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Special Issue 2.2023

Burn or sink
Planning and managing the land

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Cover photo by Giuseppe Mazzeo. Rising wheat fields on the hills of Conza della Campania, Irpinia. January 31, 2023.

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Evaluating the urban heat island phenomenon from a spatial planning viewpoint. A systematic review

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Abstract
The increasing rate of urbanization and continuous population growth in urban areas leads to several problems, including the emergence of urban heat islands (UHI), defined as urban areas where temperatures are higher than in the surrounding rural areas. UHIs have negative impacts on the health of populations and lead to increased energy consumption for cooling. One of the main causes of higher temperatures in urban areas and, therefore, the creation of UHIs is impervious surfaces, which in turn lead to poor thermal comfort in cities. Ecosystem services and, in particular, the ecosystem service of local climate regulation are valuable tools to mitigate the effects of UHI. The contribution reviews the existing literature concerning the mitigation of heat island effects through ecosystem services, in order to understand how they are studied and analyzed in the international scenario. The proposed methodological approach is based on a framework of analysis of the scientific contributions published in the last fifteen years on the subject of UHI, investigating the phenomenon through an interpretation key based on the issues addressed, the methods used and the spatial scales to which these methods have been applied.

Keywords
Urban heat island; Local climate regulation; Spatial planning.

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1. Introduction

According to the United Nations Report (United Nations, 2019) in 2018 more than 55% of the world's population lived in urban areas and it is expected that by 2050, the percentage will grow to 64%-84%. The increasing rate of urbanization and the continuous increase of population in urban areas have entailed several problems which impact negatively on health and well-being of populations and the environment in general (EEA, 2017; Rosenzweig et al., 2018). Furthermore, urbanization often leads to negative impacts that are linked to other threats in areas with heightened natural risk, like hydrogeological issues (Mazzeo & Polverino, 2023).
Urban heat island (UHI) is defined as "...an urban area that is significantly warmer than its rural surroundings due to artificial infrastructure and human activities" (Copernicus, 2021). UHIs have negative impacts on the health of populations (Heaviside et al., 2017) and lead to increased energy consumption required for cooling (Santamouris et al., 2015). One of the main causes of rising temperatures in urban areas and, thus, the occurrence of UHIs is impervious surfaces (Irmak et al., 2017), which in turn lead to poor thermal comfort in cities (Morris et al., 2017). The thermal behavior of urban structures can be significantly improved through the implementation of measures that affect only the surface cover of the buildings (Icaza et al., 2016). In literature, several methodological approaches are used to study and assess the UHI phenomenon and climate vulnerability and risks, such as methods based on field observations (Nolte et al, 2022; Li et al., 2021), empirical methods (Oliveira et al., 2021; Su et al., 2021), remote sensing techniques (Almeida et al., 2021; Chen et al., 2006; Despini et al., 2021), modelling (Mahadavi et al., 2016; Marando et al., 2022), and simulation (Sobocká et al., 2020; Elliot et al., 2020).
The determination of thermal comfort in cities represents a fundamental element in the assessment of the urban microclimate (Kalogeropoulos et al., 2022). For this reason, the implementation of appropriate land management policies and modelling techniques aimed at analyzing these phenomena is of paramount importance (Evola, 2017). The current scientific debate focuses on the need to formulate effective policies for climate change adaptation and mitigation (Pinto, 2014). In fact, several studies focus on the mitigation of impacts due to heat islands. Some studies are based on physical-microclimatic models that allow to compare two or more different scenarios, such as in the case of the ENVI-met simulation tool (Magliocco & Perin, 2014). Other studies propose the use of materials and design methods based on nature-based solutions (NBSs) and Green Infrastructure (GI) in new urban settlements and in restoration sites. Green transition of urban areas makes cities more adaptable and more resilient to the effects of UHI. With regard to the risks associated with UHIs, appropriate short- and long-term planning and management measures are required (Biasin et al., 2023). GIs represent a strategically planned network of high quality natural and semi-natural areas (Fauk, 2023), and according to the European Commission, GIs "… are designed and managed to deliver a wide range of ecosystem services" (ESs) (2013, p. 3). Subsequently, EU 2030 Biodiversity Strategy encourages Member States to map and assess ecosystems and their services (Córdoba Hernández & Camerin, 2023)
Ecosystem services and, in particular, regulating ecosystem service such as local climate regulation, are a valuable tool for mitigating the effects of UHI. Numerous studies have highlighted the relationship between land cover types and its impact on surface temperature (Semenzato & Bortolini, 2023). The increase of vegetation in urban areas allows the regulation of the macro- and microclimate and the reduction of surface temperatures (van Oorschot, 2021). In general, the increase of permeable areas is implemented through the realization of new public green spaces, the requalification of existing green areas and the tree planting in the most sealed areas. Ecosystem-based adaptation approach to urban spatial planning can be a key element of establishing urban policies focused on natural resource management (Bush & Doyon, 2019). As a result, this approach incorporates the advantages provided by ESs also in terms of socio-economic development impacts (Chen et al., 2020). On the other hand, the integration of ES within spatial planning is still limited. Longato et al. (2021) evaluate the use of ES in spatial planning by means of a literature review in order to understand the integration level, and planning strategies addressed. According to Longato et al. (2021), although the

number of studies that focus on the integration of ES in spatial planning have increased, the systematic review of the literature highlights how the main benefits of integrating ES into spatial planning concern only practical issues, such as the promotion of stakeholder participation.
Starting from this theoretical framework, the study presents an in-depth analysis of the existing literature on the mitigation of heat island effects through ecosystem services, in order to understand how these phenomena are studied and analyzed in the international scenario. The proposed methodological approach is based on a systematic review of scientific studies published in the last fifteen years on the subject of UHI, investigating the phenomenon through an interpretation key based on four aspects: general context, reasons, methods and data, and implications for spatial and urban planning. Moreover, the proposed method represents a preliminary analysis aimed at defining key elements on which to base spatial planning policies at the municipal scale.
The contribution is structured in four sections. The first, introductory section focuses on the theoretical background. The second describes the proposed methodological approach, structured in two specific evaluation phases. The third section presents the results which are discussed in the fourth section, where final considerations are provided.

2. Materials and methods

The paper proposes a systematic analysis of a part of the existing scientific literature on the mitigation of heat island effects through ecosystem services, with the aim to understand how this phenomenon is internationally studied and analyzed. The sample of papers to be analyzed was selected from the Scopus database, (01/06/2023) using the combination of words "Urban AND heat AND island AND ecosystem AND services" within the field "Article Title; Abstract; Keywords". The preliminary paper selection resulted in the identification of 331 papers spanning a period from 2007 to 2023.

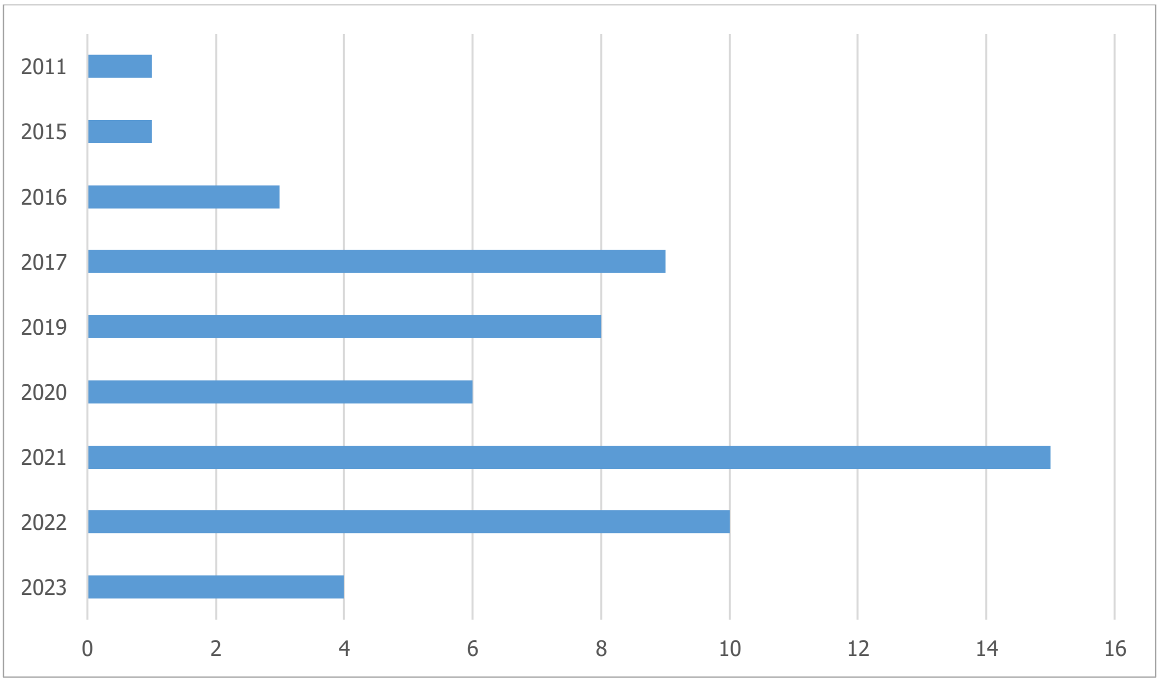

Fig.1 Time distribution of the 57 analyzed papers

The paper selection phase was structured into two evaluation steps. In the first step, all abstracts were analyzed in order to exclude papers not related to spatial and urban planning. As a result of the first step, 122 papers were selected. The second evaluation step involved a content analysis in which all 122 selected papers were analyzed. As a result of the second step, 57 papers were selected.

Source	Typology of the source	Number of paper
42^{nd} Asian Conference on Remote Sensing	Conference Proceedings	1
Chinese Journal of Population Resources and Environment	Journal	1
Computers, Environment and Urban Systems	Journal	1
Ecological Indicators	Journal	2
Ecological Informatics	Journal	1
Ecological Modelling	Journal	1
Ecosystem Services	Journal	1
Environment, Development and Sustainability	Journal	1
Environmental Impact Assessment Review	Journal	1
Environmental Research Letters	Journal	2
Environmental Science and Pollution Research	Journal	1
European Journal of Remote Sensing	Journal	1
Forests	Journal	1
Frontiers in Sustainable Food Systems	Journal	1
GIScience and Remote Sensing	Journal	1
Journal of Urban Planning and Development	Journal	1
Journal of Soils and Sediments	Journal	1
International Journal of Applied Earth Observation and Geoinformation	Journal	1
International Journal of Environmental Science and Technology	Journal	1
Land	Journal	2
Land Use Policy	Journal	1
Landscape and Urban Planning	Journal	5
Lecture Notes in Computer Science	Volume	1
Remote Sensing	Journal	2
Science of the Total Environment	Journal	4
Spatial Information Research	Journal	1
Sustainability	Journal	5
Sustainable Cities and Society	Journal	5
Urban Biodiversity and Ecological Design for Sustainable Cities	Journal	1
Urban Climate	Journal	1
Urban Ecosystems	Journal	3
Urban Forestry and Urban Greening	Journal	3
Urban Planning	Journal	1
Urban Science	Journal	1

Tab.1 List of sources where the analyzed papers were published, type of source and number of papers

The remaining 65 papers were excluded because: (a) only the abstract was freely available or only the abstract was written in English (24 papers); (b) they were theoretical and did not deal with application cases (four papers); they focused on the building scale (29 papers); and (c) they focus on the influence of specific typologies of plant species on the mitigation of urban heat island effects (12 papers). Fig.1 shows the temporal distribution of the 57 analyzed papers. Most of the analyzed papers were published from 2017 to 2019, excluding the year 2023 because the results are only partial as they refer to papers published until 1 June.

Tab.1 shows the source on which the 57 analyzed papers were published, the type of source and the number of papers published in each journal or series. With the exception of two papers, all the analyzed papers were published in 34 different scientific journals. The journals where the highest number of the analyzed papers are: Landscape and Urban Planning, Science of the Total Environment, Sustainability, and Sustainable Cities and Society.

With regard to the data analysis, the main research question was broken down into four sub-questions that guided the content analysis of the papers. Tab.2 shows the sub-questions, specified through a description of the interpretation keys.

Sub-question	**Interpretation key**
A – General context	A1 – The scale to which the analysis refers (region, city, part of the city).
	A2 – Type and number of case studies analysed.
B – Reasons	B1 – Description of the reasons why the urban heat island phenomenon is studied.
	B2 – It is described whether the phenomenon was studied individually or within a larger study.
C – Methods and data	C1 – Description of the methods used (in situ observations, remote sensing techniques, modelling and simulation).
	C2 – Description of data retrieval with reference to three parameters concerning the season in which the data was retrieved, the duration of data collection and the period of the day to which the data refers.
D – Implications for spatial and urban planning	D1 – Does the study define strategies and/or suggest recommendations for planners and policy maker
	D2 – Do you dedicate a special section to such strategies?
	D3 – What kind of strategies are defined?

Tab.2 Sub-question and description of interpretation keys for the analysis of selected papers

3. Results

Below are the results for each sub-question shown in Tab.2.

3.1 General context

In relation to the general context, 49 papers refer to the municipal scale, two concern the metropolitan scale (Kowe et al., 2021; Lonsdorf et al., 2021), two focus on an inter-municipal scale, between municipal and regional territory (Gohr et al., 2021; Chaudhuri & Kumar, 2021), three refer to the regional scale (Ashwini & Sil; 2022; Bindajam et al., 2022; Schwarz et al., 2011), and one concerns the national scale (Bassett et al., 2020) (see Fig.2). For example, Bassett et al. (2020) study the thermal contribution of land cover change to climate regulation between 1975 and 2014 in Great Britain.

Furthermore, with reference to the 49 cases that refer to the urban scale, 29 cases study the entire municipal territory while 20 focus on parts of the territory. With reference to the 29 papers that consider the entire municipal territory, in six cases a comparison between several cities is made (Han et al., 2023; Marando et al., 2022; Degefu et al., 2021; Ramaiah et al., 2020; Meerow, 2019; Estoque et al., 2017).

For example, Marando et al. (2022) analyze the mitigation of the local microclimate offered by urban green infrastructure through a model that combines land surface temperatures (LST) with air temperature, taking 601 European cities with less than 50,000 inhabitants as case studies. With reference to studies analyzing parts of the city, twelve papers consider permeable areas such as urban parks (Permatasari et al., 2021; Li et al., 2021; Cheng et al, 2015), cemeteries (Okumus & Terzi; 2023), the urban green system (Feng et al., 2022; Wo et al., 2022; Yan et al., 2021; Wang et al., 2021; Yu et al., 2017; Vaz Monteiro et al., 2016), forest areas (Yosef et al., 2022) and urban gardens (Nolte et al., 2022). In the remaining eight cases (Murtinová et al., 2022; Chen et al., 2021; Ruiz-Aviles et al., 2020; Wu & Zhang, 2019; Petri et al., 2019; Bartesaghi-Koc et al., 2019; Zhang et al., 2017b; Mariani et al., 2016), urban areas characterized by a mixed fabric comprising both sealed and permeable areas are considered. For example, Murtinová et al. (2022) study the effect of the

Surface Urban Heat Island (SUHI) in the city of Zvolen (Slovakia), analyzing the LST within three urban areas during the summer months in the period 2010-2021.

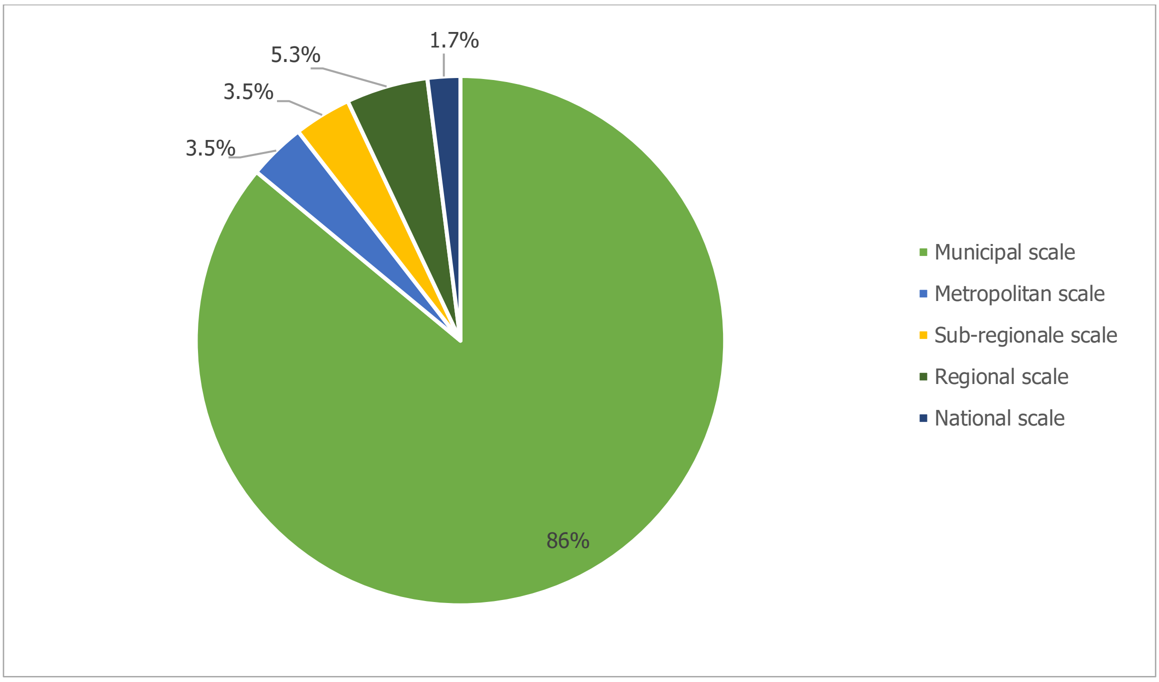

Fig.2 Scale of analysis of the papers analyzed in the study

Fig.3 shows the location of the case studies analyzed in those papers that focus on the municipal scale with the exception of the 601 European cities analyzed in the study of Marando et al. (2022). The most studied is Beijing, followed by Shenzen (China), Manila (Philippines), and Milan and Rome (Italy).

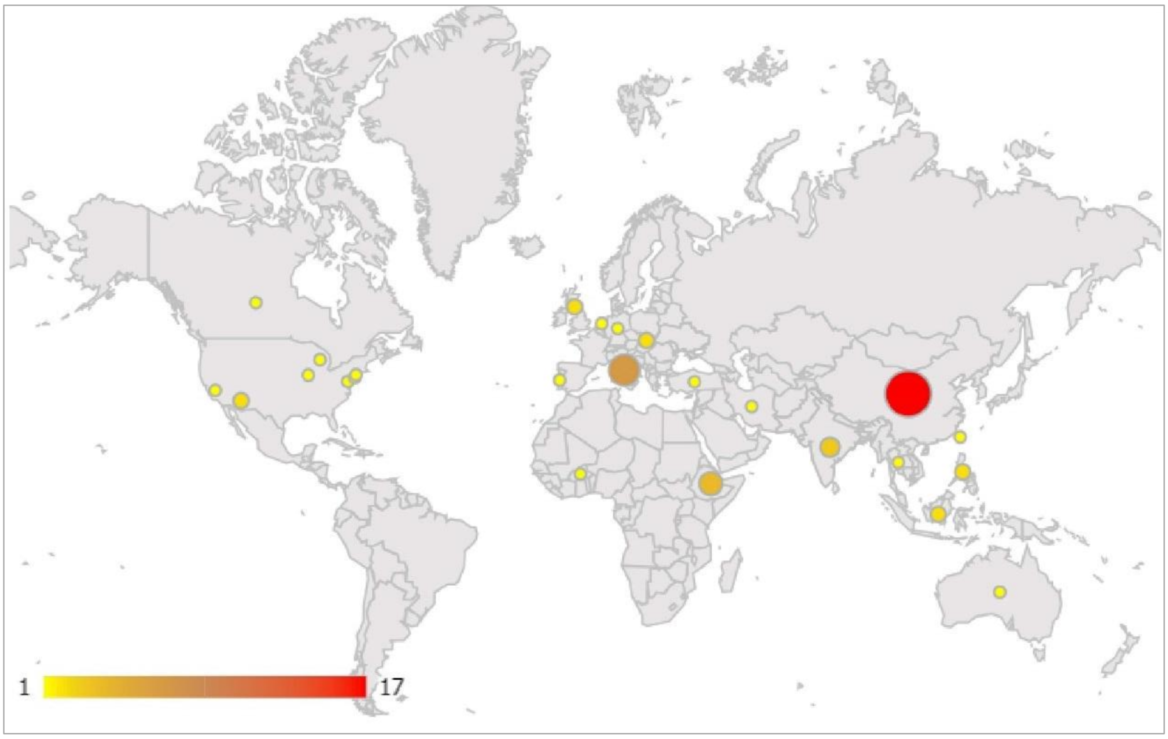

Fig.3 Localization of case studies in the case of papers focusing on the municipal scale

3.2 Reasons

With reference to the second sub-question 'motivations', 47 papers focus their study on the phenomenon of urban heat islands. In the other ten cases (Biasin et al., 2023; Feng et al., 2022; Yao et al., 2022; van Oorschot et al., 2021; Lonsdorf et al., 2021; Sebastiani et al., 2021; Meerow, 2019; Zidar et al., 2017; Meerow & Newell, 2017; Bodnaruk et al., 2017), the study of the urban heat island phenomenon is embedded within a broader study. For example, van Oorschot et al. (2021) study the best location of green infrastructure based on its ability to provide three benefits, that is three ecosystem services, one of which is the reduction of the urban heat island effect.

In reference to the papers that focus on the urban heat island phenomenon (Fig.4), 24 papers focus on the influence of permeable areas on the temperature reduction and, thus, urban heat island effects. Different types of permeable areas are studied such as urban green areas (Han et al., 2023; Murtinová et al., 2022), parks (Wo et al., 2022), forests (Yosef et al., 2022) and urban green infrastructure (Marando et al., 2019; Di Leo et al., 2016). In addition, nine papers (Amir Siddique et al., 2023; Ashwini & Sil, 2022; Bindajam et al., 2022; Permatasari et al., 2021; Li et al., 2021; Bassett et al., 2020; Elliot et al., 2020; Tayebi et al., 2019; Schwarz et al., 2011) focus on the influence of land use and/or land cover and their changes on temperatures and, thus, on reducing urban heat island effects.

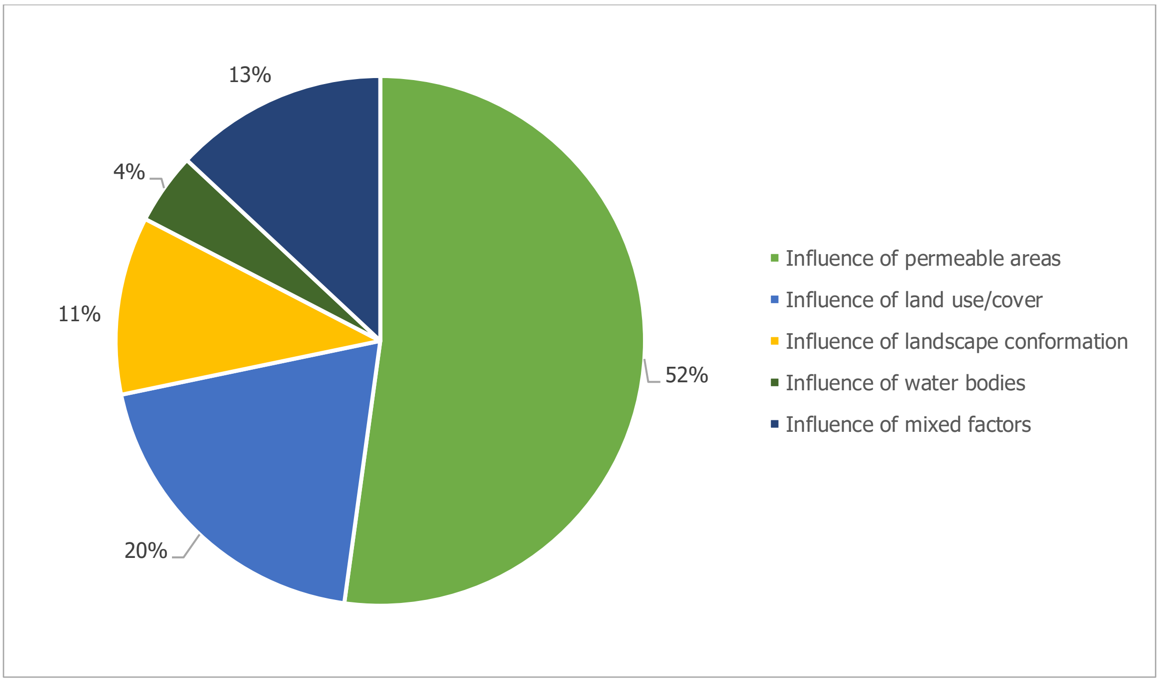

Fig.4 Factors studied by papers that focuses on urban heat island phenomenon

For example, Elliot et al. (2020) propose a study in which a simulation model of land cover changes was used to assess the effects of urban heat islands over time in the city of Lisbon. Five papers (Kowe et al., 2021; Chaudhuri & Kumar, 2021; Chen et al., 2021; Osborne et al., 2019; Estoque et al., 2017) study how landscape conformation influences temperatures and, thus, the reduction of urban heat islands.

Two papers (Ruiz-Aviles et al., 2020; Wu and Zhang, 2019) study the influence of water bodies on the urban heat island phenomenon. The remaining six papers focus on different factors (Gohr et al., 2021; Apicella et al., 2021; Ronchi et al., 2020; Shih & Mabon, 2020; Ramaiah et al., 2020; Zhang et al., 2017b). For example, Ramaiah et al. (2020) study how LST is influenced by three factors: built-up areas, vegetated areas and water bodies.

3.3 Methods and data

With reference to the "methods and data" sub-question (Fig.5), 37 papers (Okumus and Terzi, 2023; Yao et al., 2022) use remote sensing techniques to assess LST. In six papers (Nolte et al., 2022; Li et al., 2021; Lonsdorf et al., 2021; Bassett et al., 2020; Zhao et al., 2019; Vaz Monteiro et al., 2016) air temperatures are obtained through direct measurements. Two cases (Han et al., 2023; Marando et al., 2019) assess both land surface temperatures through remote sensing techniques and air temperatures through direct measurements. In the remaining twelve papers, the urban heat island phenomenon and local climate regulation are studied through other methods such as INVEST (Biasin et al., 2023; Ronchi et al., 2020) or the i-Tree cool air model (Pace at al., 2022).

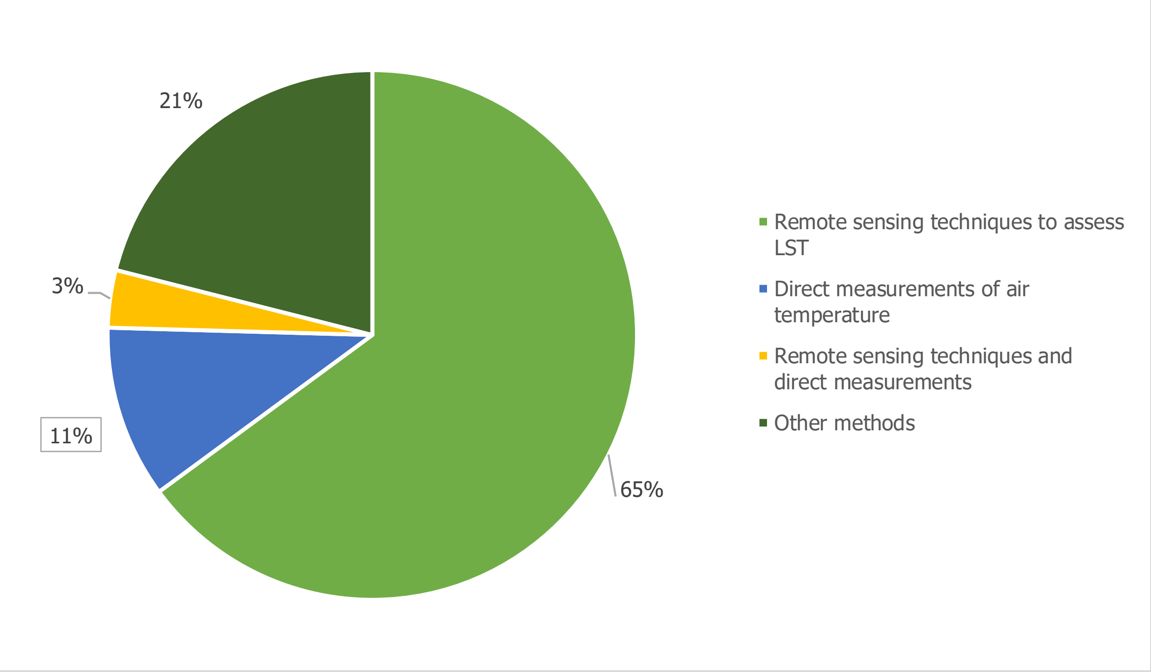

Fig.5 Methods used to study the urban heat island phenomenon

In relation to the 37 papers using remote sensing techniques, in twelve cases the images analyzed refer to a single date. Fig.6 shows to which time of day the twelve papers referring to a single date refer when assessing the urban heat island. Specifically, in five cases (Okumus & Terzi, 2023; van Oorschot et al., 2021; Yan et al., 2021; Wu & Zhang, 2019; Greene & Millward, 2019) the image refers to daytime, in one case to nighttime (Estoque et al, 2017), while in the remaining six cases the time of day to which the assessment refers is not made explicit (Feng et al., 2022; Chen et al., 2021; Permatasari et al., 2021; Sebastiani et al., 2021; Meerow, 2019; Cheng et al., 2015).

The remaining 25 papers that use remote sensing techniques analyze images that refer to several, often very distant years, of which nine (Murtinová et al., 2022; Gohr et al., 2021; Yosef et al, 2022; Wo et al., 2022; Shih & Mabon, 2021; Ruiz-Aviles et al., 2020; Ramaiah et al., 2020; Wu et al., 2020; Osborne et al., 2019) have acquired images that refer to daylight hours, two (Amir et al., 2023; Wang et al., 2021) to nocturnal hours, two (Apicella et al., 2021; Zhang et al., 2017a) to both nocturnal and diurnal hours, and in the remaining twelve cases (Ashwini & Sil, 2022; Bindajam et al., 2022; Yao et al, 2022; Degefu et al., 2021; Kowe et al., 2021; Chaudhuri & Kumar, 2021; Tayebi et al., 2019; Yu et al., 2017; Meerow & Newell, 2017; Sun & Chen, 2017; Zhang et al., 2017a; Di Leo et al., 2016) is not made explicit. Fig.7 shows the 25 papers evaluating the urban heat island phenomenon over a timeframe longer than one day using remote sensing techniques and, for each period, indicates the time of day to which the evaluations refer.

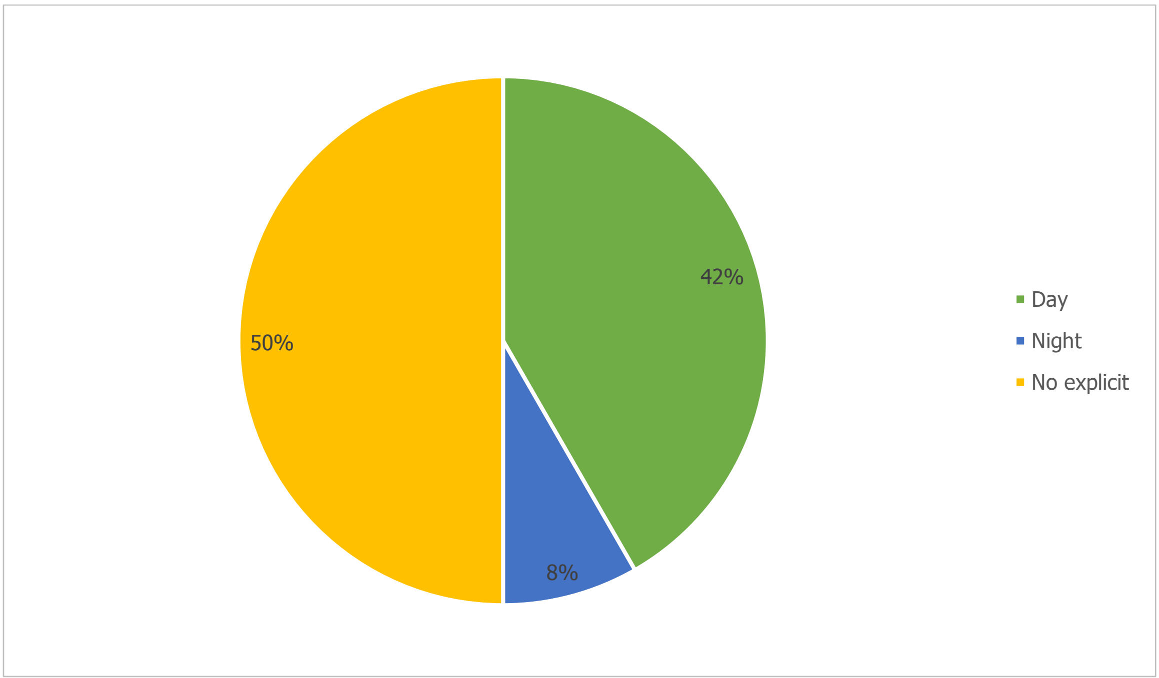

Fig.6 Time of day refers to the twelve papers considering a single date to assess the urban heat island

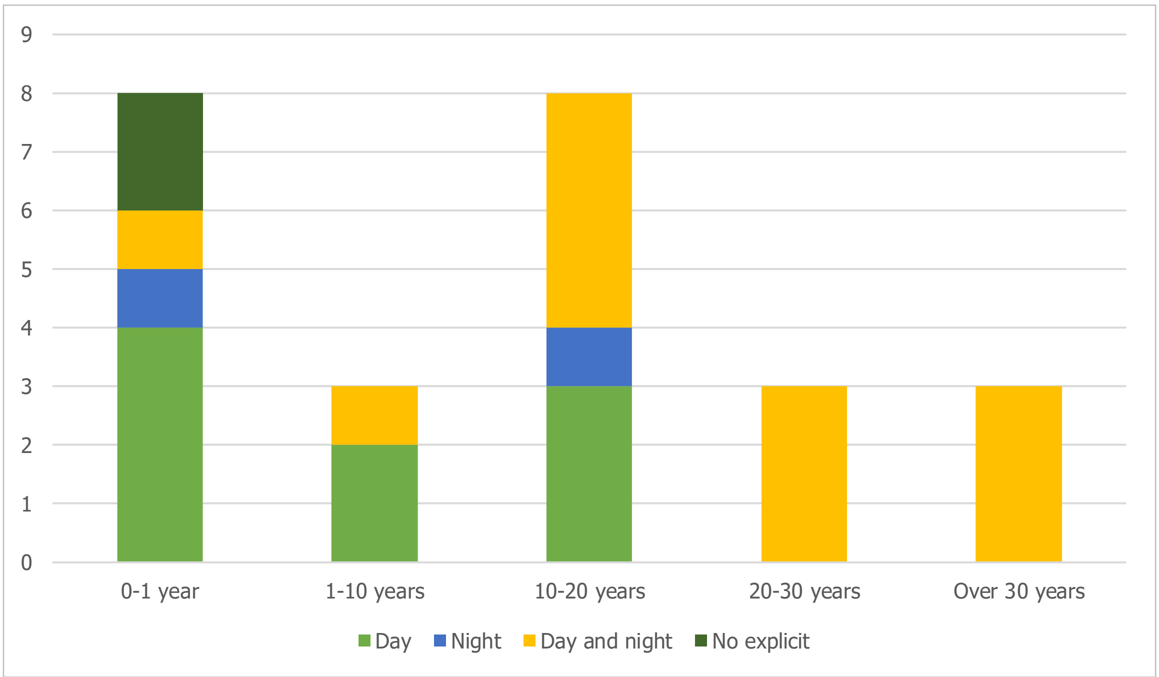

Fig.7 Identification of papers evaluating the urban heat island phenomenon over a period of time longer than one day, broken down by observation period and by time of day to which the evaluation refers

3.4 Implications for spatial and urban planning

With reference to the fourth sub-question "Implications for spatial and urban planning", 32 papers suggest strategies and/or recommendations for policy makers and planners. In thirteen cases (Han et al., 2023; Okumus & Terzi; 2023; Feng et al., 2022; Pace et al., 2022; Chen et al., 2021; Kowe et al., 2021; Li et al., 2021; Lonsdorf et al., 2021; Yan et al., 2021; Shih & Mabon, 2021; Yu et al., 2017; Zhang et al., 2017b; Di Leo et al., 2016) the authors decided to dedicate a special section to them. The 32 papers suggesting strategies and/or recommendations can be grouped into four types: strategies at the territorial scale, guidelines on individual interventions at the local scale, the methodological approach as decision support, and strategies and guidelines that address both the territorial and local scales (see Fig.8).

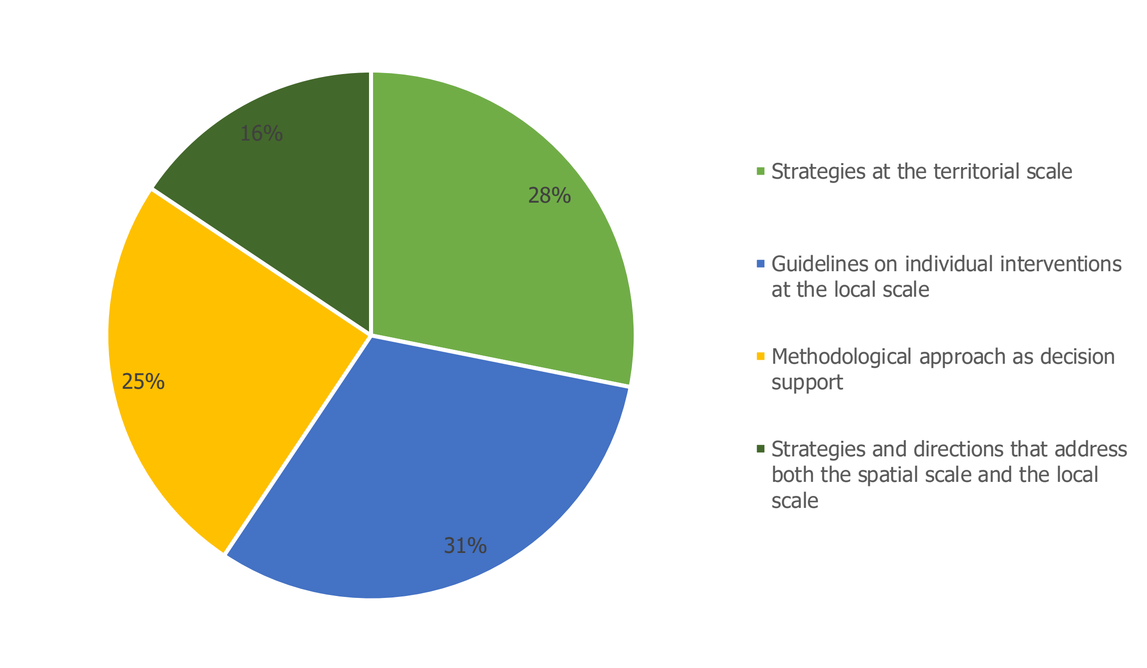

Fig.8 Type of strategies and/or recommendations suggested by the 32 papers providing them

In nine instances (Biasin et al., 2023; Yosef et al., 2022; Chen et al., 2021; Kowe et al., 2021; Lonsdorf et al., 2021; Shih & Mabon, 2021; Zidar et al., 2017; Sun and Chen, 2017; Di Leo et al., 2016), these recommendations and/or strategies refer to a spatial scale. For example, Shih & Mabon (2021) suggest favoring natural ventilation and protecting areas that promote temperature reduction.

In order to improve natural ventilation, the study suggests preserving mountain valleys from intensive urbanization by preserving green spaces along pathways where wind is channeled, especially those located along river corridors. With regard to areas that favor temperature reduction, such as agricultural land, wetlands and ponds, their continuity should be ensured within development plans also by providing forms of transfer of building rights.

In ten instances (Bindajam et al., 2022; Feng et al., 2022; Nolte et al., 2022; Yan et al., 2021; Li et al., 2021; Estoque et al., 2017; Yu et al., 2017; Zhang et al., 2017a; Greene & Millward, 2017; Vaz Monteiro et al., 2016), the recommendations and/or strategies refer to individual interventions at the local scale. For example, Ronchi et al. (2020) suggest design parameters for urban green areas, such as tree cover and area size. In relation to tree cover, the study suggests that the species planted, and the relative canopy cover are most significant elements despite the number of trees. In eight cases (Amir Siddique et al., 2023; Han et al., 2023; Ashwini & Sil; 2022; Yao et al., 2022; Marando et al., 2022; Murtinová et al., 2022; Mariani et al., 2016; Schwarz et al., 2011) the methodology is proposed as a decision-support tool, while the remaining five cases (Okumus & Terzi; 2023; Pace et al., 2022; Wang et al., 2021; Ronchi et al., 2020; Zhang et al., 2017b) provide recommendations at both the spatial and individual intervention scales.

4. Discussion and conclusions

The results of the content analysis conducted on the 57 papers highlight several important aspects. Firstly, the study of the urban heat island phenomenon in relation to ecosystem services has been a widely discussed topic in the literature for several years. The oldest analyzed paper dates back to 2011. Howard was the first

scholar to describe the urban heat island phenomenon and its causes within his work "The Climate of London" where he described the study conducted from 1806 to 1830 during which he recorded the temperature every day for a year at three sites outside London (Plaistow, Tottenham and Stratford) and one within the city (Royal Society) (Mills, 2007). Howard defines the urban heat island as the difference between the air temperature within the urban settlement and the air temperature measured in the rural areas and assumes that this value increases as one moves closer from the city limits towards the center (Mills, 2007). Howard also defines possible causes, arriving at the conclusion that "the temperature of the city is not to be considered as that of the climate; it partakes too much of an artificial warmth, induced by its structure, by a crowded population, and the consumption of great quantities of fuel in fire" (Howard, 2007, p. 2).
The second aspect concerns the factors influencing urban heat islands. According to the study conducted by Voogt (2007), they can be traced to six aspects: i. geographic location; ii. time; iii. synoptic weather; vi. city form; v. city function; and vi. city size. Geographic location takes into account climate, topography and rural surrounds. Time considers time of day (day and night) and season (winter, spring, summer, and autumn). Synoptic weather considers wind and the presence of clouds. City form concerns materials, geometry, and green spaces. City function concerns the activities that take place in terms of energy use, water use and pollution and, finally, city size is connected with the shape of the city and the functions that take place in it. However, according to Voogt (2007), mitigation measures relate to city form and city function are the only parameters on which human being can operate.
For example, Okumu and Terzi (2023) study the cooling effect of 309 cemeteries in the city of Istanbul. The study showed that the optimal distance for cooling, beyond which this regulation service decreases, is 200 m for very small cemeteries, 250 m for medium-small cemeteries and 400 m for larger cemeteries. In terms of the time factor, the intensity of urban heat islands is influenced by the seasons and day and night variations. The influence of seasons concerns two aspects: amount of solar radiation reaching the earth and metabolic activity of vegetation (Deilami et al., 2018). In addition, the influence of the seasons also depends on geographical location. In the case of cities with arid and semi-arid climates, the intensity of temperatures is lower in urban areas than in surrounding areas characterized, for example, by the presence of desert areas (Shahraiyni et al., 2016). This phenomenon is called an urban cold island (Rasul et al., 2015, 2016). With regard to night and day variations, the cooling process in cities after sunset is slower than in rural areas. This behavior is due to the high thermal capacity of certain materials such as concrete and asphalt that characterize urban areas. These materials absorb high amounts of heat during the day, which is then slowly released during the night, resulting in very high UHI values during the night hours.
The third aspect concerns the techniques used. The vast majority of papers analyzes land surface temperatures through remote sensing techniques. The analysis of urban heat islands requires a reliable and consistent dataset. Prior to the use of remote sensing techniques, the process to obtain such data was particularly laborious and costly as it required the installation of meteorological stations (Baranka et al., 2016). The process has been simplified by the use of remote sensing satellites, which have made it possible to study large urban areas due to frequent wall-to-wall coverage (Deilami et al., 2018). Furthermore, thermal information is provided both as a scene/image and as individual products making the process of deriving urban heat island intensity simpler (Li et al., 2013).
Several satellites are used to acquire the images needed to obtain urban heat island intensities, including Landsat TM, Landsat ETM, MODIS, Landsat OLI (8), etc. According to a study conducted by Deilami et al. (2018), Landsat imagery is the most widely used as it is freely available, it has worldwide coverage with an acceptable resolution of 30x30 m, it has temporal coverage dating back to 1972 and it provides both thermal and thematic spectral bands. However, Landsat images also have disadvantages. Firstly, it takes sixteen days for the satellite to re-image the same area. As a consequence, assessing the effects of urban heat islands during a day or a week is not possible. The second disadvantage relates to processing time, which could be

significant if mosaicking is required in order to process analyses on a national or regional scale, given the size of the images (Irons et al., 2012; Loveland & Dwyer, 2012). The use of MODIS imagery solves some of these critical issues, such as the time between two images of the same location (1-2 days for the Terra and Aqua MODIS satellite) and the processing time, as it provides some immediately available products that significantly reduce the time. For example, LSTs are produced daily and weekly. However, MODIS images have a low spatial resolution.

Despite the widespread use of remote sensing techniques at the expense of direct measurements, these techniques have limitations. Firstly, obtaining cloud-free images is difficult in some geographical areas (Deilami et al., 2018). In addition, the thermal and thematic bands of remote sensing have a spatial resolution of 30 m to 1 km that do not make it possible to process very detailed analyses, which would require costly downscaling and fusion approaches (Atkinson, 2013). Finally, the accuracy of the data is affected by several factors, including atmospheric effect, sensor noise, etc. For example, the study conducted by Jiménez-Muñoz and Sobrino (2006) showed that the main source of error for the determination of LST from satellite images is atmospheric effects. Krehbiel and Henebry (2016) conducted a study in which they compared urban heat island intensities obtained from direct measurements and those obtained from MODIS imagery. The urban heat island intensity during the day is much higher in the case of data derived from MODIS images than that determined from direct measurements, while the values for the night are quite similar.

The third aspect concerns the implications for spatial and urban planning. At the international level, the 2030 Agenda for Sustainable Development and the 17 Sustainable Development Goals (SDGs) provide an important framework for the identification of climate change adaptation measures. In particular, Goal 11 "Sustainable cities and communities" places resilience as a priority aspect in the future development of cities that adopt and implement climate change adaptation policies (EEA, 2020). Furthermore, Goal 13 "Climate action" in Target 13.2 calls for "Integrate climate change measures into national policies, strategies and planning" (General Assembly of United Nations, 2015). However, strategies defined at the international level have an indirect impact on adaptation at the local scale as these agreements have been negotiated and signed by national governments (Valencia et al., 2019). In fact, the adoption of these international frameworks does not lead to the implementation of concrete adaptation actions by cities. For example, the study proposed by Aguiar et al. (2018) examined 147 Local Adaptation Strategies/Plans in Europe, highlighting that the United Convention on Climate Change process promoted the elaboration of only 21 plans. Furthermore, the study shows that the issue of extreme temperatures is addressed by 35 plans.

At the national level, Athens and Stockholm represent two cities that have addressed heat islands in their climate change adaptation plans (Gancheva et al., 2022). Athens adopted the Athens Resilience Strategy for 2030 in 2017 and the latest Climate Action Plan was published in 2022. In particular, one of the main objectives of the Athens Strategy is to increase the area of green areas in order to decrease vulnerability to heat islands. To this end, Athens has quadrupled the budget for green areas, also thanks to the Greek state and European funds (Observatory On Non-State Climate Action, 2022). In 2019, Athens obtained funding on the Natural Capital Financing Facility, a new financing instrument of the European Investment Bank that finances cities for blue and green infrastructure projects. In addition, in 2021, the city of Athens signed the Urban Nature Declaration, which envisages de-impermeabilizing between 30 and 40 percent of impermeable surfaces and ensuring that at least 70 percent of the population has access to green or blue spaces within a 15-minute radius.

According to the EEA (2020), green infrastructure is one of the most effective adaptation measures to combat high temperatures. Several projects have been aimed at increasing green areas. For example, the LIFE Green Heart Project envisaged a significant increase in green areas in Toulouse, France, in order to reduce the temperature by approximately 3 °C during urban heat islands (Directorate-General for Climate Action, 2023). Furthermore, the LIFE@Urban Roof Project aims to increase green roofs in the city of Rotterdam, Netherlands.

The RESIN (Climate resilient cities and infrastructures) project funded by the Horizon 2020 Programme for the years 2015-2018 aims to improve climate resilience in European cities. The RESIN Adaptation Options Library is one of the tools developed by the Project. The library is a database on the effectiveness of adaptation measures, divided into three types (structural, social and institutional) based on an analysis of scientific studies published up to 2017 (EEA, 2020). The database is structured in four parts: general information, organization, effectiveness and cost-efficiency. The general information section provides the main information on each adaptation measure (type, scale, climate region, sector, etc.). Organization defines who should implement the adaptation measure. Effectiveness measures in terms of reducing the vulnerability and risk components. Finally, Efficiency considers the costs and benefits of implementing the adaptation measure (Mendizabal et al., 2015).
In conclusion, the study is a preliminary research that attempts to provide an overview of how urban heat islands are studied in literatures by analyzing some key issues related to the general context, rationale behind the study, materials and data, and implications for land-use and urban planning.
With reference to the general context, almost all papers focus on the municipal scale. In relation to reasons, only a small percentage of the papers analyzed study the heat island phenomenon within a broader approach that investigates other aspects. In relation to methods and data, the vast majority analyze land surface temperatures through remote sensing techniques. Finally, not all papers use their findings to propose strategies and recommendations for policy makers and planners.
The originality of the proposal consists in the construction of a framework that connects the issues due to UHI with the ES and GI topic at the municipal scale. In fact, if the urban setting represents the place where the effects of climate change are most perceived, the construction of an analytical system on which to base a climate-proof urban planning policy turns out to be a useful and important tool. It must be emphasized that adaptation will not be cross-cutting and ubiquitous (Pio, 2023), so specific analysis will be needed for each urban context.
Future research developments could concern the definition of climate-proof methodological approaches that integrate ES within spatial planning with particular reference to the local scale. The principle of climate proof-planning at the local level can be a guiding factor in territorial governance processes but, above all in the definition of a regulatory framework aimed at improving the quality of space and life in urban contexts.

Authors' contribution

Federica Isola (F.I.), Federica Leone (F.L.), and Rossana Pittau (R.P.) collaboratively designed this study. Individual contributions are as follows: F.I. wrote Section 1; F.L. wrote Sections 2, 3, 3.1, 3.2, 3.3, and 3.4. F.I. and F.L. jointly wrote Section 4. F.L and R.P. jointly analyzed data.

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Image Sources

Fig.1 to 8: Author's elaboration.

Table Sources

Tab.1 to 2: Author's elaboration.

Author's profile

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Special Issue 2024

What transition for cities?

Scientific debate, research, approaches and good practices

(Rosa Anna La Rocca)

(Under publication)

The current challenges (climate change, pandemic, social divide, lack of resources, economic crisis, population ageing, depopulation of inland areas) affecting cities require a global renewal of methodologies, approaches, tools, policies and behaviours, calling into action all urban actors (planners, decision-makers, investors, city-users, citizens). The convergence point identified as a possible solution, both in the academic and political spheres, refers to the "transition" towards more sustainable, resilient and compatible management, governance and use of cities. With this input being accepted, TeMA Journal aims to investigate possible scenarios of urban transition inviting scholars, professionals, technicians, and urban actors to present contributions that address numerous topics. The call for contributions for this Special Issue, also in a critical/provocative key, aims to delve into the state of art regarding a goal/challenge (the transition) that risks being a new "label" hard to define and implement.