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Editorial

Computational Design for Low-Carbon and Climate-Responsive Architecture and Urban Environments

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1. Context and Rationale

Climate change, carbon reduction targets, and the growing demand for healthy and resilient built environments are reshaping the theoretical and practical foundations of architecture and urban design. The built environment plays a critical role in energy consumption, carbon emissions, outdoor and indoor environmental quality, and human well-being. Therefore, low-carbon and climate-responsive design is no longer limited to passive design strategies or isolated building technologies. It increasingly depends on computational methods that can connect environmental data, performance simulation, design generation, optimization, and evidence-based decision-making. Nevertheless, the translation of computational predictions into actual low-carbon and energy-efficient performance requires careful calibration, construction quality control, operational feedback, and continuous evaluation throughout the building life cycle.

Against this background, the Special Issue "Computational Design for Low-Carbon and Climate-Responsive Architecture and Urban Environments" was launched to explore how digital technologies and computational approaches can support sustainable transformation across architectural and urban scales. This collection focuses on the integration of simulation, optimization, algorithmic design, digital modelling, machine learning, and performance-based evaluation in addressing key challenges such as energy efficiency, thermal comfort, carbon emission reduction, environmental quality, and spatial adaptability. It aims at providing a platform for interdisciplinary dialogue among architects, urban designers, engineers, environmental researchers, and computational scientists.

The papers collected in this Special Issue demonstrate the expanding role of computational design in the built environment. They cover multiple scales, including building components, classrooms, atrium spaces, traditional dwellings, elevated spaces, university buildings, old residential communities, street spaces, and regional design contexts. Together, these studies show that computational design is not only a technical tool for performance prediction but also a design methodology for linking environmental evidence with architectural and urban decision-making.

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2. Theme, Advances, and Article Highlights

This Special Issue includes studies that apply computational methods to low-carbon architecture, climate-responsive urban planning, performance-based simulation, building environmental evaluation, and spatial quality analysis. The nine papers published herein reflect several important research directions: digital carbon accounting, daylight–thermal performance evaluation, microclimate simulation, traditional dwelling adaptation, open-source building performance frameworks, multi-objective optimization, street-view-based urban perception analysis, and climate-sensitive design for diverse built environments.

Huang et al. (Contribution 1) investigate life cycle carbon emission accounting in an old residential community using digital technologies. Taking Nanyuan Xincun in Hefei as a case study, the authors address the practical difficulty of carbon accounting in existing built environments, where original drawings may be missing and site conditions are complex. By introducing digital approaches into life cycle carbon analysis, the study provides a useful reference for low-carbon renovation and stock optimization in old residential communities.

Yan et al. (Contribution 2) propose a rapid evaluation method for university classrooms using an MLP classification model based on daylight–thermal performance. The study responds to the dual requirement of improving daylight quality and reducing heating energy demand in severe cold regions. By integrating building performance simulation, multi-objective optimization, and a classification-based surrogate model, the paper demonstrates how machine learning can support early-stage decision-making in educational building design.

Ma et al. (Contribution 3) evaluate the performance of ENVI-met in simulating microclimates beneath elevated buildings in cold climates. The authors combine field measurements and numerical simulation to examine how semi-open spaces beneath elevated buildings influence microclimatic conditions. By assessing the simulation accuracy of ENVI-met, the paper contributes methodological evidence for applying microclimate simulation tools in complex architectural spaces.

Sha et al. (Contribution 4) examine wind comfort in a Beijing Siheyuan through CFD simulations and field experiments. By linking traditional Feng Shui spatial logic with contemporary wind environment evaluation, the study provides an innovative perspective on how vernacular spatial knowledge can be tested and interpreted through computational methods. This contribution illustrates the potential of CFD-based analysis for bridging traditional architectural wisdom and modern environmental performance assessment.

Song et al. (Contribution 5) study thermal comfort in plateau settlements in Qinghai through field data and simulation. The authors focus on residential buildings under high-altitude climatic conditions and explore how building morphology, orientation, and spatial scaling affect indoor thermal comfort. The paper provides climate-sensitive design evidence for plateau settlements and contributes to the adaptation of residential architecture in extreme environments.

Lin et al. (Contribution 6) develop and validate a low-cost open-source computational framework for sustainable buildings in a subtropical academic environment. The authors propose a cyber–physical system framework and apply a Random Forest-based predictive model to separate climatic effects from occupancy-related influences. This study demonstrates how open-source integration, sensor systems, and data-driven modelling can support indoor environmental quality improvement and energy efficiency.

Wang et al. (Contribution 7) conduct a multi-objective optimization study of atrium form variables for daylighting, energy consumption, and thermal comfort in teaching buildings at the early design stage in cold climates. By identifying form variables that influence environmental performance, the study provides evidence for optimizing atrium design during early decision-making. This contribution highlights the value of parametric modelling and optimization in balancing daylight, energy, and comfort objectives.

Li et al. (Contribution 8) explore urban spatial quality through street view imagery and human perception analysis. The authors integrate street view data, deep learning-based semantic segmentation, and machine learning interpretation models to understand how micro-scale spatial features shape human perception. This study extends computational design from building performance evaluation to urban spatial perception and livability assessment.

Yang et al. (Contribution 9) investigate the influence of window size on the thermal comfort of traditional One-Seal dwellings in Kunming under natural wind conditions. By focusing on the window-to-wall relationship and natural ventilation conditions, the study provides design evidence for improving the environmental performance of traditional residential buildings. It also demonstrates how computational and simulation-based methods can support the adaptive transformation of vernacular architecture.

Together, these nine contributions illustrate the breadth of computational design research in low-carbon and climate-responsive built environments. They show that computational approaches can support carbon accounting, environmental simulation, optimization, machine learning prediction, CFD analysis, field-data calibration, and perception-based urban evaluation. More importantly, they demonstrate that environmental performance should be embedded into the design process rather than treated as a post-design verification step.

3. Outlook and Gratitude

The studies collected in this Special Issue suggest that the future of low-carbon and climate-responsive architecture depends on deeper integration between computational technologies and design thinking. Several directions deserve further attention. First, cross-scale integration should be strengthened, linking component-level performance, building-level optimization, neighbourhood microclimate, and urban-scale carbon accounting. Second, computational workflows should become more accessible for early-stage design, allowing designers to evaluate daylight, thermal comfort, energy use, carbon emissions, and spatial perception before key design decisions become fixed. Third, greater attention should be given to the relationship between high-performance design and human experience, especially in educational buildings, traditional dwellings, semi-open spaces, and public urban environments. Fourth, the combination of field measurement, simulation validation, machine learning, and digital twin technologies will become increasingly important for developing robust, transferable, and context-sensitive design methods.

This Special Issue also shows that computational design is not a single method but a methodological framework. It connects environmental data, design variables, performance indicators, spatial interpretation, and decision-making. Its value lies not only in increasing analytical precision but also in helping designers formulate better questions, compare alternatives, and translate environmental evidence into spatial strategies. In this sense, computational design provides a bridge between low-carbon goals, climate adaptation, and the everyday practice of architectural and urban design. **A further issue is the balance between computer-aided design and human creativity. Computational tools can improve the capacity to test alternatives, visualize environmental consequences, and compare design options, but they should not replace the creative, cultural, and ethical judgement of designers. In architectural and urban design, creativity remains essential for framing problems, interpreting site-specific meanings, integrating social and spatial values, and transforming performance evidence into coherent spatial form. Therefore, the future development of computational design should emphasize human–computer collaboration rather than technical substitution. Digital tools should work as extensions of design intelligence, helping designers explore broader solution spaces while preserving authorship, intuition, and context-sensitive decision-making as central components of the design process.**

At the same time, computational design should not be interpreted as a guarantee of successful low-carbon or energy-efficient performance in practice. A performance gap may still occur between design intentions and actual carbon-energy outcomes after construction and operation. This gap can arise from simplified modelling assumptions, uncertain weather conditions, changing occupancy patterns, construction deviations, material substitutions, system commissioning, operational management, maintenance quality, and user behaviour. Therefore, simulation results, optimization outputs, and digitally generated design alternatives should be understood as decision-support evidence rather than final proof of performance. To reduce this gap, future computational design workflows should be more closely connected with post-occupancy evaluation, measured energy and carbon data, model calibration, commissioning feedback, and long-term performance monitoring. Computers can expand the analytical capacity of designers, but successful low-carbon design still depends on professional judgement, construction quality, operational feedback, and continuous adjustment across the building life cycle.

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Conflicts of Interest: The authors declare no conflicts of interest.

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