Landscape Architecture

ARTICLE

Design-Translation Completeness in Urban Green-Space Climate-Adaptation Evidence: A Seventy-Six Case Study Audit

Lia Jiang*

HuanTian Wisdom Technology Co., Ltd., Meishan, Sichuan, 620564, China

* Correspondence: ljiang@htwisdom.cn

Abstract

The potential for urban green space as climate-adaptive assets is well established. However, what designers and other practitioners need from evidence about outdoor urban green spaces are findings that (a) identify manipulable variables, (b) are relevant at a relevant scale, (c) state the form of any transferable guidance, and (d) make clear how a finding can guide the practice of urban streets, squares, parks, and residential open spaces. The purpose of this study is to construct a Design-Translation Completeness Audit (DTCA) capable of identifying where there are losses in usability within a 76-case record of studies on outdoor urban green spaces and climate adaptation. The audit consists of organizing the evidence into the Design Translation Record, DTR-76, consisting of six layers of information, which are connected and nested: adaptation target, scale, research method, practitioner-facing output, design relevance, and transferability. The key test is whether the usability of the knowledge base is impaired primarily by the problem of coverage (topic), proximity, methods used, output conversion (how relevant knowledge is communicated), relevance, or transferability. Findings are that there is greater usability loss in the output-conversion layer than in the scale and relevance layers. Of the 76 studies, 49 address thermal comfort; 22 address urban heat-island mitigation or urban cooling; and 5 address stormwater management. Site-, street- and multiscale research account for 52 cases; controlled field studies account for 2. For 72 practitioner-focused outputs, 41 give insight, 17 give recommendation, 4 give guideline, 2 give design proposal, and 8 other types of structured outputs. Among 72 outputs, 64 are design-relevant, but only 23 are direct outputs. The Design Translation Completeness Index is 0.761; the operational conversion value is 0.345. The main finding is the specific finding of a loss in usability of evidence. Four quantitative targets arise from the audit: 13 more design insights need to be converted to guidance; 13 more stormwater studies are needed for one-fifth representation; 7 more controlled field studies are needed for one-tenth representation; and 5 medium transfer outputs should be upgraded to high transfer guidance.

Keywords: urban green space; climate adaptation; design translation; thermal comfort; stormwater management; evidence usability; transferability; outdoor environmental design

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1. Introduction

Urban green spaces have become indispensable for urban adaptation to climate change since they alter the local climatic condition that people experience on the ground. The combination of planted vegetation (trees, shrubs, planting beds), open vegetated areas, bare soil patches, water bodies, permeable paving, artificial shading, and street-edge planting influences short-wave and long-wave radiation, evaporation/transpiration, exposure to wind, surface heat retention, soil infiltration, surface water runoff, and comfort. However, these effects are produced not by vegetation and surfaces per se, but by the particular configuration of vegetation and surfaces in the urban environment. An array of trees is effective in modifying exposure in a different way than clusters of trees. A rain garden operates in a certain manner depending on the inlet design, soil profile, catchment, and drainage routing. Permeable pavement may be able to cool the surface and control runoff if properly maintained and installed. But again, the effectiveness of the technology depends on many other things.

The rapid growth of the literature dedicated to the role of vegetation and open green spaces in climate adaptation has been prompted by growing interest in heat stress, rainfall extremes, and compromised thermal comfort in the urban environment. Several early empirical reviews have revealed that urban greening could lead to cooling towns and cities [7]. However, the scale of the effect varied depending on green space typology, dimensions, context, and measurement methods used. The concept of green infrastructure, nature-based solution, and ecosystem services helped advance discussion on urban adaptation, resilience, carbon mitigation, and human well-being. As a result, a richer vocabulary emerged to describe the potential of urban ecosystems in helping cities adapt to climate change [11, 13, 17]. However, the vocabulary became less clear to use by planners and designers who had to decide about implementation. For example, green infrastructure, nature-based solution, urban ecosystem services, and urban forests may overlap and involve different assumptions on scales, management practices, and functions of a system being studied [15, 52]. The uptake of adaptation measures will depend not only on planning policies and regulation but also on knowledge transfer mechanisms that link scientific communities, public authorities, and designers [4, 31, 40, 53].

The design- and planning-oriented review of the literature will always be driven by considerations on the decision to take under a particular situation. While the question of whether green infrastructure is good for adaptation may be of little use to a designer, the questions on what kind of arrangement, species form, planting pattern, soil type, shade provision, water element, or pavement material should be provided under an urban climate condition is very much relevant. Evidence usability in practice depends on whether it is formulated in a way allowing for an evidence-based judgement under budget, regulatory, maintenance, and site conditions. Such distance between science and implementation is not caused by poor communication alone. Rather, there is often an issue of evidence type since many empirical studies reveal climatic relations, but fail to formulate those relations in terms of decisions on morphology, composition, materiality, and maintenance.

The case of heat is instructive here. Trees, shrubs, planted surfaces, and parks are able to mitigate heat exposure by means of shading and evapotranspiration [16, 21, 36, 37, 42]. Ecosystem services delivered by urban vegetation include interception, transpiration, water retention, and surface energy exchange. Those ecosystem functions may vary based on planting conditions, soil volume, species traits, and composition [19, 29, 32, 34]. Empirical studies on thermal comfort have shown that it depends on interaction between vegetation, sky view, wind flow, water element, surface, and user activities [10, 27, 33, 41, 45]. Seasonality and climatic conditions matter since an optimal vegetation configuration in the hot season might have adverse impacts on winter sun access or comfort during cold months [1, 14, 22]. Particularly important is the configuration of urban spaces (e.g., squares and canyons) since they provide for specific interrelations among shading, air flow, and radiance that are hard to infer merely from green cover percentage [28, 51, 58]. Therefore, design guidance on urban parks and streets focuses on the canopy shape, planting spacing, street geometry, and the relation between planted vegetation and adjacent built environments [25, 38, 56]. These findings can be helpful in practice, but only when they provide clues on how to modify physical environment under a particular urban climate.

Water-sensitive urban green space design creates a similar problem. The ability of planted surfaces to intercept, delay, infiltrate, and retain stormwater depends on catchment ratio, soil properties, water storage volume, planted area, drainage routing, and maintenance practices [6, 20, 24]. Runoff management also includes evaporative cooling, meaning that the design of runoff-sensitive surfaces needs consideration of their thermal capacity. Although there is much evidence on water-sensitive and climate adaptation in urban green spaces, the latter is more prominent in studies related to thermal comfort [8]. Hydro-meteorological nature-based solutions for adaptation and risk reduction have been discussed in the literature comprehensively enough, but the evidence on particular design variables has not been presented as comprehensively [39].

One more factor adding to the distance between science and implementation is the issue of spatial scale. Climate impact studies can be done on regional, urban, district, neighborhood, street, plot, or micro-scale levels. Strategic planning and adaptation prioritization are concerned primarily with identification of high-risk neighborhoods. Site-level evidence, on the contrary, tends to address issues of specific designs, such as tree pit design or surface combinations. If there is a significant gap between the scale of decision-making and the scale of evidence, there will be a problem with implementation due to a mismatch in environmental science and policy [49]. Apart from providing robust evidence on adaptation potential, an urban climate study should also reveal which specific decision is justified by its findings.

Methodological choices have an impact on evidence usability, too. Computational simulations help compare alternatives and predict performance before the implementation of an option. Observations in urban settings identify relationships within a complex of existing features. Remote sensing helps widen the spatial extent of the investigation. However, it does not deliver much information on design variables at the ground level. Built environment experimental studies can test an isolated intervention, but they are extremely difficult to implement due to complexity, costs, and governance issues. Empirical studies of climate adaptation in urban green spaces have applied ENVI-met simulation, surface temperature analysis, field observation, remote sensing, participatory refinement, and design testing techniques [25, 26, 30, 48]. Intervention studies on urban green spaces, in particular tree pit design, ground covers, and shading configurations illustrate the importance of such evidence for design purposes [3, 35, 46]. For the purpose of design and planning practice, the most important thing is not the method that is considered universally applicable, but the one that clearly states an actionable relationship.

Thus, rather than asking whether scientific evidence on urban green space climate adaptation is usable for designers, the current paper attempts to specify at which stage of the evidence generation process it becomes least relevant for urban planning practice. To answer that question, the paper constructs a Design Translation Record (DTR) and conducts a Design-Translation Completeness Audit using DTR-76. As the outcome, we get a detailed diagnosis of the field, showing where it is already practically useful, and where it still lacks actionability.

2. Materials and methods

2.1. Design Translation Record

The analytical record was derived from the semi-systematic review [18] published in Urban Climate. This article presents a review process in compliance with established environmental and interdisciplinary science review principles that suggest clear logic of the literature search, screening and categorization criteria, and transparent category definitions [5, 47]. The article provides us with search logic, selection criteria, review variables, review flowchart, geographical distribution of case studies, journal distribution, publication trend, adaptation categories, spatial scales, methods, types of practitioner-facing outputs, design relevance grades, and transferability grades. These data allow building DTR-76 focused on the characteristics of evidence most valuable for designers and urban planners.

The process of searching started with identifying papers in Web of Science and Scopus databases. Combining 350 and 269 unique records yielded a total of 422 records. Removal of duplicates brought down the total number to 422. Filtering out articles that were unavailable, non-English, non-peer reviewed, or out of scope resulted in a list of 381 documents. Title, abstract, and keyword screening selected 93 full texts for review. Reading those texts excluded additional 17 papers, leaving only 76 cases studies. This process is reflected in Figure 1.

(**a**) Records.

(**b**) Screening.

(**c**) Full texts.

(**d**) Final set.

Figure 1. DTR-76 formation.

The narrowing shown in Figure 1 is important because it separates the broad urban-greening literature from the much smaller set of empirical studies that can be classified by design-relevant variables. Only 18.0% of the 422 unique records entered the final case-study record. The high retention from full-text assessment to final inclusion, 76 of 93 articles, indicates that the strictest loss occurred during early screening rather than during detailed reading. DTR-76 should therefore be interpreted as a selective design-relevant record, not as the entire literature on urban greening.

Table 1. DTR-76 numerical record.

Layer	Categories	Counts
Screening flow	Unique records; screened documents; full-text candidates; final case studies	422; 381; 93; 76
Adaptation target	Thermal comfort; UHI or urban cooling; stormwater management	49; 22; 5
Spatial scale	City; city region; residential district; residential quarter; city neighbourhood; city block; street; site; multiscale	5; 12; 1; 3; 2; 1; 9; 33; 10
Research method	Biophysical model; observational; remote sensing; controlled field study; multiple methods	34; 12; 5; 2; 23
Practitioner output	Recommendation; insight; guideline; design proposal; other structured output	17; 41; 4; 2; 8
Design relevance	Relevant practitioner outputs among output-bearing studies	64 of 72
Transferability	Low; medium; high	7; 30; 27

Table 1 describes the characteristics of the data set analyzed by the audit. The table is not just descriptive, but also shows the chain that evidence has to follow before it becomes practically useful. In order to be practically useful, a piece of evidence must address an appropriate adaptation target, work at a relevant scale, use a suitable research method that clarifies the relation between design variables and climate performance, produce an appropriate practitioner output, address green-space morphology or composition, and specify a distance beyond the studied case. Failure at any one of these layers makes evidence less usable for design even if it is good science.

2.2. Audit components

The DTCA assigns a separate score to each of six distinct aspects of evidence. The first of these is adaptation target balance. This score measures distribution of evidence among the three adaptation targets of heat mitigation, comfort provision, and stormwater management. It is calculated using the following normalized form of Shannon balance formula:

$$H_n = -\frac{\sum_{i=1}^{k} p_i \ln(p_i)}{\ln(k)}, \tag{1}$$

where p_i is the proportion of evidence assigned to a category within a categorical layer and there are k categories. Evidence is uniformly distributed across the category spectrum if H_n equals 1, otherwise lower values mean greater concentration of evidence. The equation is used for assessing adaptation targets and research methods since both influence the scope of practical knowledge. However, a low score cannot be interpreted as an indication of lack of quality: a focused field is valid if it addresses pressing concerns, but its focus shows that other aspects of design are underrepresented.

The second audit component is called scale contact. It reflects proximity of the research scale to the typical scale of spatial decision making by practitioners. High weights are assigned to site and street-scale studies, because they concern direct planting, shading, paving, stormwater drainage, and public space configurations. Multi-scale studies are awarded a high score because they help connect localized design actions with urban relationships at wider scales. City and city-region scales are assigned smaller weights, because they tend to support strategic prioritization rather than actual physical formation. Scale contact is calculated as follows:

$$S_c = \frac{\sum_{i=1}^{n} c_i s_i}{\sum_{i=1}^{n} c_i}, \tag{2}$$

where c_i is the number of studies conducted at scale level i and s_i is scale-contact weight for scale category i. City region: 0.55; City: 0.50; Residential District: 0.70; Residential Quarter: 0.75; City Neighbourhood: 0.80; City Block: 0.85; Street: 1.00; Site: 1.00; Multi-Scale: 0.90. It is evident that the closer to the site and street scales the evidence is, the more useful it is for actual design, although wider-scale evidence remains useful for strategic prioritization purposes.

The third audit component is output directness, which reflects clarity of communication from the researcher to the practitioner regarding what a design action means. Guidelines and design proposals are highly direct because they contain explicit instructions about the appropriate response to a particular situation. Recommendation are less direct because they are more open-ended, but still very useful. Insights are less direct than other structured outputs, because they leave designers to understand the implications of their actions. Output directness is calculated using the following formula:

$$O_d = \sum_{j=1}^{m} w_j q_j, \tag{3}$$

where q_j is the proportion of studies producing a given output type (j) among those providing any output at all (m), and w_j is its directness weight. Recommendation: 0.75; Insight: 0.35; Guidelines: 0.90; Design Proposal: 1.00; Structured: 0.55. The weights are clear and quite conservative in giving credit to insight. They do not claim that every insight is a design proposal, only that the latter is built upon the former.

Design relevance reflects proportion of output-bearing studies addressing aspects of green-space morphology or composition that can be changed by a designer. Relevance is calculated as follows:

$$R_d = \frac{64}{72} = 0.889. \tag{4}$$

This score reflects a completely different aspect of evidence from that of output directness. Whereas the latter is concerned with the clarity of a message from the scientist to the designer, relevance focuses on whether the study itself addresses an issue that a designer can change. A study can be highly relevant without being directly instructive, which is a key distinction of this paper.

The final audit component is transfer strength, which assesses generalizability of findings. Studies rated low in transferability are assigned weight 0.25, those with medium transferability weight 0.65, and those with high transferability weight 1.00. The transfer score is calculated as follows:

$$T_s = \frac{0.25 n_L + 0.65 n_M + 1.00 n_H}{n_L + n_M + n_H}, \tag{5}$$

It is important to note that generalizability does not imply universal validity of findings. Rather, conditional transferability is extremely useful if it can be defined clearly.

From these component definitions, it becomes clear why there needs to be more than one score for this audit. Otherwise, an auditor could not distinguish between lack of stormwater data, lack of controlled trials, and lack of

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guidance provided. The components make it possible to detect at which specific level the usability of the literature drops.

Table 2. Audit component definitions.

Component	Measurement logic	Design interpretation
Target balance	Normalized entropy across thermal comfort, UHI/cooling, and stormwater	Breadth of climate-adaptation coverage
Method breadth	Normalized entropy across five method classes	Diversity of evidence-producing approaches
Scale contact	Weighted proximity of research scale to design intervention scale	Closeness to site and street decisions
Output directness	Weighted share of output types	Degree to which findings are converted into usable guidance
Design relevance	Share of output-bearing studies addressing manipulable green-space features	Practical relevance of the output content
Transfer strength	Weighted share of low, medium, and high transferability outputs	Usability beyond the original study location

2.3. Composite index and threshold tests

The Design Translation Completeness Index or DTCI is the arithmetic average of target balance, method diversity, scale connectivity, output directness, design relevance, and transfer strength. Additionally, there is an operational conversion coefficient that multiplies output directness, design relevance, and transfer strength:

$$C_v = O_d \times R_d \times T_s. \tag{6}$$

Multiplication here is on purpose tougher than indexing because usability implies directness, relevance, and transferability of results simultaneously. Any of these factors failing to reach high scores will result in overall conversion dropping significantly.

3. Results

3.1. Geographical distribution and publication trend

This geographical distribution proves the existence of dynamic development within an unevenly spatially distributed field. China is leading the ranking with 20 out of 76 case studies, followed by Germany with 5, the Netherlands and Greece with 4 each, Australia, Turkey, the USA, and Japan with 3 each. Europe has more than one third of all cases in the database, whereas Latin America and Africa are poorly represented, having a handful of each other. Annual outputs grew very quickly after 2016, producing 12 cases in 2017, 12 in 2018, 14 in 2019, and 11 by October 2020. The distribution can be seen in Figure 2.

The pattern in Figure 2 matters for transfer because climate-adaptation design is context-sensitive. A high proportion of cases from China and Europe does not reduce the value of those studies, but it does mean that designers working in underrepresented climatic, economic, and institutional settings need clearer boundary conditions before using findings. For example, a street-tree strategy tested in a dense Chinese city or a European park may not transfer directly to a hot-arid city, an informal urban edge, or a low-maintenance municipal context. Geographic concentration therefore reinforces the need for explicit transfer statements in every design-facing output.

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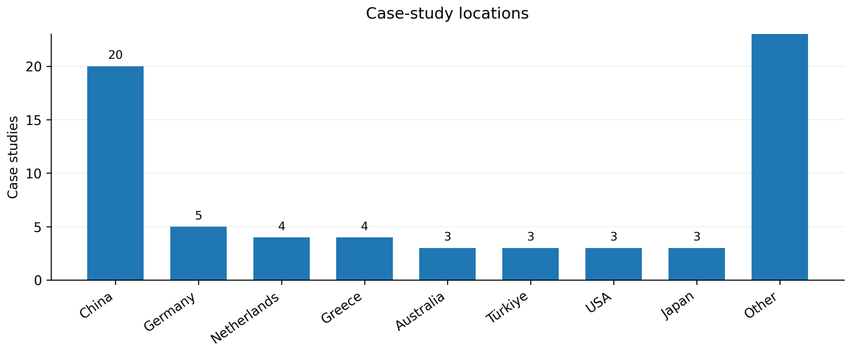
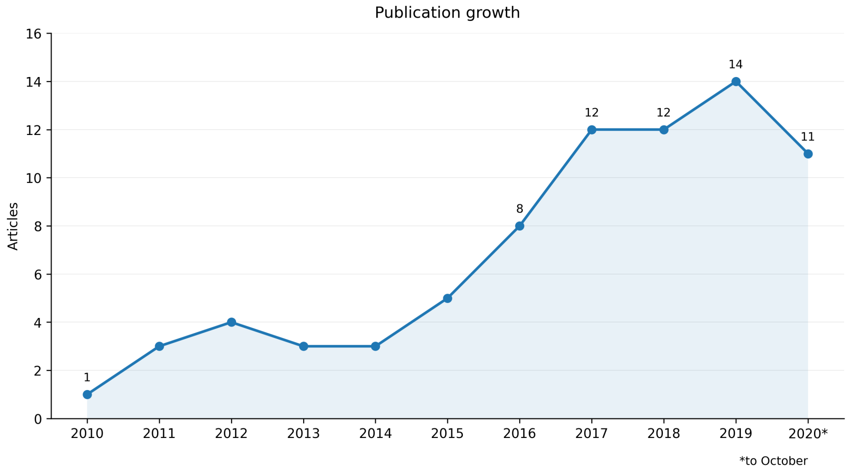
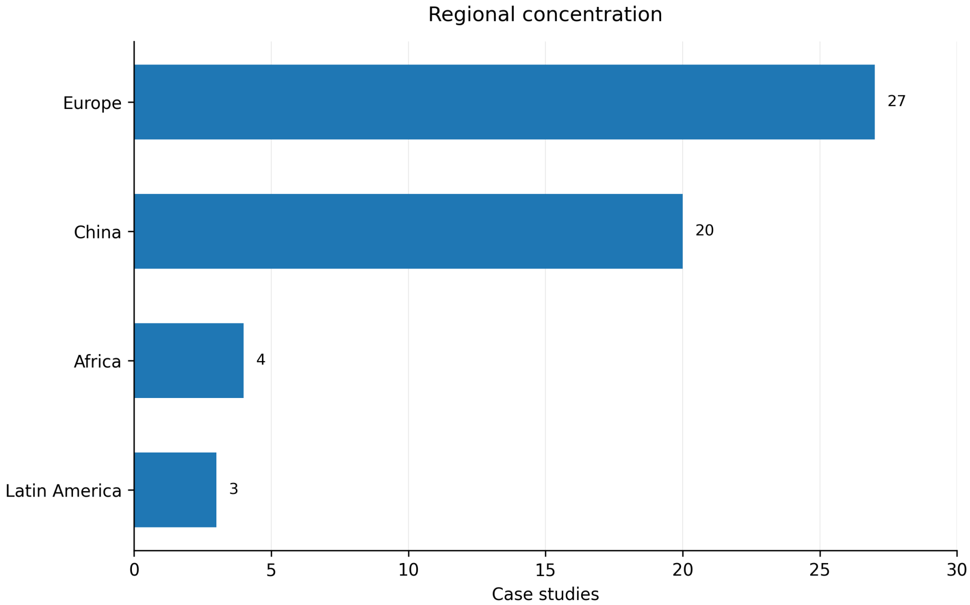


(a) Locations.



(b) Annual output.



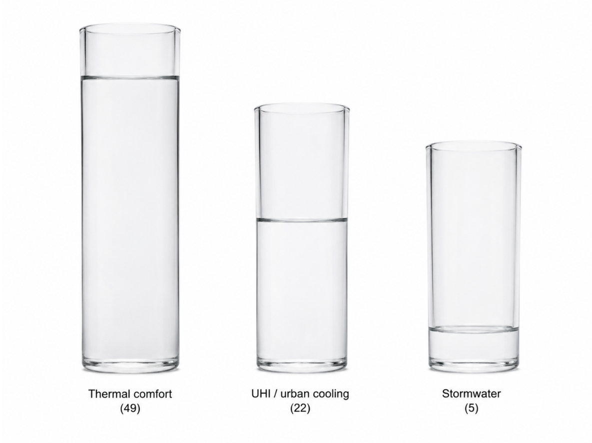
(c) Regional concentration.

Figure 2. Geography and time.

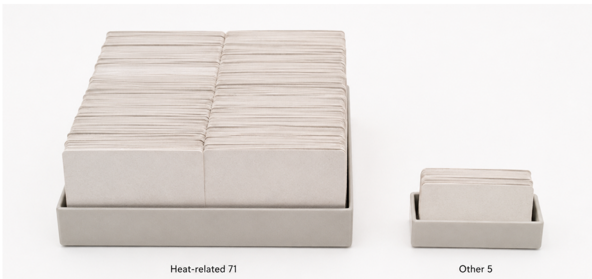
3.2. Adaptation-target coverage

Adaptation-target coverage is strongly weighted toward heat. Thermal comfort accounts for 49 studies, UHI or urban cooling for 22, and stormwater management for 5. The two heat-related categories together account for 71 studies, or 93.4% of the corpus. The target-balance value is 0.747, which indicates moderate distributional breadth but strong concentration around heat and comfort. This distribution is shown in Figure 3.

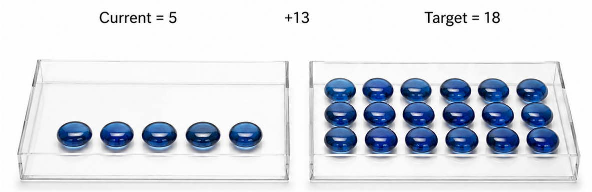
Figure 3 clearly demonstrates that there is far more evidence on heat and outdoor comfort design guidance than stormwater design guidance. While it is in line with the visibility of the topics, such distribution poses a problem for integration. In reality, urban spaces usually do not have to address either heat or runoff alone but need to integrate both issues at once along with managing shading, cooling surface, infiltration, and maintenance. Thus, a relatively low number of stormwater-related studies means that design decisions for stormwater management are based on a thinner evidence base than the current one.



(a) Categories.



(b) Heat-related cases.



(c) Water shortfall.

Figure 3. Adaptation targets.

The threshold estimation makes clear the actual gap in terms of needed resources. To increase stormwater studies from 5% to 20% of the whole expanded corpus, we need 13 additional stormwater studies because $(5 + 13)/(76 + 13) = 20.2\%$. To achieve a 25% share, 19 additional stormwater studies are needed. Matching current UHI or cooling studies will require 17 additional studies for stormwater management. While the values are feasible to consider as a coordinated research effort, they are significant enough to demonstrate that the issue is not of insufficient attention; it is rather under-represented in the record.

3.3. Spatial scale and research method

The distribution by the spatial scale shows a better position of the studies for design application. Site studies make up 33 of total studies, while street studies add another 9, and multiscale – yet another 10. Taken together, the site, street, and multiscale categories account for 52 out of 76 cases, or 68.4%. The city region category includes

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12 studies, city-scale – 5, while other intermediate categories like residential district, residential quarter, city neighbourhood, or city block make only a few appearances in the current sample. As a result, the scale-contact score reaches 0.862, the highest value in the audit. The related distribution of research methods, however, is less favourable. Biophysical models include 34 cases, multiple-method approaches cover 23 studies, observation – 12, remote sensing – 5, and controlled field experiment – only 2.

In Figure 4, the first pattern of diagnostic scores identifies the first result. The primary loss of usability is not due to studies being overly distant from design scale. Most studies are already sufficiently close to the street/site/cross-scale design scales. The second pattern of methods conveys a different meaning altogether. Modelling studies and studies employing multiple methods dominate, while controlled built environment studies are rare. This does not imply poor methodological diversity in modelling but rather the lack of sufficient intervention-based evidence on a range of urban ecology variables such as tree-pit openness, canopy spacing, soil volume, planted infiltration strips, permeable surfaces, or the functioning of water features. The significance of the lack of built environment-based studies increases even further when the results of those studies aim at guiding interventions.

An increase in the number of built environment studies from the current 13 to 7 more would be enough to take the current value of method-breadth index (0.800) up to 10 percent of an expanded corpus. An even higher increase of 12 controlled built environment studies to be added to the corpus will bring the number up to 15 percent. Thus, a relatively modest effort can be expected to strengthen the causal evidence chain by expanding the methodological coverage.

3.4. Practitioner outputs

Translation losses are most pronounced in practitioner-oriented outputs. Among 72 studies with some type of output, there are 41 providing insights, 17 recommendations, 4 guidelines, 2 design proposals, and 8 other types of structured outputs. The number of directly actionable outputs, i.e., recommendations, guidelines, and designs, totals 23. Insightful and other structured outputs are 49 in total. The output-directness index stands at 0.515, which is the lowest score among all indices examined in the audit. Figure 5 shows the distribution of output types.

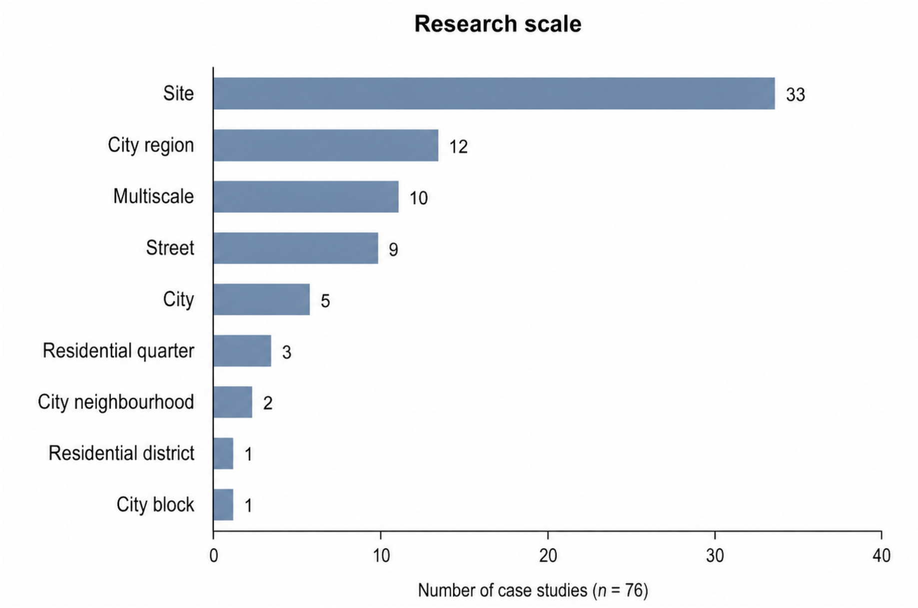
The identified trend reflects the primary obstacle to the effectiveness of evidence-based practices. Articles frequently deliver their results not as outputs, but as insights. This is important. Insights convey findings such as the effect of tree cover on thermal stress reduction, the effect of planting bed configuration on thermal comfort, or the influence of green-space size on temperature drop. Outputs indicate which relations between canopy cover, surface treatment, planting bed configuration, and water routing should be taken into account. Therefore, the field is not lacking in knowledge relevant for design decisions, but in its conversion into design outputs.

The parity test allows estimating the quantity of the problem in numbers. There must be 36 directly informative outputs (out of 72) in order to make up for half of the output corpus. This will require the transformation of 13 outputs from insight form to recommendations or design suggestions. These transformations may take place via improved articles' conclusions, design tables, conditions, and visual sections that correlate climatic mechanisms with design variables. As opposed to research, improvements of this kind do not require a new body of field knowledge.

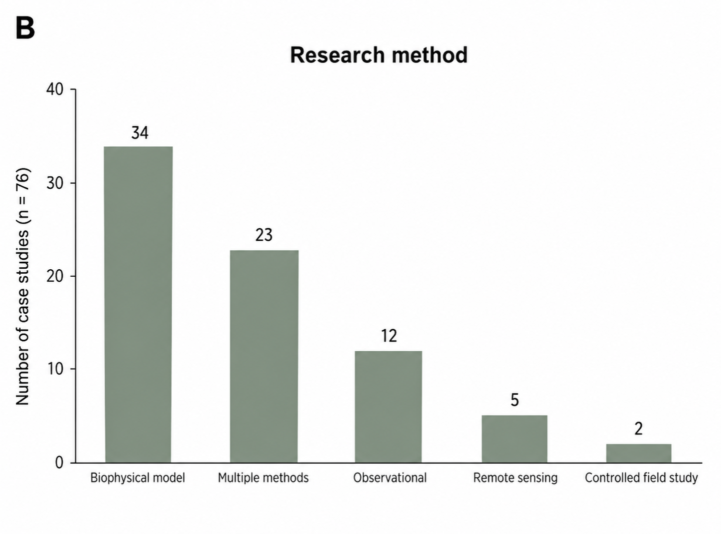
3.5. Relevance and transferability

Both the relevance layer and transferability layer indicate that the field is somewhat improved after output bearing papers are filtered out. Out of 72 outputs, 64 are relevant. Out of these 64, there are 7 outputs with weak transferability, 30 outputs with medium transferability, and 27 outputs with strong transferability. Thus, transfer ability = 0.754.

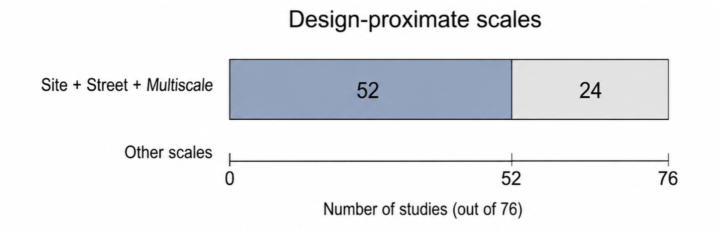
The retention shown in Figure 6 prevents an overly negative interpretation of the record. Most output-bearing studies are relevant to design, and most relevant outputs have at least medium transferability. The weakness therefore does not lie in a total absence of practical content. It lies in the combination of relevance with insufficient directness. A finding may concern a manipulable design variable and still require substantial work before it can guide a project.



(a) Scale.



(b) Method.



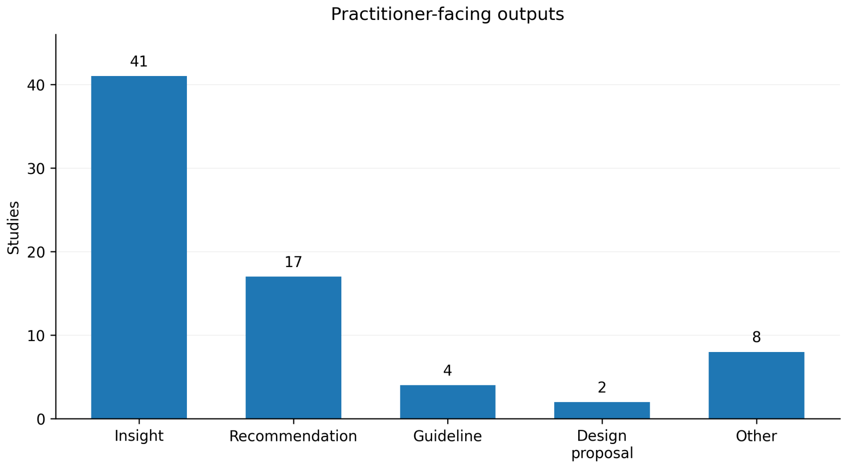
(c) Design-proximate cases.

Figure 4. Scale and method.

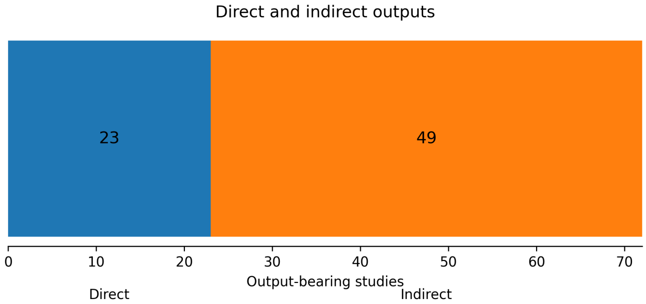
Medium transferability also signals that many findings can travel only under similar conditions, which makes clear reporting of climate, geometry, vegetation structure, soil condition, and maintenance assumptions essential.

3.6. Audit scores and improvement targets

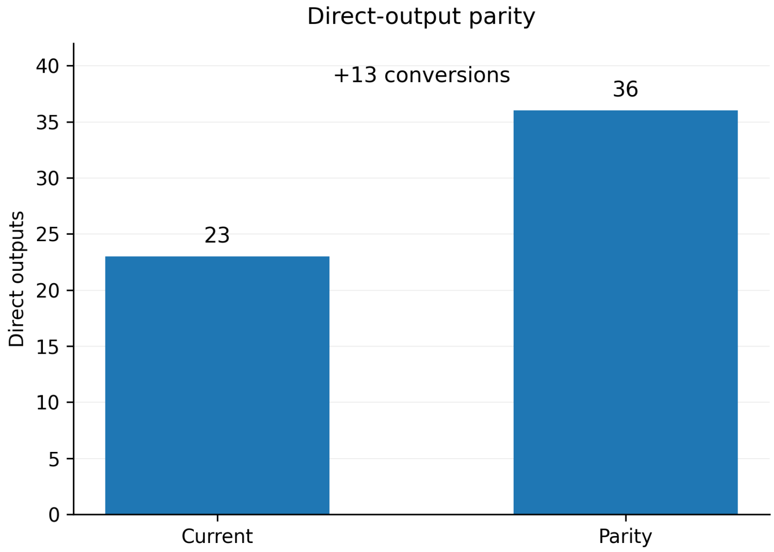
The scores in Table 3 show why the diagnosis must be made at layer level. Scale contact and design relevance are strong, so the field is not primarily failing because it is too abstract or unrelated to design variables. Output



(a) Output types.



(b) Directness split.

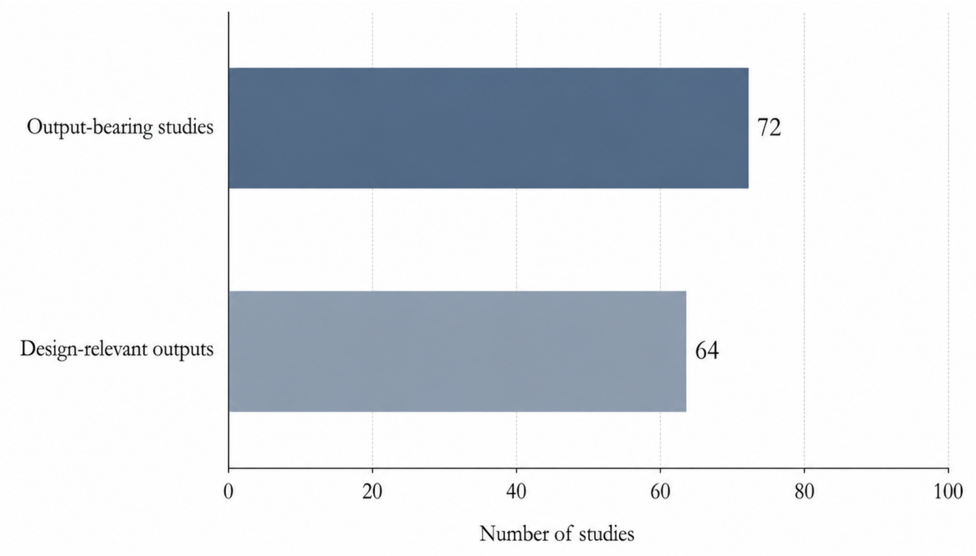


(c) Parity target.

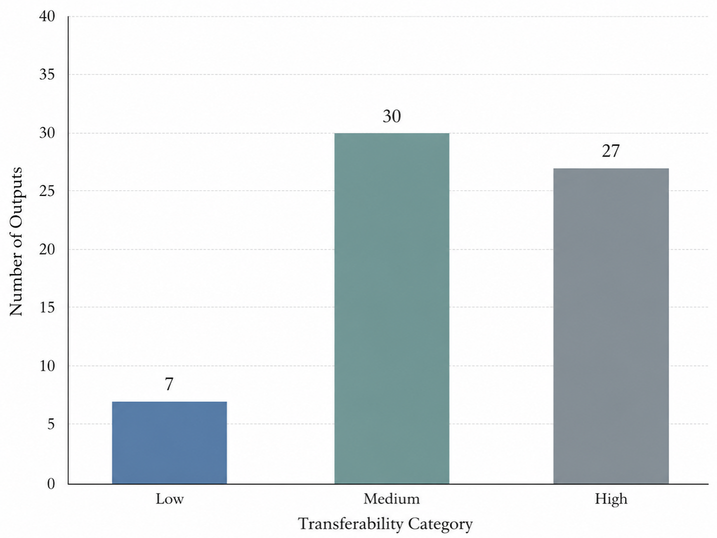
Figure 5. Output conversion.

directness is the weakest component, and the operational conversion value is much lower than the DTCI because directness, relevance, and transferability must coincide to produce usable guidance. This difference between 0.761 and 0.345 is the central quantitative result of the paper.

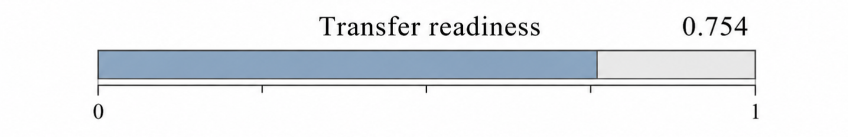
The component profile is visualized in Figure 7. The design-translation components show that output directness sits well below scale contact and design relevance. The DTCI value of 0.761 indicates a field with substantial design potential, whereas the conversion value of 0.345 indicates that only a smaller portion of that potential is expressed as guidance that is direct, relevant, and transferable at the same time.



(a) Relevance.



(b) Transfer classes.



(c) Transfer score.

Figure 6. Relevance and transfer.

The visual separation in Figure 7 is useful for manuscript review and research planning. A high DTCI alone could suggest that the field is already well prepared for design practice. The lower conversion value prevents that conclusion. The combination means that the evidence contains many of the necessary ingredients for practice, but they are not consistently assembled into usable instructions. This is a different result from a simple claim that more studies are needed. More studies are needed in specific areas, but the existing record also needs better translation into design language.

Threshold tests identify the minimum changes required to strengthen practical usability. The four quantified changes are an increase in stormwater studies from 5 to 18, an increase in controlled field studies from 2 to 9, an increase in direct outputs from 23 to 36, and an increase in high-transferability outputs from 27 to 32. The values are shown in Figure 8 and Table 4.

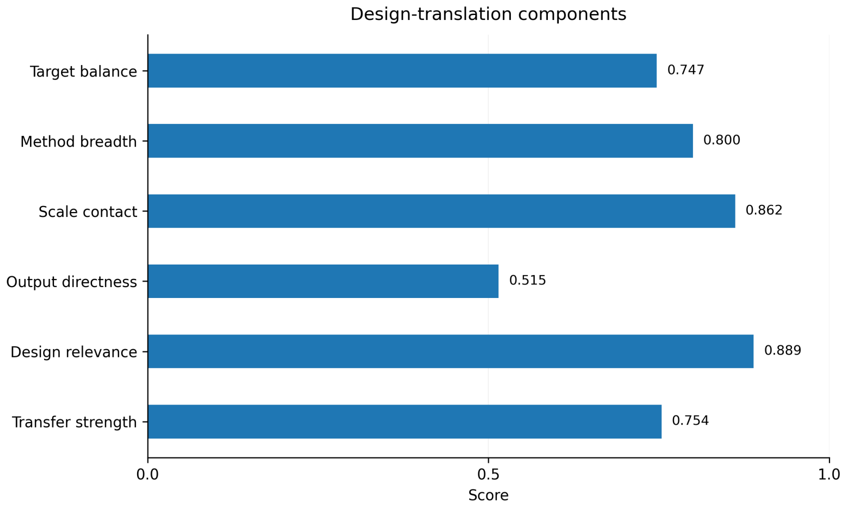
Table 3. DTCA scores.

Component	Score	Interpretation
Target balance	0.747	Heat-related evidence dominates over stormwater work
Method breadth	0.800	Several methods are present, but controlled studies remain rare
Scale contact	0.862	Site, street, and multiscale evidence is strongly represented
Output directness	0.515	Most practitioner outputs require added interpretation
Design relevance	0.889	Most output-bearing studies address manipulable green-space content
Transfer strength	0.754	Medium and high transferability dominate relevant outputs
DTCI	0.761	The evidence chain has strong potential but uneven conversion
Operational conversion value	0.345	Direct, relevant, and transferable guidance remains limited

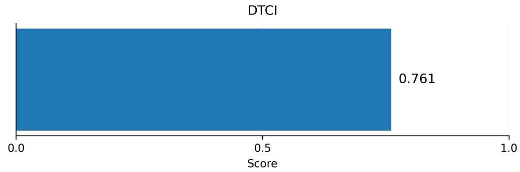
Based on the quantities in Figure 8 and Table 4, the discipline can improve its evidence base by adopting both an empirical and an editorial strategy. There is room for 13 further stormwater-related studies in an adaptation target that remains relatively neglected. Another seven controlled built-setting studies are needed in order to increase causal evidence. Another 13 transformations would change the practical nature of current knowledge. Finally, five transfer improvements would help practitioners evaluate whether or not a finding is transferrable outside of its original context. The optimal strategy therefore does not involve untargeted expansion, but carefully selected strengthening of the weakest links in the evidence chain.

Table 4. Minimum changes.

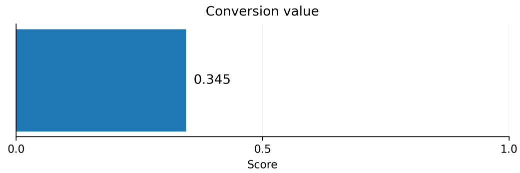
Target condition	Change required	Practical interpretation
Stormwater studies reach 20% of the expanded record	13 added studies	Water-sensitive green-space design becomes visibly represented
Controlled field studies reach 10% of the expanded record	7 added studies	Intervention evidence gains a minimal practical foothold
Direct outputs reach half of output-bearing studies	13 output conversions	Interpretive findings become recommendations, guidelines, or design proposals
High-transfer outputs reach half of relevant outputs	5 transfer upgrades	Boundary conditions become clearer and more widely usable



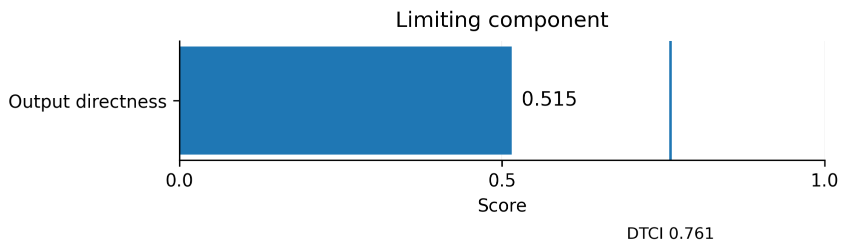
(a) Components.



(b) DTCI.



(c) Conversion.



(d) Limiter.

Figure 7. Design-translation scores.

4. Discussion

4.1. Principal findings

According to the DTCA result, there is a certain hierarchy of constraints facing climate adaptation design. Output-conversion constraints lead to the largest losses of usability and therefore represent the most significant barrier in the process of making use of climate adaptation research. Topic imbalance, especially regarding stormwater-sensitive green space, is another barrier. A further limitation arises from the low presence of controlled evidence generated through built-setting studies. These constraints are important because urban green space adaptation is a field where practice cannot wait for perfectly designed evidence but cannot settle for generic principles either.

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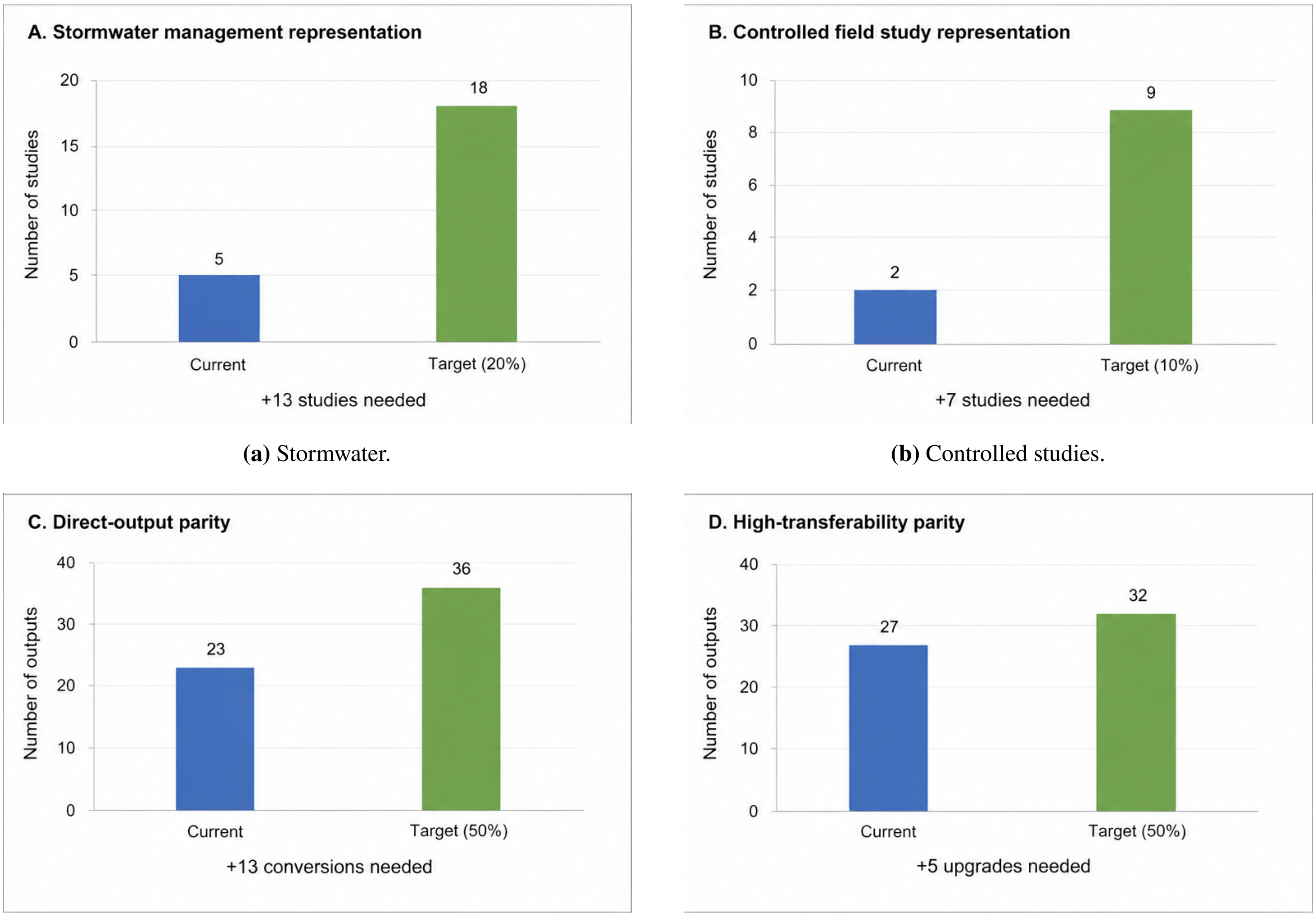

(a) Stormwater.

(b) Controlled studies.

(c) Output parity.

(d) Transfer parity.

Figure 8. Improvement quantities.

4.2. Heat versus water in design evidence

While the heat prevalence in the evidence record is justified and even necessary, it also implies a certain lack of usability. Thermal stress in urban environments is clearly observable and directly related to the issue of climate adaptation. Research into heat exposure has produced convincing and practically applicable results showing how shade, tree cover, water, pavement coverage, and urban morphology can affect the outdoor microclimate [23, 54, 55]. Several urban studies of public squares, parks, residential areas, and streets have resulted in sufficient heat-related evidence [9, 43, 50, 59, 60]. The problem here is not the overemphasis on heat, but the relative neglect of stormwater.

Urban green spaces are usually expected to solve more than one issue. For example, a tree trench can provide shade, a root system, a place for infiltration, and a buffer between cars and pedestrians. A rain garden can hold water, cool the surrounding area via evapotranspiration, create habitat conditions for different species, and organize pedestrian movement. Similarly, permeable surfaces can decrease the amount of runoff and keep the ground cooler, but their effectiveness will depend on installation and maintenance. Such combinations require that the interaction between heat and water be considered and that relevant evidence be found. While there is ample literature concerning rain gardens and water-sensitive design, the number of stormwater cases in DTR-76 is quite limited.

4.3. Scale proximity and method choice

While the high score in the scale-contact component implies that the evidence record cannot be criticized for remoteness from urban practice, the problem is not the distance, but the fact that it is not always associated with a corresponding degree of output directness. A study at a site or street level does not guarantee usable evidence, and large-scale regional studies can sometimes be useful depending on the criteria they establish. However, the proximity itself does not play a major role in the usability of a finding; the relationship between scale and output type is the key.

The discussion of research methods is similarly complicated, but the general pattern emerges nonetheless. Modeling of different urban heat and wind effects is crucial for climate adaptation, as the modeling can test several possible interventions, such as various canopy systems, street geometries, and building materials [2, 48]. Field and remote observation allows researchers to explore already-existing conditions and provides the wider perspective on land-surface temperature and vegetation patterns [12, 44, 57]. The scarcity lies in controlled field studies isolating particular design variables. Without these studies, design practitioners have insufficient evidence on the consequences of changing the openness of tree pit openings, continuity of planting beds, infiltration depths, and surface types.

A series of controlled urban trials can be very effective. Comparative analysis can be performed based on pairs of street segments where only certain variables differ. For instance, the trials can compare continuous tree trenches and scattered pits, analyze differences between square designs with and without infiltration plants, study schoolyard conditions under hard and permeable pavement, and compare the performance of canopy density and understory plantings in public parks. The idea is not to replace modelling, but to provide anchors for models and make them more credible in practice.

4.4. Output directness and transfer use

The output-conversion result is important for both researchers and journal editors. While some articles conclude with a list of implications, these implications are not necessarily related to urban design. A conclusion aimed at practitioners should contain the following information: the design variable in question, the type of climatic effect, the appropriate spatial context, and the transfer boundaries. Simply stating that tree canopies improve thermal comfort is not a sufficient output. Instead, it is better to describe whether it refers to canopy continuity, species characteristics, tree spacing, shade time, evapotranspiration, or soil water availability. Stating that stormwater green infrastructure is beneficial is not good enough either. Instead, one needs to refer to particular cases of catchment connection, infiltration capacity, plant tolerance, overflow situations, and required maintenance.

It should be noted, however, that design evidence does not necessarily have to be simplified. On the contrary, conditional recommendations are preferable since medium transferability can be quite useful provided that the conditions of transfer are known. The point is that designers should understand whether or not a particular finding can be applied to an urban street, park, or residential open space depending on the climatic zone, seasonality, sky view factors, surface materials, vegetation structure, irrigation regimes, soil conditions, and other design considerations.

4.5. Design-variable interpretation

Figure 9 provides an example of translating a design evidence record into urban practice by means of realistic streetscape visualization. All variables present in the illustration are concrete design conditions that mediate between evidence and design: tree canopy, pedestrian surface, planted infiltration, subsurface drainage, permeable street surface, canopy continuity, and runoff conveyance. They can all be linked to particular climatic effects and transfer conditions. As a result, the visualized streetscape represents the last stage in the process described in this paper: evidence usability is achieved when it reaches the level of designable urban conditions.

The streetscape in Figure 9 is also important as a reminder of how heat and stormwater conditions interact in the process of creating climate-proof urban green space. Tree canopy has multiple impacts on urban environment. While providing shade and influencing the overall thermal microclimate, it also affects soil water and root growth conditions. Planted strips provide infiltration and stormwater holding capacities, but they contribute to evapotranspiration and surface cooling at the same time. Permeable surfaces influence runoff, but their proper functioning is contingent upon proper installation and maintenance. In other words, climate-ready urban green space cannot be seen as a combination of isolated design elements but as a coordinated urban form.

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Figure 9. Design translation.

The audit itself also sheds light on literature review practice and can prove especially useful for reviewing applied environmental design disciplines. Most reviews analyze themes, methods, and locations used in existing literature but rarely discuss the issue of output directness and usability. The DTCA method adds a new component to this list by measuring how the evidence record changes while moving from research topic to practice guidelines. It makes it possible to understand the strengths and weaknesses of the existing record and find ways to improve them.

4.6. Limitations

The main limitation of the audit is the reliance on the category classification in the existing review. While a new full-text coding could improve the precision of analysis, the use of preexisting categories allows for faster auditing and makes it simpler and more consistent. Another limitation lies in the subjective judgment of weights assigned to components, which can vary from one researcher's experience to another. Moreover, the audit does not measure the quality of evidence, but the practical aspects of usability. In other words, an output conversion constraint does not imply that the corresponding output is scientifically flawed.

5. Conclusions

This paper has identified the critical point of decline of output directness in the chain of outdoor urban green space evidence and has assessed its strength against the background of other constraints. In DTR-76, the output-conversion constraint is the strongest: while the record includes 52 of 76 studies conducted at a site or street scale, and 64 of 72 outputs relevant to the morphological and compositional issues of urban green space, there are only 23 direct outputs. The latter accounts for 55% of output-bearing studies and 32% of the whole evidence record, and the output-directness score of 0.515, as well as the operational conversion value of 0.345 are among the weakest in the audit.

As a result, it is possible to suggest a new direction for improving the usability of the evidence record in question. First, an increase in output directness is possible via addition of 13 output-bearing studies. Second, the presence of stormwater evidence can be increased by adding another 13 studies, which will account for approximately one-fifth of the expanded evidence record. Third, an improvement in controlled evidence can be achieved by conducting 7 more studies, which will constitute one-tenth of the new record. However, the most immediate improvement is conversion of 13 outputs from insightful results into direct guidance, increasing the share of outputs to half.

In summary, urban green space adaptation requires design evidence identifying the design variable, the climate effect, spatial context, and transfer boundary. In other words, a finding about cooling, thermal comfort, and stormwater management is only partially design-related until it mentions how exactly these issues can be tackled through canopy, planting, soil, water routing, surface, or maintenance manipulations and where they can be successfully applied.

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