

Mapping the Scope of Computational Design

Jozef Sedláček, Martin Pařenica²

¹Mendel University in Brno/Czech Republic · jozef.sedlacek@mendelu.cz

²Mendel University in Brno/Czech Republic · mparenicam@gmail.com

Abstract: This study investigates the scope of computational design and environmental parameter integration within landscape architecture and planning. Employing a structured scoping review and scientometric co-occurrence analysis of literature published between 2010 and 2025, the research explores the relationships between spatial scales, environmental metrics, and digital workflows. The results indicate a significant bias toward the built environment, where BIM/BEM and parametric tools are predominantly used for energy and comfort optimization at the building and urban block levels. Conversely, ecological and hydrological systems are largely relegated to analytical roles within GIS frameworks rather than serving as active drivers for design optimization. The findings highlight a critical gap in computational tools for green-blue infrastructure, which currently hinders the effective integration of landscape parameters into BIM/BEM simulation and further application in Life Cycle Assessments (LCA).

Keywords: Computational design, landscape architecture, environmental parameters, design optimization, scientometric analysis, parametric design

1 Introduction

The paper considers design as a process, which involves analysis, defining of a problem and problem solution. With the emergence of design thinking in the first half of 20th century, the purpose of a design is the integration of knowledge into the problem solution and the providing of a scientific base for the design (BUCHANAN, 1992). The landscape as such precedes the landscape architect, while, in comparison, a piece of architecture under no circumstances precedes the architect (GIROT, 1999). The massive digitization of all aspects of the environment (FRICKER & MUNKEL 2015) and the design process has provided designers with powerful tools for the optimization of their designs.

Sensu lato, the optimization involves evaluating a design according to a set of predefined performance criteria and selecting the best-performing alternatives from a range of possible configurations. In architectural design the optimization refers to circulation pathways, floor plan layouts, or energy performance (WORTMANN & NANNICINI 2017). In landscape architecture, similar optimization workflows are used to evaluate hydrological performance, solar exposure, or habitat connectivity – linking design intent with environmental processes (HARMON 2024, MROSLA et al. 2025).

The term data-driven design refers to using measured or simulated environmental data as an input that feeds the process of computational design. Speaking of simulation, we need to contextualize the topic and distinguish between simulation and optimization. Simulation refers to a process that evaluates performance of a particular design against criteria, whereas optimization aims at the best-performing design based on simulated results (WORTMANN & NANNICINI 2017). However, in most cases the process incorporates both methods (TYC et al. 2024).

Optimization is enabled due to the widespread presence of parametric design environments such as Grasshopper (RUTTEN 2013) that generates a wide range of possible designs that can

be evaluated against a selected set of criteria or generate and optimize architectural forms or site layouts.

The authors have a professional background in landscape architecture and planning, utilizing 3D modeling software and GIS in their practice. This article was developed to map specific environmental parameters that can be modeled and simulated within the context of landscape architectural practice and identify gaps that might be focused on in further research community. Identification of gaps might provide better integration of simulation of a digital tool into scenario-based planning or life cycle assessment. In this paper, we present a comprehensive review of the literature that integrates environmental parameters within the framework of data-driven and computational design. The study aims to identify the range of environmental parameters addressed, the types of data most frequently utilized, and, ultimately, the spatial and methodological scales at which the projects are conducted.

2 Method

This paper employs a structured scoping review with semantic classification (TRICCO et al. 2018) to investigate how environmental performance parameters are operationalized within computational design frameworks in landscape architecture, followed by an evaluation via scientometric co-word analysis. Co-word analysis is a content analysis technique that uses patterns of co-occurrence of pairs of items in a corpus of texts to identify the relationships between ideas within the subject areas presented in these texts (HE, 1999). Literature searches were conducted across Web of Science, Scopus and Google Scholar with a set of four queries (Tab. 1). Query sets combined parametric or data-driven design concepts with landscape-, GIS- or Grasshopper-oriented modeling contexts. The initial queries were aimed at selecting topic in the field of landscape architecture, urban design and landscape planning spanning from 2010 to 2025.

Table 1: List of initial queries used for Web of Science, Scopus and Google Scholar Database

Query	Focus	Structure (concept clusters)
Q1 – Broad / GIS	Landscape × Parametric × GIS	(“parametric design” OR “parametric modeling” OR “data-driven design” OR “design optimization” OR “computational design”) (“landscape architecture” OR “landscape planning” OR “urban design” OR “green infrastructure”) (“GIS” OR “QGIS” OR “ArcGIS”)
Q2 – Broad / Grasshopper	Landscape × Parametric × Grasshopper	(“parametric design” OR “parametric modeling” OR “data-driven design” OR “design optimization” OR “computational design”)
Q3 – Narrow / Grasshopper + Environmental metrics	Parametric × Grasshopper × Stormwater / UHI etc.	(“parametric design” OR “parametric modeling” OR “data-driven design” OR “design optimization”) (“Rhino” OR “Grasshopper”) (“stormwater” OR “runoff” OR “infiltration” OR “soil carbon” OR “soil disturbance” OR “biodiversity” OR “microclimate” OR “building energy” OR “urban heat island”)
Q4 – Narrow / GIS + Environmental metrics	Parametric × GIS × Stormwater / UHI etc.	(“parametric design” OR “parametric modeling” OR “data-driven design” OR “design optimization”) (“GIS” OR “QGIS” OR “ArcGIS”) (“stormwater” OR “runoff” OR “infiltration” OR “soil carbon” OR “soil disturbance” OR “biodiversity” OR “microclimate” OR “building energy” OR “urban heat island”)

The initial search performed via the Publish or Perish 8 software (HARZING 2022) yielded 2014 records, which were de-duplicated and filtered to exclude non-English and thematically irrelevant outputs. A dataset of 1000 publications was retained for manual semantic screening. Article titles and abstracts were screened and included only if they addressed design-oriented modeling in architecture and landscape architecture. This resulted in a curated subset of approximately 597 publications positioned at the intersection of landscape architecture, urban design, landscape planning that leverages computational methods, either design or analysis.

Table 2: Environmental parameters and affiliated keywords

Category	Cluster Group	Keywords
Scale	Buildings	building, architecture, architectural, indoor, interior, façade, facade, energy efficiency, HVAC, building envelope, retrofit, thermal comfort, BIM, indoor comfort, ventilation
	Urban	city, urban design, block, infrastructure, mobility, municipality, urban, urban planning, urban morphology, street, public space, square, zoning, neighborhood, neighborhood, park
	Urban / Landscape:	green space, parks, park, stormwater, urban vegetation, urban forest, urban green, green infrastructure, blue infrastructure, green space, open space, nature-based solution, NbS, sustainable drainage, SuDS, Sponge city, urban heat, urban heat island, heat island, UHI, open spaces, outdoor thermal comfort
	Landscape / Regional	watershed, catchment, region, ecosystem, biodiversity, hydrology, land use, gis, remote sensing, landscape planning, climate change, landscape, river basin, basin, floodplain, agriculture, grassland, ecosystem, biodiversity, soil, regional, territory
Environmental Parameters	Climate / Environment	climate, microclimate, temperature, heat, cooling, humidity, atmosphere
	Sun / Shading	sun, solar, daylight, insolation, sunlight, shading, shade, irradiance
	Energy / Comfort	energy, performance, thermal, comfort, efficiency
	Water / Hydrology	runoff, stormwater, infiltration, hydrology, flood, drainage, water
	Ecology / Landscape	biodiversity, vegetation, soil, green, ecological, ecosystem, habitat
	Connectivity / Other Spatial	connectivity, accessibility, integration, network, visibility, walkability
Data Type / Workflow	GIS	GIS, geospatial, ArcGIS, qGIS, spatial analysis, remote sensing, mapping
	Rhino / Grasshopper	Rhino, Grasshopper, parametric, computational design, generative
	CFD	CFD, fluid dynamics, airflow, wind, ventilation, aerodynamics
	BIM/BEM	BIM, building information modeling, energy model, simulation, Revit, thermal performance

The dataset of 597 publications was then subjected to semantic screening based on scale (building, urban, urban/landscape, regional landscape), the environmental parameters used, and the workflow and data types. Initially, individual groups were categorized based on specific keywords (Tab. 2); a category was assigned to a Cluster Group if the keyword appeared in the title or abstract. In cases where keywords from two different categories were identified within the same title or abstract, an entry was assigned to both Cluster Groups. Subsequently, the presence of the keywords “Design”, “Generative Design”, “Simulation Analysis” and “Optimization” was incorporated to determine their frequency within each Cluster Group. The frequency of keywords within individual Cluster Groups was then evaluated using the same methodology. Semantic classification was conducted using RStudio (Posit 2025).

3 Results

This research focused on mapping the computational design landscape by analyzing domain representation across different spatial scales, environmental parameters, and data-driven workflows. The study tested the premise that design and optimization tools are concentrated at the building and urban block levels, while GIS is utilized primarily for regional and city-wide analysis. In the second step, we evaluated the distribution of individual environmental factors, that can be modelled and optimized, such as microclimate, shade, runoff, etc., and compared them to their workflow GIS/BIM/RHINO. Lastly, we reviewed the occurrence of keywords *design*, *optimization*, *simulation*, *analysis*, and *generative design* within subjected workflows.

The findings are illustrated through chord diagrams that evaluate the co-occurrence between keywords and cluster groups, alongside Sankey diagrams that function similarly by establishing links between these variables. In the Sankey diagrams, cumulative results may exceed 100% in instances where a single keyword is attributed to multiple categories.

3.1 Computational Workflows and Their Affiliation with Spatial Scales and Environmental Parameters

First of all, it is necessary to mention several key facts ensuring proper interpretation of these results. While the analysis shows that the four spatial scales (building, urban, urban landscape, and landscape-regional) are equally represented, the environmental factors indicate that the dataset is biased toward built-environment design and optimization. Natural or nature-based processes are less frequently simulated or parametrized, as evidenced by the low occurrence of the Connectivity (5.4%), Ecology & Land (10.3%), and Water & Hydrology (13.4%) categories.

BIM/BEM shows the highest degree of spatial specialization, with 74.2% (N=89) of its applications focused on the building’s scale. Similarly, Rhino/Grasshopper serves as a bridge between the architectural and neighborhood levels, with significant representation in both Buildings (N=206) and Urban (N=164) scales. These findings strongly support the hypothesis that parametric design and building-performance simulation tools are concentrated at the building and urban block levels. On the other hand, GIS is the dominant tool for large-scale analysis, appearing in 36.6% of all technology co-occurrences and showing its strongest presence at the Landscape Regional level. This confirms that while design-centric tools (Rhino/

BIM) handle the “micro” and “meso” scales, GIS is the “macro” engine for city-wide and regional territory mapping. These were the expected outcomes. Less expected was that BIM/BEM are currently the least utilized tools for the design and simulation of green blue infrastructures like parks, green spaces, and urban vegetation, which are led by GIS-based workflows instead.

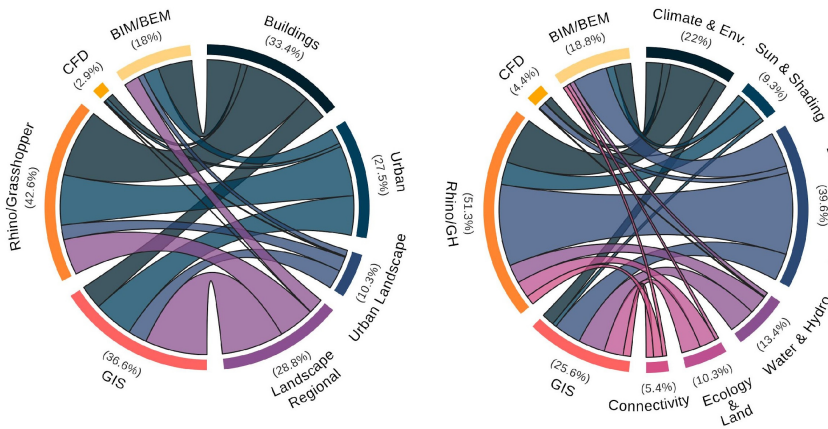


Fig. 1: Chord diagrams showing relationship of workflow and spatial scale (left) and environmental cluster groups

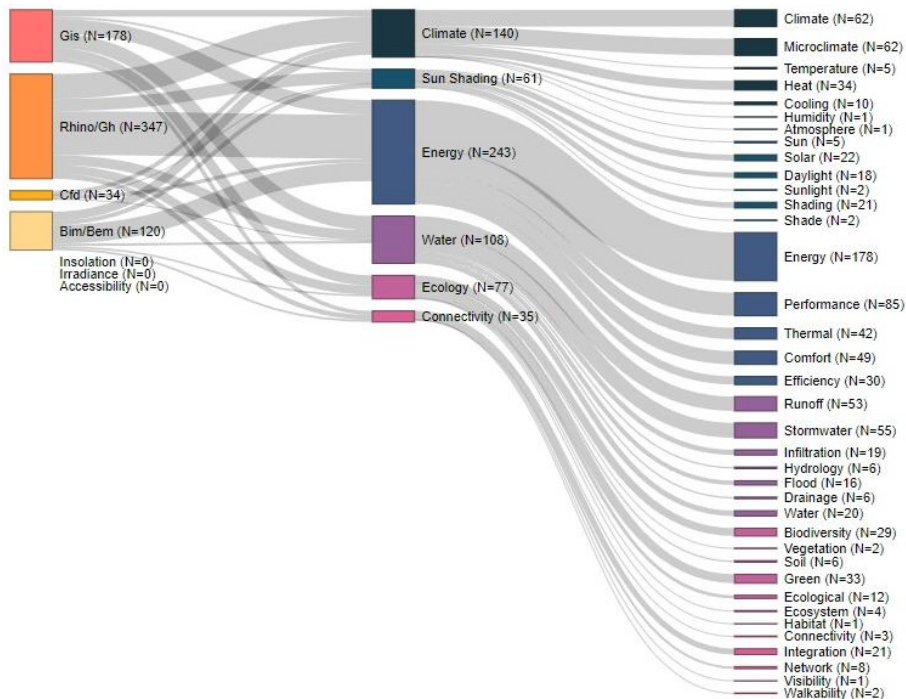


Fig. 2: Chord diagrams showing the relationship between workflow (left) and environmental cluster groups (middle) and keywords within the cluster groups (right)

Regarding environmental modeling, Rhino/Grasshopper serves as an all-containing hub, displaying the most diverse inputs by connecting all evaluated environmental parameter cluster groups. BIM/BEM and CFD workflows are more specialized, concentrating heavily on Climate, Energy/Comfort, and Sun/Shading, and least on Water, Ecology, and Connectivity. A parametric workflow where geometry is iteratively optimized based on light and thermal performance is an established territory. The GIS workflow is dominant in Hydrology and Ecology and, surprisingly, in Energy, while being less frequent in Climate. These findings justify the expectations of the authors and delineate two distinguished domains: BIM/BEM for Climate, Energy, Sun, and Shading at the building and urban block scale, and the GIS domain for modeling environmental flows – such as water, ecology, and connectivity – in large-scale and non-built-up environments.

3.2 Keywords: Design, Simulation, Optimization and Analysis

The results underscore a significant technological partitioning that depends on the environmental parameters being modeled. The design integration rate – defined as the frequency with which a parameter is explicitly coupled with design methodologies – demonstrates that Sun and Shading (51%) and Energy and Comfort (47%) are most closely tied to performance-driven design. This finding is corroborated by the technological profiles of Rhino/Grasshopper (84.1%) and CFD (85.3%), which exhibit the highest prevalence within the design category. In contrast, territorial processes such as Water (20%) and Ecology (33%) exhibit lower design integration and remain primarily analytical. This observation is reinforced by the functional orientation of GIS-based workflows, which prioritize Analysis (23.6%) over Simulation (12.9%), and BIM/BEM, where the focus shifts predominantly toward Simulation (70.8%). Collectively, these findings suggest that computational design practices remain concentrated on building-scale energy optimization and form-environment interactions, whereas ecological and hydrological systems are predominantly treated as analytical constraints rather than active design drivers (Fig. 3., Tab. 3).

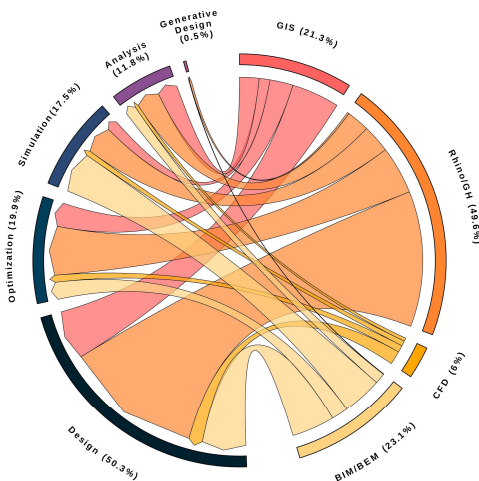


Fig. 3.:
Co-word occurrence of design related keywords with workflows presented as a chord diagram

Table 3: Co-word occurrence of design-related keywords and workflows indicates the total paper count for each keyword

Keyword	GIS (N=178)	Rhino/GH (N=347)	CFD (N=34)	BIM/BEM (N=120)
Design (N=489)	57.90%	84.10%	85.30%	76.70%
Optimization (N=242)	28.10%	29.70%	44.10%	30.00%
Simulation (N = 162)	12.90%	17.30%	32.40%	70.80%
Analysis (N = 168)	23.60%	14.10%	20.60%	19.20%
Generative Design (N=5)	0.00%	1.20%	0.00%	0.80%

The analysis of frequency shows dominant integration of Energy & Comfort into the Sankey diagram revealing a highly centralized computational landscape where environmental design is fundamentally driven by building performance metrics. The massive flow from Design (N=489) and Optimization (N=242) toward the Energy & Comfort cluster – specifically targeting keywords like Energy (N=250), Performance (N=218), and Efficiency (N=144) – demonstrates that algorithmic tools are primarily utilized as engineering engines for energy-efficient synthesis.

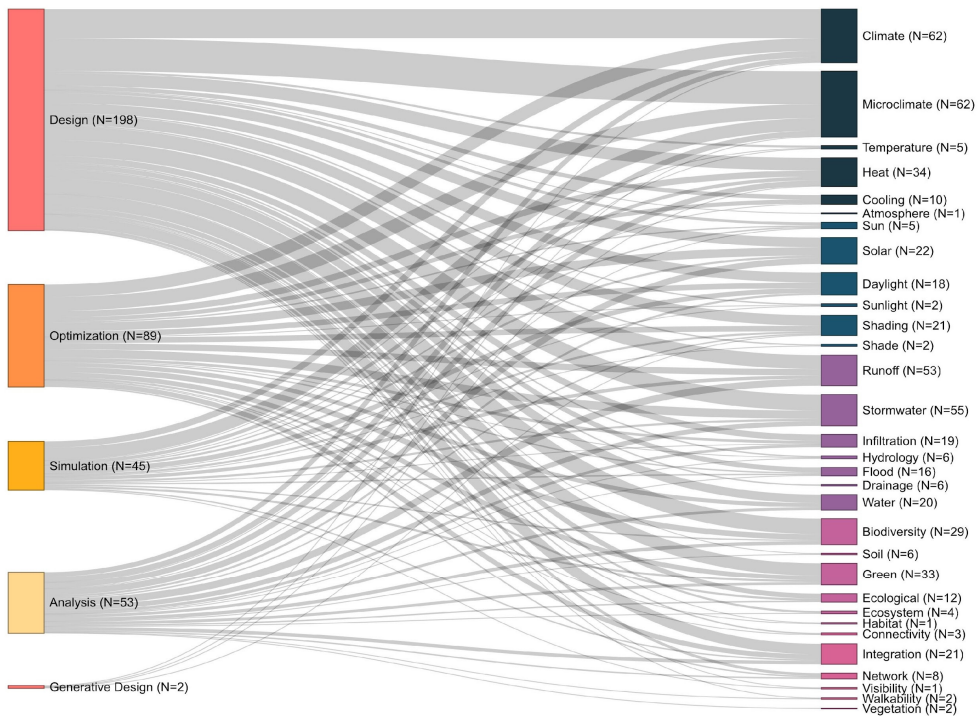


Fig. 4: Sankey diagram showing the relationship of workflow (left) and its abundance within individual keywords (right). The cluster groups were disaggregated into individual keywords.

When the dominant Energy & Comfort cluster is removed (Fig. 4), a more nuanced visualization of environmental parameters is revealed. The design integration rate – indicating how often “Design” is explicitly coupled with environmental parameters – reveals that Sun and Shading (73.8%) and Energy and Comfort (76.5%) are the most deeply integrated into performance-driven workflows. In contrast, Water and Hydrology and Ecology show significantly lower design coupling, at 47.2% and 58.4% respectively, appearing more frequently in purely analytical contexts. Notably, specific territorial parameters like Stormwater exhibit a remarkably low explicit analytical labeling, with only 7 out of 55 papers (12.7%) using the term “analysis”.

4 Discussion

During the research, several factors emerged that may have influenced the findings and their interpretation. The authors consider it essential to address these points to provide the reader with the necessary context for interpreting the results.

Although the keywords were selected to capture a broad spectrum of both analytical and design-oriented articles, the resulting dataset exhibits a noticeable skew toward building architecture and construction. This is evident from the significant volume of papers focusing on energy and comfort, as well as the relatively low representation of GIS in relation to environmental parameter modeling. This discrepancy may be attributed to terminological nuances, specifically the varying use of terms such as “modeling”, “analysis”, “assessment”, and “evaluation”. Furthermore, the broad definition of “design” – which is frequently applied in diverse contexts beyond creative disciplines like architecture and landscape architecture – impacts the results. Consequently, environmental parameters more closely associated with landscape architecture and green infrastructure appear less prominent. This is further compounded by the fact that landscape architecture remains a niche field, in quantitative analyses often overshadowed by more dominant disciplines.

Potential bias may also stem from the nature of the Scopus and Web of Science databases, which primarily prioritize scientific research; architectural fields are often under-indexed, and their publication frequency is significantly lower than that of purely scientific disciplines. To mitigate this, we incorporated data from Google Scholar, which indexes sources such as CuminCAD and other architecture-focused publication outlets.

In the field of landscape architecture, the relevance of design optimization gains importance with regard to the Life Cycle Assessment (LCA) method that may evaluate design impact service throughout its entire life cycle (NUGENT et al. 2022). A valid premise suggests that building design can be optimized to improve its Life Cycle Assessment, however, a pertinent question arises: Can landscape architecture achieve a comparable impact on LCA assessment?

The dual role of design lies in distinguishing between the carbon footprint and the carbon handprint (WESTERHOLM 2024). While the former represents the environmental burden (emissions generated by the project itself), the Handprint is generated in a way that the design choices lead to avoided emissions or enhanced sequestration for the city or the adjacent building. A possibility to predict and evaluate carbon handprints of a design may improve the acceptance of nature-based solution not only sociologically, but also economically.

5 Conclusion

Optimization and design workflows are well-established, particularly within the architectural domain, facilitating the inclusion of building-scale parameters in Life Cycle Assessments (LCA). However, a significant gap in the literature remains regarding the optimization of external environmental parameters – such as connectivity, urban greenery, stormwater management, and surface runoff. Although workflows utilizing platforms such as Revit and Dynamo, Rhino.Inside.Revit, or Vectorworks, as well as Rhino-based plugins like Lands Design already exist, their application to these specific metrics is underrepresented. This suggests that computational tools for the vegetative components of landscape architecture are either insufficiently documented, inadequate, or perceived as niche. This deficit prevents a full integration of green infrastructure benefits into the LCA of both individual buildings and entire districts, identifying a critical trajectory for future research and development. Furthermore, the traditional dichotomy – where GIS is reserved for analysis and Rhino/CAD for design – was not confirmed by evaluating the presented dataset. Instead, new domains are emerging: BIM/BEM dominates the scale of buildings and urban blocks, while the GIS domain remains the primary vehicle for modeling environmental flows, such as water and ecology, within large-scale and non-built environments.

Supplementary Dataset

RAW anonymized csv dataset is available here:
<https://figshare.com/s/3ca90f87d63911614b42>

Acknowledgement

“The paper was supported by project IGA-ZF/2023-ST2, titled ‘Evaluation of selected tree characteristics via integrated remote sensing and field inventory,’ funded by the Internal Grant Agency of Mendel University, Faculty of Horticulture.”

References

- BUCHANAN, R. (1992), Wicked Problems in Design Thinking. *Design Issues*, 8, 5-21.
- FRICKER, P. & MUNKEL, G. (2015), Data Mapping: Interactive Big Data Visualization in Landscape Architecture. In: HAYEK, U. W., FRICKER, P. & BUHMANN, E. (Eds.), *Peer Reviewed Proceedings of Digital Landscape Architecture 2015 at Anhalt University of Applied Sciences* (pp. 141-150). Wichmann, Berlin/Offenbach.
- GIROT, C. (1999), Towards a General Theory of Landscape. *Topos: European Landscape Magazine* (1999), 33-41.
- HARMON, B. (2024). *Computational Design for Landscape Architects*. Routledge, Taylor & Francis Group.
- HARZING, A.-W. (2022), *Publish or Perish* (Version 8).
- HE, Q. (1999). Knowledge Discovery Through Co-Word Analysis. *Libr. Trends* 48.

- MROSLA, L., FABRITIUS, H., KUPPER, K., DEMBSKI, F. & FRICKER, P. (2025), What grows, adapts and lives in the digital sphere? Systematic literature review on the dynamic modelling of flora and fauna in digital twins. *Ecological Modelling*, 504, 111091.
- NUGENT, A., MONTANO-OWEN, C., PALLARES, L., RICHARDSON, S. & ROWLAND, M. (2022), EU Policy Whole Life Carbon Roadmap for buildings (Roadmap). World Green Building Council, London, UK.
- RUTTEN, D. (2013), Grasshopper: Algorithmic Modeling for Rhino.
- TRICCO, A. C., LILLIE, E., ZARIN, W., O'BRIEN, K. K., COLQUHOUN, H., LEVAC, D., MOHER, D., PETERS, M. D. J., HORSLEY, T., WEEKS, L., HEMPEL, S., AKL, E. A., CHANG, C., MCGOWAN, J., STEWART, L., HARTLING, L., ALDCROFT, A., WILSON, M. G., GARRITTY, C., LEWIN, S., GODFREY, C. M., MACDONALD, M. T., LANGLOIS, E. V., SOARES-WEISER, K., MORIARTY, J., CLIFFORD, T., TUNÇALP, Ö. & STRAUS, S. E. (2018), PRISMA Extension for Scoping Reviews (PRISMA-ScR): Checklist and Explanation. *Annals of Internal Medicine*, 169 (7), 467-473. <https://doi.org/10.7326/M18-0850>.
- TYC, J., AHMETI, A., SUNGUROGLU HENSEL, D. & HENSEL, M. (2024), The ECOLOPES Voxel model: multi-domain data integration for ontology-aided generative computational design of ecological building envelopes. *Intelligent Buildings International*, June 2025, 1-24. <https://doi.org/10.1080/17508975.2025.2508896>.
- WESTERHOLM, N. (2024), Assessing the Carbon Impacts of Five Apartment Buildings with Different Timber Frames: A Finnish Study. *Architectural Research in Finland* 8, 420-444. <https://doi.org/10.37457/arf.147227>.
- WORTMANN, T. & NANNICINI, G. (2017), Introduction to Architectural Design Optimization. In: KARAKITSIOU, A., MIGDALAS, A., PARDALOS, P. M., RASSIA, S. (Eds.), *City Networks – Planning for Health and Sustainability*. Springer International Publishing, Cham, Switzerland. <https://doi.org/10.1007/978-3-319-65338-9>.