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Planning for Extreme Heat: A Review

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Extreme heat is a growing concern for cities, with both climate change and the urban heat island (UHI) effect increasingly impacting public health, economies, urban infrastructure, and urban ecology. To better understand the current state of planning for extreme heat, we conducted a systematic literature review. We found that most of the research focuses on UHI mapping and modeling, while few studies delve into extreme heat planning and governance processes. An in-depth review of this literature reveals common institutional, policy, and informational barriers and strategies for overcoming them. Identified challenges include siloed heat governance and research that limit cross-governmental and interdisciplinary collaboration; complex, context-specific, and diverse heat resilience strategies; the need to combine extreme heat "risk management" strategies (focused on preparing and responding to extreme heat events) and "design of the built environment" strategies (spatial planning and design interventions that intentionally reduce urban temperatures); and the need for extensive, multidisciplinary data and tools that are often not readily available. These challenges point to several avenues for future heat planning research. Ultimately, we argue that planners have an important role to play in building heat resilience and conclude by identifying areas where scholars and practitioners can work together to advance our understanding of extreme heat planning.

Keywords: Extreme heat; heat waves; urban heat; urban heat island; urban planning; urban resilience.

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1. Introduction

Climate change and the urban heat island (UHI) effect are increasing the number of dangerously hot days in cities worldwide. Climate change is raising average global temperatures and leading to more frequent and prolonged heat waves (Edenhofer *et al.* 2014). Through the UHI effect, the form of the built environment, including the materials used in buildings and urban infrastructure and anthropogenic heat waste, increases urban temperatures beyond rural and natural areas (Oke 1973; Stone and Rodgers 2001). We use the term "extreme heat" to encompass both the acute and chronic heat risk that is exacerbated by the UHI effect and climate change. Extreme heat is context specific, with variables such as day and nighttime temperatures, humidity, exposure, and acclimation impacting risk (U.S. Environmental Protection Agency 2006).

Extreme heat is the deadliest of all weather-related disasters (Hondula *et al.* 2015) and was attributed to over 700 deaths in the 1995 Chicago, Illinois heat wave (Davis *et al.* 2003), over 70,000 deaths in Europe during the 2003 heat wave (Robine *et al.* 2008), and 55,736 deaths in the Russian heat wave of 2010 (Guha-Sapir *et al.* 2011). Vulnerable populations, including children, the elderly, and low-income households, are especially at risk for heat-related health concerns (Chow *et al.* 2012; Kovats and Hajat 2008). Hospital admissions for mental health and behavioral disorders also increase as much as 7.3 percent during heat waves (Hansen *et al.* 2008). In 2017, an estimated 153 billion hours of labor was lost globally due to extreme heat (Watts *et al.* 2018) and heat increases are projected to decrease global economic productivity by 20 percent during hot months by 2050 (Zander *et al.* 2015). In addition to the quality of life and economic impacts, extreme heat can also raise energy demands (Magli *et al.* 2015; Santamouris *et al.* 2015), increase water usage (Guhathakurta and Gober 2007), impact the functionality of urban infrastructure (Dobney *et al.* 2010; Golden 2004; Jenkins *et al.* 2014), cause additional stress to urban ecosystems (Brans *et al.* 2018; Grimm *et al.* 2015; Nitschke *et al.* 2017), and in extreme cases, may threaten the viability of cities (Pal and Eltahir 2016).

While the UHI effect was first documented in London, UK in the 19th Century by Howard (1833), extreme heat was not a widespread concern until recently (O'Neill *et al.* 2009). Consideration of extreme heat in the design and planning of cities was mainly the purview of scholars of desert cities, such as Golany (1983), who articulated best practices in urban design, and Vefik Alp (1991), who argued for the use of traditional architectural vernacular as a heat-adaptive solution. Extreme heat is distinct from other climate risks for several reasons, including its historic lack of governance and legal regulatory structure (Bernard and

McGeehin 2004; Kaloustian *et al.* 2016), spatial and temporal complexity (Coseo and Larsen 2014; Good 2016), compounding of other risks and impacts (Bouchama *et al.* 2007), and invisibility (Luber and McGeehin 2008). In contrast, flood risk has established governance structures (floodplain managers and flood insurance in the US), mapped risks (FEMA floodplain maps in the US), directly measurable impacts (loss of property and life), and is a more visible risk (images in the media of flood devastation) (Plate 2002; Schanze 2007).

As concerns about extreme heat grow, scholars from different disciplines are advancing the understanding of causes and responses to this risk. Advances include documenting the contributions and interactions of controllable and non-controllable factors in the UHI effect (Memon *et al.* 2008), identifying and managing sources of heat vulnerability among the population (Reid *et al.* 2009), managing heat risk through emergency response preparation and inter-agency collaboration (Berisha *et al.* 2017), and long-term heat reduction in the built environment through efforts such as green infrastructure and reflective or lighter building materials (Kleerekoper *et al.* 2012; Solecki *et al.* 2005; Stone *et al.* 2013). We use the inclusive term "heat resilience" to describe these efforts undertaken at a local level to both prepare for and adapt to extreme heat risks. Heat governance includes the full range of public–private networks and actors that deliberate and make decisions about heat resilience (Mees *et al.* 2014).

The planning profession's specific role in heat governance remains unclear. In one recent US survey, 70 percent of planners were worried about extreme heat risk in the community they work, and heat ranked 4th out of 14 possible natural hazards in terms of concern (National Drought Mitigation Center 2018). In contrast, an assessment of over 3,500 climate adaptation resources in the US found that only 4 percent focused specifically on heat (Nordgren *et al.* 2016). Even when heat risks are widely acknowledged and heat resilient practices are understood locally, they are often not given priority over other community values such as aesthetics (Hatuka and Saaroni 2014).

Recognizing the urgency of extreme heat as a mounting climate risk to cities, we conducted a systematic literature review to advance the understanding of planning for extreme heat and to answer the following questions: (1) what are the trends in peer-reviewed literature related to planning for extreme heat; (2) what barriers and strategies do studies identify to increase heat resilience; and (3) what are the critical next steps needed in research and practice to support planning for extreme heat?

In the next section, we outline the methods used for a systematic review of the literature on heat planning. In Section 3, we provide an overview of this literature, including the primary methodological and geographic focus of the articles, trajectory, and source titles. We then delve into the smaller subset of articles that specifically address planning processes in Section 4, discussing key themes. We conclude by summarizing the findings of our review and reflecting on the role that planners play in heat resilience and meaningful avenues for future research.

2. Methods

To assess the current state of knowledge on heat planning, we conducted a systematic literature review (Xiao and Watson 2017). We searched Scopus, the largest citation database of peer-reviewed literature, for all English language articles and review papers published through the end of 2018 containing the terms "urban heat" or "extreme heat" and "planning" in the title, abstract, or keywords. We excluded articles in subject areas that were highly unlikely to be publishing urban planning work, such as medicine, the natural sciences, and computer science. These search criteria resulted in a dataset of 589 articles.

We then carefully read the title and abstract of each paper in the dataset, and categorized them based on their primary focus: (1) planning processes; (2) modeling; (3) impacts; (4) design; (5) literature review; and (6) other. Planning processes papers included those that focused primarily on planning, governance, and how information is used in policymaking. Modeling studies included any paper focused on the development or application of a map or model to understand extreme heat. Papers categorized as impacts included those focused primarily on understanding the effects of extreme heat, for example, public health, perceptions, and the economy. Design studies included those exploring relationships between extreme heat and elements of the built environment but did not focus primarily on a model. We categorized any papers that reviewed the literature on a topic or established a research agenda as literature review studies. Papers that did not fit into one of these six categories were coded as others. We also noted the geographical focus of the study, for example, the city the study modeled.

Through this initial coding exercise, 39 articles were categorized as planning processes. Two researchers independently read through the titles, abstracts, and in some cases the full article, to determine whether the papers really were focused on planning processes, and therefore should be reviewed in depth. We discussed and reconciled any discrepancies in our determinations. Ultimately, 21 of the original 39 articles were included in the in-depth review. We analyzed each of these papers, focusing on their definition of extreme heat, theoretical framework, and barriers and strategies related to procedural and institutional concerns, policies, technical and design considerations, and climate information. We then synthesized these notes and identified common themes across the studies, which we discuss in Section 4.

While our primary goal was to be systematic in our review in order to apply a replicable approach and get a representative overview of the heat planning literature, we acknowledge several limitations of our approach. First, some research is excluded from the Scopus database, for example, books and non-peer-reviewed reports or the so-called grey literature (Archambault and Lariviere 2010). We were also limited to English language publications. Our initial screening and categorization of the literature were based on the title, abstract, and subject area of journal, therefore it is possible that some articles included more planning-related content than was apparent from the abstract. We also recognize that some relevant literature may not be included in our dataset. The results are sensitive to the search terms, for example, a study might not use the terms "extreme heat" or "urban heat" specifically, and some heat planning work may be in public health journals categorized within the field of "medicine."

3. Overview of Literature

In this section, we summarize the characteristics of the extreme heat planning literature, including the main approaches used in research, the trajectory of papers published, geographic focus of studies, and the journals. We discuss both the full body of literature identified in Scopus and the much smaller selection of these papers that focus specifically on planning processes.

3.1. *Overview of the extreme heat planning literature*

Of the 589 articles on extreme heat planning identified in the Scopus database, the vast majority are not primarily focused on planning processes. In fact, we initially categorized just 39 studies, less than 7 percent of the dataset, as focused on planning processes. In contrast, we categorized 68 percent (399) of the studies as modeling papers, 14 percent (82) as design, 5 percent (32) look at heat impacts, 4 percent (22) are literature reviews, and 3 percent (15) do not fit into any of these categories. In addition, we identified 20 of the 589 studies in the dataset as not being relevant to urban heat planning despite fitting the search terms (e.g., a paper that was focused on groundwater heating). Other scholars have also recognized the lack of research on heat planning processes. For example, Mahlkow and Donner (2017: 385) observe that "only recently has the scientific community given more attention to the way planners and policymakers perceive and deal with the particular climate change adaptation issue of urban heat." Indeed, looking at the number of publications by year (Figure 1), it is clear that the overall research on heat planning has increased over time, with over 60 percent of all papers in the dataset having been published in the last five years.

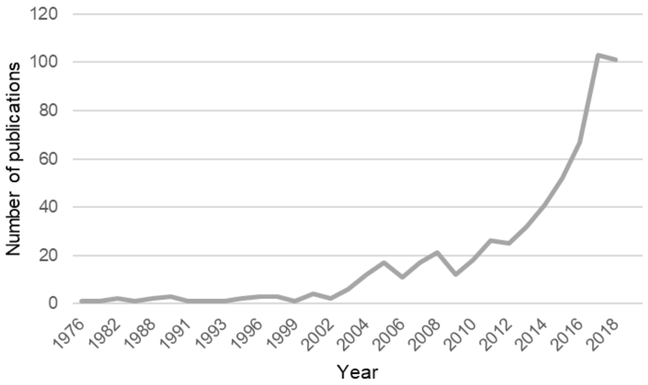

Fig. 1. Number of publications on extreme heat planning in the Scopus database, by year

The papers are quite diverse in terms of their geographic focus, although some countries and cities are overrepresented. The greatest number of studies focus on China and the US (Figure 2); in fact, these two countries together represent over 30 percent of the dataset. This is likely indicative of academic publishing patterns more broadly since China and the US are the largest producers of scientific articles (Tollefson 2018). While Australia, Germany, and the UK are all among the top five most commonly studied countries, they collectively account for just 10 percent of the dataset. It is notable that Australia is third, despite its relatively small population, perhaps because of the saliency of heat for the county. Looking at specific cities, the most common study sites are in China, with Beijing, Wuhan, Hong Kong, and Shanghai being the focus of over 10 publications. Other cities in Asia such as Seoul, South Korea, and Singapore are also popular study sites. In the US,

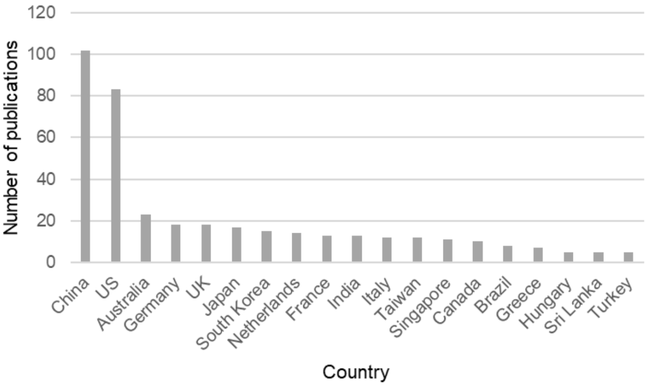

Fig. 2. The geographic focus of heat planning publications (all countries with more than 5 publications)

Phoenix, Arizona stands out, with over ten studies, which is not surprising given its high summer temperatures. In Europe both Paris, France, and London, UK are common research locations. Both cities saw a major increase in mortality rates during the 2003 heat wave (D'Ippoliti *et al.* 2010). Thus, the geographic focus of the papers seems to reflect both broader publication patterns as well as literal hotspots where extreme heat is a particularly salient issue such as in Phoenix or in Australian cities.

Extreme heat planning literature is published in a wide range of journals. In terms of the number of studies in the dataset, the top five titles are *Building and Environment* (35 papers), *Landscape and Urban Planning* (33), *Sustainability* (28), *Urban Climate* (28), and *Energy and Buildings* (26).

3.2. *Overview of the literature on extreme heat planning processes*

The geographic focus and source titles for the 21 studies focused on planning processes are somewhat different from the overall dataset, as shown in Table 1.

Table 1. Extreme Heat Planning Process Studies Reviewed in Depth

Citation	Journal	Geographic Focus
Bolitho and Mille (2017)	*Local Environment*	Australia
Corburn (2009)	*Urban Studies*	USA
Dhalluin and Bozonnet (2015)	*Sustainable Cities and Society*	France
Donner *et al.* (2017)	*Journal of Environmental Assessment Policy and Management*	Germany
Downes and Storch (2014)	*Planning Practice and Research*	Vietnam
Guindon and Nirupama (2015)	*Natural Hazards*	Canada
Hamilton *et al.* (2010)	*Proceedings of the Institution of Civil Engineers: Urban Design and Planning*	UK
Hatvani-Kovacs *et al.* (2018)	*Urban Climate*	Australia
Icaza *et al.* (2016)	*Sustainability*	Netherlands
Kingsborough *et al.* (2017)	*Climate Risk Management*	UK
Koop *et al.* (2017)	*Water Resources Management*	Netherlands
Lambert-Habib *et al.* (2013)	*Urban Climate*	France
Lu *et al.* (2017)	*Sustainability*	Taiwan
Mahlkow and Donner (2017)	*Journal of Planning Education and Research*	Germany
Mahlkow *et al.* (2016)	*Urban Climate*	Germany
Morawetz and Koemle (2017)	*Journal of Urban Planning and Development*	Austria
Quattrochi *et al.* (2000)	*Photogrammetric Engineering and Remote Sensing*	USA
Richardson *et al.* (2009)	*Canadian Journal of Urban Research*	Canada
Sailor *et al.* (2016)	*Sustainability*	USA
Stone (2005)	*Journal of the American Planning Association*	USA
Zaidi and Pelling (2015)	*Urban Studies*	UK

Only two cities in Asia are represented, with the majority of the studies focusing on cities in Europe (11), the US (4), and Canada (2). Similar to the full dataset, the articles are published in many different journals, with only *Urban Climate*, *Sustainability*, and *Urban Studies* containing more than one study. The planning process studies represent a variety of different disciplines or theoretical frameworks including urban planning, urban governance, urban climatology, economics, and political ecology.

4. Common Themes from the Literature on Extreme Heat Planning Processes

Our in-depth review of the 21 papers that focus on heat planning processes suggests that there are important institutional, policy, technical, and informational barriers that need to be addressed in order for cities to more effectively plan for growing heat risks. On a more positive note, the literature seems to largely agree on what these challenges are, and it is beginning to identify potential strategies to overcome them.

When it comes to defining the extreme heat challenge, which will naturally influence proposed solutions, most studies acknowledge the combined heat threat posed by climate change and the UHI effect (e.g., Bolitho and Miller 2017; Guindon and Nirupama 2015; Mahlkow and Donner 2017; Richardson *et al.* 2009; Zaidi and Pelling 2015). However, at least one study does not explicitly refer to climate change (Morawetz and Koemle 2017). A smaller subset of the papers also emphasize the relationship of the extreme heat risk to indoor temperatures (Donner *et al.* 2017; Hatvani-Kovacs *et al.* 2018; Sailor *et al.* 2016) and the relationship between increased temperatures and air quality, specifically ozone levels (Quattrochi *et al.* 2000; Stone 2005).

4.1. *Institutional challenges and opportunities*

Almost all of the heat planning process studies identify institutional barriers and potential strategies for overcoming them. In general, there is a recognized need for "more governance capacity" around extreme heat risk, which is seen as lacking in comparison to other challenges cities face, including other climate risks (Koop *et al.* 2017: 3437).

4.1.1. *Breaking down extreme heat planning siloes*

One of the most persistent themes across the papers is the recognition that siloes and fragmented decision-making inhibit effective extreme heat planning and that more collaboration, or knowledge integration, is needed across city departments, levels of government, academic disciplines, and stakeholder groups. Case studies from cities in Germany (Mahlkow and Donner 2017), Australia (Bolitho and Miller 2017), and Vietnam (Downes and Storch 2014) all point to the need for more coordination.

This need for more collaboration begins with extreme heat research. Studying extreme heat is complex and necessarily involves different disciplines, including climatology, public health, as well as urban planning (Bolitho and Miller 2017; Hatvani-Kovacs *et al.* 2018; Richardson *et al.* 2009). This means that extreme heat research must be interdisciplinary (Sailor *et al.* 2016). Research should also be co-produced, or the product of close collaborations between urban heat practitioners and researchers (Mahlkow *et al.* 2016). This requires that researchers engage with stakeholders at all stages of the research process — ideally iteratively — to ensure that research outputs and information are relevant and get used. As Sailor *et al.* (2016: 3) note, “a fuller integration of stakeholders throughout the scientific research process is a necessary step to assure that results will be more relevant and readily implemented by policy-makers.” Similarly, Quattrochi and Colleagues (2000) argue that heat data (e.g., maps identifying hotter areas), plans, and monitoring all need to be undertaken through an iterative process with both stakeholders and researchers participating.

Much of the literature recognizes that extreme heat planning issues cut across traditionally separate sectors or planning departments and that more integrative approaches to addressing heat are needed (Hatvani-Kovacs *et al.* 2018; Mahlkow and Donner 2017). As Bolitho and Miller (2017: 687) write:

> “A demanding issue for policy implementation is the complex coordination required to ensure the reach of communications and services to protect vulnerable people. Whilst health has been the primary area where research and responses have occurred, it is increasingly recognised that extreme heat cuts across a number of policy areas, including emergency management, social services, critical infrastructure, housing, urban planning, and local government.”

Besides finding ways to bring different city departments together, it is also crucial to increase collaboration between different neighboring local government jurisdictions (Sailor *et al.* 2016) and vertical levels of government (Mahlkow and Donner 2017). In the case of Berlin, Mahlkow *et al.* (2016: 276) find that “conflicting notions of responsibilities and respective endowment with resources between the district and city level as well as other actors lead to an overall loss of potential for strategic risk reduction action." Heat governance is of course not solely within the purview of governments, thus it is equally important to involve nongovernmental stakeholders, such as private developers, whose decisions have a major impact on heat vulnerability (Bolitho and Miller 2017; Dhalluin and Bozonnet 2015).

4.1.2. *Mainstreaming and finding the appropriate planning scales*

Related to the issue of siloes, studies recognize the challenge of mainstreaming urban climate considerations across different city units (Mahlkow and Donner 2017) and day-to-day processes (Donner *et al.* 2017). For example, Mahlkow *et al.* (2016) see the failure to incorporate the climate impacts of development into mandatory comprehensive plans as a missed opportunity. They suggest that a solution might be to create a Climate Commissioner position whose job it is to coordinate heat issues into different departments and districts (Mahlkow *et al.* 2016).

The literature is somewhat divided on the ideal scale for extreme heat planning. On the one hand, studies recognize that climatic effects of different land use or policy changes cut across jurisdictional scales, suggesting the need for a more regional approach (cf. Sailor *et al.* 2016). On the other hand, studies suggest that there are significant microclimates and impacts of many interventions are very localized so there is a need to address heat at a neighborhood scale (Richardson *et al.* 2009). Lambert-Habib *et al.* (2013) argue that the growing emphasis on regional planning for sustainability more broadly may be problematic for extreme heat planning, which they argue needs a much finer-scale focus on microclimates. This leads us to conclude that extreme heat planning will ultimately need to take a nested governance approach, working simultaneously across different scales from the design of microclimates at sites to larger neighborhoods, city, and regional planning scales.

4.1.3. *Legal structures needed for extreme heat planning*

Studies identify a number of legal and regulatory barriers to effective extreme heat planning and propose different strategies for addressing them, either by integrating heat efforts into existing regulatory frameworks or enacting new policies. Case studies of French cities suggest that the lack of a national regulatory framework for urban heat is problematic (Dhalluin and Bozonnet 2015; Lambert-Habib *et al.* 2013). Kingsborough *et al.* (2017) bemoan the fact that London's only heat-related legal requirement is to have a plan for heat waves, which as previously noted is limited in scope (Zaidi and Pelling 2015). Building standards provide a potential opportunity for enhancing heat resilience, especially underexamined yet deadly indoor overheating; however, this is rarely considered (Hatvani-Kovacs *et al.* 2018). Even when local climate is a legally protected environmental good, as in Germany, local plans are already "overloaded" with concerns such as soil health, biodiversity, and noise pollution. This makes it difficult to prioritize heat (Mahlkow *et al.* 2016: 274). Stone (2005) argues that ambient heat should be regulated in the US as an air pollutant, which would provide more support through the Clean Air Act for regulation and ultimately, resilience. On the heat response side, Bolitho and Miller (2017) argue that heat should be officially recognized as an emergency (i.e., heat waves lead to an emergency declaration), which could help focus more resources and attention on the issue. In short, these legal and regulatory barriers, spanning local to national governance levels, were similar across all papers.

4.1.4. *Acknowledging complexities, different priorities, and limited resources*

Another major institutional challenge discussed in many of the studies focuses on the fact that extreme heat planning must compete for limited time and resources with numerous other urgent urban issues, some of which are usually seen as higher priority (Downes and Storch 2014; Mahlkow and Donner 2017; Mahlkow *et al.* 2016). For example, Mahlkow *et al.* (2016) note that in Germany, the top priorities for urban policy are increasing housing and facilitating investment. Similarly, Donner *et al.* (2017) find that in Berlin, despite available information on heat-at-risk areas, these considerations are not incorporated into planning processes because the lack of housing is seen as more important. The suggestion is that to be effective, planners will need to identify policies that are "compatible" with other priorities (Icaza *et al.* 2016: 2). It is also important to acknowledge the complexity of both urban planning generally, and extreme heat planning specifically. Land use planning inevitably requires balancing many competing priorities and integrating climate considerations adds to this burden (Donner *et al.* 2017; Hamilton *et al.* 2010). Planning action on extreme heat planning will thus be limited until it becomes a priority or is seen as complimentary with other community issues such housing availability.

4.2. *Strategies for addressing extreme heat*

One of the reasons that extreme heat planning is so complicated is that there are many different approaches to enhancing heat resilience, or in other words, many different strategies that could be included in plans. The difficulty lies in choosing from among them, especially as the universal appropriateness and effectiveness of different strategies continue to be debated. Guindon and Nirupama (2015) divide these into two categories: so-called "active" strategies that focus on emergency response and preparedness and "passive" strategies that focus on spatial planning and design. While this categorization is helpful as there is a strong focus within the literature on spatial planning and design to reduce the UHI effect, we find this somewhat contradictory with existing hazard mitigation planning terminology. For this reason, we will refer to these as extreme heat "risk management" and "design of the built environment," hereafter just "design," strategies respectively. Examples of risk management strategies promoted in the reviewed studies include various warning systems for extreme heat events (Bolitho and Miller 2017; Hatvani-Kovacs *et al.* 2018). Some of the most commonly cited heat reduction strategies include adding vegetation (Dhalluin and Bozonnet 2015; Guindon and Nirupama 2015; Hamilton *et al.* 2010; Stone 2005) and increasing the reflectivity, or albedo, of roofs, roads, and other surfaces (Corburn 2009; Hatvani-Kovacs *et al.* 2018; Quattrochi *et al.* 2000; Stone 2005). To be most effective, extreme heat planning should probably combine these approaches. Indeed, Kingsborough and colleagues (2017: 74) argue that "a range of actions including land-use planning, building design, community resilience, and emergency planning and response must be considered together for cities to manage long-term heat-risk."

Focusing first on the risk management approaches, the studies suggest that there is a tension between managing heat threats primarily as an emergency as opposed to a chronic social issue, and policy strategies differ depending on the approach. As Bolitho and Miller (2017: 685) put it:

> "The way events and processes are framed has implications for individual actions and institutional responses. Current policy and institutional responses reflect a tension between framing heat as an emergency and as a source of chronic stress, and that different kinds of impacts and responses are prioritised as a result."

Zaidi and Pelling's (2015) case study of London finds that the city focuses on heat specifically as a medical emergency, rather than a chronic social issue. Thus, London's Heat Wave Plan is implemented through the health department and healthcare providers, meaning that it is mostly reactive. This excludes other social care workers, limits awareness of the plan outside the health care sector, and stifles learning and innovation from other perspectives. This focus on reacting to heat as an emergency is particularly problematic given that several studies recognize the need to better understand the root or social causes of heat vulnerability (Bolitho and Miller 2017; Richardson *et al.* 2009; Zaidi and Pelling 2015). In addition to understanding what drives vulnerability, there appears to be a lack of research on what specific "policy instruments" are effective in reducing health risks (Mahlkow and Donner 2017: 386)

While the literature did not provide much in the way of solutions to address social factors (e.g., rising inequality or racial inequities) that increase vulnerability to heat, many of the studies we reviewed analyze and recommend specific planning and design of the built environment strategies in order to reduce the UHI effect and its impacts. These design strategies relate to adding vegetation, buildings and urban infrastructure, and land use and urban form, each of which is described in more detail below. A consistent theme across these studies is how context-specific these design strategies are based on climate, geography, urban form, and the different scales of the built environment. Several papers also acknowledge that it is easier to plan for these strategies and ensure that they are implemented on public buildings and land than on privately owned infrastructure. As Mahlkow and Donner (2017: 392) note with respect to vegetation, "even though private greening initiatives are crucial to achieve the goals set by the government, especially on private plots, they can only be an addition to a publicly planned comprehensive approach to realize a heat-adapted urban design."

4.2.1. *Vegetation*

Many of the papers discuss increasing vegetation as a heat resilience design strategy including urban forestry, green roofs, and parks. For example, multiple studies propose mandatory green space ratios or requirements for green roofs and walls (Hatvani-Kovacs *et al.* 2018; Mahlkow and Donner 2017). Dhalium and Bozonnet (2015) find that urban vegetation, including green spaces, facades, and roofs, is the action most often taken in response to the UHI effect in several cities in France. In particular, many papers recommend increasing the urban canopy (Guindon and Nirupama 2015; Hamilton *et al.* 2010; Kingsborough *et al.* 2017; Mahlkow and Donner 2017; Mahlkow *et al.* 2016; Quattrochi *et al.* 2000; Richardson *et al.* 2009), although trees' ability to decrease the UHI effect is context-specific. The two main benefits of the urban canopy are increased shade and evaporative cooling (Richardson *et al.* 2009). After several sequential community workshops and models, Corburn (2009) reports that additional tree planting is the preferred solution to mitigate the UHI effect in the South Bronx area of New York City, New York, despite uncertainty about their effectiveness after multiple analyses. Morawetz and Koemle (2017) find that 92 percent of survey respondents in Vienna, Austria also preferred additional trees over other potential options, such as the installation of drinking fountains. Both Sailor *et al.* (2016) and Mahlkow *et al.* (2017) discuss the need for robust maintenance plans and ongoing investment if vegetation is used as a heat resilience strategy, since, for example, the full benefits of added canopy cover are not realized until the trees reach maturity. This is part of a bigger challenge for extreme heat planning, namely that financial support for climate adaptation projects are often short-term where many heat-related strategies need long-term support (Mahlkow *et al.* 2016). Vegetation strategies, while one of the most discussed design strategies across the papers, are also inherently specific to a city's geography and climate, making it difficult to make generalized recommendations.

4.2.2. *Buildings and urban infrastructure*

Another common design strategy that the reviewed studies recommend is improved and updated standards for buildings and urban infrastructure. Zaidi and Pelling (2015) point out that in cities with older housing stock, such as London, UK, there may be limited capacity for additional greening or land use changes to mitigate heat, which increases the need for better understanding of building and urban infrastructure resilience strategies. Another study of London finds that extensive greening alone is likely not sufficient to address increasing heat risk and concludes that more widespread adoption of air conditioning will likely be required (Kingsborough *et al.* 2017).

4.2.3. *Land use and urban form*

Hatvani-Kovacs *et al.* (2018) discuss the increased heat risk posed by newer more energy-efficient buildings that have higher levels of insulation, yet in the future heating needs are likely to decrease and cooling needs will increase. This challenge is also discussed by Dhalliun and Bozonnet (2015), who recommend the installation of low energy mechanical cooling systems or passive cooling designs to overcome the overheating of newer buildings. The use of reflective and lighter-colored materials in both buildings and urban infrastructure is another theme throughout many of the papers, often in the form of reflective roofs, lighter streets, and lighter parking lots (Guindon and Nirupama 2015; Quattrochi *et al.* 2000; Stone 2005). Less commonly mentioned design strategies included the installation of more public drinking fountains, non-vegetated shade structures, and mechanical pavement humidification to reduce temperatures on the street level (Dhalluin and Bozonnet, 2015; Lambert-Habib *et al.* 2013). These strategies could increase initial construction costs by 5–15 percent, making the calculation of benefits over the life of the project important (Dhalluin and Bozonnet 2015).

Several papers discuss land use configurations and the design of the urban form to reduce the UHI effect. Hamilton *et al.* (2010) recommend that new development be considered with heat resilience factors including the size of development (number of units, floor space, or plan area), location (vulnerable heat risk areas), energy intensity (high waste heat), and significant land use changes (loss or addition of greenspace). Conservation of natural lands, in the form of "oases of freshness," to help ensure that the UHI effect does not drastically increase due to new development, is also recommended (Lambert-Habib *et al.* 2013: 17). Several trends in land use planning are specifically recognized for their UHI effect reduction benefits. Stone (2005) identifies efficient land use patterns that decrease automobile usage, and the waste heat associated with it, as a design strategy. Several papers also reference the UHI effect reduction benefits of smaller parking lots (Quattrochi *et al.* 2000; Richardson *et al.* 2009). Mahlkov *et al.* (2016) discuss how urban forms that support walkability and bicycle use increase public health outcomes, which in itself leads to reduced vulnerability to extreme heat. The land use strategies discussed in the papers related to reducing the UHI effect are within the regulatory toolbox of the planning profession and overlap with other common professional goals such as improved public health outcomes and reduction of greenhouse gas emissions.

4.2.4. *Complexities, trade-offs, and maladaptation*

Most papers recognize the need to combine various design strategies to reduce the UHI effect and complexities related to how these strategies interact. Regardless of whether a policy is more focused on reducing the UHI effect through design or managing extreme heat risk, studies suggest that solutions need to be targeted to a city's unique needs. For example, when considering increased vegetation as a design strategy, it is important to consider a city's climate and potential temperature and humidity tradeoffs, thus it may not be a universal heat solution (Sailor *et al.* 2016). Similarly, when developing heat alerts, they should be customized for particular social groups (Hatvani-Kovacs *et al.* 2018). Engaging the public in local planning processes could help to contextualize these strategies.

There are many potential trade-offs that need to be weighed in heat and broader climate planning. For example, Sailor (2016) suggests that cool roofs on tall buildings may reduce the overall UHI effect, but not measurably reduce temperatures at street level. An Australian study by Hatvani *et al.* (2018) warns that water conservation efforts may potentially lead to decreases in vegetation and stymie heat reduction efforts. While only Dhaliun and Bozonnet (2015) specifically refer to the term maladaptation, many papers discuss the vicious cycle whereby increasing temperatures will lead to more widespread air conditioning as an adaptation, also increasing greenhouse gas emissions and raising temperatures further. Strategies that cool buildings and reduce cooling costs in the summer may also increase heating costs in the winter and vice versa (Sailor *et al.* 2016).

Increased density has clear greenhouse gas emissions benefits, but denser areas often have a higher UHI effect. Despite this, the quantity of excess heat generated per person is often higher in lower density areas (Mahlkow and Donner 2017). Mahlkov and Donner (2017) also make the point that current energy efficiency efforts often also reduce waste heat, yet are not frequently discussed in terms of heat mitigation. To that end, while maladaptive strategies are possible, there are also actions currently being taken for greenhouse gas mitigation efforts that may also provide unrecognized heat reduction benefits.

4.3. *Information to inform extreme heat planning*

Almost all the studies reviewed discuss challenges and barriers related to information for extreme heat planning. Common themes include the need for better understanding of UHI modeling and mapping, the use of future climate change scenarios, heat-health risks and vulnerabilities, and quantifying costs and benefits.

4.3.1. *UHI modeling and mapping*

While the majority of papers focused on UHI mapping and modeling were excluded from this review based on our selection criteria, the use of satellite imagery for UHI mapping is still the most prevalent heat data source (Corburn 2009; Dhalluin and Bozonnet 2015; Hatvani-Kovacs *et al.* 2018; Icaza *et al.* 2016; Lu *et al.* 2017; Mahlkow and Donner 2017; Quattrochi *et al.* 2000; Richardson *et al.* 2009). In these cases, UHI mapping is developed through a combination of satellite imagery and land-cover models to display a thermal gradient showing temperature differences. These UHI maps are useful for an overview of landscape patterns and heat differences (Icaza *et al.* 2016) and can be used to identify areas with higher heat risk for extreme heat planning interventions (Hatvani-Kovacs *et al.* 2018; Quattrochi *et al.* 2000).

Other papers urge the appropriate use of UHI mapping in planning, as heat is highly temporal and spatially diverse (Corburn 2009; Icaza *et al.* 2016; Mahlkow *et al.* 2016). Mahlkow and Donner (2017) argue that the low resolution of many UHI maps limits their practical usability, and Dhalluin and Bozonnet (2015) recommend improved mapping at both the city and neighborhood scale. Corburn (2009: 419) also points out the importance of other heat data sources such as, "near-surface temperature, or the temperature at 2 m above the ground in the human breathing zone, rather than just the surface temperature." Sailor *et al.* (2016: 10) further recommends that research focus on additional parameters, "such as humidity, mixing heights, and urban wind fields." The complexities of measuring heat, whether via satellite imagery or ambient air temperature readings, can make it difficult for decision-makers to use the information. Two of the papers note the particular need for more UHI mapping data in mid-latitude and temperate cities (Koop *et al.* 2017; Mahlkow *et al.* 2016). Koop *et al.* (2017: 3437) argue that northern cities such as Amsterdam may face more risk to extreme heat as they have fewer adaptations to it, such as air conditioning. While the papers reviewed demonstrated the growing sophistication in UHI modeling and mapping, improving the understanding of how the maps and models are used by decision-makers was not well covered.

4.3.2. *Climate change projections*

In contrast to the prevalence of UHI modeling and mapping, fewer papers examine the use of climate change projections to guide extreme heat planning. The fact that policymakers rely on previous experiences, rather than climate change projections, means that scientific information is not well integrated into the decision-making process (Lu *et al.* 2017: 12). Mahlkow *et al.* (2016) also report that planning is most often focused on responding to historic conditions and past experiences, making incorporating projections of future conditions difficult. Richardson *et al.* (2009) reason that communities need to incorporate climate projections into plans in order to appropriately prepare for future temperature increases. When discussing international building standards, Hatvani-Kovacs *et al.* (2018: 56) conclude that “To design and build sustainable buildings that can withstand the test of time, historical climate data should be replaced with modeled future climate data.” The focus on historic conditions and past experiences could leave communities approaching new climate thresholds unprepared for unprecedented extreme heat impacts.

4.3.3. *Heat-health risks and vulnerabilities*

The papers also identify a lack of information on heat-health risks and vulnerabilities for extreme heat planning. While UHI maps and models provide a spatial approximation for areas of heat risk, many factors affect exposure, so it is difficult to implement strategies based on spatial data alone (Mahlkow and Donner 2017). Several papers recommend assessing additional contributors to heat stress beyond spatially identifying areas of high vulnerability on UHI maps (Donner *et al.* 2017; Mahlkow and Donner 2017; Zaidi and Pelling 2015). The fact that “little is known of the interactions between health, infrastructure, and social factors, and between emergency and chronic experiences of extreme heat,” further complicates understandings of heat-health risks (Bolitho and Miller 2017: 685). Zaidi and Pelling (2015) also note that typical ways of measuring heat resilience focus on spatial mapping and do not capture social variables, individual perceptions, and social networks. They go further and state that, "The spatially, temporally and socially diffuse distribution of vulnerability to urban heat waves is not easy to reconcile with traditional vulnerability assessment approaches that frequently rely on secondary information derived from census data sets" (Zaidi and Pelling 2015: 1221). Richardson *et al.* (2009: 77) recommend three questions that planners need to address to reduce heat-health risk, "How do UHIs form and what can be done to reduce their frequency and severity? What measures may be used to keep people away from areas prone to dangerous UHIs? What factors contribute to human vulnerability to heat and what can be done to fortify people's ability to withstand heat stress?" The lack of information on heat-health risks and vulnerabilities contributes to the higher risk that marginalized communities in particular face related to extreme heat impacts.

4.3.4. *Quantifying costs and benefits*

Another information need identified in several papers is the quantification of costs and benefits of heat mitigation strategies. Interviews with key stakeholders in several French cities in the Dhalluin and Bozonnet (2015: 296) study reveal that interviewees reported difficulty in quantifying UHI effect mitigation benefits, leading to uncertainty over how to prioritize strategies. Both Richardson *et al.* (2009) and Kingsborough *et al.* (2017) also discuss the lack of quantification of costs and benefits for specific adaptation actions. Another theme is the lack of strategies in place for planners to monitor changes in the UHI effect due to new development. A study of a Southern Taiwan Science Park, for example, identifies strategies to monitor changes in flooding with construction but recognizes that planners have no information or tools available to monitor similar changes in the UHI effect (Lu *et al.* 2017: 10). Hamilton *et al.* (2010) similarly point to limited knowledge on how new development increases the UHI effect and what building types should be recommended to reduce heat. These findings are not surprising given the nascent stage of planning for extreme heat, but could limit efforts to increase heat resilience if decision-makers do not know the costs and benefits of their actions.

4.3.5. *Awareness and expertise*

Several studies suggest that decision-makers lack the necessary training for extreme heat planning. Planners need to know how to interpret satellite imagery as the maps and the information they display is "not straightforward," (Icaza *et al.* 2016: 6). Hatvani-Kovacs *et al.* (2018: 52) find that "Current knowledge is incomplete about the means through which to develop a policy to implement heat stress resistance in building regulations." It is also not always clear who the actual end-user of the information is and thus what extreme heat planning tool should be used (Hamilton *et al.* 2010). Similarly, Donner *et al.* (2017) find that despite the availability of heat information, the stakeholders they interviewed did not know how to incorporate the data into their daily activities. Dhalluin and Bozonnet (2015: 295) also find that stakeholders involved in the development of retirement and nursing homes in several cities in France were largely unaware of extreme heat impacts on their projects' residents and heat-related adaptation measures happening in their city. Complicating matters further, heat risk is typically a lower priority than disruptive disasters like flooding that receive more interest than gradual changes in temperature (Lu *et al.* 2017: 12). As previously noted, this lack of concern and awareness hinders extreme heat from being addressed in relation to other pressing planning issues (Donner *et al.* 2017). This suggests a need for improved awareness and education on extreme heat planning across the spectrum of disciplines associated with it and the broader public that must live with heat impacts.

4.3.6. *Potential solutions*

A final key theme across the papers acknowledges that the extreme heat information being produced is not always useful for decision-makers. Koop *et al.* (2017: 3439) state that, "existing knowledge often fails to provide applicable insights that can help decision-makers achieve their intended goals and objectives," and Downes and Storch (2014: 232) conclude that, "A lack of information has resulted in a failure to identify and implement policies and measures to address the risks posed." To help increase the production or translation of more usable extreme heat information for planning purposes, studies offer several recommendations and possible solutions, such as adaptation pathways (Kingsborough *et al.* 2017); constellation analysis (Mahlkow *et al.* 2016); and creative mapping processes (Icaza *et al.* 2016). Corburn (2009: 425) recommends the co-production of climate science, suggesting that it "offers a framework for regulatory science or science policy that: crosses disciplinary lines; enters into previously unknown investigative territories; requires the deployment of new methods, instruments, protocols, and experimental systems; and involves politically sensitive processes and results." Kingsborough *et al.* (2017) demonstrate that the use of adaptation pathways could be a useful framework to approach the complex trade-offs involved in extreme heat planning. Dhalliun and Bozonnet (2015) recommend the development of more practical heat mitigation guides aimed at various professions involved in building and suggest that successful energy savings programs could serve as a template for UHI effect mitigation programs. Research guided by the decision-maker needs identified in our review would help advance heat resilience planning.

5. Conclusion

Extreme heat is already one of the deadliest hazards and the threat is worsening in cities worldwide because of the combined impacts of climate change and the UHI effect. It is therefore increasingly critical to effectively plan for extreme heat resilience. Our systematic literature review of extreme heat planning — to our knowledge the first such effort — has shown that while there is a significant and growing literature that connects extreme heat and planning, the vast majority of these studies (68 percent) are focused on modeling as opposed to planning processes. These modeling studies often suggest that their results can be used to inform planning but provide a limited discussion of how this would work in practice or with the many constraints planners face. We identified just 21 studies that focused on extreme heat planning processes, which we then reviewed in depth. This analysis revealed common themes related to institutional barriers and opportunities, different risk management and design strategies, and informational gaps for extreme heat planning.

Institutionally, extreme heat planning in both practice and research is challenging because it requires different disciplines, government departments, levels of government, and stakeholders to all collaborate. Traditional siloed governance is a barrier to the knowledge integration needed for effective management of extreme heat risk and reduction of the UHI effect.

Research also suggests that it is important to mainstream extreme heat considerations into relevant departments and planning processes. This includes creating a legal or regulatory basis for extreme heat risk management and UHI effect reduction, which is currently lacking when compared to other climate risks such as flooding. Mainstreaming is especially important because planners must juggle many conflicting priorities, and extreme heat is frequently not perceived as an urgent issue.

To further complicate matters, there are many different proposed strategies for increasing extreme heat resilience. We divide these into extreme heat "risk management" strategies that focus on preparing for and responding to extreme heat events, and "design of the built environment" strategies that use spatial planning and design to intentionally cool the urban environment and reduce the UHI effect. We found more studies focused on the latter, with recommendations including increased vegetation, updated building standards, and land use patterns that incorporate extreme heat considerations. This tendency to focus on "technological and material solutions" as opposed to addressing social inequities to enhance heat resilience fits with broader critiques of the current shift toward "climate urbanism" (Long and Rice 2019: 994). Also, while there is a growing literature on climate justice (e.g., Schlosberg and Collins 2014; Shi *et al.* 2016), this was not a focus of the heat planning literature. Where inequities were discussed, they were usually framed around vulnerability and vulnerable populations. Ultimately, a combination of both risk management and design strategies are needed, but a key challenge is how to customize the suite of strategies to each city's unique physical and social context and negotiate trade-offs. Indeed, decision-making for heat resilience, like planning for sustainability more generally, means finding some balance between conflicting goals: economy, environment, and equity (Campbell 1996).

Selecting the appropriate strategies for a particular city requires considerable information, including fine-grained UHI maps and models, future climate scenarios, socio-demographic data, and the costs and benefits of different strategies. Decision-makers often lack this information, and even if it does exist, they may not have the time or expertise to interpret and use it. More co-produced research might help to address this gap between modeling research and practice. Extreme heat varies by city and is spatially and temporally complex within particular sites in the same city. Extreme heat is also less visible than other hazards, such as flooding, which makes it challenging to raise awareness of the risk. UHI mapping is the most visual method to identify areas most vulnerable to extreme heat risk, but UHI mapping does not capture all the actual complexities of the risk. Additional cultural and economic characteristics and local perceptions of extreme heat that influence vulnerability and must be considered as strategies are weighed (Sampson *et al.* 2013; Wilhelmi and Hayden 2010).

Despite the challenges, we argue that planners are well situated to play a leading role in advancing extreme heat resilience. That extreme heat currently has no "problem owner" (Klok and Kluck 2018) has been identified as "the most important barrier to action," (Runhaar *et al.* 2012: 786). First, planners have a history and professional expertise in working across disciplines (Levy 2016). Second, planning as a profession is committed to enhancing the health and safety of communities (Corburn 2007). This commitment is part of the stated mission of the American Planning Association, which also formally recognizes the threat of climate change and the need for planners to address it (Meerow and Woodruff 2019). Third, the regulatory tools that planners have at their disposal (e.g., long-range plans, zoning, land use regulations, and building codes) play an important role in shaping land use and urban form (Kaiser and Godschalk 1995), which are key factors in reducing the magnitude of the UHI effect. While public participation was not a major theme across the papers reviewed, the planning profession's expertise at engaging the public and elevation of local knowledge (Fischer, 2000) could better contextualize geographic and climate-specific extreme heat strategies. Engaging stakeholders in heat-related policies has been shown to improve outcomes (Akompab *et al.* 2013). Moreover, current planning ideals — such as increased density and walkability — may simultaneously affect, and be impacted by, changing local climates.

Future research can help planners meet these challenges, and our review reveals several promising avenues. First and foremost, there is a clear need for more studies of extreme heat planning processes including public participation, not just modeling the risk or urban form and design factors. Given the fact that extreme heat is currently impacting public health and well-being around the world, research outputs need to be useful for decision-makers. This suggests that planners and urban climatologists need to work together (Hebbert and Mackillop 2013). Moreover, while this study focuses on planning, we recognize that it is just one part of broader extreme heat governance, which necessarily involves other fields such as public health professionals and engineers. Our review has clearly demonstrated that extreme heat planning is complex and challenging. Future empirical work needs to examine what institutional and policy approaches actually lead to increased heat resilience in different cities. In particular, research should address unresolved questions such as, what is the most appropriate scale for extreme heat planning? What institutional structures facilitate collaboration? What is the right balance between strategies that manage or reduce extreme heat? What type and format of information are most useful for decision-makers? Answering these questions can help cities to increase extreme heat resilience, improve quality of life, and save lives.

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