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**How urban form influence urban heat island: perspectives and strategies from  
different scales and disciplines**

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**Abstract**

*Urban heat island (UHI) has been a widespread problem attracting particular attentions for years, and recent studies have shown that urban form is crucial to the formation of UHI at all scales. The relationship between urban form and UHI from the perspective of different scales and disciplines has been investigated with a systematic review.*

*Firstly, we discuss the influence of urban form on UHI at three kinds of scales.*

*1)at regional scale, the UHI effect of specific urban agglomeration is studied. It's indicated that UHI is more likely to be affected by the urban geometric characteristics and the level of urban development and construction at this scale.*

*2)at urban scale, natural surface like greenspace and water body could significantly alleviate UHI effect, while building density and population density show the opposite impact. Sky view factor has complex mechanism on influencing the UHI that may lead to the contradictory results.*

*3)at block scale, urban form is referred to the layout and structure of buildings, streets and open spaces. The key issue of UHI mitigation in this scale is to promote air circulation and heat dissipation.*

*Secondly, we analyse the academic background of scholars. scholars from geography discipline focus on the external factors that lead to the formation of UHI like urbanization. Researchers from urban environment pay more attention to the urban ecosystem and the way to alleviate the UHI effect. Scholars from planning and design discipline focus more on studying the impact of streets and buildings on the UHI effect from the perspective of practical construction.*

*Finally, we point out the existing problems of the research and put forward improving strategies for the future study, which is the interaction effect between the element of urban form should be more explored and the importance of urban green space need to be highlighted.*

**Keyword:** urban form, urban heat island, research scale, multi-discipline

**Introduction**

Urban heat island (UHI) has been a serious climate issue that draws attention across disciplines for years. It has been proved that urban form is decisive in the formation of UHI. Due to the difference of methodologies and objectives, the scholars with various academic backgrounds attempt to solve the problems from different angle. In order to have an in-depth comprehension of this field, it's essential to carry on a detailed review of the previous research. This paper retrieved the relevant literatures of urban form and UHI from the Web of Science. Next, selected the most representative literatures to furtherly explore the relationship between urban form and UHI study from the perspectives of research scale and discipline. Last but not the least, pointed out the existing problems of the research and put forward improving strategies for the future study.

**Background**

Urban heat island (UHI), caused by the change of underlying surface and increasing anthropogenic heat due to the accelerated urbanization, has been a wide-spread problem attracting attentions for years (Zhou et al., 2017a ; Aflaki et al., 2017). With the expansion of urban population, the related issues like environment pollution, energy consumption, public health and social justice have become the major concerns for people seeking high quality and sustainable life (MacKenzie et al., 2019 ; Litardo et al., 2020 ; Vanos et al., 2015 ; Aggarwal et al., 2012). “As the key element for understanding urban systems as social-economic-natural hybrids” (Sun et al., 2019), urban form has been proved to be decisive in formation of UHI (Schwarz and Manceur, 2015 ; Hu et al., 2016). However, due to its relatively complex concept, the interpretation of urban form varies across disciplines when it comes to UHI research. Moreover, through the preliminary analysis of the literatures, the studies carried out at different scales may differ from the others in the selection of influencing factors. Therefore, this paper reviews the literatures of urban form and UHI from two aspects of research scales and academic background of the authors, expecting to provide strategies for future urban planning and design from multi-dimension and multi-discipline perspective.

## **Methodology**

Firstly, the search string of “Topic: “urban heat island” AND Topic: (“urban form” OR “urban morphology”)” are created to conduct the search in the Web of Science core collection. Because most researches did not distinguish the difference between urban form and urban morphology, and even use the both words in one paper to refer the same meanings, the search of this study involved both words to return relevant papers as much as possible. To make sure the accuracy of the search, only the research articles and reviews are included in this study. By the search time of July 7<sup>th</sup> 2021, 230 related papers published from 1996 to 2021 are retrieved, in which 92.2% papers are published after 2010, especially there are remarkably increases in 2018 and 2020, indicating the related research gains continuous attentions in the recent decade. Next, all the literatures are been read in detail and categorized according to the research topic, among which the most related papers are selected for further investigation from the perspectives of research scale and disciplines. At last, based on the discussion of the results, the existing problems and potential improvement are put forward.

## **Results and Discussions**

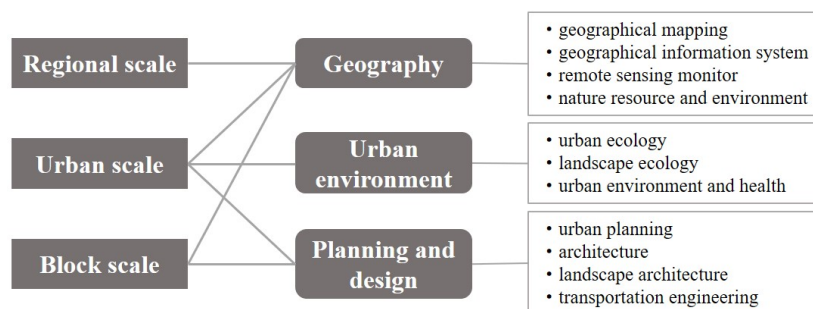
### **1. The urban form indexes**

When it comes to the impact of urban form on UHI, scholars tend to apply a series of indexes to quantify the urban form. By sorting out the papers, the commonly used indexes are grouped into four categories. The first category is the basic attributes of the city, including the geometry characteristic, geography and topography. The second category is the indicators related to the development and construction of the city, comprising expansion mode, development scale, infrastructure and land use. The expansion mode means the future expansion of the city is in a compact or disperse mode. The development scale of is reflected from the size,

economy and population of the city. The construction of infrastructure in the city can be used to indicate the degree of urbanization in a way. Land use reveals the changes of underlying surfaces in the urbanization process. In addition to the proportions of different types of land use, the landscape index is also applied to quantify the composition and configuration of land use. The third category is urban ecosystem, consisting of greenspace and water body. The fourth category is indicators referring to streets and buildings, such as the structure of the streets and building features.

## 2. The urban form and UHI research from perspectives of scale and discipline

It's indicated that most researches are carried out at three kinds of scale, the regional scale which targeting the specific urban agglomeration, the urban scale that aiming at one city, and the block scale that focusing on blocks or building complex. With regard to the academic background of first-authors, three disciplines stand out, which are the geography, urban environment, planning and design. Geography discipline is expert at natural science and technique. Urban environment discipline focus on the natural environment and ecosystem that is closely related to the public health for people living in the city. Planning and design discipline is emphasis on the practical construction of the city. Figure 1. below illustrates the selection of research scale across disciplines and representative majors in each discipline. The scholars conducting research at regional scale are mostly from geography discipline, while those doing research at block scale are generally from geography discipline as well as planning and design discipline. And all disciplines carry out research at urban scale with different emphasis. It's assumed that scholars conduct research at multi-scale based on their specialty. Following parts are the detailed analysis aiming at different scales.



*Figure 1. the selection of research scale of different disciplines*

### 3.1 The regional scale

The researches at regional scale concentrate on the UHI effect of specific urban agglomeration, which is a spatially and economically connected urban group relying on highly developed infrastructure networks, with more than one megacity as the core and more than three cities as constituent units (Fang and Yu, 2017). The level of urban development in urban agglomerations will show a certain radiation pattern from the centre to the periphery. Therefore, it is necessary to consider the aggregation effect of surrounding cities when study the UHI effect at larger scale. The urban form at this scale focus more about the geometric characteristics of the city as well as the contents related to development and construction. For example, Long Yang et al. (2016)

and Sachiho A. Adachi et al. (2014) took the Beijing metropolitan area and the Tokyo metropolitan area as examples, respectively, to study the impact of urban form on the thermal environment in two scenarios of future cities' expansion modes: compact and dispersed. The research of Beijing shows that dispersed cities can effectively reduce the average UHI intensity, but produce greater heat burden and deeper thermal feedback at regional scale. The research of Tokyo indicates compact cities are more effective in reducing night surface temperature. However, in the downtown area, compact cities will aggravate thermal environmental problems due to dense populations. Therefore, the impact of a certain mode of urban expansion on the future climate is two-way and needs to be considered comprehensively. Ze Liang et al. (Liang et al., 2020b ; Liang et al., 2020a) took the Beijing-Tianjin-Hebei urban agglomeration in China as an example to investigate the difference of UHI intensity along the urban development gradient as well as the diurnal variation and seasonal differences of the relationship between urban form and UHI from 2000 to 2015. The results show that as the level of urban development increases, the contribution rate of geometric indexes to the formation of UHI will gradually increase, greenspace indicators will gradually weaken, while the development and construction indicators present an inverted U-shape trend. Greenspace indexes contributes the most during the day, while the size of the city is the dominant factor at night. It is suggested that more targeted urban form optimization strategies are needed at different stages of development.

### **3.2 The urban scale**

The urban scale mainly focuses on the UHI effect within the city, which is mainly caused by the decrease of heat flux and increase of heat absorption due to the change of the underlying surface and the increasing of anthropologic heat (Li et al., 2020). By comparison, the geography discipline concerns more on the development and construction of the city, while the urban environment emphasis on the geometric characteristics, and the planning and design discipline prefers studying the impact of buildings on UHI.

In general, green space and water bodies have the most significant mitigation effects on UHI (Steenefeld et al., 2011), and there are certain thresholds of their cooling effect, when the value of NDVI and water surface coverage were larger than 3% and 8% respectively, the decline of LST slowed down (Sun et al., 2019). Building floor area ratio has a significant negative impact on UHI, while population density and building density are the opposite (Sun et al., 2019 ; Xu et al., 2019). The combination of different indicators has stronger explanatory power for UHI effect (Zhao et al., 2011), and the influence of urban form on UHI shows a certain spatial heterogeneity (Mehrotra et al., 2020). SVF is an important indicator of urban form, however, its impact on UHI is complicated and context-dependent (Huang and Wang, 2019). The research results of the relationship between SVF and UHI are contradictory in some cases, both positive (Scarano and Sobrino, 2015), negative (Berger et al., 2017) and changing from negative to positive under certain circumstances have been reported (Huang and Wang, 2019 ; Hu et al., 2020 ; Guo et al., 2016). On the one hand, the higher SVF can enhance the air circulation and wind speed therefore decrease the LST, while the underlying surface will absorb more solar radiation. On the other hand, lower SVF can prevent the incoming solar radiation to

penetrate into surface thus reduce the LST, however, trap the heat inside the street canyon at the same time (Guo et al., 2016 ; Yang et al., 2013 ; Jamei et al., 2016). Besides, the difference of the calculation method of SVF (Hu et al., 2020), the spatial resolution of original data (Scarano and Mancini, 2017), the local climatology, geography, surface topology and ecological backgrounds (Zhou et al., 2017b ; Guo et al., 2016) may also lead to the conflicting results.

### **3.3 The block scale**

At block scale, urban form refers to the layout and structure of buildings, streets and open spaces. The thermal environment of this scale is closely related to the ventilation condition of street canyon, which is mostly influenced by the building height and density as well as the underlying surface. Therefore, the key issue is to promote air circulation and heat dissipation by improving the spatial structure of the block and the underlying surface (Zhen et al., 2019). Scholars who carry out research at this scale primarily come from the fields of geography and planning, and they are basically similar in the selection of urban form indicators.

Overall, the greatest impact on LST is the impervious surface ratio in land use, while green space and water bodies are critical factors in mitigating UHI effect (Yin et al., 2018 ; Liu et al., 2017). Building density is positive correlated with UHI, and has the highest contribution rate to UHI compared with other building-related indicators (Yin et al., 2018). Moreover, the impact of urban form indicators on temperature is various in different time periods (Yu et al., 2020). And it's indicated that UHI is stronger in areas with high street network centrality, and lower in the area with high connectivity (Erdem et al., 2021). In addition, some researches apply the software to simulate series of scenarios to propose the optimal thresholds for comfortable thermal environment. Luis GR Santos et al. (2021) put forward that when the building height is not higher than 81m and the density is medium (40%) or low (30%), the impact on the environment and external energy exchange can achieve a certain balance. Junyan Yang et al. (2020) proposed that when the building density is between 40-50% and the average height is 8-17 floors, the overall thermal environment of the block is the best.

## **4. Discussion**

Urban form is a study of urban material space form and its evolution process, and the relationship between urban material space form and non-material form (Duan and Qiu, 2008). The study of urban form in a broad sense includes two main aspects: social form and physical environmental form (Gu, 2001). From the literature review, it can be seen that when studying urban form involving the UHI, scholars prefer to select a series of indicators to quantify the urban form. To a certain extent, these specific indicators can guide the practice of urban planning more explicitly and easy to operate. However, the studies mainly focus on the influence of single index. There are few researches mention the combination effect of the indexes (Zhao et al., 2011), but not consider the interaction between those indexes. For example, the greenspace in the compact city centre may perform different cooling effect compared with the greenspace in the suburb because of the difference of the surrounding built-up area (Liu et al., 2015). Urban is a complex organic system that each element is

not individual. Therefore, it is necessary to interpret the connotation of the urban form in detail, not only the impact of a single element should be considered, but also the interaction between the elements and the system combined with different elements need to be addressed.

It's concluded from the literatures that greenspace is decisive in mitigating UHI. As the only spatial entity in the urban ecosystem with natural biological activities and renewal mechanisms that can actively alleviate the UHI effect (Zou and Wang, 2021), the importance of urban greenspace needs to be emphasized. However, the indicators of urban greenspace in the current research are relatively simple indicators such as green space ratio, tree coverage ratio and NDVI, which only illustrate the proportion of green space in the underlying surface of the city. In addition to the area, the shape, boundary, spatial pattern, internal composition of green space, and its relationship with the surrounding built-up area may also play a role (Li and Zhou, 2019 ; Masoudi et al., 2019 ; Liu et al., 2015 ; Wang et al., 2020). Hence, in the future research, it is necessary to emphasize the significance of greenspace in urban form, especially in mitigating the UHI effect, notice the complex biological mechanism of greenspace and its temporal and spatial relationship with the surrounding environment, and further optimize the urban greenspace system planning to improve urban climate issues.

## Conclusions

This paper reviews the relevant literatures of the impact of urban form on the UHI from the perspective of research scale and disciplines. It's shown that related research began in 1996, and have attracted increasing attentions in the last decade. The selection of urban form indicators is mainly divided into four aspects: urban geometric characteristics, urban development and construction, urban ecological system, street and buildings. The researches are mostly conducted at three scales, regional scale, urban scale and block scale by the scholars from the disciplines of geography, urban environment, planning and design. Authors with different academic background have their own emphasis on the selection of research scales and urban form indicators due to the difference of methodologies and specialities. In general, scholars from geography disciplines focus on the external factors that lead to the UHI formation. Researchers from environment pay more attention to the urban ecosystem and the way to alleviate the UHI effect. Scholars in planning and design focus more on studying the impact of streets and buildings on the UHI effect from the view of practical construction. Future research should consider more about the interaction between the elements of urban form and highlight the importance of urban greenspace as well as integrate the multi-discipline knowledge.

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