

Review

A Scientometric Examination on Performance-Driven Optimization in Urban Block Design Research: State of the Art and Future Perspectives

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Abstract: The study of performance-driven optimization (PDO) in urban block design is essential in the context of architectural form and urban sustainability. PDO focuses on the integrated and comprehensive optimization of various quantifiable performances of buildings, such as solar energy usage, thermal comfort, and energy efficiency. This method aligns urban spaces with sustainable development principles, ensuring they are not only aesthetically pleasing but also functionally efficient. This study explores the existing deficiency in the literature by conducting an in-depth scientometric analysis of PDO in urban block design. Employing science mapping coupled with bibliometric analysis using Python, this study meticulously analyzes the prevailing literature to map out the current intellectual landscape, understand trends, and identify key themes within this domain. This review identifies the key trends, methodologies, and influential works shaping the dynamic field of PDO. It emphasizes the critical roles of computational simulation, artificial intelligence integration, and big data analytics in refining urban block design strategies. This study highlights the growing importance of energy efficiency, environmental sustainability, and human-centric design elements. This review points to an increasing trend towards using sophisticated modeling techniques and data-driven analysis as essential tools in urban planning, crucial for developing sustainable, resilient, and adaptable urban spaces.

Keywords: performance-driven; optimization; urban block design; scientometric analysis



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1. Introduction

With rapid urbanization, cities are confronting a multitude of environmental challenges, such as urban heat islands [1] and air pollution, which pose significant threats to public health. Urban blocks, intimately connected to the scale of our daily lives, have a profound impact on human activity and health [2,3]. It argues that the design of urban blocks should transcend the traditional focus on space efficiency. Instead, it should actively contribute to environmental sustainability and enhance public health. This complex process entails the strategic configuration of various urban elements, such as buildings [4], streets [5], and public spaces [6], which collectively define the functional, aesthetic, and socio-economic fabric of the urban environment. Moreover, other elements, like trees, water bodies, and green spaces, have also been subjects of investigation regarding their optimal configurations for enhancing the urban environment [7–9]. Crucially, such configurations play a pivotal role in advancing global sustainability strategies. This includes efforts to reduce the urban carbon footprint and the potential creation of positive energy districts (PEDs) [10], thereby contributing to a more sustainable and energy-efficient urban landscape [11]. Numerous studies have delved into the designs of urban blocks and their implications, highlighting the importance of these considerations.

At the intersection of architectural form and urban sustainability, performance-driven optimization (PDO) emerges as a key paradigm in urban block design. Performance-driven architectural design emphasizes the integrated and comprehensive optimization of various quantifiable performances of buildings [12]. This method involves optimizing various performance indicators, such as solar energy usage [13–15], thermal comfort [16], and energy efficiency [17,18], to create urban spaces that are not only aesthetically pleasing but also align with the principles of sustainable development. PDO often involves the use of data and analytical models to assess how different design choices impact the performance criteria, including simulations to predict energy use, daylight exposure, pedestrian flow, and other relevant factors. A diverse array of tools and technologies have been employed and developed by researchers for analyzing, simulating, and optimizing building performance. Key tools include parametric design software like Grasshopper for Rhino and performance simulation software, such as EnergyPlus, OpenFOAM, ENVI-met, and varied plugins for Grasshopper, each crucial for various aspects of building performance analysis [19–24]. The growing focus on PDO in urban block design has sparked a significant increase in scholarly research and publications. However, although this expanding body of work is advantageous, it also poses a challenge in comprehending the current state of the field. Key issues and potential areas for further investigation might be overlooked amidst the rapidly expanding and evolving research landscape. Therefore, a detailed and systematic analysis is crucial in urban block design, especially concerning performance optimization, to effectively grasp and address these evolving challenges.

Numerous researchers in the field have developed and advocated for the use of various morphological indicators, approached from diverse perspectives. These indicators have been systematically integrated with performance optimization metrics in their research studies, facilitating a more comprehensive and multidimensional analysis of urban design and planning. Table 1 displays some of the most commonly used morphological indicators based on our incomplete survey, reflecting the efforts to integrate these indicators with performance optimization measures. The table categorizes the indicators into two main types: those that apply to the block as a whole and those specific to individual buildings. Typically, a single study incorporates multiple morphological indicators. As cities grapple with environmental degradation and the imperative to preserve natural habitats, urban block design is increasingly seen as a conduit for fostering sustainable urban environments.

Table 1. Commonly used morphological indicators within urban block studies.

Block Morphological Indicators			Building Morphological Indicators		
The Land Area	LA	[15,25]	Floor Area Ratio	FAR	[15,26,27]
The Openness	OP	[28,29]	Building Height	BH	[30–32]
Spatial Compactness	SCS	[33,34]	Building Height Fall	HF	[27,35]
Site Coverage	SC	[15,27,36]	Block Surface Ratio	BSR	[36]
The Sky View Factor	SVF	[35,36]	Roof Surface Ratio	RSR	[24,37]
Enclosure Degree	ED	[35]	Width to Height Ratio	WHR	[26,36]
Building Density	BD	[30,35]	Building Shape Coefficient	BSC	[36]
Street Orientation	SO	[25,38]	Building Form	BF	[27,38]

There is a noticeable gap in studies that offer an inclusive overview and understanding of the trends, challenges, and status quo in the field. This research aims to address this gap by presenting a thorough scientometric review of PDO in urban block design. Employing quantitative methods, such as science mapping, this study seeks to analyze the existing intellectual core and landscape of this domain, identifying the scope, quality, and potential areas of improvement in the current body of knowledge. To achieve a thorough scientometric review, this study adopts a quantitative approach, specifically science mapping [39], coupled with a bibliometric analysis utilizing custom-developed code in Python. This methodological combination enables a detailed exploration and visualization of the research landscape of PDO in urban block design, providing clarity and depth to the

analysis. The primary objective of this study is to provide a comprehensive scientometric review of PDO in urban block design. This involves a meticulous analysis of the prevailing literature to map out the current intellectual landscape, understand trends, and identify key research themes within this domain.

2. Methodology

The research methodology of this study is anchored in two principal methods, comprising bibliometric and scientometric analyses. The bibliometric analysis provides a preliminary quantitative assessment of the literature, focusing on publication trends and citation metrics. Subsequently, the scientometric analysis offers a deeper exploration of research dynamics, including network patterns and emerging themes in PDO in urban block design. This dual approach ensures a comprehensive and scientific examination of the field [40].

2.1. Bibliometric Analysis and Data Collection

A bibliometric analysis was conducted to gather the essential data for the subsequent scientometric analysis. This step involved selecting and collecting data from the Web of Science (WoS) Core Collection, renowned for its extensive coverage across various academic disciplines [41,42]. Chosen for its high-quality records and influential citation data, WoS provided a robust foundation for this study. To conduct a comprehensive literature search, a structured approach was implemented, progressively refining the search queries across various categories. The initial search, aimed at covering the broadest scope in urban design (T_A category), utilized the query " $TS_A = ((urban* OR city* OR street* OR outdoor) AND (design* OR planning*))$ ". This foundational query set the stage for more focused searches in subsequent categories. For the T_B category, which concentrates on urban form design, the search was further specified by appending " $(morphology* OR form* OR layout*)$ " to the initial TS_A string. This addition aimed to capture literature pertaining more specifically to the physical form and layout aspects of urban design. Moving to the T_C category, focusing on urban block form design, the query was further refined by adding " $(block* OR neighbo?rhood*)$ " to the previously enhanced TS_B string. This inclusion aimed to narrow the search to literature dealing with the design and planning of urban blocks and neighborhoods. For the T_D category, which delves into optimization in urban block form design, the query was expanded by incorporating " $(optim*)$ " into the TS_C string. Subsequently, for the T_E category, a meticulous screening process was applied to the T_D category's search results. This careful selection aimed to isolate and identify the most pertinent and insightful articles within the already refined T_D dataset, focusing on highly specialized and relevant topics within the realm of urban block form optimization. This final step in the search process ensured a targeted and in-depth exploration of the most advanced and specific aspects of the field. Throughout this process, the search queries were specifically tailored to target the "Topic" field of journal articles. Boolean logic was employed extensively with "AND" used to combine different criteria and "OR" to broaden the search within each set of criteria. Wildcard characters, like asterisks (*) and question marks (?), were strategically used to expand the search scope, capturing variations in keywords. Additionally, the search parameters were set to include the entire available historical record, ensuring a comprehensive sweep of the relevant literature. The methodological framework of the bibliometric analysis is illustrated in Figure 1.

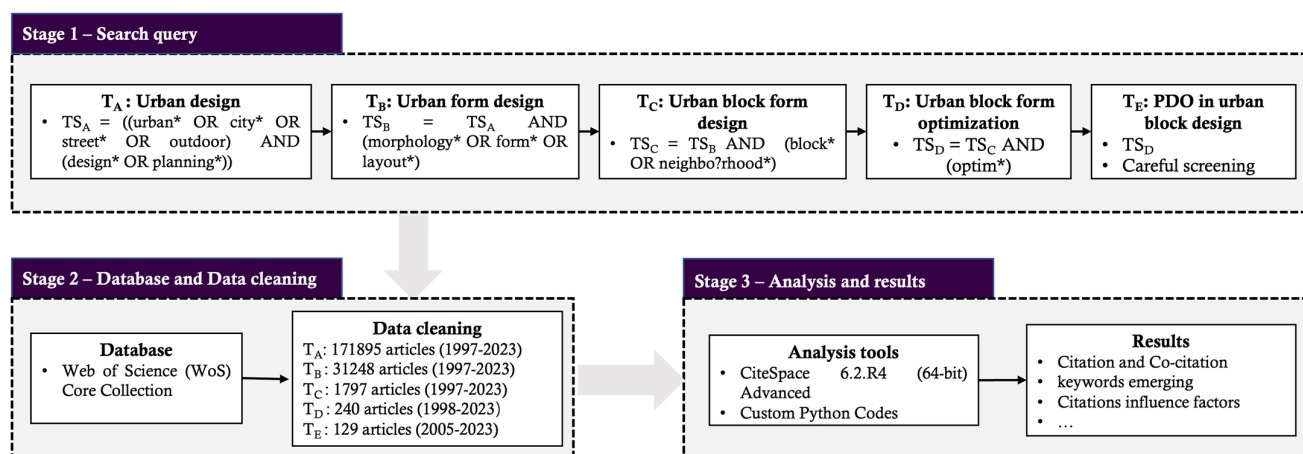


Figure 1. The methodological framework of the bibliometric analysis.

The literature search for the T_A category, focusing on urban design, yielded a substantial dataset of 171,985 articles, covering publications from 1997 to 2023. The starting point of this dataset, 1997, was established based on the publication date of the earliest article found in the T_A category. Similarly, the search within the T_B category, dedicated to urban form design, resulted in the retrieval of 31,248 articles. Notably, the earliest article in this category also dates back to 1997, aligning with the commencement year identified for the T_A category. This extensive collection of articles reflects a broad and in-depth exploration of the respective fields over more than two and a half decades. The search for the T_C category, which focused on urban block form design, resulted in the retrieval of 1,797 articles. The earliest article in this category dates back to 1997. In the T_D category, centered on optimization in urban block form design, a total of 240 articles were identified. The commencement year for this collection was 1998, reflecting the emergence of scholarly interest in this specific area a year after the earliest publications found in the T_C category. For the T_E category, which involved a more specialized and targeted search, the literature yielded 129 articles. The earliest publication in this set is from the year 2005, marking a more recent focus in the field compared to the other categories. These findings across different categories reveal varied historical trajectories in the publication of articles. The trends and patterns in these publications, including the evolution of research focus over the years, will be further discussed and analyzed in the subsequent sections of this study.

2.2. Scientometric Analysis

The scientometric analysis, the second step of our methodological framework, extends the bibliometric approach to map the intellectual landscape and dynamics of PDO in urban block design. In the scientometric analysis conducted for this study, a range of specialized tools was utilized to methodically dissect and interpret the extensive data found in the scientific research. Notably, CiteSpace and VOSviewer were employed for their proficiency in conducting co-citation and co-word analysis, generating visual network maps and identifying emerging trends within the field [41,43,44]. Specifically, CiteSpace 6.2.R4 (64-bit) Advanced was chosen as the primary tool for its robust capabilities in uncovering trends and patterns in scientific literature. To augment this analysis, a custom Python code was developed, offering additional analytical depth. This amalgamation of CiteSpace's focused scientometric functions with the adaptability of Python coding created a powerful and comprehensive toolkit, enabling a thorough examination of the PDO landscape in urban block design. In the interpretation of the graph produced using CiteSpace, two critical metrics, 'betweenness centrality' and 'burst strength', were key to the analysis. Betweenness centrality, a concept from graph theory, measures a node's centrality based on the shortest paths traversing through it, offering insights into the overall structure of the network. In CiteSpace, this metric is normalized on a scale from 0 to 1. Nodes

demonstrating high betweenness centrality, indicative of their role as pivotal connectors bridging two or more large clusters within the network, are visually distinguished with purple rings in the generated network graph [45].

3. Results and Analysis

In this section, the results and analysis derived from a comprehensive review of PDO in urban block design are explored. Through a scientometric examination of a wide array of studies, key findings, patterns, and insights that have emerged in the field are synthesized. The analysis, encompassing various facets of PDO, ranges from theoretical frameworks and methodological approaches to practical applications and case studies. The influence of recent advancements in technology, especially in computational simulation and data analytics, on urban block design is examined.

3.1. Dynamics of Publications

3.1.1. Publication Trends

Figure 2a presents the trend in article publications from 1997 to 2022 within the categories T_C , T_D , and T_E , deliberately excluding 2023 to avoid the inclusion of partial and potentially misleading data. The publications in T_C , shown in light gray, indicate a consistent upward trajectory in research output with a marked increase noted after 2010. The publications pertaining to the T_D category were notably infrequent prior to 2013. However, a significant uptick in publication frequency has been observed after 2013 with optimization-related research accounting for approximately 10% of all studies within the urban block design field. A detailed comparison was conducted for the publications in the T_D and T_E categories, focusing on the period after 2005, as illustrated in Figure 2b. This year marks a significant point, as it is when the first publication in the T_E category was documented. It can be observed that T_E has experienced a marked increase in recent years, comprising 71.8% of the publications within the T_D category, highlighting its rising significance in the realm of optimization research. In addition, in the span from 2013 to 2023, the T_E category, dedicated to PDO in urban block design, generated a substantial total of 124 papers. Given that the cumulative number of papers since 2005 amounts to 129, these data suggest a notable increase in research interest and output in this specialized field, especially in recent years. This trend underscores a heightened focus within the academic and professional communities on this particular facet of urban design with the bulk of research activity occurring within the past decade.

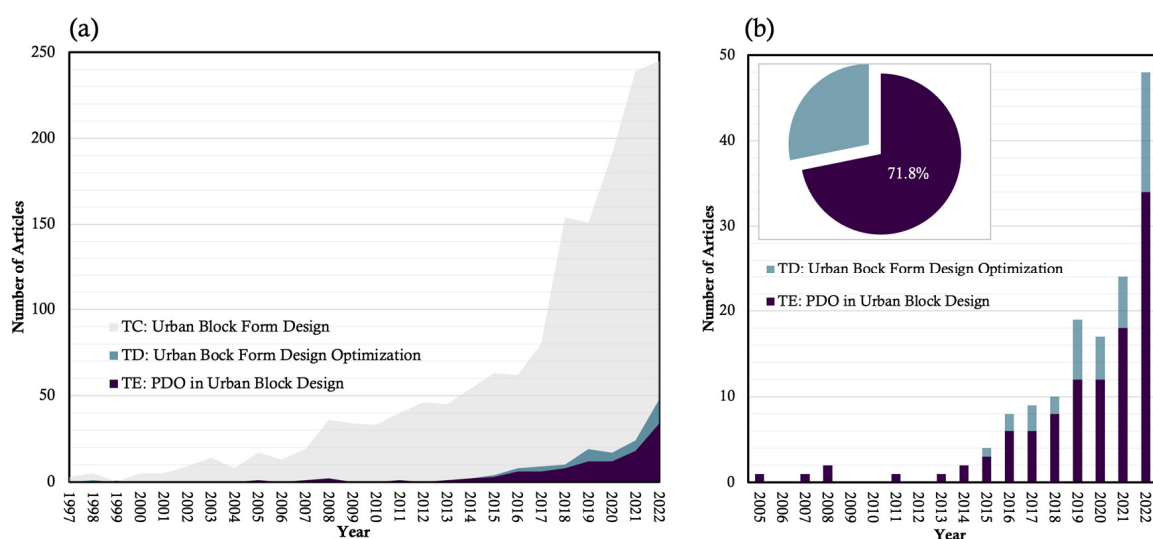


Figure 2. Publication dynamics in urban form design (1997–2022): (a) comparative article counts across T_C , T_D , and T_E categories; (b) trends in T_D and T_E categories.

3.1.2. Geographic Distribution

Figure 3a presents a detailed analysis of global research production in PDO in urban form design. China and the USA are observed to be at the forefront in total publications (TP) and citations (TC), reflecting a substantial impact and dominance in the field. In addition, China's percentage of total publications (PTP) has reached 45.5%, indicating that approximately half of the research output is contributed by China, underscoring its pivotal role in the PDO research community. Collaboration metrics reveal that China and the USA also excel in international cooperative efforts. First author (AU1) and corresponding author (AUC) counts highlight China's active participation in leading research, while the H-index, an indicator of research quality and consistency, reaffirms China's authoritative stance in the field. In contrast, Chile and Switzerland, though producing fewer publications, show remarkable impact through the highest citation percentages, indicating the high quality and influence of their research contributions. Italy, Australia, Singapore, and Spain also demonstrate high citation ratios, marking their substantial contributions. In summary, while China and the USA lead in volume, countries with lower output, like Chile and Switzerland, command considerable influence, contributing high-quality research to the evolving discourse on PDO in urban form design.

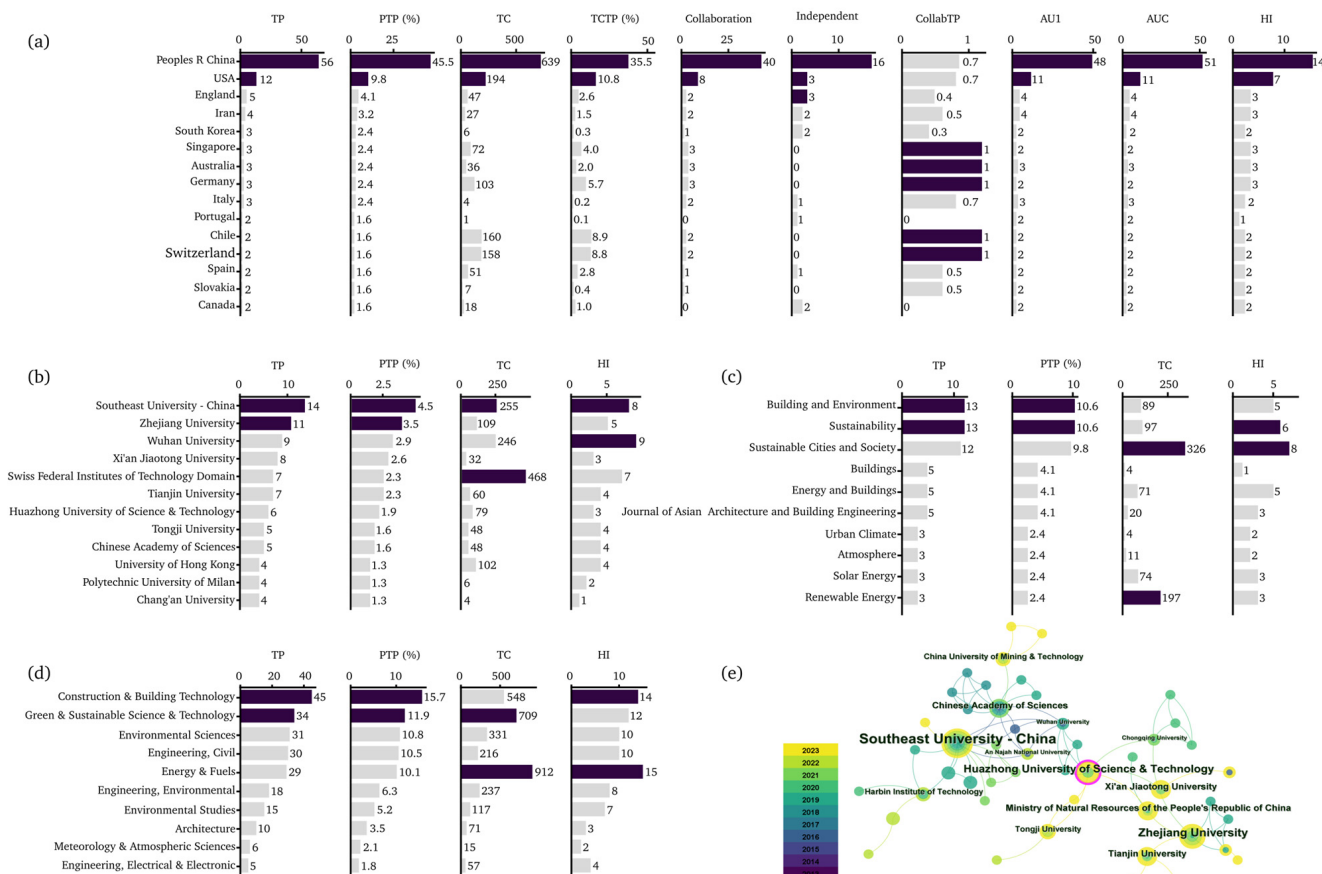


Figure 3. Publication leaders in PDO in urban block design research: (a) top 15 countries/regions by publication volume; (b) top 10 research areas by publication count; (c) top 10 journals of publications; (d) top contributing institutions analysis; (e) institution co-citation network.

3.1.3. Research Areas and Influential Journals

To elucidate the research focus within the field, the research areas were sorted by publications with tallies for the number of papers, total citations, and H-index, as illustrated in Figure 3b. Construction and building technology tops the list with 45 publications, comprising 15.7% of the corpus, signaling its centrality in urban form design research.

Subsequent areas include green and sustainable science and technology with 34 publications (11.9%), environmental sciences with 31 (10.8%), civil engineering with 30 (10.5%), and energy and fuels with 29 (10.1%). Collectively, these areas make up roughly 60% of the output, underscoring the importance of sustainability and technological innovation in this research domain. Notably, energy and fuels stands out in terms of citations, receiving 912 citations, and achieving the highest H-index of 15, emphasizing its critical impact on the study of urban form design. In conclusion, the results suggest a research landscape heavily influenced by sustainability and the application of technology within the field. The prominence of energy and fuels in citations and H-index reflects the importance of energy considerations in current and future urban planning research, pointing to the area's integral role in shaping environmentally conscious and energy-efficient urban spaces.

Figure 3c delineates the distribution of publications among the leading journals in the field of urban sustainability. *“Building and Environment”* emerges as the most prolific with 13 publications and a notable H-index of 15, underscoring its impact on the field. Matching in publication count, *“Sustainability”* distinguishes itself with a higher citation count of 97. *“Sustainable Cities and Society”* commands attention with 12 papers and a remarkable citation count of 326, highlighting its significant influence in urban sustainability discussions. Journals like *“Buildings”* and *“Energy and Buildings”* along with *“Journal of Asian Architecture and Building Engineering”* each contribute five papers, underscoring the importance of energy considerations in urban design. Additionally, *“Urban Climate”*, *“Atmosphere”*, *“Solar Energy”*, and *“Renewable Energy”*, with three papers each, point to nascent yet growing interests in the sector. Notably, *“Renewable Energy”* achieves a substantial citation count of 197, indicating its significant impact and the growing importance of renewable solutions in the realm of urban development. Collectively, these journals with their emphasis on energy and environment serve as pivotal platforms for the dissemination of research and advancements in PDO in urban block design.

3.1.4. Top Contributing Institutions

Figure 3d presents twelve top-contributing institutions with ten hailing from China, underscoring the country's significant input in the domain. Southeast University-China and Zhejiang University are at the forefront, boasting 14 and 11 total publications, respectively, which signals their prominent roles in advancing the field. Notably, Swiss Federal Institutes of Technology Domain, despite sharing fifth place with seven publications, commands a disproportionate citation influence with 468 total citations, accounting for 66.9% of the total citations, reflecting the considerable reach and impact of its research contributions. To enhance the understanding of institutional interconnections, a co-citation network analysis was performed using CiteSpace, as illustrated in Figure 3e. In the network, node size represents the quantity of publications, and the color and thickness indicate the publication timeline and frequency, respectively. Nodes with a yellow hue signal recent publication, underscoring the evolving nature of research. It can be observed that institutions with a larger volume of publications display thicker yellow rings, denoting their active and recent contributions to the field. Huazhong University of Science & Technology, marked with a purple circle, commands a significant position within the network due to its high betweenness centrality. This designation indicates its central role in connecting diverse research groups, demonstrating that its influence extends beyond its publication quantity.

3.2. Thematic Keyword Analysis

3.2.1. Keyword Frequency and Trends

Table 2 presents the frequencies and centralities of keywords within the scope of PDO in urban block design research. The keyword ‘impact’ has the highest frequency of 31, which indicates its prominence in the discourse, and is coupled with a notable centrality score of 0.24, suggesting its bridging role in connecting various research themes. ‘Simulation’ stands out with the third frequency of 21 but has the highest centrality of 0.35, suggesting that simulation may be the key method for the PDO research. The keyword list

highlights terms such as ‘energy consumption’, ‘outdoor thermal comfort’, ‘ventilation’, and ‘thermal comfort’, all related to building performance. This points to a research focus on energy efficiency and thermal environmental management, essential components of building performance. Figure 4 visualizes the interconnectivity and thematic relationships within the field, complementing the data from Table 1. It is evident that keywords with a high frequency (larger node size) and significant betweenness centrality (indicated by nodes with purple circles) are predominantly filled with warmer tones, suggesting that these terms are not only pivotal in connecting various research themes but also currently prevalent within the field.

Table 2. Top contributing keywords frequency and centrality.

Rank	Keywords	Frequency	Centrality
1	impact	31	0.24
2	design	27	0.22
3	simulation	21	0.35
4	performance	20	0.14
5	city	17	0.17
6	optimization	17	0.15
7	climate	15	0.18
8	density	14	0.12
9	buildings	13	0.1
10	model	12	0.17
11	energy consumption	11	0.09
12	heat island	9	0.03
13	outdoor thermal comfort	9	0.01
14	ventilation	8	0.04
15	thermal comfort	7	0.04

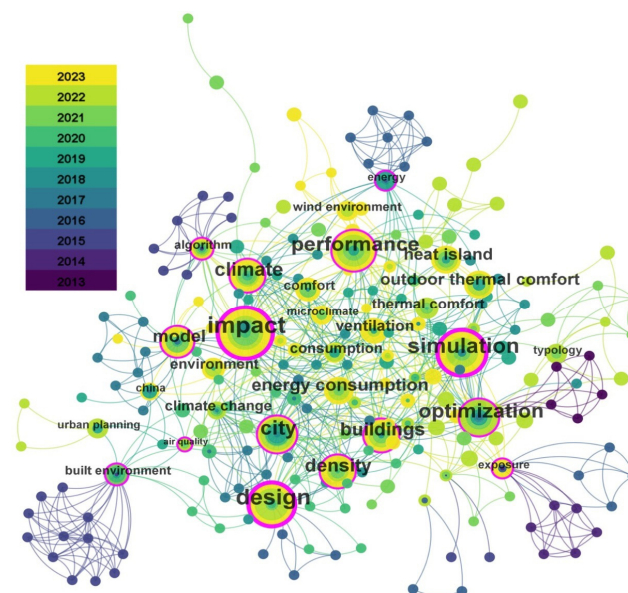


Figure 4. Network of co-occurrence of keywords.

Figure 5 displays the timeline of keyword co-occurrence in the research network with connecting lines signifying co-mentions of keywords in the literature. The varying thickness of these lines denotes the frequency and, thus, the strength of the association between keywords. The figure clearly reveals that, prior to 2018, research keywords were primarily concentrated around fundamental terms, such as ‘optimization’, ‘density’, ‘impact’, ‘simulation’, and ‘climate change’. After 2018, however, there is a noticeable

expansion in the diversity of keywords across various research aspects. The growing web of keyword interconnections highlights a shift toward holistic and interdisciplinary research, responding to the evolving complexities of PDO in urban block design. This pattern reveals a dynamic scholarly exchange, integrating new ideas with traditional concepts, thus steering urban block design studies toward fresh investigative paths and breakthroughs.

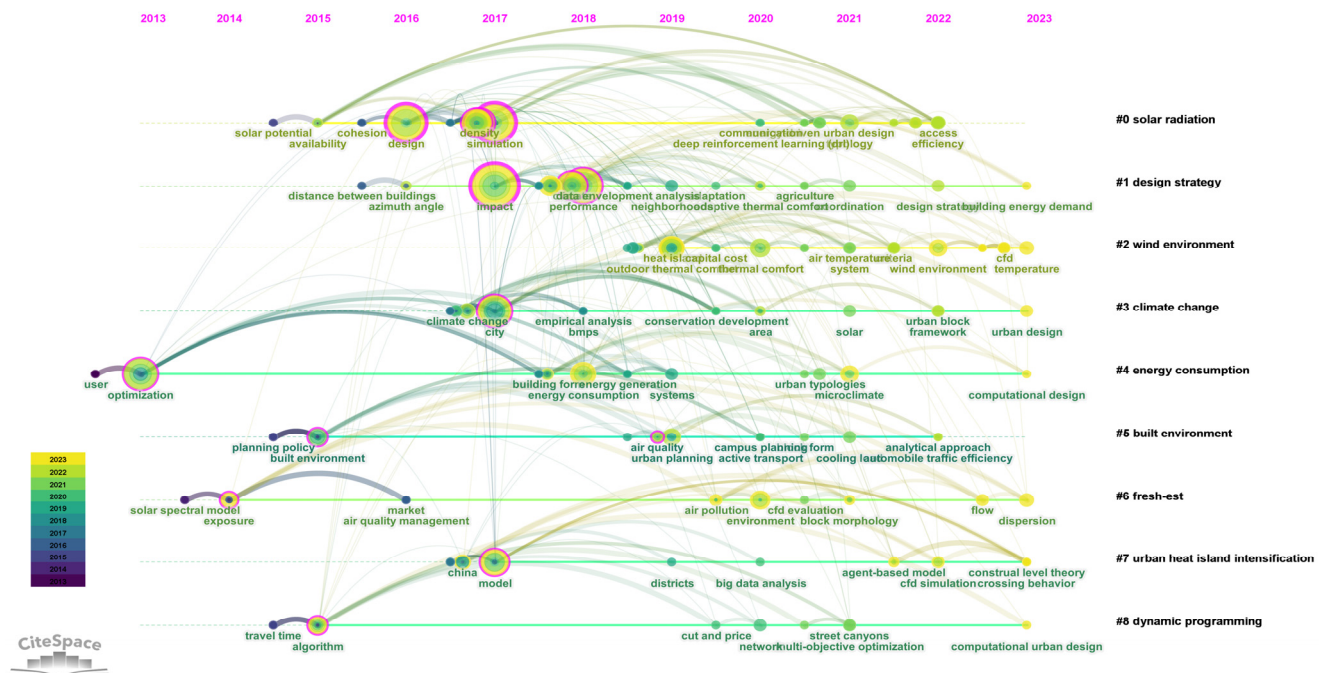


Figure 5. Timeline view of co-occurrence of keywords network.

3.2.2. Thematic Clusters Identification

Table 3 presents an analysis of thematic clusters identified in the domain of PDO in urban block design, each characterized by key terms and the mean year of the cluster's emergence. For the label selection algorithm, the log-likelihood ratio (LLR) method was employed due to its ability to generate high-quality clusters in terms of uniqueness and coverage [46]. The silhouette indices of the clusters all exceed 0.79, indicating a high degree of homogeneity and reliability within each cluster of the study. Cluster #0 that is labeled with "solar radiation", which is the largest with 35 studies, focuses on 'solar radiation' and 'solar potential', indicating a strong research interest in energy resources and their management with terms like 'sensitivity analysis' and 'daylighting' suggesting a nuanced approach to energy efficiency. Cluster #1, emerging in 2018, is labeled around 'design strategy', incorporating aspects of climate and community spaces, such as 'pocket parks' and 'neighborhoods', reflecting a holistic approach to urban planning. Wind-related factors form the core of Cluster #2, as observed in 2021, with 'wind environment', 'thermal stress', and 'wind street grid' central to discussions about environmental comfort and urban airflow. Cluster #3 with a mean year of 2018 engages with 'climate change', highlighting the use of advanced techniques, like 'agent-based spatial modeling' and 'generative adversarial network', to assess risks and impacts. 'Energy consumption' is the focal point of Cluster #4, integrating traffic and urban dynamics, indicating the interplay between urban mobility and energy use. Cluster #5, concurrently emerging, addresses the 'built environment', linking air quality and health, suggesting the importance of policy and planning in creating livable urban spaces. The remaining clusters, #6 through #8 with smaller sizes ranging from 15 to 17, explore fresh themes like 'fresh-est', 'optimizations', 'urban heat island intensification', and 'dynamic programming'. These reflect emerging interests in urban microclimates, pollution, sustainability, and advanced computational methods for urban planning, signaling evolving

research priorities that respond to contemporary urban challenges. Each cluster's position within the table and the associated mean year serve as indicators of the evolving focus areas in the research landscape, providing a roadmap for future investigations in performance-driven urban block design.

Table 3. Cluster analysis.

ID	Size	Silhouette	Mean Year	Cluster Label (LLR) and Key Terms
#0	35	0.878	2019	# Solar radiation; solar potential; resource management; sensitivity analysis; daylighting
#1	30	0.92	2018	# Design strategy; impact; climate; pocket park; neighborhoods
#2	29	0.79	2021	# Wind environment; thermal stress; wind corridor; wind; street grid
#3	25	0.884	2018	# Climate change; agent-based spatial modelling; runoff; risk analysis; generative adversarial network
#4	23	0.791	2017	# Energy consumption; traffic conflicts; ladybug tools; two-stage stochastic programming; uncertainty
#5	23	0.914	2017	# Built environment; air quality; cluster analysis; planning policy; livability health promotion
#6	17	0.89	2017	# Fresh-est; optimizations; ultraviolet; shell; traffic pollutant
#7	17	0.957	2019	# Urban heat island intensification; urban morphology indicators; stormwater management; cover changes; path finding; blocking
#8	15	0.895	2017	# Dynamic programming; microclimate-sensitive design; small data; suburban bus route design; parametric design

3.2.3. Emerging Keywords

Figure 6 shows the top ten keywords with the strongest citation bursts. With the exception of “city”, which does not describe any research development, all the other keywords are about building performance. “energy” has been a focal point since 2016 with ‘consumption’ gaining prominence in 2018. The keywords ‘Outdoor Thermal Comfort’ and ‘Thermal Comfort’ collectively exhibit an extended citation burst spanning five years, which is ongoing, highlighting an increased and enduring focus on human-centric comfort considerations in urban block design within the scholarly community. The year 2022 saw a surge in the emphasis on ‘wind environment’, ‘energy use’, ‘solar radiation’, ‘access’, and ‘efficiency’, indicating a shift toward sustainable and accessible urban design practices.



Figure 6. Top 10 keywords with the strongest citation bursts by CiteSpace.

To further understand the research on building performance, a closer examination of the literature post-2018 condenses the discourse into ten salient categories of building performance, as shown in Figure 7. ‘Energy’ is at the forefront, particularly focusing on the optimization of energy use, harnessing solar energy potential, and designing efficient energy systems. ‘Vitality’ emerges as the second most discussed theme, encapsulating the dynamic aspects of urban life, such as walkability, transport networks, and green

spaces. ‘Thermal’ considerations highlight an integrative approach to energy efficiency and occupant comfort. While topics like ‘Water management’, ‘Air Pollution’, ‘Traffic’, and others may not dominate the conversation, their presence marks a comprehensive view of building performance, intertwining environmental stewardship with urban functionality. This multifaceted research trajectory indicates a field evolving towards a holistic interpretation of urban development, marrying technical efficiency with socio-environmental responsibility. In the subsequent Discussion section, we will delve deeper into the specific research contents of these building performance aspects.

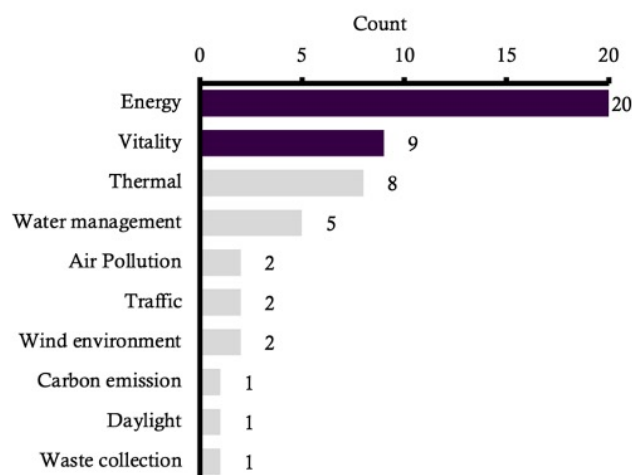


Figure 7. Building performance in post-2018 research.

3.3. Research Influence Mapping through Citations

3.3.1. Influential Works

The top 10 most-cited studies in Table 4 encompass a range of themes critical to sustainable urban design from harnessing solar energy to mitigating pollution and promoting walkability. The research by Sarralde et al. demonstrates that optimizing specific urban form variables could significantly amplify solar energy capture in London’s neighborhoods [47]. Similarly, Lobaccaro et al. uncover how urban morphology directly influences solar potential, especially in colder climates [48]. Mavromatidis et al. highlight the importance of accounting for uncertainty in the design of energy systems [49], while Vartholomaïos et al. delve into how urban architectural forms affect household energy demands for climate control [21]. In addressing urban pollution, innovative models reveal the impact of building dimensions on air pollution spread with studies suggesting strategic urban planning to reduce pollutant levels. Remote sensing data have been instrumental in mapping PM2.5 concentrations, pinpointing urban design elements that contribute to air quality, as demonstrated in research focused on Wuhan [50]. Xu et al. advance this by applying a SWMM-based methodology for environmental management practices in Tianjin, proving effective in reducing runoff and pollution [51]. Li et al.’s application of deep-learning techniques sheds light on the myriad of factors that contribute to urban vitality [52], and Sevtsuk et al. challenge conventional wisdom on block size and pedestrian accessibility, revealing that larger blocks might actually enhance walkability [53]. Natanian et al.’s parametric approach to urban design in Mediterranean contexts underscores the interplay between design, energy efficiency, and daylighting [54]. Collectively, these pivotal studies underscore a shift toward multidisciplinary methods and data-driven insights to advance sustainability and quality of life in urban design.

Table 4. Top 10 most-cited studies in the field.

No	Author	Citation	Year	Journal	DOI
1	Sarralde et al. [47]	146	2015	Renewable Energy	https://doi.org/10.1016/j.renene.2014.06.028 , accessed on 30 January 2024.
2	Mavromatidis et al. [49]	128	2018	Applied Energy	https://doi.org/10.1016/j.apenergy.2018.04.019 , accessed on 30 January 2024.
3	Yang et al. [3]	109	2020	Sustainable Cities And Society	https://doi.org/10.1016/j.scs.2019.101941 , accessed on 30 January 2024.
4	Vartholomaïos et al. [21]	88	2017	Sustainable Cities And Society	https://doi.org/10.1016/j.scs.2016.09.006 , accessed on 30 January 2024.
5	Xu et al. [51]	82	2017	Frontiers of Environmental Science & Engineering	https://doi.org/10.1007/s11783-017-0934-6 , accessed on 30 January 2024.
6	Natanian et al. [54]	78	2019	Applied Energy	https://doi.org/10.1016/j.apenergy.2019.113637 , accessed on 30 January 2024.
7	Lobaccaro et al. [48]	50	2017	Solar Energy	https://doi.org/10.1016/j.solener.2017.04.015 , accessed on 30 January 2024.
8	Li et al. [52]	48	2022	Cities	https://doi.org/10.1016/j.cities.2021.103482 , accessed on 30 January 2024.
9	Yuan et al. [50]	45	2019	Journal of Cleaner Production	https://doi.org/10.1016/j.jclepro.2019.02.236 , accessed on 30 January 2024.
10	Sevtsuk et al. [53]	40	2016	Urban Morphology	https://doi.org/10.51347/jum.v20i2.4056 , accessed on 30 January 2024.

3.3.2. Citations Influence Factors

The number of citations a paper receives is often viewed as a reflection of its quality and scholarly impact. However, it is also shaped by non-scholarly factors. These include the length of the title, the quantity of cited references, the paper's length, and the number of contributing authors. In an effort to understand the broader determinants of citation frequency, a comprehensive analysis encompassing the full range of urban block design literature was conducted. Figure 8 illustrates the correlations, distinguishing PDO-focused articles in urban block design (marked in purple) from the broader field on urban block design optimization (marked in grey). Importantly, this analysis is confined to papers with fewer than 100 citations to prevent distortion by highly cited papers. This approach ensures a more accurate assessment of the diverse factors that contribute to a paper's citation frequency.

The length of a paper's title, ranging from brief to lengthy, can significantly impact its citation rate. An optimal title length that balances clarity with detail tends to enhance a paper's visibility and citation count. To investigate the relationship between title length and citation frequency, the papers were classified into groups: very short (≤ 5 words), short (6–11 words), moderate (12–16 words), long (17–25 words), and very long (≥ 26 words). Box plots were used to illustrate this correlation, as shown in Figure 8a,b. The data analysis reveals a correlation between title length and citation impact. Titles of moderate length, specifically within the 12–16 word range for PDO-focused research, correspond to the highest median citation counts, suggesting that these articles achieve optimal visibility and scholarly reach with concise titles. In contrast, the broader urban block design literature exhibits a preference for longer titles, ranging from 17 to 25 words, indicating that additional descriptive depth may enhance citation potential in this wider field. PDO-focused articles exhibit a more uniform citation distribution across varying title lengths as opposed to the broader field, where citation range increases with title length, potentially signifying a diverse research audience. Outliers present in both domains, especially within the 6–11 and 12–16 word count ranges, highlight the presence of exceptionally impactful studies, which attract citations regardless of their title's brevity or expansiveness. This analysis indicates the nuanced relationship between title articulation and citation frequency, reflecting different trends and preferences in research dissemination within the fields of PDO and urban block design.

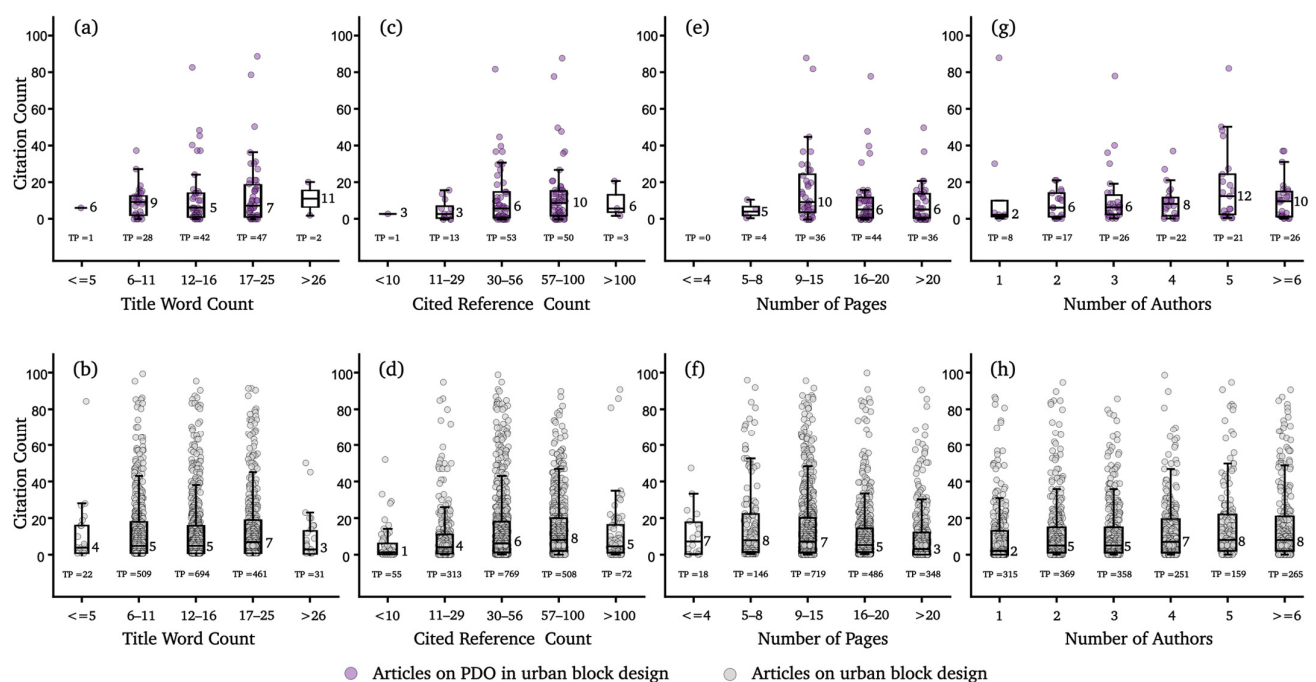


Figure 8. Correlation of influence factors with citation frequency: (a,b) the title word count; (c,d) cited reference count; (e,f) number of pages; (g,h) number of authors.

The correlation between citation frequency and the number of references cited in urban block design and PDO-focused articles is presented in Figure 8c,d. The papers are grouped according to reference count quartiles: very few (<10), few (11–29), moderate (30–56), many (57–100), and extremely many (>100). The analysis indicates that articles with a moderate to high number of citations (specifically in the 57–100 range) generally receive more citations, suggesting a correlation between the depth of literature engagement and higher citation impact. Conversely, articles with over 100 references tend to see a drop in citation frequency, implying that excessively extensive reference lists may not enhance and may even detract from an article's influence. Additionally, articles with fewer references are noted to garner lower citation counts, potentially reflecting limited scope or engagement with existing literature. This pattern underscores the importance of a well-curated reference list that is neither too sparse nor excessively comprehensive to optimize a paper's academic impact.

Paper length demonstrates a nuanced relationship with citation impact, as both brevity and excessive detail can influence a study's reception. The analysis depicted in Figure 8e,f categorizes the papers into varying lengths to assess their citation performance: short (<4 pages), relatively short (5–8 pages), medium (9–15 pages), relatively long (16–20 pages), and long (>20 pages). The medium-length papers (9–15 pages) tend to have a higher median citation count across both fields, indicating that a balanced paper length, which provides enough room to detail methods and discuss results without being overly verbose, is generally preferred by the academic community. The relatively long papers (16–20 pages) also exhibit a substantial median citation count, especially in PDO-focused research, suggesting that comprehensive studies in this specialized area are well-received. However, very long papers (>20 pages) do not necessarily translate into higher citations, which could suggest that overly detailed papers might dilute the core message and overwhelm readers. The trend implies that conciseness coupled with sufficient depth is appreciated in scholarly works within urban block design and its specialized PDO research.

The number of authors on a paper can reflect the extent of collaborative research and is often associated with the study's reach and impact. Authorship patterns and their influence on citation frequency were examined by categorizing the papers according to the number of contributing authors, as shown in Figure 8g,h. The purple markers representing PDO-focused research show a notable trend: papers with a higher number of authors

tend to receive more citations, suggesting that collaborative efforts may result in studies of higher impact or visibility in the field. This trend is less pronounced but still observable in the broader field of urban block design, marked with grey markers. Interestingly, while papers authored by four to five individuals seem to achieve a good balance between collaboration and citation frequency, those with more than six authors do not necessarily garner significantly higher citations. This could indicate that, beyond a certain point, additional authors may not contribute to a proportional increase in citations. The data suggest that multi-author papers are well-received in the academic community, but the correlation between the number of authors and citations does not appear to be linear.

4. Discussion

4.1. The Knowledge Structure

Figure 9 delineates the knowledge structure within PDO in urban block design studies with a three-tiered model that maps the evolution of the field. The foundational tier or knowledge base encompasses the core concepts that dominate the discourse, evidenced by the top 30 most frequently co-cited terms, such as “energy consumption,” “climate change,” and “urban planning.” These terms represent the persistent threads in research discussions. Ascending to the knowledge domain, we encounter nine principal research themes that define the current landscape of PDO in urban block design. Document co-citation analysis has surfaced clusters like “Solar radiation” and “Urban heat island intensification” as significant research areas, underscoring the breadth and depth of inquiry within the field. The apex of this structure, the knowledge evolution tier, charts the dynamic trajectory of PDO research. It showcases key terms that have surged in academic prominence with temporal markers indicating their active periods. For instance, the focus on “Energy” and “Consumption” spans from 2016 to 2019, while “Thermal Comfort” emerges as a salient theme from 2020 to 2023. This shift signals a growing scholarly preoccupation with the granular aspects of urban inhabitability and environmental integration. This tripartite framework captures not only the stable bedrock of urban soundscape studies but also its fluid progression, reflecting a field that is continually responding to and being reshaped by emerging insights and societal imperatives.

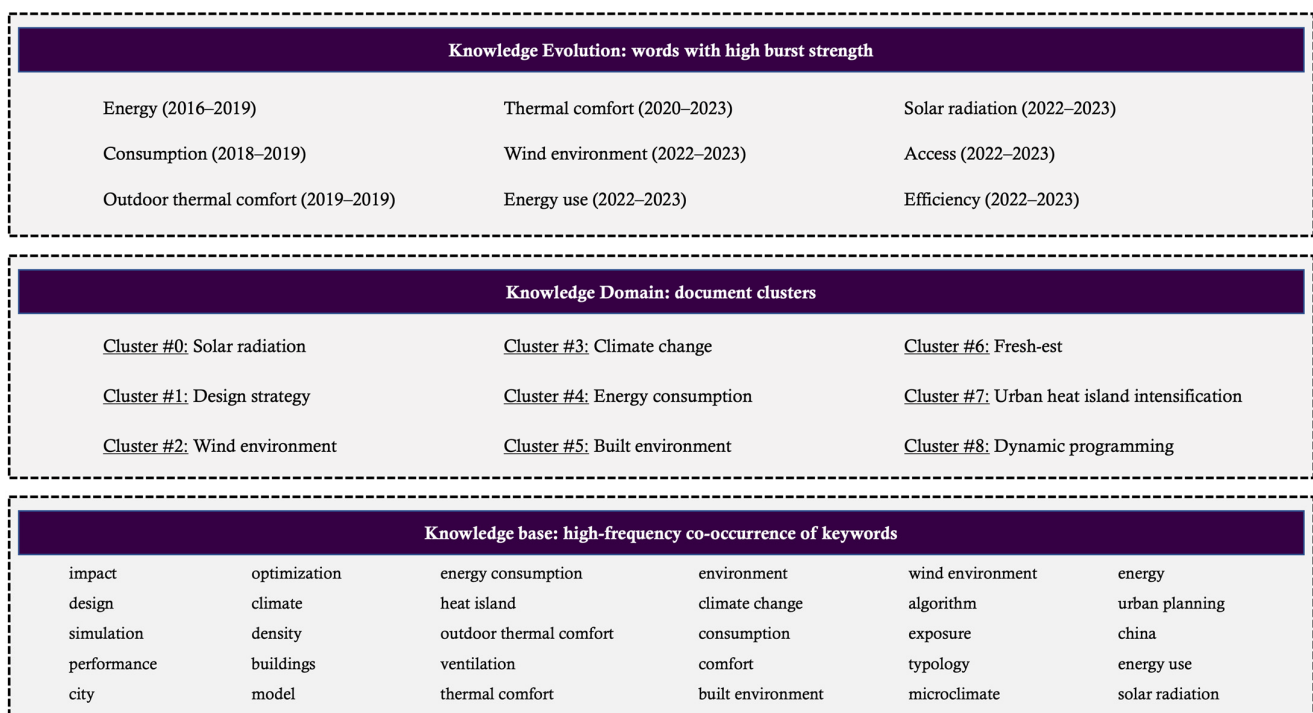


Figure 9. Knowledge structure of the PDO in urban block design.

4.2. Specific Contents of PDO in Urban Block Design

4.2.1. Study Methods and Tools

In the preceding sections, we identified ten building performance aspects in recent research (Figure 7). We step forward to investigate the study methods and tools used in this field, aiming to gain a clearer understanding of how these performances are quantified and evaluated based on recent research papers. Typically, research in the field of building performance employs three primary methods of study. The method in building performance studies typically encompasses measurement (M), which involves both on-site assessments and scaled laboratory experiments, and computational simulation (CS). With technological advancements, artificial intelligence (AI) has been integrated with computational simulations, introducing advanced emulation techniques into the research toolkit. Additionally, the incorporation of big data (BD) analytics has harnessed AI's capabilities to dissect and understand complex datasets, which enhances the precision of predictions and depth of analysis in identifying trends and results in building performance. It is evident that traditional computational simulation remains the most used method, as shown in Figure 10. However, there is a significant uptake in the use of artificial intelligence to augment computational simulations, reflecting a growing trend in the application of more advanced, predictive analytics in the field. Big data analytics, while not as prevalent as CS and CS+AI, show a solid presence, where it can effectively analyze patterns of human activity [52,55]. Conversely, direct measurement methods are less frequently employed, often serving to validate the results of simulation studies, indicating a shift in the field toward more data-driven and predictive approaches [30,56].

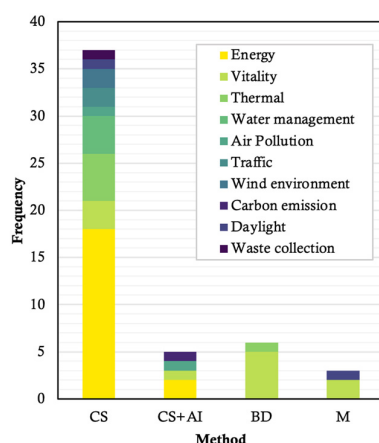


Figure 10. Frequency of methods in building performance evaluation.

Table 5 compiles a representative set of studies focusing on building performance, highlighting the specific computational simulation tools and performance indicators employed in each research endeavor. It reveals that energy performance, encompassing a range of indicators from load match index to solar radiation access, is commonly assessed using the Grasshopper platform and its associated plugins, such as Dragonfly, Honeybee, and Ladybug. Thermal comfort is often evaluated using indices like the Universal Thermal Climate Index (UTCI) with Grasshopper plugins and ENVI-met being the tools of choice. In the realm of water management, maintenance and routing models are preferred, while air quality studies utilize OpenFOAM and scSTREAM for their robust simulation capabilities. Traffic patterns are explored through dynamic programming approaches, bespoke for the specific research requirements. Wind environment assessments, which focus on velocity and pedestrian-level comfort, utilize commercial CFD software, such as Phoenix and ENVI-met. Daylight analysis is conducted with Grasshopper's Honeybee and Ladybug plugins, emphasizing the need for adequate natural lighting in design. Lastly, waste collection efficiency is quantified using cost-analysis tools like MATLAB and Lingo, showcasing the application of computational simulations in optimizing practical aspects of urban man-

agement. The applications span from conceptual analyses to practical problem-solving with the Grasshopper platform and its extensive plugins, such as Dragonfly, Honeybee, and Ladybug, being the most widely adopted tools for their versatility and integration capabilities.

Table 5. Tools and performance indicators in research using computational simulation.

Building Performance	Source	Performance Indicators	Tools
Energy	Liu et al. [14]; Xia et al. [57] 2/1/2024 4:48:00 PM	Average monthly load match index; Total energy use intensity; Sunlight hours; Annual energy consumption; Holistic analysis; Annual solar radiation access	Grasshopper platform: Dragonfly; Honeybee; Ladybug
	Shareef et al. [58,59]	Cooling plant load; The average of conduction heat gain	IES-VE software
	Ge et al. [35]	Annual heating load; Annual cooling load	Grasshopper platform: The Urban Renewable Building and Neighborhood optimization (URBANopt)
Thermal	Sun et al. [56]; Xu et al. [32,38] 2/1/2024 4:48:00 PM	Universal Thermal Climate Index (UTCI)	Grasshopper platform: Butterfly; Honeybee; Ladybug
	Jiang et al. [60]	Air temperature	ENVI-met
Water management	Fontecha et al. [61]	Feasibility; Maintenance cost per unit time	An iterative procedure with two models: a maintenance model (MM) and a routing model (RM)
Air pollution	Wu et al. [62]	Air quality index (AQI); Concentration	OpenFOAM
	He et al. [63]	Area-averaged velocity; Concentration	scSTREAM
Traffic	Wang and Qu [64]	The total length of the bus route	Self-coded dynamic programming approach
Wind environment	Wu et al. [65]	Wind velocity Gini index; Wind velocity ratio	Phoenix
	Feng et al. [66]	Mean pedestrian-level wind velocity ratio	ENVI-met
Daylight	Xia et al. [67]	Daylighting factor; Sky view factor	Grasshopper platform: Honeybee; Ladybug
Waste collection	Gruler et al. [68]	Total cost of collecting waste	MATLAB; Lingo

4.2.2. Optimization Algorithm

In computer science, “search” or “optimization” involves algorithmic processes aimed at identifying the most effective solution or result within a defined space or dataset. In the field of PDO in urban block design, three prevalent methodologies are employed: exhaustive search, heuristic search, and random search. Figure 11 shows the distribution of these optimization methods.

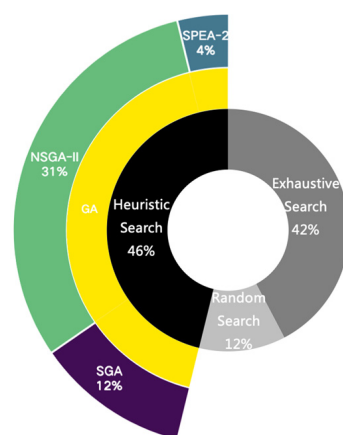


Figure 11. Proportion of optimization algorithms used in PDO in urban block design studies.

Exhaustive search meticulously generates and evaluates all possible solutions, guaranteeing the identification of the global optimum. This method is computationally intensive as it leaves no option unexplored, reflected in its 42% usage. The literature review reveals that actual exhaustive search is not commonly implemented in PDO-related studies. Instead, a series of potential solutions are derived within the study's scope through discretization with specific rules. This approach ensures that, by calculating across all generated cases, the optimal solution is systematically determined [58]. Heuristic search employs specific rules to guide the search process, standing out as the primary method at 46% due to its efficiency in finding satisfactory solutions rapidly. Among various algorithms, such as genetic algorithm (GA), simulated annealing (SA), ant colony optimization (ACO), and particle swarm optimization (PSO), GA is notably prevalent according to our literature review. For single-objective optimization, the simple genetic algorithm (SGA) is preferred, whereas the non-dominated sorting genetic algorithm II (NSGA-II) and strength pareto evolutionary algorithm 2 (SPEA-2) are deployed for multi-objective challenges. These algorithms operate on evolutionary principles to search for optimal solutions in complex spaces. In the application of GA within urban block design, the Grasshopper platform stands out, offering tools, like Galapagos for SGA [32,56,69], Wallacei for NSGA-II [15,25,27,29], and Octopus for SPEA-2 [70], to facilitate the optimization process. Random search potentially yields feasible or near-optimal solutions through ample sampling, experiencing the least usage of 12%. Based on specific criteria or categories, an initial set of solutions is randomly generated and subsequently evaluated to find the optimal solution [32].

4.3. Possible Research Directions

The field of PDO in urban block design is rich with potential for future research, branching into various dimensions that promise to enhance and revolutionize the way urban spaces are conceived and realized. The integration of AI and big data presents a significant opportunity for developing more accurate predictive models and enabling real-time optimization of urban design, propelling PDO into new realms of efficiency and effectiveness. There is a growing need to delve deeper into sustainable and renewable energy solutions, focusing on how these practices can be incorporated into urban block design to improve energy efficiency and reduce carbon footprints. The human-centric aspect of urban design, which includes improving pedestrian friendliness, accessibility, and community spaces, is another crucial area that promises insights into creating more livable and inclusive cities. Recognizing the diversity of climatic and socio-economic contexts is essential for the global applicability of PDO strategies, underlining the need for research that spans different geographical locations and considers a variety of environmental and societal factors.

The role of policy and urban governance in shaping and optimizing urban planning decisions is a fertile ground for exploration, offering insights into the dynamics between governance structures and the effectiveness of PDO. As technology advances, there is an increasing scope for the development of advanced computational tools and simulation methods that provide deeper insights and more accurate predictions, further enhancing the capabilities of PDO in urban block design. The adaptability and resilience of urban spaces, especially in the face of changing environmental conditions and potential disasters, are vital areas of study, essential for future urban planning and sustainability. Lastly, fostering an interdisciplinary approach that melds urban planning, environmental science, sociology, and technology will enable a more holistic and comprehensive understanding of urban block design. This approach will facilitate the development of urban spaces that are not only efficient and sustainable but also responsive to the needs and well-being of their inhabitants.

While PDO presents innovative approaches for sustainable urban development, its practical application faces numerous obstacles. These include technological limitations, especially in the computational resources and data acquisition capabilities necessary for detailed simulation and analysis. Additionally, there is often a gap between theoretical

optimization models and real-world applicability, stemming from diverse urban contexts and varying socio-economic conditions. Furthermore, regulatory and policy constraints can hinder the adoption of PDO strategies, as current urban planning frameworks may not be sufficiently equipped to integrate advanced optimization methods. These challenges underscore the need for not only technological advancements but also adaptive policy reforms and stakeholder engagement to facilitate the seamless integration of PDO into mainstream urban design practices. Addressing these barriers is imperative for realizing the full potential of PDO in enhancing urban sustainability and resilience.

5. Conclusions

This review, conducted through a meticulous examination of existing literature and studies, has provided a comprehensive overview of the current state and potential future directions of performance-driven optimization (PDO) in urban block design. By systematically analyzing scholarly articles, case studies, and experimental research, we have identified key trends, methodologies, and influential works shaping this dynamic field. This review underscores the critical role of computational simulation, AI integration, and big data analytics in refining and advancing urban block design strategies. It also highlights the growing importance of considering energy efficiency, environmental sustainability, and human-centric design elements to create urban environments that are not only functional but also conducive to the well-being of inhabitants. As the field of PDO continues to evolve, it is imperative to embrace multidisciplinary approaches and leverage technological advancements to address the intricate challenges of sustainable urban development. Our analysis indicates a clear trend towards utilizing sophisticated modeling techniques and data-driven analysis as pivotal tools in urban planning. This approach is essential for developing sustainable, resilient, and adaptable urban spaces that can withstand the test of time and changing environmental conditions.

The future of urban block design lies in harmonizing technical innovation with socio-environmental responsibility. As urbanization progresses, the principles and practices derived from PDO research will play an increasingly significant role in shaping the cities of the future. This review serves as a foundation for future research, emphasizing the importance of continuous exploration and innovation in the field. By considering the comprehensive insights gathered from diverse studies and adopting an integrated approach, urban block design can significantly contribute to enhancing the quality of life in urban settings while promoting environmental stewardship.

This paper has limitations, chiefly that the search query may not encompass the full spectrum of relevant literature. While the search terms and parameters were extensive, they might have overlooked some studies using different terminologies or falling outside the set criteria, potentially leading to an incomplete dataset. However, the search strategy was crafted to be as inclusive and thorough as possible, utilizing diverse keywords and Boolean logic to cover a wide range of literature. Furthermore, the analysis of publication outputs by country does not adjust for the number of active researchers in each country, which could lead to skewed perceptions of national research productivity. This study also does not delve deeply into the intricacies of citation practices, including the impact of collegial citations, potentially affecting the interpretation of citation influences across diverse research cultures. Moreover, the decision to exclude other databases, such as SCOPUS due to its extensive volume of publications, presents a limitation in terms of achieving a more comprehensive scope of literature. Despite the possibility of missing certain studies, this method still yields a significant and representative collection of research, providing a robust basis for analysis in urban design and performance-driven optimization.

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