

Review

Integrating Microclimate into Landscape Architecture for Outdoor Thermal Comfort: A Systematic Review

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Abstract: Global climate change and urban heat island intensification are making many cities dangerously hot during heat waves and uncomfortably hot much of the time. Research has identified ways that urban environments can be designed to reduce the heat, but much of the information is too technical or has not been interpreted or communicated so as to be available to landscape architects. This study identifies ways that landscape architecture researchers have applied microclimate information in design to proactively create more thermally comfortable outdoor environments. A systematic review that assessed the growing recognition of microclimatic factors in design revealed four main approaches: principles and guidelines, strategies, mapping, and evaluation. The advantages and limitations of each have been noted, and a diagram has been developed that matches each approach with specific steps in the landscape architectural design process. The study also identified four areas where microclimate has potential for use in landscape architecture but that are currently not being very actively studied: education, modeling and visualization, policy, and ideation. Microclimatic design has the potential to enhance the health and well-being of the public through the design of thermally comfortable outdoor environments.



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Keywords: microclimate; landscape architecture; urban design; urban heat island; urbanism; urban ecology; global climate change; thermal comfort

1. Introduction

The global climate has been gradually warming and the frequency and duration of extreme heat events have been increasing. These trends are being exacerbated by urban heat island intensification (UHII), resulting in increasingly dangerous heat waves in many cities [1,2]. Research has identified the main causes of UHII and suggested ways that cities can be designed so they are cooler rather than hotter during heat waves [3–5]. This information is often very technical and is not generally available to the professionals designing urban environments, but recently there has been an increased interest by landscape architects to apply this information, generally known as microclimate modification, to their profession.

Applying microclimate information in the landscape architectural design process can enhance a design's social, economic, and ecological sustainability. Essential benefits include, but are not limited to the following list. First, a microclimate can help create thermally comfortable conditions in response to global warming and extreme regional climates caused by geographic factors [6]. Designing cooler cities is an urgent challenge that needs a close integration of microclimates and landscape architecture. Second, providing a thermally comfortable environment can be an effective way to encourage people to spend more time outdoors, which means people may get more exercise and be healthier [7]. Studies show that spending more time outdoors can bring the benefits of being happier, improving concentration, and healing faster [8]. Third, applying microclimate information into landscape architecture has an advantage in energy efficiency. Brown and Gillespie [9]

described how design with microclimate could save significant amounts of energy used to heat and cool buildings. Fourth, it can directly contribute to public health. For example, the potential for cancer caused by long-term exposure to excessive ultraviolet radiation can be reduced by implementing microclimate design [10]. Fifth, the microclimate can function as an element of landscape design [11]. A site's microclimate may cause unique weather phenomena, such as icing and fog, which can potentially add a lot of interest to landscape projects. Sixth, a microclimate can serve as a resource for tourism. Greiser et al. [12] demonstrated that microclimates have been utilized in tourist attractions and landscape creation, construction, and the tourism industry's management practices. For example, the microclimates of the seaside, mountain, and high-latitude regions have attracted tourists to experience cool natural microclimates, such as low temperature, comfortable wind, fresh air, etc. [12]. Different regions have different featured microclimate landscape elements, which could be developed as tourist attractions. Seventh, the inclusion of microclimate factors in design considerations is beneficial to protecting the life of animals and plants in the landscape [13,14]. Almost every living thing on earth needs a thermally neutral environment. If microclimate factors are not considered in landscape design, they may cause adverse effects on the activities of animals or plants, thereby affecting the vitality of landscape places. Eighth, a microclimate can affect the maintenance of landscape facilities [15]. Considering microclimate factors in landscape design can help select landscape materials effectively and correctly, extending the material life and reducing maintenance costs. Finally, the microclimate is likely to influence all kinds of landscape elements. Due to the respective complexity of microclimate factors and landscape elements, sometimes designers might overlook the link between them, but small problems may lead to large losses. Microclimate analysis is necessary in the design process, so problems can be prevented before they happen.

Microclimate has been used in the field of landscape architecture for a long time. The concept of feng shui (wind and water) has played a significant role in the practice of ancient Chinese landscape architects for over 2000 years [16]. Feng shui involves examining the geographical conditions of mountains and waters before selecting auspicious conditions and subsequently building city walls, houses, and graves to achieve the ideal of "unity of man and universe" [17]. It encompasses the principles of geology, hydrology, ecology, microclimate, and environmental landscape. In the Middle East, historical Islamic gardens are well-known to be not only ornamental or theological but also used to control and improve the microclimate around and inside the buildings [18]. Islamic landscape design considers the composition of vegetation and water using the environmentally-responsive design principles of water, vegetation and shade, and walls and pavilions. Early North American farmers also used microclimate knowledge in the process of living with the natural environment. This included such practices as nestling farmsteads into south-facing hillsides, planting deciduous trees on the south sides of farmhouse buildings for shade, and the use of windbreaks [19]. There is a long history of microclimate affecting the design of places, but it used to be more 'trial and error,' and later became a scholarly study.

Olgyay [20] was one of the first people to study the impact of climate on shelter design. He used biology, engineering, meteorology, and physics to extract concepts for climate control [20]. Enis [21] proposed that landscape architects must relate to all climatic factors when dealing with landscape and site planning issues. Their main concern is to improve the microclimate of open space and buildings' climatic conditions by landscape planting. Depending on the amount of solar radiation, wind, precipitation or humidity, and resulting temperature, the microclimate provides different levels of human comfort [21]. Booth believed that microclimate could be regarded as one of the design elements, including sun exposure, wind exposure, and precipitation accumulation [22]. Bagneid quantified the microclimatic effect of each of the following elements within the courtyard: fountains, vegetation, ponds, and wetting of surfaces [23]. There was also apparently considerable early scholarly work in applying microclimate to landscape architecture in Europe, but unfortunately it was not written in English so it wasn't available for this study.

Over the past 25 years the number of research projects that integrate microclimate and landscape architecture has grown, but there is no clear pattern to the focus of the various studies. Several different approaches have been suggested for integrating microclimate information into landscape architecture, but there is no overview of how the different approaches relate to each other and when the different approaches are most effectively used. The goal of this study was to investigate, through a structured literature review, the ways in which microclimate has been applied to landscape architecture in the scholarly literature, and to assess the growing recognition of microclimatic factors in design by identifying trends, patterns, and comprehensiveness. It focuses primarily on studies that proposed ways to design for human thermal comfort. This paper is not intended to provide direct guidance on how to apply the microclimate to landscape architecture, but rather to assess what work has been done by others and to provide an overview and perspective on what is known and what still needs to be done.

2. Methods

2.1. Search Strategy

A structured literature review [24] started with a search by using the following combinations of keywords:

“microclimate and landscape architecture and process,”
“microclimate and landscape architecture and strategy,”
“microclimate and landscape architecture and method,”
“microclimate and landscape architecture and methodology,”
“microclimate and landscape architecture,” and
“microclimate and landscape design.”

For each contribution, the title was used to determine preliminary relevance (Figure 1). According to the title, if the content seemed to discuss the method of applying microclimate knowledge to landscape architecture, the full reference (including author, year, title, and abstract) was accumulated for further evaluation.

Three commonly used databases (Google Scholar, Web of Science, and EBSCOhost) were used in this study for online searching. Considering that technological advancements changed methods for archiving and retrieving information, the search was limited to publication dates from 1995 to 2020 (articles published in the past 25 years) which is essentially the digital age [24]. Firstly, we used Google Scholar to search by using broad keywords, “microclimate and landscape architecture”, and “microclimate and landscape design”. By reviewing the first 25 pages of search results, altogether 90 potentially relevant articles were found. Then, we refined our keywords. We searched Web of Science using the keywords “microclimate and landscape architecture and process”, “microclimate and landscape architecture and strategy”, “microclimate and landscape architecture and method”, and “microclimate and landscape architecture and methodology”. A total of 33 studies were identified. A search on EBSCOhost using the same keywords as those used on Web of Science got 32 articles. Modified keywords were used later in the Google Scholar search after the initial stage where two keywords were used, but no new studies were found. Finally, through searching by authors, backward searching and forward searching, 50 studies were found. Combining all these outlets, 205 articles were identified.

2.2. Study Selection

After excluding duplicates, we read the abstracts of the 188 articles to further decide their relevance to the research. The studies were appraised by matching the established review inclusion criteria. The inclusion criteria were: (1) studies involving the interaction between microclimate and landscape architecture; (2) research on specific geographic areas; and (3) written in English. A total of 150 studies were deemed relevant, and we obtained the full-text articles for eligibility assessment.

To assess the eligibility of the research, we read through the full-text papers and further checked the relevance of the articles to our research direction. After this process,

122 articles published between 1995 and 2020 were selected for literature extraction. These articles were classified into three categories: “Microclimate information that can be used to make design decisions”, “How elements in the landscape affect the microclimate”, and “How microclimate affects the energy budget and/or thermal comfort of people”. A total of 91 articles fit into these categories. These articles were assessed in terms of relevance and 34 articles published between 1995 and 2020 were identified as being studies that specifically identified ways that microclimate information could be used to make design decisions; these were selected for detailed assessment. Extracted data were synthesized to document evidence of how each of them applied microclimate to landscape architecture.

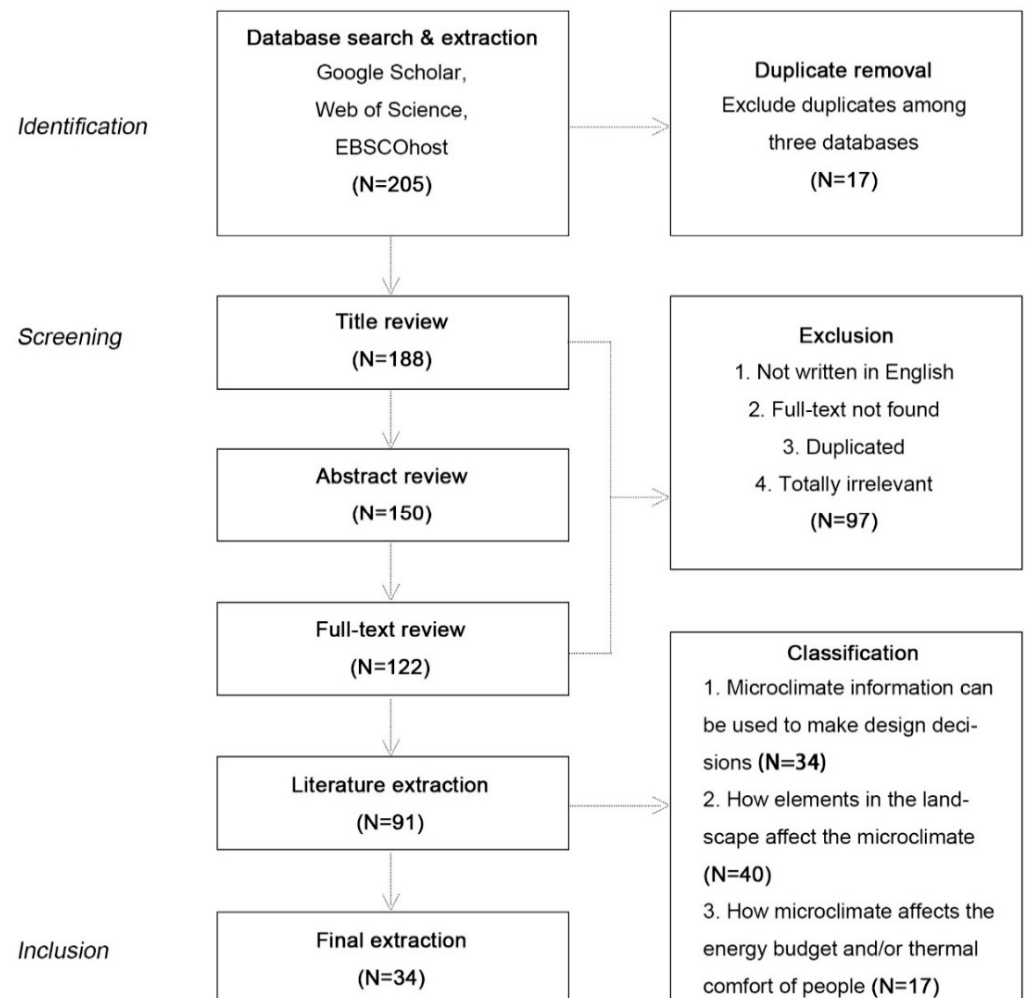


Figure 1. Review structure of literature search and selection.

2.3. Data Synthesis

The literature was first summarized and key data compiled (see Table 1) identifying the type of resource, scale, climate zone, climate element(s) focused on, and approaches to applying microclimate information to landscape architecture.

In order to further identify the methods by which microclimate has been applied to landscape architecture, the 34 articles were categorized into four types: through principles and guidelines, through strategies, through mapping, and through evaluations.

3. Results

3.1. Overview of the Research Trends

Although the earliest research publications were in 1995, only since the 2010s has there been a relatively steady number of research publications that have paid attention to

the method of applying microclimate to landscape architecture (Figure 2). In general, the annual total publication number is relatively low. Articles about strategies and evaluations emerged early and provided a large proportion of the total contributions. Conversely, mapping, and principles and guidelines, appeared later and provided a relatively low amount. Overall, the principles and guidelines account for 14.7%, strategies for 47.1%, mapping for 8.8%, and evaluations for 29.4% of the publications.

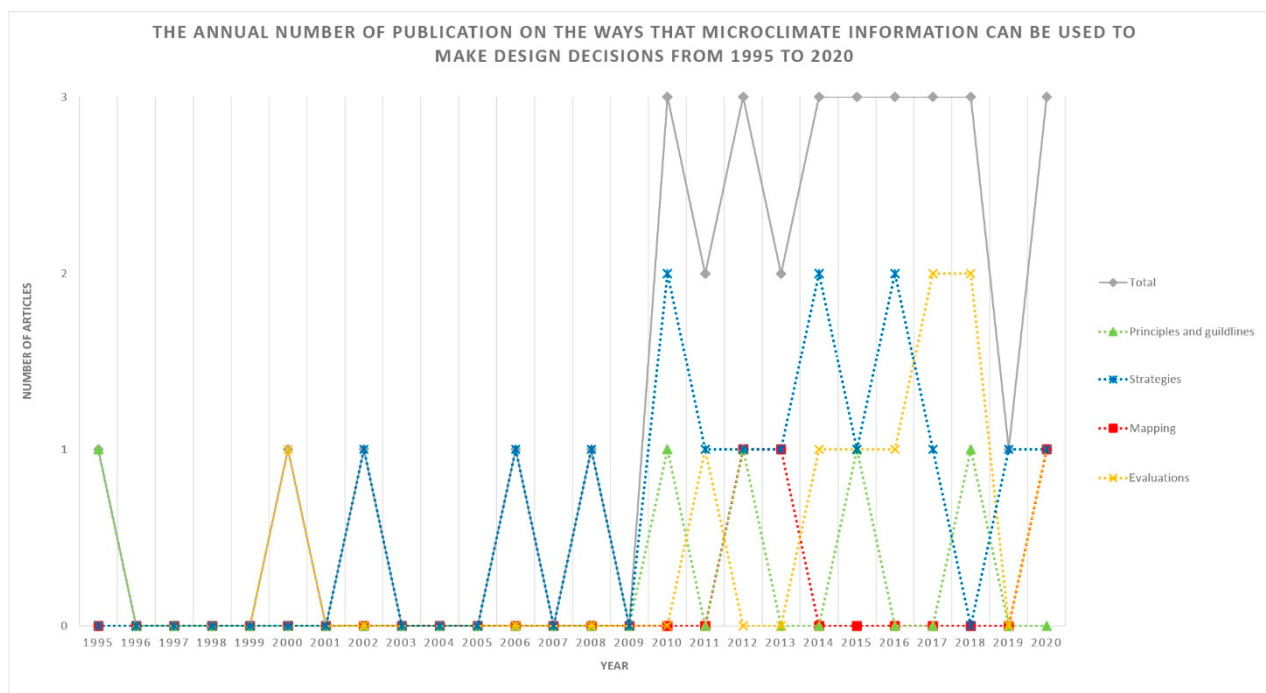


Figure 2. Annual number of publications on the way that applying microclimate to landscape architecture from 1995 to 2020.

3.2. Approaches to Applying Microclimate to Landscape Architecture

3.2.1. Principles and Guidelines

The first method of applying microclimate to landscape architecture is exploring and creating principles and guidelines. There are five articles that used this approach (#6, #8, #10, #19, and #23). They discussed the comprehensive and fundamental laws of microclimatic design and provided a broad indication and outline of conduct. They can be divided into two categories. One provides principles and guidelines for a specific objective, such as improving a specific landscape element. Boc (#6) [25] discussed tree species selection guidelines in the background of bioclimatic landscape design. The other offers principles and guidelines for a general objective. In this category of studies, the general objective is creating thermally comfortable outdoor space. There are two books that explored and clarified the basic principles and guidelines of creating thermal comfort and energy efficiency (#10, #8) [9,26], and two articles separately focused on a region with typical geographical and climatic characteristics (#23, #19) [6,27]. The benefit of focusing on general objectives is that it provides more space for reflection on bigger ideas than one that focuses on a specific objective, and a little more license to be more adventurous in the approach to the topic. The drawback is that it is broad so that the details may not as specific as an article that focuses on a specific goal. By comparison, articles focused on specific objectives are more concise. They usually have a clear-cut theme and have more data support. The limitation of them is that they are less comprehensive.

Principles and guidelines provide a thorough understanding of how to incorporate the microclimate into landscape architecture. It summarizes well the existing findings and points out a variety of clear, practical directions. These principles and recommendations

have been created and developed with an increasing understanding of the microclimate application to landscape architecture, and there is much potential for extension in the future.

3.2.2. Strategies

There are 16 articles demonstrating the application of microclimate to landscape architecture through the strategies approach (#1, #3, #4, #5, #13, #14, #15, #16, #18, #21, #25, #26, #27, #31, #33, and #34). Strategies are the most common approaches for applying microclimate information to landscape architecture, and were used in a very high proportion in the reviewed articles. The strategies-related contributions mainly focused on providing specific suggestions and recommendations to improve thermal comfort or energy efficiency. Unlike principles and guidelines, strategies give specific instructions and/or ideas on what to do instead of just tips that help guide in the right direction. They can be divided into two parts: object-oriented strategies and goal-oriented strategies. Specifically, in this literature review, the characteristics of object-oriented studies consisted mostly of strategies based on landscape elements (e.g., vegetation, water, etc.) and microclimate parameters (e.g., wind), while the goal-oriented studies started from one or more specific goals, such as passive cooling strategies, or mitigating strategies to thermal comfort (#1, #3, and #25) [18,28,29]. These two types of strategies complement each other, each with their own advantages and disadvantages. Object-oriented studies propose a comprehensive strategy after the analysis of each landscape element or microclimate parameter. Correspondingly, goal-oriented studies also discuss concrete strategies according to landscape elements separately after identifying general strategies. The advantage of object-oriented strategies is that they can focus more on details to illustrate a small point clear, but may not be comprehensive, while goal-oriented strategies provide an overall vision, but can be limited in details.

3.2.3. Mapping

There were only three articles showing the application of microclimate to landscape architecture through a mapping approach (#2, #12, and #29). Mapping of microclimates links necessary information with spatial information effectively and represents the resulting information clearly. This category has only a small number of examples, but mapping is an integral part of landscape architecture. According to the analysis of the reviewed articles, mapping can be divided into three different approaches: creating maps through microclimatic software directly (such as using ENVI-met software, Rayman software, etc.), mapping through non-software methods (such as using photographic and video techniques), and combining maps obtained in different ways to create new maps using Arc GIS software. In three papers, ENVI-met software was used to spatially represent predicted mean vote (PMV) maps and park cool island (PCI) maps (#2, #12) [30,31], while Rayman software was used to making spatial variation of thermal comfort maps (#29) [32]. Non-software methods, photographic and video techniques, were used to record children's behavior in the schoolyard (#29) [32]. In Declet-Barreto et al. and Tsirogiannis et al., they combined the data of microclimatic and spatial maps to make new maps using Arc GIS software (#29) [32].

Directly using microclimatic software to make maps has advantages in convenience and objectivity. However, it cannot satisfy all mapping needs, such as the mapping of human behavior. Using the non-microclimate software method to make maps provides flexibility. It has a wider usage range and can serve as a good supplement to microclimate software. The main drawback is that it requires additional equipment and may not directly generate maps, requiring extracting information from the collected data and making them into maps. The third way, integrating the software method and non-software method, has the advantage of comprehensiveness. It can almost cover all mapping needs, but the complexity and difficulty will increase correspondingly.

3.2.4. Evaluations

A total of 10 articles discuss the application of microclimate to landscape architecture through the evaluations approach (#7, #9, #11, #17, #20, #22, #24, #28, #30, and #32). Evaluation is a critical part of applying microclimate to landscape architecture because it provides a systematic method to study an intervention or a practice to understand how well it achieves its goals. Evaluations help determine what works well and what could be improved in a program or initiative. It can be divided into three parts based on the commonalities and differences of reviewed articles: (1) examine the effect of the constructed environments, (2) evaluate simulation outcomes, and (3) assess a particular type of landscape. Brown (#9) [33] noted that built landscapes should be evaluated to determine if they achieved their microclimate modifying objectives. Testing by using microclimate simulation software is not only a significant step in RTD (research through design) but also a common procedure before construction (#20) [34]. There are five articles focused on the evaluation in a specific space, including intensive green roofs, traditional courtyards, urban public space, community atrium open space, and high-rise residential area (#17, #24, #28, #30, and #32) [35–39]. The advantage of evaluating the effect of the built environment is that it is easier to collect reliable and valid microclimate data, and the evaluation results can serve as a reference for future improvement. Evaluating simulation outcomes has benefits in providing a basis for the feasibility of the design. Evaluation of different spaces helps to broaden our understanding of microclimate function in different spaces, which will facilitate the formulation of the microclimatic design principles and guidelines for corresponding spaces.

4. Discussion

Four approaches were identified through the structured literature review: principles and guidelines, strategies, mapping, and evaluations. Each of the approaches has specific times when they are most effectively incorporated into the design process (Figure 3).



Figure 3. Stages of the approaches/design process (after [40]).

The landscape architectural design process typically involves five stages [40]: background study, site inventory and analysis, design development, detail design, and design assessment. Mapping dominates the initial phase, principles and guidelines are mainly applied in the second phase, strategies mainly play a role in the third phase, and evaluation is concentrated on the final phase. Notably, there is not only one approach at each phase. Evaluation may also be used in the first phase, contributing to pre-design information gathering. Strategies can be used in the second phase and can also be an integral part of concept exploration, although it is not as important as principles and guidelines at this phase. Principles and guidelines can appear in the third phase because it is beneficial to concept modification. Mapping can help to illustrate the process of evaluation clearly, so it can also be included in the final phase.

An urban park design project can be used to illustrate how microclimate information can be considered in landscape architecture. The first step is to collect prevailing climate information about the site. This includes annual and monthly solar radiation, air temperature, humidity, wind speed, and prevailing wind directions at the site. During the inventory and analysis of the site, mapping can be an effective way to show the information, and overlay mapping can identify microclimatically-appropriate areas for development. At this stage, historical information on the site's microclimate should also be evaluated [40]. Based on an understanding of the site microclimates, the designer will begin to move into design development stage. They will set a series of design goals and objectives, design principles, design criteria, etc. The focus on microclimate principles and guidelines will

differ according to different project goals and objectives. For example, in urban park design, the microclimatic goal might be to create a thermally comfortable environment to meet the public's activities needs. The objectives might be "achieving thermally comfortable environments for people eating lunch in the park" or "provide thermally comfortable seating for visitors." Correspondingly, these principles of microclimatic design could be considered: 1. Landform characteristics that will have the most impact on the microclimate are slope and aspect [22], and 2. Information on vegetation that most influences the microclimate concerns type and density [21]. A number of creative strategies will be proposed during the period of transformation of design development into detailed design. For instance, the strategies could include: adding standing water area for cooling the area near it during the day and keeping the area relatively warmer at night, or adding more deciduous trees, which provide solar access during leafless period and obstruct solar radiation during leafed periods [9]. Diverse microclimatic strategies and other design strategies need to follow microclimatic principles and guidelines. Appropriate strategies will then be chosen and applied to the detailed design stage. When the detailed design is completed, the design impact should be assessed. It can clearly and directly show the benefits that the design can provide. Microclimatic design impacts are usually simulated and evaluated using professional microclimate software.

Mapping is an effective and efficient way to apply microclimatic information to landscape architecture through the use of professional software. It has an important function and has appeared as a research tool in some studies, but lacks sufficient articles to show clear patterns [30–32]. Principles and guidelines are a common and successful method of applying microclimate information to landscape architecture. Evaluation is a very useful approach for applying microclimate to landscape architecture. In the case of unconstructed landscape projects, a simulation of the built environment is required to predict the likely microclimate results [41]. In the case of built landscape projects, testing is required to justify whether it meets the pre-set design criteria [33,42]. In addition, the evaluation of a specific landscape element or microclimate parameter often plays an essential role in some practical landscape projects [35,38]. Strategies are the most common approach according to the literature review results, consisting of goal-oriented strategies and object-oriented strategies. All four of these approaches have potential value for further research. However, due to the particular characteristics mentioned above, the principles and guidelines rely more on the accumulation of predecessors' research results, and the other three are relatively more appropriate as directions for research in the near future.

Suggested Areas of Future Research

When considering the landscape architectural design process as a whole, there are some areas that are not included in the four main approaches in the literature. These gaps provide a roadmap for future research. The first gap is that some landscape architects are not very familiar with microclimate, so that they consider it less at the concept exploration phase [43–47]. Including microclimate modification in landscape architecture education can improve student understanding and appreciation of the role of microclimate in design. Two recent papers have suggested ways that this can be done [10,48] but there is potential for more work in this area.

Second, in the stages of design development and detail design, landscape architects often use 3D modeling programs to visualize their design ideas. Unlike other traditional landscape architecture materials, most microclimate elements are invisible and intangible, making it difficult for them to be inserted into common 3D modeling software, like Sketchup, Rhinoceros, Luminon, etc. Integrating microclimate parameters into a model through virtual reality (VR) technology might help to fill this gap [49].

In VR, people can even feel the temperature by wearing special-made temperature-sensitive clothing [50]. While this is currently mainly used in the area of games, there is no reason that it cannot be applied to the field of landscape architecture. Patel [51] discussed

microclimate perception in a landscape, and research in this direction has potential for use in the future era of VR.

Third, policy implementation needs to be taken into consideration. Microclimate has a significant impact on people's health and well-being, and it is necessary to improve relevant policies to ensure that it gets the attention it deserves.

Finally, there is a gap at the stage of background study in which landscape architects learn the site's culture and history. A site's microclimate can have a strong relationship with culture and history. This was given great importance by traditional landscape architects, but many modern landscape architects pay less attention to it. Exploring the relationship between a site's microclimate and local history and culture will greatly help improve background study, especially for tourism projects [11].

In the development process of different regions and nationalities, people will form their philosophical views and methodology to adapt to the unique local climate [30,36]. For instance, feng shui is filled with a lot of microclimate knowledge and has served as a tool for Chinese people to guide design practice of landscape architecture for thousands of years [52]. Future research can be conducted based on the combination of microclimate and regional culture to create regional cultural tourism features.

Table 1. Characteristics of included studies.

#	Reference	Resource Type	Scale	Climate Zone	Climate Element(s) Focused on	Approaches to Applying Microclimate Information to Landscape Architecture			
						MAP	P&G	EVAL	STRAT
1	Ak and Ozdede (2016) [28]	Journals	Large, neighborhood	Temperate oceanic climate	Wind				x
2	Altunkasa and Uslu (2020) [30]	Journals	Large, neighborhood	Hot-summer mediterranean climate	Temperature, humidity, wind	x			
3	Attia (2006) [18]	Not peer reviewed	Small, courtyard-buildings	Tropical and subtropical desert climate	Temperature, humidity, wind				x
4	Attia and Duchhart (2011)	Not peer reviewed	Large, neighborhood	Hot desert climate	Radiation, humidity, wind				x
5	Boc (2016)	Journals	Large, neighborhood	Hot desert climate; tropical and subtropical desert climate; humid subtropical climate; temperate oceanic climate	Temperature, wind				x
6	Boc (2018) [25]	Journals	Medium, urban green areas	Humid subtropical climate	Humidity, wind		x		
7	Bonan (2000) [42]	Journals	Large, neighborhood	Tropical and subtropical steppe climate	Temperature, humidity, wind			x	
8	Brown (2010) [26]	Reputable company published Books	Medium, local	Not mentioned	Radiation, temperature, humidity		x		
9	Brown (2011) [33]	Journals	Large, neighborhood; Medium, local; Small, personal	Not mentioned	Radiation, temperature, humidity, wind			x	
10	Brown and Gillespie (1995) [9]	Reputable company published Books	Medium, local; Small, personal	Not mentioned	Radiation, temperature, humidity, wind		x		
11	Brown et al. (2015) [6]	Journals	Large, neighborhood	Tropical rainforest climate; Hot semi-arid climate; Humid subtropical climate; Hot desert climate; Hot-summer humid continental climate	Radiation, temperature			x	
12	Declet-Barreto et al. (2013) [31]	Journals	Large, neighborhood	Tropical and subtropical desert climate	Temperature	x			
13	El-Bardisy (2014) [3]	Not peer reviewed	Medium, local	Tropical and subtropical desert climate	Radiation, temperature, humidity, wind				x
14	Erell and Williamson (2012)	Reputable company published Books	Large, neighborhood; Medium, local	Mediterranean climate; tropical rainforest climate	Radiation, temperature, humidity, wind				x
15	Klemm (2014) [45]	Not peer reviewed	Medium, local	Mediterranean climate	Radiation, temperature, wind				x

Table 1. Cont.

#	Reference	Resource Type	Scale	Climate Zone	Climate Element(s) Focused on	Approaches to Applying Microclimate Information to Landscape Architecture			
						MAP	P&G	EVAL	STRAT
16	Lai et al. (2019) [4]	Journals	Large, neighborhood; Medium, local; Small, personal	All sorts	Radiation, temperature, humidity, wind				x
17	Lee and Jim (2020) [35]	Journals	Small, green roof	Humid subtropical climate	Radiation, temperature			x	
18	Lenzholzer (2010)	Not peer reviewed	Large, urban squares	Marine west coast climate	Radiation, temperature, humidity, wind				x
19	Lenzholzer (2012) [27]	Journals	Large, urban squares	Marine west coast climate	Radiation, temperature, wind		x		
20	Lenzholzer and Brown (2014) [34]	Not peer reviewed	Medium, local	Warm summer continental climate; Marine west coast climate	Radiation, wind			x	
21	Lenzholzer and Brown (2013) [48]	Journals	Large, neighborhood	Marine west coast climate; warm-summer humid continental climate	Radiation, temperature, humidity, wind				x
22	Lenzholzer and Brown (2016)	Journals	Large, neighborhood; Medium, local; Small, personal	All sorts	Radiation, temperature, wind			x	
23	Mazhar et al. (2015) [6]	Journals	Medium, local	Mid-latitude steppe and desert climate	Radiation, temperature, humidity, wind		x		
24	Nasrollahi et al. (2017) [36]	Journals	Small, courtyards	Cold semi-arid climate	Radiation, temperature, humidity, wind			x	
25	Ogunsote and Prucnal-Ogunsote (2002) [29]	Not peer reviewed	Small, personal	Tropical climate	Radiation, temperature, humidity, wind				x
26	Panagopoulos (2008)	Not peer reviewed	Medium, local	Not mentioned	Temperature				x
27	Patel (2015) [51]	Not peer reviewed	Medium, local	Humid subtropical climate	Radiation, temperature, humidity, wind				x
28	Santos Nouri et al. (2018) [37]	Journals	Medium, local	All sorts	Temperature			x	
30	Wu and Hsieh (2017) [38]	Journals	Large, neighborhood	Humid subtropical climate	Wind			x	
31	Xiong et al. (2020)	Journals	Medium, local	Humid subtropical climate	Temperature, humidity, wind				x
32	Yang et al. (2018) [39]	Journals	Large, neighborhood	Tropical climate	Radiation, temperature, humidity, wind			x	
33	Zhang et al. (2017)	Journals	Medium, local	Hot summer continental climate	Radiation, temperature, humidity, wind				x
34	Zhang (2010)	Not peer reviewed	Medium, local	Not mentioned	Radiation, temperature, humidity, wind				x

MAP—Mapping, P&G—Principles and guidelines, EVAL—Evaluations, STRAT—Strategies.

5. Conclusions

The goal of this study was to investigate, through a structured literature review, ways in which microclimate has been applied to landscape architecture in the scholarly literature, and to assess the growing recognition of microclimatic factors in design by identifying trends, patterns, and comprehensiveness. It focused primarily on studies that proposed ways to design for human thermal comfort. In total, eight approaches for integrating microclimate into landscape architecture were identified. Four of them were identified directly through the systematic literature review, including principles and guidelines, strategies, mapping, and evaluations. The other four, identified by considering the needs of landscape architects for microclimate information after synthesizing the data from the literature review, were education, modeling and visualization, policy, and ideation.

Microclimatic landscape design can be effective in ameliorating extreme conditions caused by global climate change and urban heat island intensification, providing people

with thermally comfortable and heat-safe environments. The amount of research has been increasing over the past 25 years and there is tremendous potential for additional work.

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