systematic review and meta-analysis was carried out to assess the state-of- the-art of cultural heritage risk assessment methodologies within urban systems in the context of climate change, specifically historic urban areas. For this purpose, a systematic search was applied using Web of Science and Scopus. The search identified and characterized existing methodologies on vulnerability and risk assessment for cultural heritage in a changing climate following the PRISMA protocol, and it synthesized knowledge gaps to be addressed in the near future. This study aims to bring risk assessment methodologies closer to urban planners for more efficient climate change adaptation policies.

The research concluded that there is an unbalance between the amount of methodologies for the different climate change derived hazards and their impacts on historic urban areas. The amount of methodologies focused on flooding highlights that further research is needed for other relevant hazards, like heat and cold waves, that contribute to a holistic perspective.

1. Introduction

Average global temperatures are estimated to increase between 0.3 and 0.7 °C before 2035 and by 2 °C before 2100 [1]. Even if no action is taken, global warming and climate change will inevitably continue, and, urban centers and their areas of influence which house a high proportion of the world population and the human activities that generate greenhouse gas emissions, are at very high risk [2]. Rising temperatures are the main climate change with such consequences as sea-level rise and an increasing frequency and intensity of natural hazards such as storms, heatwaves and other extreme events [3]. This fact poses serious challenges for cities and highlights the need for risk assessment methods and adaptation strategies utilizing cities inter-dependent systems towards more resilient urban environments [2].

Cities are complex systems formed by several layers [4]. Within them, cultural heritage represents an essential layer, with historic urban areas or centers assuming special importance, due to their relevance as the main source of cultural capital [5], and characteristic sense of place [6,7]. Throughout this review historic urban areas will be conceptualized following the ICOMOS definition from the Washington chapter, and considering within them as urban heritage "all those material and spiritual elements that express their character" [8].

Heritage assets are especially vulnerable to changes in weather patterns [9]. Besides the physical impacts to the built fabric, the cultural landscape can also be severely affected, such as changes to population patterns and disruption to socio-economic activities such as tourism [10].

At its 29th session in 2005, the World Heritage Committee recognized climate change as an emerging threat to the conservation of many cultural and natural sites [11], and its currently updating its policy

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document on the impacts of climate change on World Heritage properties [12], in both recognizing climate change as one of a range of factors affecting natural and cultural heritage,. Furthermore, the Intergovernmental Panel on Climate Change (IPCC) recognized that the destruction of heritage will form part of the overall impacts of climate change, including damage to the physical fabric, loss of traditional practices and an overall sense of place [13]. Further to this, the Sendai framework [14] considers “Direct economic loss to cultural heritage damaged or destroyed attributed to disasters” as a indicator to measure global progress in its implementation.

Analyzing the risk of a changing climate and climate-related catastrophe, heritage needs to be understood as a cultural capital of both local and national communities [15], as it is key in the process of developing a sustainable relationship between people and their environment, strengthening the sense of belonging and the sense of place [7]. Cultural heritage is therefore an essential resource for sustainable development for both the elaboration and the implementation of successful strategies to manage the impact of climate change. This fact is reinforced by the Sustainable Development Goals (SDGs) of the 2030 Agenda [16]. The Agenda refers to cultural heritage in the context of sustainable development, and Target 11.4 of the SDGs calls for “strengthening efforts to protect and safeguard the world’s cultural and natural heritage”, while Goal 13 calls for taking “urgent action to combat Climate Change and its impacts”.

In the last decades, a growing interest and focus on climate change has become evident in both the reports and the work plans of such heritage organs as ICOMOS and its climate change working group [17]; and UNESCO, which has published several reports [18,19] and policy documents addressing the impacts of climate change on World Heritage Sites [12,20]. Furthermore, the European Union is also contributing to the topic through its inclusion of cultural heritage risk assessment and prevention on the same agenda as the EU Work plan for Culture 2019–2022 [21], which includes a topic on adaptation to climate change and several recommendations as the one from the Committee of Ministers (CM/Rec(2018)3) to member States on cultural heritage facing climate change [22,23]. When developing strategies to protect cultural heritage and urban areas from any environmental hazards, risk assessment is an essential step [24]. While climate change impacts on natural, socio-economic and urban systems have, in general, been well documented [13], there has been little research on climate impacts on cultural heritage and historic areas [25] and as stated by E. Brabec and E. Chilton [7] there is a need for research in this area.

Hence, specific approaches are needed for assessing climate-change-related risks that threaten the conservation of historic areas, due to the specific characteristics of those areas with regard to both vulnerability and resilience [6,7,26].

The aim of this research work is to provide a critical review of the state of the art on climate change risk assessment methodologies for historic urban areas, considering the different climate change related hazards. The final goal is to identify future scientific needs to promote the resilience of urban cultural heritage.

The methodological approach that was followed consisted of three steps. As a preface, a conceptual background and the particularities of a vulnerability or risk assessment of a historic urban area were summarized. Second, systematic data-base (Scopus and Web of Science) searches were performed and a consequent meta-analysis of the results following the PRISMA-P protocol [27,28]. Based on the PRISMA guidelines this step includes the identification, analysis, and cataloguing of the existing developments on climate change related risk assessment methodologies for historic urban areas. Finally, as a third step, the conclusions will identify knowledge gaps and future research needs to support the scientific community in its decision making for future actions (Fig. 1).

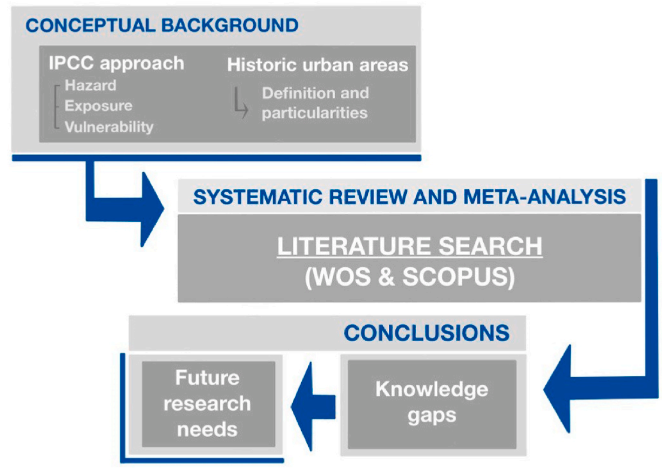

Fig. 1. Layout of the research work.

2. IPCC approach for risk assessment

A brief conceptual background on the changing meaning of the terms of risk, hazard, exposure and vulnerability is needed to lay the foundation for risk assessment. The Office of the United Nations Disaster Relief Coordinator (UNDRO) in its meeting report for Natural Disasters and Vulnerability Analisys, cites a definition from UNESCO for risk, as “the probability of loss resulting from the product of seismic hazard, vulnerability and value”[29, p.5]. This definition has been widely adopted and adapted by the institutions dealing with disaster risk, such as the United Nations Office for Disaster Risk Reduction (UNISDR) and the IPCC. The IPCC adapted this definition for climate change assessment, developing it in each subsequent report. In its Fifth Assessment Report (AR5) [13, p.36], risk was defined as a “probability or likelihood of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur”; risk was therefore characterized as the “result of the interaction between hazard, vulnerability (susceptibility to harm) and exposure” [13, p.36]

Additionally, the IPCC introduced the term “impact” in relation to “the effects on natural and human systems of extreme weather and climate events and of climate change. Impacts generally refer to effects on lives, livelihoods, health, ecosystems, economies, societies, cultures, services and infrastructure, due to the interaction of climate changes or hazardous climate events occurring within a specific time period and the vulnerability of an exposed society or system”[1, p.5].

The hazards for the review were identified following the IPCC climatic drivers for urban areas mentioned in the 8th chapter of the AR5, “Climate change will lead to increased frequency, intensity, and/or duration of extreme weather events such as heavy rainfall, warm spells and heat events, drought, intense storm surges, and associated sea level rise”[13, p.552]. Within this chapter temperature means and extremes, storms, flooding derived from either sea level rise or heavy rainfall are mentioned as main hazards. Following the IPCC approach, the following hazards derived from climate change that impact on urban areas were identified: extreme temperature events: cold and heat waves; flooding events following extreme precipitation, storms and sea level rise; and climate change as a whole, major temperature fluctuations and consequential change in climate. A climate extreme or extreme event are defined by the IPCC as “The occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable”[30, p. 545].

Exposure in this framework [1, p.5] is defined as “The presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected”. Hence, it refers to the elements in the area affected by the hazard.

The concept of vulnerability is key to the characterization of risk, and its assessment implies characteristics and processes that are evaluated in different ways, depending on the discipline [31,32]. Hence, following the AR5 definition, vulnerability is "the propensity or predisposition of an element exposed to extreme events (*i.e.*, climate change events) to be adversely affected" [1, p.5], and this vulnerability combined with hazard and exposure will determine the risk. This definition of vulnerability involves the elements or systems sensitivity to the hazard and their lack of capacity to cope with the adverse effects of climate change. While sensitivity is a relatively straightforward concept defined as "susceptibility to harm"[30, p.560], coping capacity is defined as: "the ability of people, institutions, organizations, and systems, using available skills, values, beliefs, resources, and opportunities, to address, manage, and overcome adverse conditions in the short to medium term." [30, p.560]

As well as showing the explained risk assessment approach from the AR5 framework [1], Fig. 2 contains the proposed impact chain for historic urban areas with a holistic vision, identifying the relation between risk-assessment concepts and the impact chain and adding the dimension of cultural heritage to the urban system.

3. Historic urban areas and their climate-change risks

The field of climate change risk assessment for urban areas has been gaining relevance over past years and is emerging as a priority when developing policies to reduce the impact of extreme events on the built environment [33,34]. Currently, slightly over 50% of the global population resides in urban areas, yet an increase to over 60% in that figure is estimated by 2050 [35].The spatial and physical characteristics of cities and the vulnerability of the growing population add a complexity, that in conjunction with the critical nature of environmental challenges provide urgency and particularities that determine risk assessment and adaptation strategies to climate change in urban areas [36,37]. Furthermore, presently, climate change and related extreme events are causing negative effects on the health, assets, wellness and livelihoods of urban residents [13,38].

Even if cities are exposed to the same climatic conditions as their surroundings, low soil permeability, higher population densities, higher concentrations of productive activities, urban planning, *etc*. are some of the factors and characteristics that cause urban specific phenomena [37]. These factors are referred to as drivers, which and can amplify the negative consequences of different climatic events and therefore cause even greater impacts [13]. The main hazards mentioned previously in relation to the effects of climate change on cities were extreme precipitation, sea-level rise and extreme temperatures (heat and cold waves), which urban characteristics accentuate, such as low soil permeability ([13] and the urban heat-island effect [39].

Urban areas are, therefore, complex systems and require a specific approach when assessing their climate change risks [13,37]. An intrinsic component within an urban system, even if it is not frequently considered when assessing urban areas, is cultural heritage. Objects of heritage alongside practices shape our community identity [40], with historic city centers and historic urban areas being the origin and the source of identity of cities [41]. ICOMOS, in the Washington Charter 1987 [8], defined an historic urban area as a city, a town or a historic center or quarter, along with their natural and built environments. Apart from their "role as historical documents, they reflected the values of traditional urban cultures" [8].

As historic urban areas are usually located in central areas of cities, the consequences of climate related phenomena have to be carefully considered, especially in view of their constructive and socio-economic characteristics, such as narrow streets [42], presence of green spaces andpermeable soil, the specificities of the population, and economic characteristics such as traditional socio-economic activities or an economy linked to tourism. Furthermore, when analyzing urban cultural heritage, the specificities of buildings in these areas, their materials and construction techniques, as well as cultural value and importance must also be taken into account.

As referred to in the UNESCO recommendation on Historic Urban Landscapes (HUL) in 2011 [43], both present and future urban conservation policies urgently require "the definition and implementation of a new generation of public policies identifying and protecting the historic layering and balance of cultural and natural values in urban environment". To do so, a proper assessment methodology that assesses the challenges of climate change and that prioritizes the most vulnerable assets will be essential when developing protection strategies and policies.

4. Methodology for the systematic review

4.1. Rationale and objectives

As previously mentioned, the systematic review [44] with consequent meta-analysis of the results in this manuscript follows the PRISMA-P protocol [27,28]The research question driving the systematic review was: *what risk or vulnerability assessment methodologies have been developed for historic areas against climate change?* The context of the meta-analysis and the definition of the objectives led to the need for some specifications [45] *e.g., what it is considered a risk/vulnerability assessment methodology?* and, *what hazards and systems are tackled in risk/vulnerability assessment methodologies?* A critical analysis and

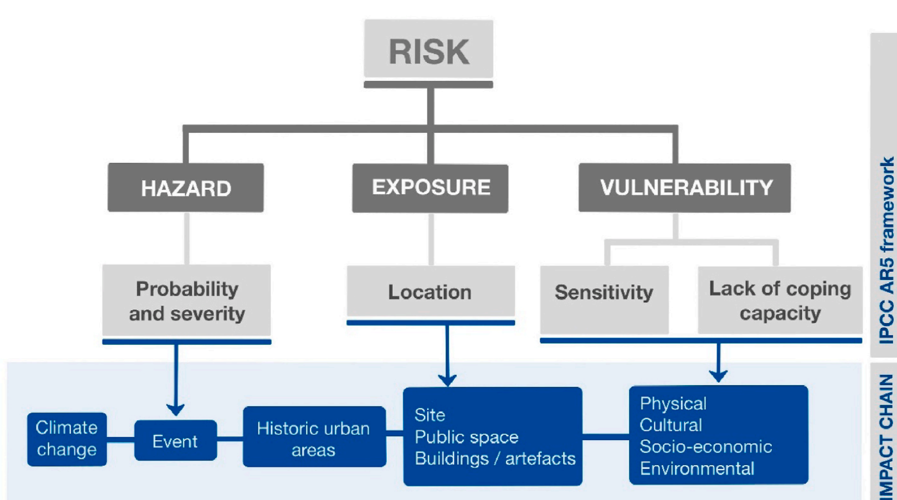

Fig. 2. Relation between the impact chain in historic urban areas and risk assessment according to the IPCC AR5 framework.

evaluation of the approaches and scope of each methodology found concluded in the identification of the knowledge gaps.

To answer these questions, the definition of two main concepts is essential, (i) what is considered as a risk assessment methodology, and (ii) the scope of the definition of a historic urban area. For the definition of risk assessment methodology the criteria from IPCC [46] and European Environment Agency (EEA) [47] has been followed. Based on data, an assessment methodology should identify the most relevant risks by determining theirimpacts and the vulnerabilities associated to the elements under study. For this purpose, it is necessary to identify and characterize the impacts and assess their magnitude following a specific and accepted method. As for historic urban areas, as stated through section 3 of this manuscript, it will follow the ICOMOS definition from the Washington chapter (ICOMOS, 1987).

The climate change related hazards were selected following those addressed by the IPCC [13], as specified in the hazard analysis of this manuscript (section 2). Extreme precipitation is not included in the search, as floods are its main consequence and preliminary searches showed that the results were repetitive. Impacts or consequences of the hazards were not considered in the selection of keywords e.g. spread of microorganisms due to the change in climate conditions, changes in human patterns, as a review on this subjects would require an in depth analysis of each of them.

4.2. Search strategy

The searches were conducted using Scopus and Web of Science databases in November of 2020, which looked up the keywords included in the title, keywords and abstract. Due to language limitations, only the literature with keywords in English was included. The search included articles (included in journals and books) and conference proceedings that were accessible through the databases mentioned.

Consequently, and considering all the previously formulated research questions, the keywords for the search were selected as the combinations of keywords shown in Table 1, with the asterisk signaling that the endings to some of their root words might vary.

4.3. Eligibility criteria

The different combination of keywords in both platforms produced 616 total results; many of them were repeated in the different searches. A first filtration through title and abstract was limited to the identification of the literature related to the subject, excluding the ones from other areas of study and following the criteria stated in Fig. 3. The results were then reviewed individually through the abstract and full text to determine if they actually defined a risk assessment methodology or considered climate change related hazards and their impact on cultural heritage. For this filtration, it was analyzed if (a) they followed a methodology that characterize risks and assess their magnitude following a specific and accepted method and (b) considered climate change related hazards. It is important to clarify that as mentioned in the rationale only studies considering the hazards considered by the IPCC were included, not considering articles that tackled other hazards e.g. earthquakes, subsidence, and so on, that are not considered directly related to climate change.

This systematic evaluation led to 29 papers that have been assessed in detail within this study. These selected papers were reviewed in their entirety and classified in relation to the hazard addressed and the risk-assessment elements of the IPCC approach that were considered (hazard, exposure, vulnerability). The year of publication was also analyzed to detect the rates of interest in the subject over time.

In this process, information on the articles was entered on a spread sheet and sorted by publication data (year, title, author, source, DOI) and the results of the critical analysis were focused on the type of hazard addressed, the aspects of risk (hazard, exposure, vulnerability) and the (socio-economic, cultural, governance and physical) systems within the historic urban areas. Full information is shown in Annex I.

Following the conclusions drowned from the research questions, the review will be divided into three parts: starting with an analysis of the hazards addressed by the studies, followed by the risk aspects and systems assessed, to finish with an overview of the interest in the subject looking at the publication dates of the selected literature.

Table 1
Combinations of keywords used in the systematic search.

	AND	Climate change			AND	
		OR				
		Heat wave	AND	**Climate change**		
Risk assess*		OR				**Heritage**
		Cold wave				
		OR				
OR		**Flood***				OR
		OR				
		Storm				
Vulnerability assess*		OR				**Historic area**
		Sea level rise				

5. Cutting edge science in climate change risk assessment methodologies in historic urban areas. Meta-analysis

5.1. Hazards

As mentioned, a key parameter when reviewing the different methodologies was the climate change related hazard and climatic driver considered in each model. As previously established, cold waves, heat waves, floods deriving either from sea level rise, stormsor heavy precipitation events are all among the hazards that are researched. Even if wildfire was not a specific keyword derived from the hazard selection, a study was found through the searches with climate change as keyword, and included in the review as is a hazard derived from climate change.

Once the search results had been filtered for suitability with the established criteria, a total of 29 papers were identified. Having sorted the papers according to the hazard addressed in the methodologies developed in each research work, it was observed, as shown in Fig. 4, that flooding was the most studied hazard with a total of 22 flood-related methodologies. These studies include flooding from rising sea level and storms [48–66]. Moreover, floods are analyzed in combination with other hazards in the three multi-hazard methodologies found in the search, along with global warming [67], non-climate change related hazards such as earthquakes, landslides and wind [68] and higher global temperatures [69].

In all, seven of the 29 studies found in the review considered that the general change in climate caused by climate change was a hazard [67, 69–74] and one wildfire-specific methodology was found [75].

Finally, no search results were found on either cold waves or on heat waves; the general climate change search results fared no better at including either of those hazards. Therefore, as shown in Fig. 4, taking into consideration the climate change-related hazards among the 29 studies, three of which were multi-hazard, floods were analyzed in 22 methodologies, the general change in climate in eight, and wildfires in one.

5.2. Risk aspects and systems within the studies

Following the IPCC approach, the methodologies were reviewed to identify the risk-assessment aspect and the particularities of the historic urban areas that they evaluated. The analysis carried out for this review breaks down the results into three groups: (i) studies that only

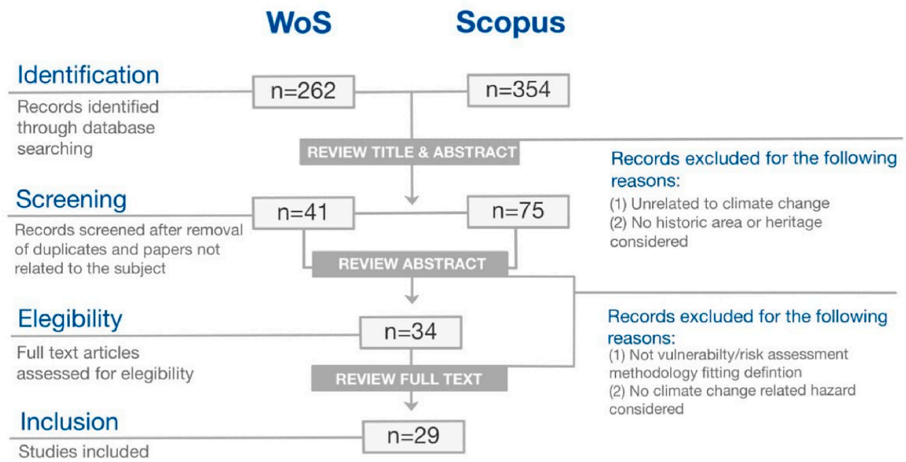

Fig. 3. Literature search and evaluation for inclusion in the critical review (adapted from Ref. [28]).

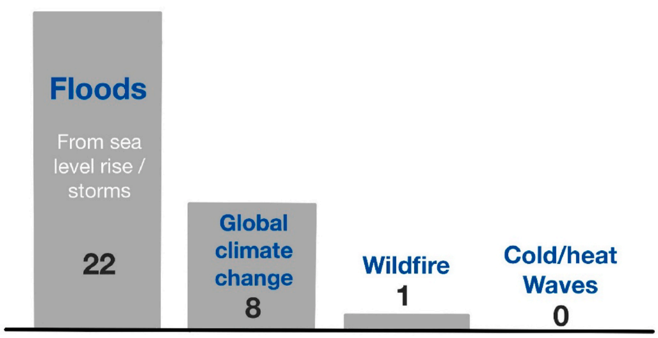

Fig. 4. Number of methodologies that consider each hazard.

characterize hazard likelihood and severity, (ii) methodologies that also consider exposure, and (iii) studies that, besides hazard and exposure assess the vulnerability, differentiating between sensitivity and coping capacity (see Fig. 5).

Hazard likelihood and severity were considered in seven of the methodologies under analysis [54,56,59,66–68,71], and exposure of the elements was only included in the analysis of one methodology [75].

Several studies mentioned vulnerability, but on further analysis it was verified that only sensitivity indicators and not coping capacity indicators had been applied. Therefore, the analysis distinguishes between studies that considered sensitivity (10 studies), and the ones that included sensitivity and coping capacity indicators (11 studies).

The characteristics of historic urban areas were considered in the vulnerability assessment methodologies that were organized into five systems: social, economic, cultural, governance (services and resources) and physical (gathering tangible characteristics of all infrastructures, elements and buildings).

Reviewing the systems included in the vulnerability assessment methodologies (see Fig. 5), 19 of the 21 methodologies included physical vulnerability, which was the sole focus of 10 to the exclusion of other systems, [49,52,53,60,65,69,70,72,74,76]. One was specifically focused on governance vulnerability [57], and another one, on social vulnerability [48]. With respect to the eight studies on the vulnerability of various systems, all included physical vulnerability along with cultural [58,62], social and economic [58,64,77], governance [51] and social and economic aspects [50].

Therefore, the most common combination found in the review was the assessment of physical vulnerability to flooding [49,52,53,55,60,61,65,66]. It should be also highlighted that cultural vulnerability evaluated in terms of the cultural value of the asset has only been addressed in five papers, all focused on flooding (see the various papers by A. Gandini, and one by Vojinovic et al., 2016).

5.3. Chronological analysis

Fig. 6 shows the number of papers published each year. As shown in Fig. 6, the first papers found on the subject were published in 2015.

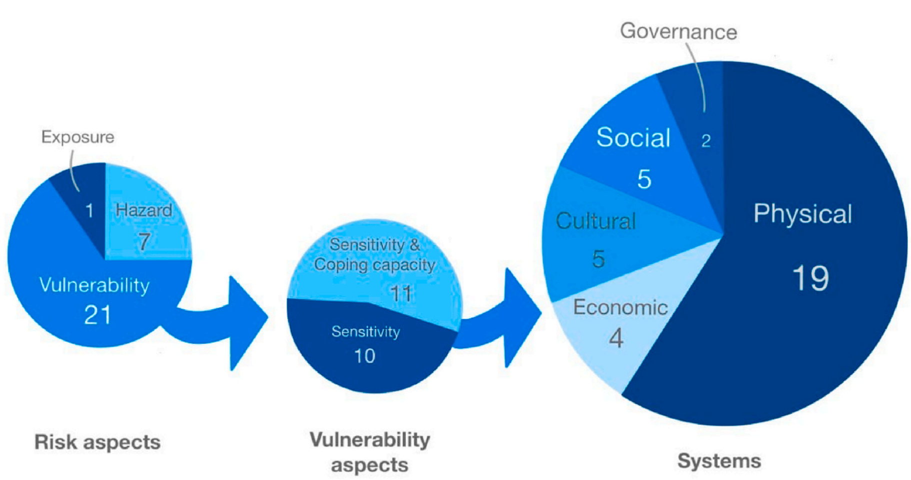

Fig. 5. Number of methodologies that consider risk and vulnerability aspects and the systems analyzed.

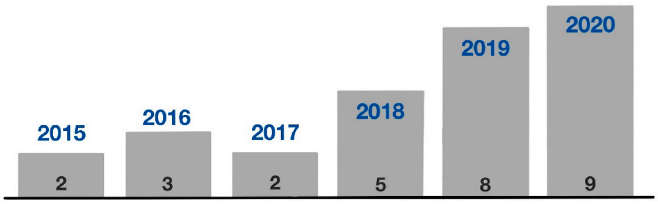

Fig. 6. Articles published each year.

Interest in the subject has since increased over the past five years, as it can be noted that 17 out of the 29 publications had been published over the past two years. An interesting observation is that the nine papers published in 2020 were all focused on flooding from among which, the physical vulnerabilities of the buildings were mainly assessed in 7.

6. *Identification of gaps and future research needs*

Starting with the hazards caused by climate change, the critical review is clear in determining that there is a large body of literature in WOS and Scopus addressing flooding (76%), from either sea level rise or storms, and the consequences of climate change are considered in a high number of studies (28%). Other important hazards are rarely or not present in the literature (fire 3%, cold and heat waves none).

With respect to the vulnerability and risk-assessment methodologies, the vulnerability of urban environments is frequently linked in the literature to their physical, cultural, socio-economic and governance systems, depending on characteristics such as geographical position, materials, urban plot and morphology, wealth, population age, *etc*. These characteristics will constrain the severity of the resulting impacts. In the case of historic urban areas, as seen in this review, there is a close focus on the physical vulnerability of the built environment (62% of the papers) while social vulnerability is addressed in 14% of the papers, economics in 14%, cultural matters in 14% and governance in 7%, showing very few studies of relevance on cultural, socio-economic and governance vulnerability. Therefore, as the climate change related impacts on historic areas depend on the complex relationships between physical, social, economic, and cultural aspects, all these systems have to be considered when assessing the foreseeable hazards. Hence, the research on more holistic risk assessment approaches is fundamental to defining the path that the ongoing research work should follow.

The growing interest in this line of research is very noticeable, especially in 2019 and 2020,58% of the papers under review were published in the past two years, showing the high relevance and momentum for this line of research.

The search strategy for this review might have limited the results in three lines: (1) literature published in languages other than English and not indexed in the chosen databases (SCOPUS and WEB OF SCIENCE) (2) literature focused on specific impacts and not including generic terminology within the climate change framework and impacts derived from it (e.g. risk analysis for change in population, tourism patterns, change in biotic factors, etc.) and (3) literature analyzing other climatic drivers derived from main hazards (landslides, droughts, etc.). Therefore, future literature reviews should include different terminology and study the literature focused on other climatic drivers and their derived impacts.

7. Conclusion

Even if risk assessment for urban areas to safeguard against climate change impacts is currently a very active line of research, noticeable gaps in knowledge have been unearthed in the current research work. There is an especially perceptible gap in the literature in relation to risk-assessment methodologies with holistic approaches that are specific for historic urban areas, taking into consideration not only physical damage to built-heritage, but also impacts on such other systems as socio-economic, cultural and governance. Even though the existing gap on the topic, there is some recognition of the importance and the need for a broader holistic approach to climate change risk and vulnerability assessment of cultural heritage, supported by the increasing literature published on the matter. Although the impact of floods within urban areas has previously been carefully discussed, there is little work on other hazards, such as heat waves and cold waves. Even if it can be argued that, the absence of literature on these hazards might indicate a lack of importance in relation to climate change, there is an abundance of literature on specific effects of heat and cold waves on heritage materials and intangible processes such as tourism.

The chosen review type (systematic review following the PRISMA protocol) provided a solid framework for the development of the study and analysis of the results. However, impacts and risks derived from climate change are a very relevant and broad subject, with an extensive terminology that proved difficult to narrow to keywords. Specific reviews focused on each individual hazard and their specific impacts, with broader terminology could be a future step to this review.

The consideration of loss of heritage and cultural values as a risk and understanding the climate change related impacts that urban heritage faces might promote the resilience and sustainability of the systems to which they belong. Moreover, the importance of cultural heritage in the "sense of place" makes its endangerment a very relevant risk for the sustainability of any community. Hence, urban planners need effective risk assessment tools, including all the particularities of historic urban areas, for supporting their decision-making. To facilitate their work, this research work aims to identify main studies on the topic. However, multidisciplinary teams (urban planners, cultural heritage managers and climate change adaptation managers) promoting in-detail methodologies to face climate change impacts on urban cultural heritage are recommended.

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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9. Annex I – Papers reviewed

	References	Year	Citations	Author keywords	Hazard (s)	Risk aspects/Systems
1	[49]	2020	0	Damage Assessment; Climate-Change; Precipitation; Future; Model; Management; Framework; Hazard	Floods	Vulnerability/Physical
2	[60]	2020	1		Floods	Vulnerability/Physical

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	References	Year	Citations	Author keywords	Hazard (s)	Risk aspects/Systems
				Urban Flood; Flood Risk Assessment; Risk Management; Historic City Centre Of Guimaraes		
3	[61]	2020	2	Cultural heritage; Flood risk; Flood impact; Vulnerability; Risk assessment; Large-scale assessment	Floods	Exposure/Physical
4	[62]	2020	0	City GML; Extreme events; Historic buildings; MIVES; Urban areas; Vulnerability assessment	Floods	Vulnerability/Physical, Cultural
5	[65]	2020	0	Flood Risk; Cultural Heritage; Meso-Scale; Flood Hazard; Flood Vulnerability; Castile And Leon; Spain	Floods	Vulnerability/Physical
6	[51]	2020	0	Analytic hierarchy process; Flood hazard; GIS; Thailand, World heritage site	Floods	Vulnerability/Physical, Governance
7	[55]	2020	0	Climate change adaptation; Cultural heritage; Canary Islands; Coastal fortifications; Sea level rise; Coastal flooding	Floods	Exposure/Physical
8	[56]	2020	0	Central Europe; Climate projection; Climate risk indices; Cultural heritage safeguarding; Extreme events; Heritage climatology; Preparedness; ProteCHt2save	Floods	Hazard likelihood and severity/-
9	[57]	2020	3	Climate change; Cultural heritage; Europe; Vulnerability assessment; World Heritage Sites	Floods	Vulnerability/Governance
10	[48]	2019	2	Behavioural design; Evacuation simulation; Flooding evacuation; Flooding risk assessment; Historical urban scenario risk; Natural hazards	Floods	Vulnerability/Social
11	[71]	2019	1	Cultural heritage; Case studies; Resilience; Disaster risk management	Change in climate	Hazard likelyhood and severity/-
12	[70]	2019	1	Built Heritage; Categorization; Climate Change Adaptation	Change in climate	Vulnerability/Physical
13	[66]	2019	0	Cucuteni; Cultural heritage; Flood; Romania; Vulnerability	Floods	Hazard Likelyhood and severity/-
14	[67]	2019	0	Climate change; Climate modelling; Cultural heritage; Sea level rise	Change in climate/floods	Hazard Likelyhood and severity/-
15	[76]	2019	0	Indoor Climate; Painting Damage; Risk Assessment; Taiwanese Historical Temple; Wood Construction	Change in climate	Vulnerability/Physical
16	[52]	2019	8	Flood vulnerability assessment; Exposure; Sensitivity; Historic sites; Historic centre of Guimaraes	Floods	Vulnerability/Physical
17	[68]	2019	0	Climate change analysis; Crete; Cultural heritage; protection; Greece; Hazard assessment; Historic centre of Rethymno; Risk assessment	Earthquake, landslide, wind, coastal flooding	Hazard Likelyhood and severity/-
18	[59]	2018	6	Cultural heritage; Climate change; Adaptive management; Climate adaptation; Puerto Rico	Floods	Hazard Likelyhood and severity/-
19	[64]	2018	4		Floods	Vulnerability/Physical, Socio-Economic, Cultural
20	[77]	2018	0	Climate change; Cultural heritage; Flooding; Urban data model; Vulnerability assessment	Floods	Vulnerability/Physical, Socio-Economic, Cultural
21	[72]	2018	11	Accuracy Assessment; Biological Damage; Building Simulation; Climate Change; Heating; Indoor Climate; Mechanical Damage; Painted Wood; Risk Assessment	Change in climate	Vulnerability/Physical
22	[54]	2018	34		Floods	Hazard Likelyhood and severity/-
23	[73]	2017	6	Climate Change; Historic Cities; Cultural Heritage; Sustainable Cities	Change in climate	Vulnerability/Social, Physical, Economic, Cultural
24	[50]	2017	18	Climate change; Extreme precipitation; Flood damage; Risk assessment; Uncertainties; Urban flooding	Floods	Vulnerability/Physical, Socio-Economic
25	[69]	2016	15	Climate change; Cultural heritage; Australia; Disaster risk reduction; Risk assessment; Index	Change in climate, intense precipitation, storms, floods	Vulnerability/Physical
26	[75]	2016	17	Image Segmentation; Rapideye; Landsat 8; Random Forests; Landscape Wildfire Behavior; Wildfire Exposure; UNESCO World Heritage Properties	Wildfire	Hazard Likelihood and severity, Exposure
27	[58]	2016	41	Flood risk; Flood management; Risk perception; Vulnerability; Cultural heritage; Holistic approach	Floods	Vulnerability/Physical, Socio-Economic, Cultural
28	[53]	2015	39	Climate Change; Coastal Vulnerability Analysis; Erosion; Sea-Level Rise	Floods	Vulnerability/Physical
29	[74]	2015	40	Climate change; Damage and risk assessment; High resolution climate modelling; Indoor climates; Whole building simulation	Change in climate	Vulnerability/Physical

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