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Editorial

Introducing the Built Environment in a Changing Climate: Interactions, Challenges, and Perspectives

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1. Introduction

Planning for climate change adaptation is among the most complex challenges cities are facing today. Worldwide, unprecedented levels of urban overheating have been recently recorded. Hosting more than half of the world population, cities are major receptors and drivers for climate change with disruptive and mutually empowering impacts on both the natural and the socio-economic environment [1,2]. Global and local dimensions of a changing climate are especially worrisome in cities because the rate of change in the patterns of human settlement, energy use, transportation, and industry is escalating much faster than elsewhere, causing a complex network of feedback and amplifying loops. Furthermore, cities are fertile ground for the interaction between heat and pollution hot spots to the point that where an urban heat island (UHI) exists, likely an urban pollution island (UPI) co-exists [3–5], causing compound effects on human health. On top of that, extreme events, such as heatwaves, floods, bushfires, and cold spells, are becoming more frequent, severe, and longer lasting, which is projected to double-to-triple the concerted effect on mortality rates [6,7]. Indeed, climatic alterations put a strain on (i) energy needs for cooling and release of anthropogenic heat, (ii) mortality and morbidity due to overheating and air pollution, (iii) productivity and wellbeing, and (iv) accessibility to public spaces and social prosperity. Recognizing the potentially negative consequences of these events is key to take active and bold actions, to stem the tide of change, and move towards adaptation and resilience [8].

Therefore, some critical questions arise:

- What is the future of the urban realm in a changing climate?
- What is the role of a growing population with expanding patterns of urbanization and consumption?
- How can we mitigate buildings' and cities' burden on local/global environmental change?
- How can we design to provide adequate housing and outdoor spaces to the vulnerable population?

It is now very well documented that urban overheating causes the cooling energy consumption of buildings to double [9,10], forces the construction of new power plants to compensate for increasing peak electricity demand [11], and empowers social injustice [12]. Several mitigation and adaptation technologies have been proposed [13], and many successful examples have been recently demonstrated [2,14,15], yet a full understanding of how cities are supposed to reach enough dynamicity to cope with climate change is still unveiled.

2. Aims and Scope

The Special Issue on "The Built Environment in a Changing Climate: Interactions, Challenges, and Perspectives" is aimed to collect answers to the above questions on a worldwide scale. Submissions were encouraged that contribute to:

- collecting criteria and methods to develop meteorological datasets including climate changes;
- establishing innovative monitoring systems to capture the multifarious impacts of an evolving climate on the built environment;
- defining the energy and comfort metrics in future buildings;
- estimating the impacts in terms of air quality and heat-related mortality and morbidity rates;
- investigating the interaction between global and local climate changes;
- defining governance models, legal frameworks, and agenda-setting methods to prioritize climate policies; and
- defining criteria and targets for urban- and building-integrated design in a warmer world.

3. Presentation of the Published Papers

This Special Issue collects 11 studies from all continents around the world (see Figure 1). Four macro topics are covered and discussed in detail in the following subsections: (1) future-proof design criteria, (2) urban heat island (UHI) mitigation, (3) urban health in a changing climate, and (4) development of new methodological frameworks. Most papers (36.4%) deal with topic 1, 27.3% with topic 2, and 18.2% with topic 3 or 4. The same macro topic could be addressed by a variety of perspectives and scales ranging from individual building level to city level. Each paper is identified with a different marker on the map in Figure 1: the colour code discriminates across macro topics, whereas the marker shape denotes the scale of investigation.

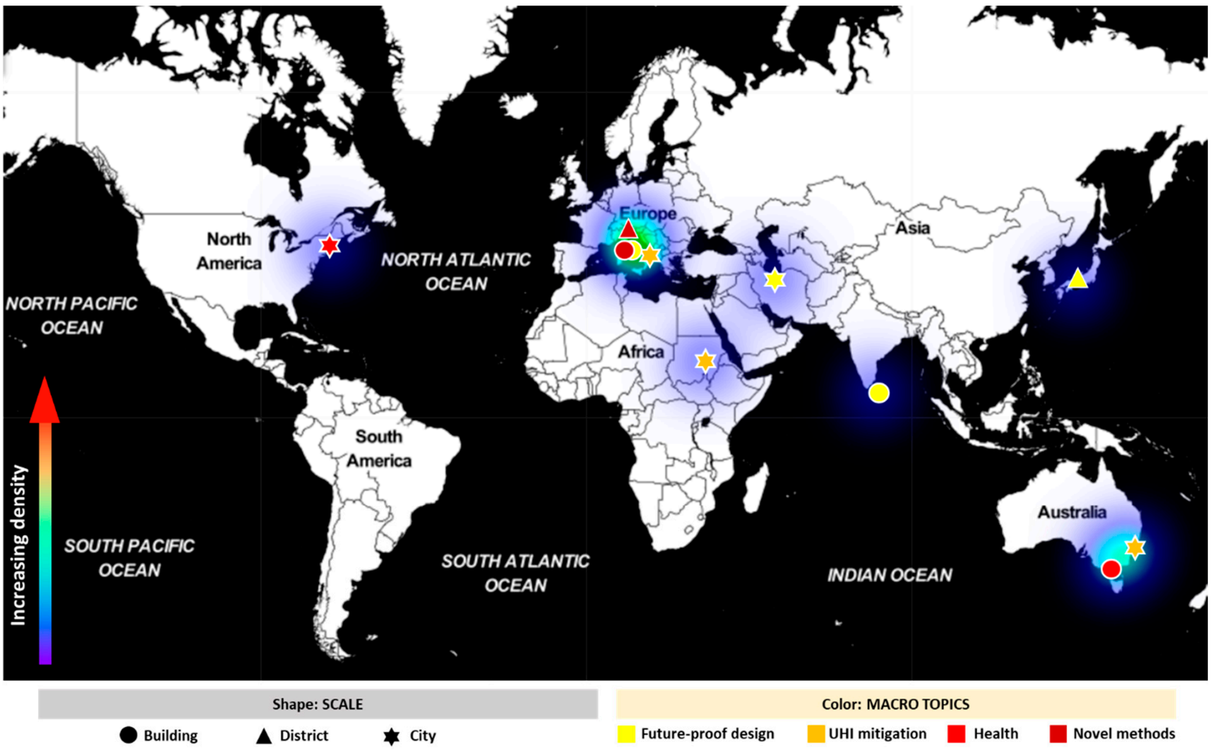

Figure 1. Density heatmap of the studies collected in the Special Issue across the globe. The shade goes from violet to red for increasing number of papers in the same geographic areas, whereas markers identify the cities where the studies were conducted: the shape defines the scale; the colour defines the macro topic. For multiple-city studies and for continent-wide studies, as those conducted in Australia, we used the most populous city or the city of affiliation.

3.1. Future-Proof Design Criteria

Long-lasting, comfort-oriented redesign measures are the core topic of four papers in this collection. In [16], the indoor heat stress in modern, air-conditioned, multi-level office buildings is investigated in the tropics (Colombo, Sri Lanka). Design interventions on plan layout, orientation, sectional layout, and envelope characteristics are assessed in terms of heat-gain risk and associated energy consumption in 12 case studies. Plan form is identified as the key driver for heat vulnerability. Deep plans allow better control and homogeneity of the heat transfer to the indoors, as compared to shallow and covered layouts. The peripheral zones are most vulnerable to heat extremes, exceeding 40 °C when the air conditioning is inactive. Shading and insulation are found to mitigate the local heat stress together with a careful design of the building sectional layout, especially in terms of night ventilation. The study overlooks factors like space lighting systems and occupancy patterns, as these varied only marginally across the investigated buildings.

Climate change may cause premature obsolescence of todays' energy efficient paradigms, too. This is addressed in [17], where the authors propose a methodology to evaluate the change in energy performance for near-zero energy buildings (nZEBs) by comparing present and future demand under the hypothesis of unchanged nZEB legislative requirements. Two future scenarios from the IPCC Fifth Assessment Report (AR5) [18] are considered that incorporate not just the effects of global warming but also the change in radiative forcing. Indeed, both temperature and solar gains are critical variables in the energy balance of current nZEB definitions. A case study in Rome is used to perform hourly dynamic simulations, following the calculation method in force, described in ISO 52016-1:2017 [19]. The annual power consumption is demonstrated to increase by almost 20% in the future, largely caused by longer-lasting use of air conditioning and intensified peak demand. Comfort is jeopardized for 5–6% more time during the year. However, newly-developed, long-term comfort metrics based on the statistical temperature distribution reveal a milder penalty, since diurnal and annual swings are strongly levelled out in future scenarios.

Thermal environmental design is key to ensure (and preserve) not just indoor but also outdoor liveability. It requires a comfort-oriented selection and allocation of built elements (e.g., buildings, pavements, roads), vegetated areas (e.g., parks, tree-lined avenues, gardens, green roofs), and water features (e.g., fountains, pools, sprinklers, ponds). In [20], a redevelopment plan for Central Osaka Station is proposed by combining different heat island countermeasures and by applying computational fluid dynamics, surface heat budget equation, and GIS to track wind distribution, surface temperatures, and mean radiant temperatures. The results are compared in terms of standard new effective temperature (SET*) on a typical summer day. Solar shading is the most impactful redesign strategy in terms of SET* reduction at peak hours (6 to 8 °C), followed by surface material change (0 to 2.5 °C) and ventilation (0 to 1.5 °C). A general conclusion is that climate-resilient outdoors can be effectively achieved by adjusting the shade provided by buildings and that provided by trees and by selecting appropriate surface materials.

A conclusive critical point on future-proof design discussed in the Special Issue is the need for re-inventing even the way we set the right conditions for fighting climate change, especially at the local scale. Some cities in the world act as flagships in implementing and testing the effects of climate-resilient urban plans. This is, for instance, the case of Tehran in Iran, where the impacts of climate upheavals have been especially worrisome in recent years [21]. In this collection, Ghasemzadeh and Sharifi [22] investigate the barriers that are hindering climate change adaptation, notably in low-resilience districts, to appreciate their significance, interconnectedness, and hierarchy. The analysis is approached through a mixture of qualitative and semi-qualitative methods, including focus group discussion, questionnaire-survey, interpretive structural modelling, and confirmatory factor analysis. The most critical barrier is found right in the "structure and culture of research", which deals with the absence of a centralized research body that coordinates and supervises studies and pilot projects for climate adaptation, policy and decision-making processes, and academic efforts towards winning strategies and experiences. The second greatest independent barrier is imposed by "laws and regulations", which are untargeted, incongruous, and loopholed when it comes to climate change and performance verification. Last, but not least is the barrier in "Planning", triggered by a lack of local policy-making bodies and authorities to build up cohesive land use plans, adaptation models, assessment schemes, and integration mechanisms. The study lays the basis for restructuring the way climate adaptation is typically tackled by stressing the need for identifying and removing/softening the barriers before attempting any uncoordinated and unsupported urban plans.

3.2. Urban Heat Island Mitigation

The Urban Heat Island intensity can be determined based on air temperature (atmospheric UHI or AUHI) or surface temperature (SUHI). In [23], a micro-scale experimental investigation of the AUHI intensity and spatial distribution in Bari, Italy is conducted on a daily, monthly, seasonal, and annual basis across five years (2014–2018). The study elucidates how sea breeze and urban attributes modulate local hot spots. The UHI intensifies during the summer and typically overnight. On a 24h basis, it gets exacerbated in high-density local climate zones (LCZ = 2 according to the classification by Stewart and Oke [24]) reaching 4.0 °C. However, the daytime maxima (nearly 5 °C) are measured in lower-density areas (LCZ = 5), countervailed by reduced night-time intensity (less than 3 °C). Future scenarios are evaluated at selected locations by downscaling the trends depicted by the IPCC A2 scenario [25]. A 2 to 4 °C maximum increase in urban air temperature is expected between 2071 and 2100, thus posing further strain on urban liveability.

Coastal cities are especially cumbersome when it comes to UHI mitigation design. This is thoroughly expressed in [26] by Yenneti et al., who review the impacts of urban overheating on health, energy, labour productivity, and social behaviour and quantify the urban cooling potential in Australian cities by collecting evidence from several heat-mitigation strategies. The dualistic effect of sea breeze and hot desert winds in most Australian cities establishes a highly dynamic interaction with the local heat island circulation, which results in extreme temporal and spatial UHI heterogeneity. Despite the complex mechanisms at stake, the use of reflective or green materials and the implementation of water-based technologies proved to considerably alleviate the thermal unbalance with respect to rural and suburban areas. The average maximum mitigation potential of individual heat mitigation strategies is quantified at 1.0 °C for urban greenery (e.g., trees, hedges), 0.1–0.2 °C for building greenery (e.g., green roofs, vertical gardens), 0.3 °C for reflective surfaces (e.g., roofs, pavements), and 1.0–2.0 °C for water features (e.g., misting systems, sprinklers, fountains). The combination of multiple techniques on account of local specificities is the winning strategy in most studies, with average maximum UHI mitigation in the order of 1.5 °C.

However, the key drivers for UHI generation and intensification may be profoundly different in developed, developing, and undeveloped countries, which ultimately defines the set of best practises in terms of mitigation and adaptation. In [27], the authors present the unique case of East Africa, where UHI is escalating fast, caused by the collective effect of climate change and rapid urban population growth, but very little is the limelight in international literature. The study focusses on the five most populated cities in different climatic zones, namely Khartoum in Sudan, Dar es Salaam in Tanzania, Nairobi in Kenya, Addis Ababa in Ethiopia, and Kampala in Uganda. The comparison is based on annual daytime and night-time SUHI intensities across time (2003 versus 2017) and space. SUHI drivers are found in climate conditions, urban development patterns, and informal settlement growth. Blue and green features are identified as essential means of urban heat mitigation and comfort enhancement to be carefully planned not just in view of microclimatological constraints but with due attention to potential gentrification, social unrest, and spread of disease.

3.3. Urban Health in a Changing Climate

In [28], the authors evaluate the heat-related mortality at home and outside of the home on hot days in Boston, MA, between 2000 and 2015. Subject and neighbourhood-scale attributes are analysed to interpret the degree of associativity between hot days and mortality at three temperature thresholds, while geography-weighted regression is used to further scrutinize the spatial heterogeneity. It is found that at-home mortality is triggered by both social and environmental vulnerabilities. Among social factors, low-to-no income and limited English proficiency are conducive to higher mortality. On the bright side, even small-scale or individual heat mitigators, such as street trees and enhanced energy efficiency, are associated with significantly reduced death risk, which encourages the implementation of a wide range of adaptation solutions.

However, the exacerbation of temperature extremes is only one manifestation of a strongly multi-faceted, changing climate that has disruptive effects on the healthcare system. Again, in Australia, bushfires demonstrated their increasing destructive potential during the Black Summer in 2019/2020. In this Special Issue, Rajagopalan and Goodman deal with the need to design future-proof buildings not just to preserve a pleasant thermal environment, but also to protect the indoors from the acute and chronic health effects of air pollution [29]. This becomes an imperative during extended bushfire events when people seek shelter in residential buildings. In actuality, the current building stock in Australia offers inadequate air tightness and filtration. The manuscript explores the potential benefits of re-designing the building envelope and the filtration system and informs on the use of portable air cleaners as coping mechanisms during extreme pollution episodes. Long-lasting air quality preservation calls for coupling of reduced smoke infiltration and improved ventilation if not extraction. Further, analysis of current filtration technologies demonstrates the need for new technological developments to be effective against gaseous pollutants and particulate matter.

3.4. Novel Methods

As the dynamics at building, district, and city scale change, so does the sophistication of methodological frameworks. Two crucial questions arise: (1) How can we plan for the future if our predictions are inaccurate or limited? (2) What is the scale of analysis, action, and prediction? Is it inter-urban, intra-urban, individual-building, or somewhere in-between?

To answer the first question, in [30], the authors focus on the need for reliable and robust future weather estimators and weather files generators by comparing three commonly used tools based on statistical downscaling (WeatherShift, Meteonorm, and CCWorldWeatherGen) against the typical meteorological year prediction obtained by high-quality regional climate modelling and dynamic downscaling. The energy consumption of a residential house and an apartment in Rome (Italy) was simulated by forcing the boundary conditions in accordance with the four generated future datasets. Interestingly, the differences between the two families of weather estimators were not only driven by the different forecasting approach but showed sensitivity to the building type, too. This demonstrates that overlooking regional and local specificities will contribute to forecasting inaccuracies and uncertainties. As such, the smaller scale will become vital in planning based on future urban energy budgets.

The benefits of working against a scale that is smaller than the city but bigger that the individual building become critical when concepts like energy flexibility and smart grid come into play. In an ever more connected and intercommunicating network of buildings that consume and produce energy at the same time (prosumers) and that may exacerbate as well as mitigate local hot spots, there is a growing need for building energy models that take into account the mutual interactions. A dedicated module has been recently introduced as part of the EUReCA (Energy Urban Resistance Capacitance Approach) platform, described in [31]. The authors test the module in Padua (Italy) during the cooling season. The urban energy demand is predicted through a bottom-up approach that integrates mutual shading, heat island effects, and single-building energy demand. The analysis demonstrates the spiral of feedback loops between local heat island and degraded HVAC's efficiency, which results in increased waste-heat rejected from cooling systems. Quantifying these feedbacks is pivotal not just to return accurate estimates of district-level energy consumption, but also to fully appreciate the positive impacts of heat-mitigation strategies.

4. Conclusions

The papers included in this Special Issue tackle multiple aspects of how cities, districts, and buildings could evolve along with climate change and how this would impact our way of conceiving and applying design criteria, policies, and urban plans. Despite the multidisciplinary nature of the collection, some transversal take-home messages emerge:

- Today's energy-efficient paradigms may lose their virtuosity in the future unless accurate estimates of future scenarios are used to design modelling platforms and to inform legislative frameworks;
- Acting at the local scale is key. Future climate change adaptation will be implemented at the local level. Overlooking regional and local specificities will contribute to inaccurate and inefficient action plans. As such, the smaller scale will become vital in predicting future urban metabolic rates and corresponding comfort-driven strategies;
- Energy poverty, heat vulnerability, and social injustice are emerging as critical factors for planning and acting for future-proof cities on par of micro- and meso-climatological factors;
- given that the impacts of climate change will persist for many years, adaptation to this phenomenon should be prioritized by removing any prominent barrier and by enabling combinations of different mitigation technologies.

These topics will receive a global reach in few decades, since also developing and underdeveloped countries are starting their fight against local climate change, with cities at the forefront.

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