Toward interdisciplinary integration of architecture and climatology

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Climate change is affecting human health, and humans spend the vast majority of their lives in buildings. Architecture is the optimal solution after matching outdoor climate and indoor microclimate. Therefore, the interdisciplinary integration of architecture and climatology is of great significance.

The inherent differences in epistemologies and research methods in architecture and climatology hinder interdisciplinary collaboration. In the context of climate change, this divide affects the shift toward long-term sustainability in global sustainable architecture design and energy systems, and thus dialogue is required between the disciplines to enable effective interdisciplinary collaborations. Therefore, there is an urgent need to clarify the disciplinary gap and potential integration space between architecture and climatology. Thus, we propose a targeted path for future research.

Buildings account for as much as 45% of the energy consumed worldwide, and a similar share of greenhouse gas emissions. Thus, the building sector is the biggest single contributor to anthropogenic climate change.[1] Architects are primarily responsible for achieving superior energy and environmental performance. The functions of the discipline of architecture include architectural design, selecting materials, and construction to produce suitable building spaces for particular functions. Architecture is required to provide some form of protection, usually from the outdoor climate, and thus it needs to meet the intimate practical requirements of human existence but also to add beauty to everyday life in a progressive society. It is widely acknowledged that most aspects of design can be changed in the early stage of architectural design, but the possibility of change becomes lower and the cost of change is increasingly higher as the architectural design process continues.[2] Frustratingly, the building sector has developed over thousands of years, but most current builders and architects still lack specific ideas and solid approaches regarding how to design architecture with low energy consumption and low carbon emissions.

Similar to other forms of engineering design, architectural design involves several key steps, including identifying needs, defining a problem, creating and selecting a concept, developing the details, and finally, implementation and evaluation.[2] In the architectural design process, various factors must inevitably be considered, such as the user needs, outdoor climate, and indoor environmental requirements depend greatly on the building type and uses, which are restively fixed.[1] However, it is evident that uncertainties are increasing regarding the design and operation of buildings due to changes in the outdoor climate. Indeed, climate change is an irreversible trend according to countless scientific studies. Recently, the frequencies of extreme weather events and natural disasters have been on the rise.

Various industries are undergoing extensive and profound changes in order to rectify the relationship between humans and the environment under the goal of reaching carbon neutrality. Consequently, the intersection between architecture and climatology is important for ensuring the construction of a healthy and sustainable built environment in the future. In fact, if we consider the origin of architectural design, its primary purpose is to enhance the relationship between humans, the environment, and climate. Therefore, the intersection between architecture and climatology is indeed a fundamental issue that affects the future development of architecture. In the past, humans mainly relied on their experience and wisdom to build comfortable and livable houses, but in this new era with the aim of reaching carbon neutrality and coping with climate change, it is important to apply new approaches such as artificial intelligence, big data, and other disciplines to improve the design and construction of buildings.

CURRENT SITUATION AND CHALLENGES

There are several differences between the needs of architecture and the focus of climatology research. Over the past 40 years, green buildings, low energy buildings, and low carbon buildings have been the focus of architectural design, where they all aim to ensuring the comfort and health of the occupants, while also making the building energy consumption as low as possible. Thus, the thermal performance of buildings must be enhanced by installing suitable systems, as well as adapting to the outdoor climate and indoor environment. Basic design and calculated parameters, such as the typical meteorological year (TMY), are essential requirements for improving the energy efficiency of buildings, and they must be defined for an architectural design problem. Outdoor calculating parameters are determined based on statistical weather data, which comprise various continuous time series meteorological parameters, such as the temperature, humidity, wind, and solar radiation. Design engineers must consider daily and hourly parameters, including surface meteorological variables (air temperature, relative humidity, wind, etc.) and solar radiation (global, direct, and diffuse radiation), preferably based on 30 years of data or no less than 10 years.[3] By contrast, in Earth sciences sectors such as climatology, more attention is paid to obtaining model predictions with individual parameters under long-term climate trends. The interactions between these parameters are often overlooked. In fact, meteorological parameters simultaneously affect the performance of buildings, and thus it is necessary to consider the co-occurrence

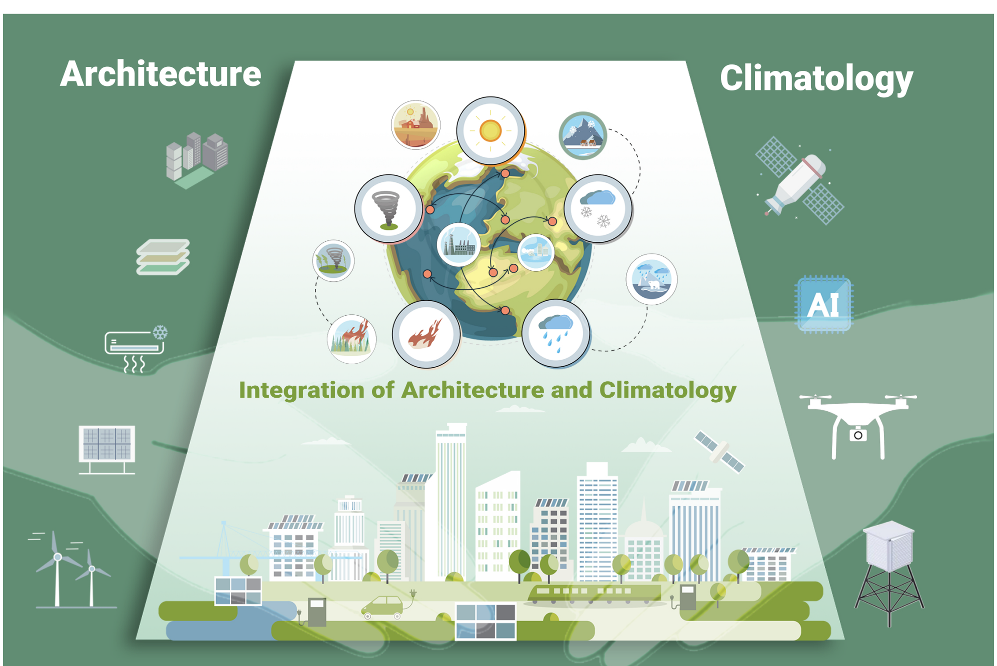

Figure 1. The relationship between architecture and climatology

between meteorological parameters.[4] In addition, oversimplifying the mathematical descriptions of models can neglect critical details and affect the accuracy of estimation, as well as leading to differences in evaluations of energy efficiency performance for buildings. In terms of the spatial distribution of meteorological parameters, meteorological data at a large scale and the same grid size are always employed in the Earth sciences. By contrast, the building sector requires local meteorological data for areas that are suitable for human settlement and building construction. Thus, meteorological data are needed for individual cities or township to eventually form an unevenly distributed grid. This unevenness may reduce the modeling and computational costs, and improve the accuracy and efficiency. Therefore, it is crucial to determine the appropriate size and distribution for the grid.

Carbon emissions from buildings are mainly generated from carbon-based energy sources comprising coal, gas, and oil. However, due to the emergence of new requirements as a consequence of climate change and the goal of carbon neutrality, it is important to completely transform the energy infrastructure by employing renewable energy sources such as solar, wind, and hydrogen. Randomness and intermittency are the most obvious characteristics of solar and wind energy sources. Thus, it is necessary to consider the stability and reliability of renewable energy systems. In addition, the system supply and building demand must be balanced as renewable energy generation is greatly affected by the weather conditions. Moreover, the indoor comfort requirements of occupants are gradually increasing. Thus, energy systems need to respond to the indoor environmental requirements (thermal, humid, light, etc.) in a timely manner which demands the availability of weather data at a fine time scale, such as minutes or even the next few days. Spatial scale data are required with a resolution of kilometers or even meters. Some energy systems such as distributed energy systems need to be built in open spaces, thereby requiring consideration of the weather conditions according to the combined influence of the topography, landform, climate, and other factors at a specific location. A finer uneven grid will be formed based on the original meteorological parameter grids. In addition, the climate has changed significantly and the frequency of extreme events such as severe heat waves has increased in recent years. This not only affects the demand of the building, but also affects the reliable performance of energy systems in the long run. Therefore, it is important to have the capacity to predict possible extreme events in the future.

These changes in terms of new demands have led to changes in the meteorological parameters applied in the building sector. Fortunately, advances in science and technology, as well as the intersections of disciplines have created opportunities for obtaining meteorological data to meet new requirements. The traditional meteorological parameter model is driven by physics, and good results have been achieved through the development of theory and improved observation systems, but predicting the weather in the future and extreme weather events is still highly challenging. The rapid development of satellite remote sensing and artificial intelligence can facilitate the establishment and improvement of parametric meteorological models.[5] In recent years, the development of satellite remote sensing technology has allowed the collection of information about the land surface, oceans, and atmosphere vis real-time or near real-time monitoring and data transmission. These data can be used to extract highly accurate weather conditions and provide the basis for building parametric meteorological models. Moreover, artificial intelligence can be applied to change the research paradigm for meteorological prediction models by identifying complex and nonlinear relationships among various parameters to help establish more accurate predictive models. Machine learning has flourished with the support of big data and advanced algorithms, and provided new approaches for improving the accuracy and efficiency of climate prediction. Artificial intelligence can be employed to establish a large model by combining climate parameter predictions, building needs, and energy system supply, information in order to predict supply and demand in real time. Another important research area is management the rapid response and adjustment of energy systems according to the weather conditions and building needs.

DEVELOPMENT AND PROSPECTS

A new integrated interdisciplinary framework could be constructed to meet the requirements for meteorological parameters in the building sector. Architecture professors and researchers in universities and other institutions should consider conducting interdisciplinary research and providing appropriate courses. Incorporating educational elements that emphasize the interplay between responding to climate change, the goal of carbon neutrality, and architectural design can enrich the understanding and skills of students in these intersecting fields. The mutual participation of experts from different disciplines in climate change response research projects can redefine the boundaries and research scope and promote the development of data standards. Considering the characteristic variations in meteorological parameters and requirements of practical engineering applications, it is necessary to explore the universality and suitability of the current method. Based on this interdisciplinary research, a convenient model for engineering applications can be formulated to describe the relationships among various parameters and obtain more accurate predictions. In addition, industry leaders could be invited to participate in courses. It is also a necessary to further integrate researchers and practical architectural projects.

To facilitate scientific research at the intersection of architecture and climatology, there is an urgent need to establish an interdisciplinary research system by incorporating several new technologies. In particular, recent rapid progress in artificial intelligence has allowed the combined development of integrated climate and architecture research, and the production of engineering solution. Research that combines traditional physics-based modeling with modern data-driven machine learning approaches could rapidly unify these two fields to facilitate the formulation of integrated building climate parametric models. The aim of this research should include coupling architecture, heating ventilation and air conditioning systems, and renewable energy sources, rather than treating each independently. The response time must be improved from the hourly to minute level to significantly improve the accuracy of future predictions. The spatial resolution can be enhanced by moving from observational data provided by meteorological stations to raster data, where any point could even be specified. The accuracy and speed of climate data prediction under the influence of complex urban environments will be significantly improved.

Energy has become a major concern throughout the world. The effective operation of new power systems based on wind and photovoltaics depends on the accurate prediction of weather conditions. Therefore, it is necessary to establish a new mechanism for data sharing via an open, shared database. Recently, meteorological observation systems have improved greatly, but there is no fully effective data sharing between the climate/meteorological sector and other sectors. Consequently, meteorological stations are being constructed repeatedly in different sectors for both research purposes and applications. A holistic approach to developing observational instruments and data sharing would obtain huge cost savings. For instance, observational data could be disclosed by level and category. Clearly, this is a long-term objective and it will also be necessary to integrate the knowledge and capacities of all stake-holders such as governments, research institutions, universities, and companies in a common aim to form an open, shared database.

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DECLARATION OF INTERESTS

The authors declare no competing interests.