



## Emerging Paradigms in Architecture: A Bibliometric Review of AI, Computational Design, and Smart Built Environments

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### Abstract

The integration of artificial intelligence (AI), computational design, and robotic technologies into architectural practice and research represents one of the most transformative disciplinary shifts of the contemporary period. Despite rapid growth in scholarly output, the structural intellectual landscape of this field remains inadequately mapped. This study addresses that gap by conducting a comprehensive bibliometric analysis of 224 peer-reviewed publications spanning 1997 to 2026, drawn from the Dimensions database and analyzed using Biblioshiny and VOSviewer. The analysis reveals an exponential surge in research activity following 2020, an annual growth rate of 9.53%, and a heterogeneous but increasingly convergent knowledge structure distributed across 111 publication venues and 37 countries. Keyword co-occurrence analysis identifies six thematic clusters: AI-assisted computational design; digital fabrication and robotics; human-centered intelligent environments; smart and sustainable built environments; architectural pedagogy and digital literacy; and biomimicry and generative systems. Author collaboration network analysis reveals three distinct scholarly communities, with fragmented cross-cluster integration and the emergence of key bridging scholars. The study identifies critical research gaps and proposes a future research agenda for a more holistic, equitable, and theoretically grounded approach to intelligent architectural systems.

**Keywords:** Bibliometric; Artificial Intelligence; Computational Design; Digital Fabrication; Smart Built Environments; VOSviewer; Biblioshiny

### Introduction

Architecture, as both a discipline and a professional practice, is undergoing a profound transformation driven by the convergence of artificial intelligence (AI), computational design, digital fabrication, and intelligent building systems. Where conventional architectural production relied on hand-drawn representation, material intuition, and linear design processes, contemporary practice increasingly engages algorithmic optimization, generative modelling, robotic fabrication, and data-driven decision-making. This transition is not merely technological it redefines the epistemic foundations of design itself, altering what architects know, how they work, and what buildings are capable of doing. The scholarly response to this transformation has been vigorous and multidisciplinary. Research has emerged from architectural theory, engineering, computer science, cognitive psychology, environmental science, and education studies, producing a corpus that is

simultaneously rich and fragmented. Individual studies have charted advances in parametric modelling, BIM-integrated workflows, occupant-responsive environments, and AI-mediated design generation, but the structural patterns that organize this body of knowledge, including its thematic clusters, intellectual foundations, leading contributors, and research gaps, have not been systematically examined. Without such a map, researchers risk duplicating effort, missing opportunities for cross-disciplinary synthesis, and neglecting emergent domains at the periphery of established conversation. Bibliometric analysis provides a rigorous, reproducible, and scalable method for addressing this challenge. By applying quantitative analytical tools to publication metadata, including authorship, citation patterns, keyword co-occurrence, and institutional affiliation, bibliometric studies generate objective portraits of research fields that complement and extend traditional narrative literature reviews (Zupic & Cater, 2015). This approach has been successfully deployed to map domains in entrepreneurial ecosystems (Velt, Torkkeli, & Laine, 2020) and digital construction (Oraee et al., 2017), but has not been applied with full methodological rigor to the intersection of AI, computational design, and smart built environments. This study fills that gap by drawing on a dataset of 224 publications extracted from the Dimensions database, spanning 1997 to 2026, and analysed using Biblioshiny and VOSviewer, we provide the first comprehensive bibliometric portrait of this emerging domain. Our analysis pursues four objectives: (1) to characterize the temporal growth and structural composition of the literature; (2) to identify leading countries, institutions, journals, and scholars; (3) to map the thematic structure through keyword co-occurrence and author collaboration networks; and (4) to identify research gaps and propose directions for future inquiry.

## **Methodology**

### **Research Design and Philosophical Positioning**

This study adopts a bibliometric design, which Zupic and Cater (2015) describe as a method of applying statistical analysis to the bibliographic features of academic publications to map the intellectual structure of a research domain. Bibliometric approaches are recognised as rigorous, transparent, and relatively bias-free complements to systematic literature reviews and meta-analyses, particularly in domains characterised by high interdisciplinary complexity and rapid evolution (Donthu et al., 2021). The research process follows a six-step framework—formulation, identification, selection, confirmation, analysis, and synthesis.

### **Database Selection and Search Strategy**

Publication data were extracted from the Dimensions database, selected for its broad coverage of architectural and engineering literature, structured metadata, and compatibility with Biblioshiny and VOSviewer export formats. The search strategy employed Boolean operators and truncated keyword strings targeting the core themes of the study, generating an initial pool of 774 documents published between 1997 and 2026. First inclusion criteria. Following established bibliometric practice, only peer-reviewed journal articles, books, book chapters, and conference papers were retained. Furthermore, as mainstream academic journals and common scientific knowledge are predominantly written in English, the dataset was restricted to English-language publications. We acknowledge that this criterion may have led us to overlook relevant works published in other languages, which constitutes a limitation of the present study. Selection criteria. Titles of all retrieved documents were reviewed against the core themes of the study; where necessary, abstracts and introductory sections were examined to confirm topical relevance. Documents matching related but out-of-scope keyword domains including computer architecture, software architecture, network architecture, and information and communications technology (ICT)—were systematically excluded, as these fields share terminology with the target domain but address fundamentally different research questions.

Following this screening process, the confirmed final dataset comprised 224 documents published between 1997 and 2026.

### Analytical Tools and Methods

Two primary analytical platforms were employed. Biblioshiny (Aria & Cuccurullo, 2017) was used for descriptive bibliometric analysis including annual scientific production, source analysis, author productivity, country-level output, life cycle modelling, and citation frequency. VOSviewer (Van Eck & Waltman, 2010) was used for mapping intellectual network structures, specifically keyword co-occurrence networks producing density, network, and overlay visualizations, and author collaboration networks. These complementary tools together provide both macro-level descriptive statistics and meso-level intellectual structure analysis.

### Descriptive Bibliometric Findings

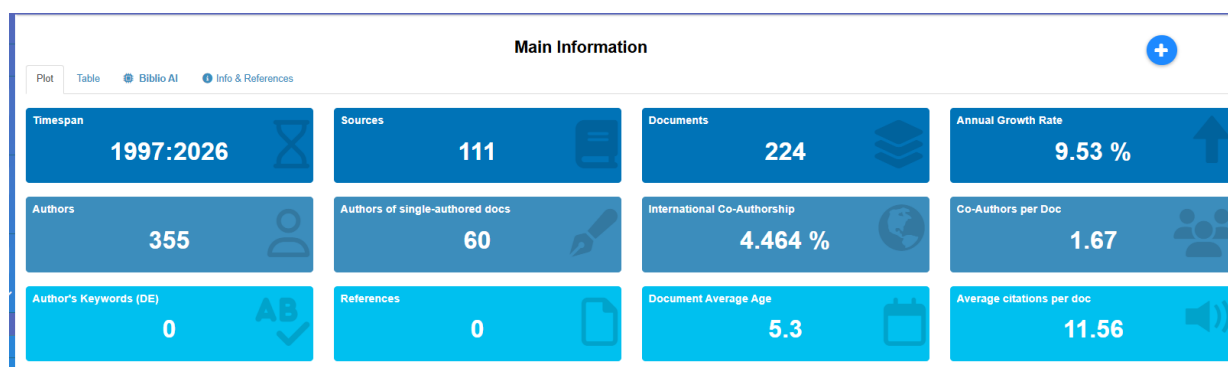
#### Dataset Overview

The confirmed dataset comprises 224 publications spanning 1997 to 2026, distributed across 111 unique publication sources. Key descriptive statistics are presented in Table 1. The annual growth rate of 9.53% places this field among moderately fast-growing interdisciplinary domains, while the average document age of 5.3 years confirms that the corpus is dominated by recent publications—characteristic of fields undergoing rapid contemporary development rather than long-established consolidation.

**Table 1. Dataset Overview and Key Descriptive Statistics**

Parameter	Value	Interpretation
Timespan	1997–2026	Nearly three decades of scholarship
Total Documents	224	Emerging but growing corpus
Unique Sources	111	High interdisciplinary dispersion
Annual Growth Rate	9.53%	Sustained acceleration post-2020
Avg. Citations/Doc	11.56	Moderate citation density
Average Document Age	5.3 years	Predominantly recent publications
Total Citations	2,602	Growing scholarly engagement

Source: Biblioshiny analysis of Dimensions database ( $n = 224$ )

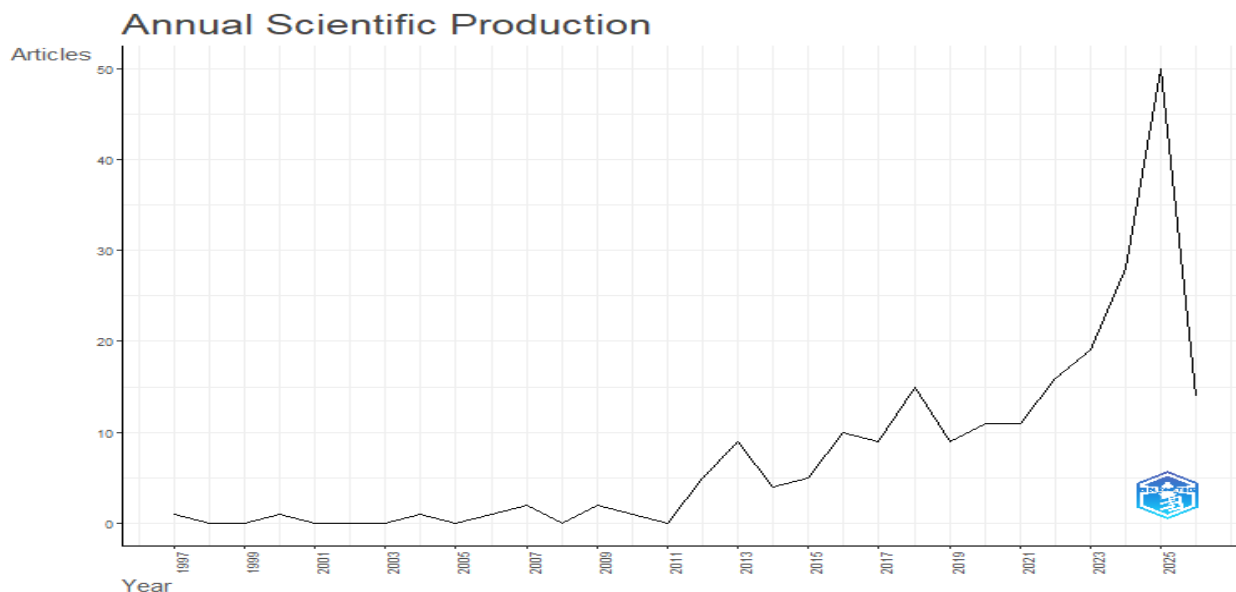


#### Annual Scientific Production

Annual publication trends reveal a biphasic growth pattern consistent with the emergence lifecycle of interdisciplinary fields (Figure 1). During 1997 to 2010, output was minimal no more than two documents in any single year. Research activity began increasing gradually from 2012, reaching 15

documents in 2018, before accelerating dramatically after 2020 to reach 50 publications in 2025 alone.

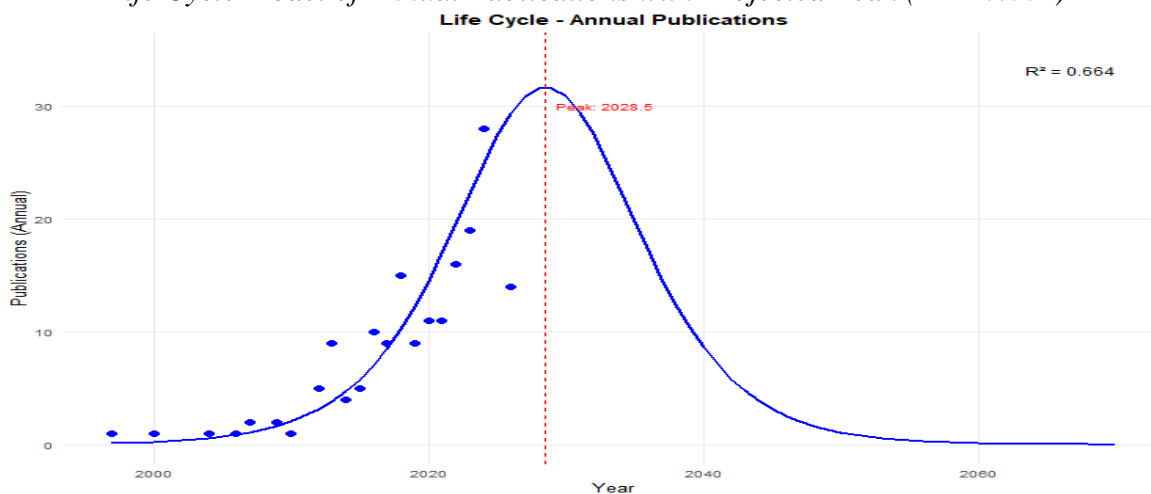
**Figure 1**  
*Annual Scientific Production (1997–2026)*



Source: *Biblioshiny analysis of Dimensions database.*

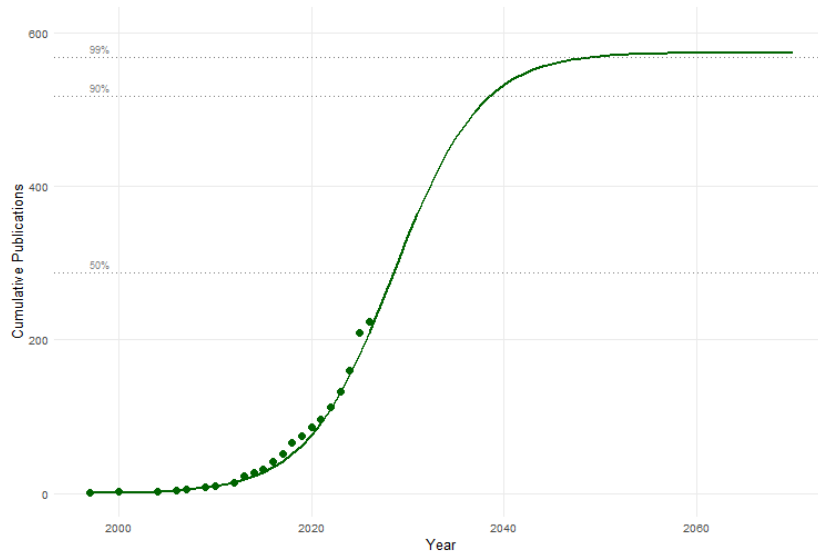
The Biblioshiny life cycle model (Figure 2) fits the annual publication data with a Gaussian curve ( $R^2 = 0.664$ ), projecting a peak publication rate around 2028.5. This finding is statistically significant: it indicates the field is currently in its ascent phase rather than consolidating, meaning foundational theoretical contributions and interdisciplinary synthesis opportunities remain highly viable. The complementary cumulative growth curve (Figure 3) confirms an S-curve trajectory, with the steepest inflection point occurring in the 2020–2026 windows.

**Figure 2**  
*Life Cycle Model of Annual Publications with Projected Peak ( $R^2 = 0.664$ )*



Source: *Biblioshiny. Red dashed line indicates projected publication peak at year 2028.5.*

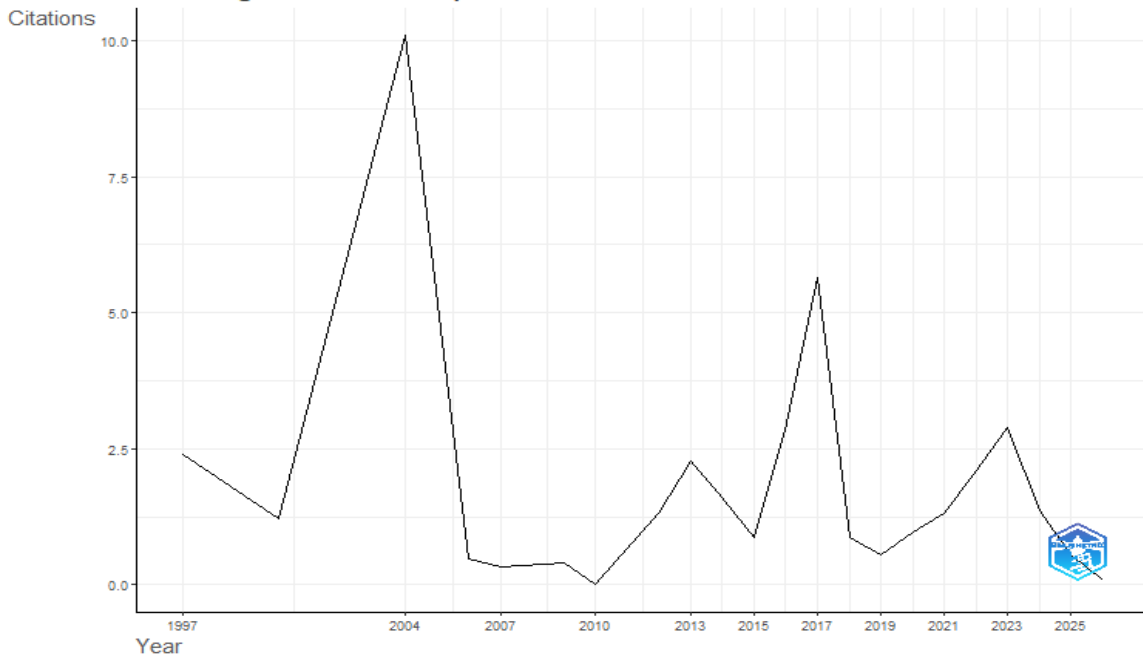
**Figure 3.**  
*Cumulative Growth Curve of Publications (1997–2026)*  
 Cumulative Growth Curve



Source: Biblioshiny. Dotted horizontal lines indicate 50%, 90%, and 99% thresholds.

The average citations per year chart (Figure 4) reveals an uneven citation accumulation pattern, with peak citation intensity centred on foundational works published in 2004 and 2017. The recent uptick from 2021 onwards reflects the growing citation engagement with current AI-focused research.

**Figure 4.**  
*Average Citations per Year (1997–2026)*  
 Average Citations per Year



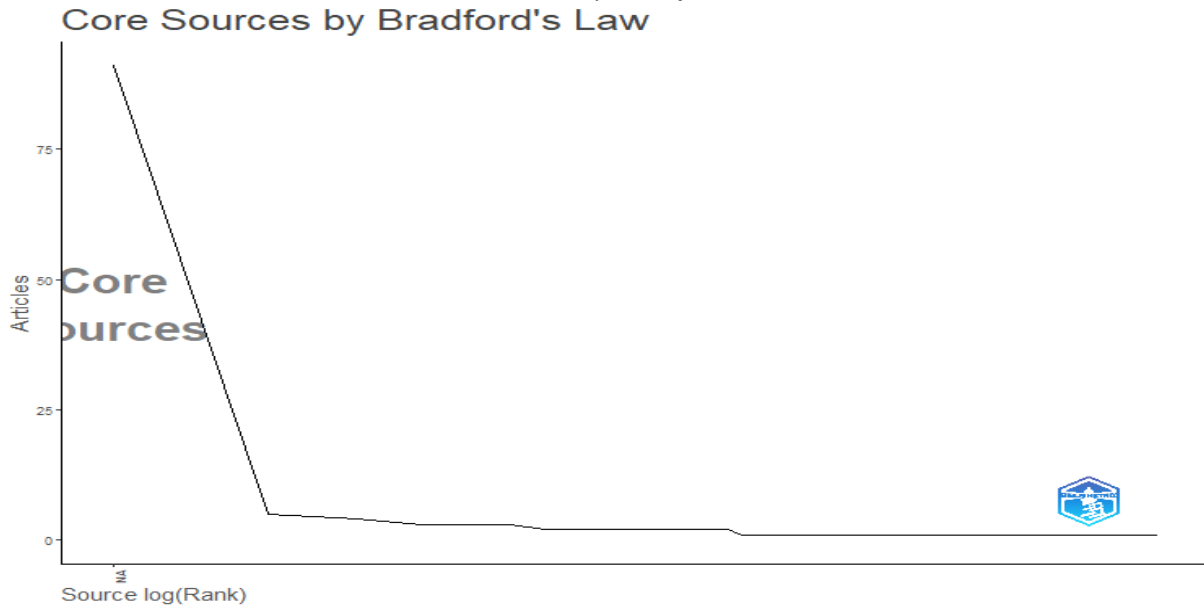
Source: Biblioshiny analysis of Dimensions database.

## Source Journals

The 224 documents are distributed across 111 unique publication sources, demonstrating high interdisciplinary dispersion consistent with Bradford's Law (Figure 5). The most relevant sources by document count are visualized in Figure 6.

**Figure 5**

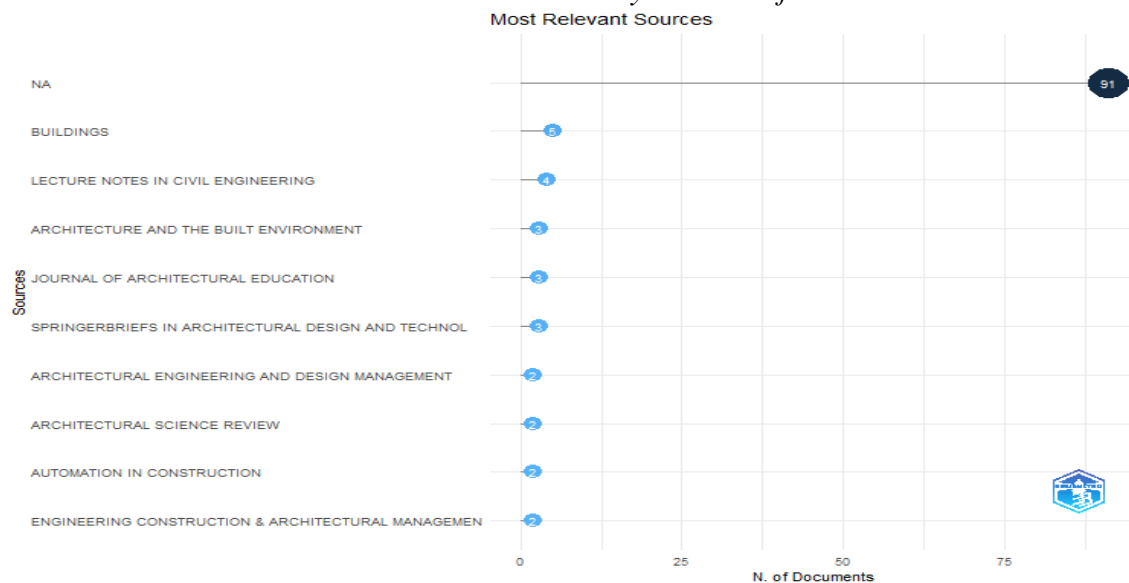
*Core Sources by Bradford's Law*



*Source: Biblioshiny. The steep initial descent confirms high concentration of output in a small number of core journals.*

**Figure 6**

*Most Relevant Source Journals by Number of Documents*



*Source: Biblioshiny. NA category reflects book chapters without a designated journal.*

Examining the sources' local impact by H-index (Figure 7) reveals that the NA category comprising book chapters and conference proceedings—holds the highest within-dataset H-index (17), highlighting the continued authority of edited volumes and conference series in this domain. Among

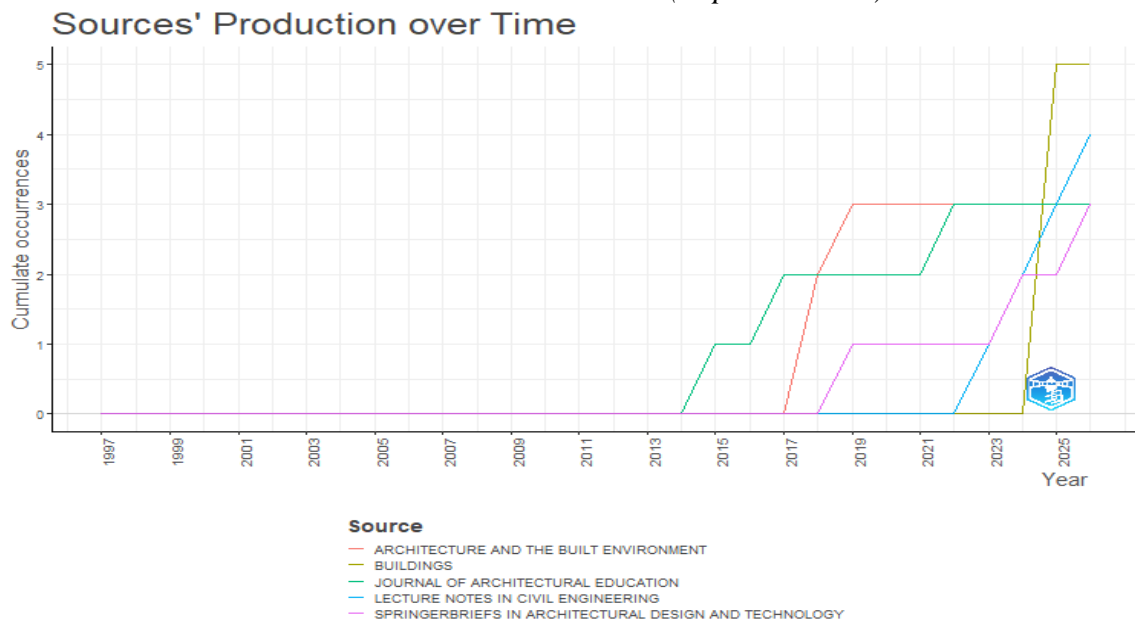
standalone journals, Architectural Engineering and Design Management, Architectural Science Review, and Automation in Construction each achieve H-index scores of 2 within this dataset, indicating sustained quality publication records. Figure 8 shows the temporal trajectory of top source production, confirming that meaningful multi-publication engagement by key journals only begins post-2015 and accelerates sharply after 2023.

**Figure 7**  
Sources' Local Impact by H-Index



Source: Biblioshiny. H-index reflects within-dataset citation performance of each source.

**Figure 8**  
Sources' Production over Time (Top 5 Journals)

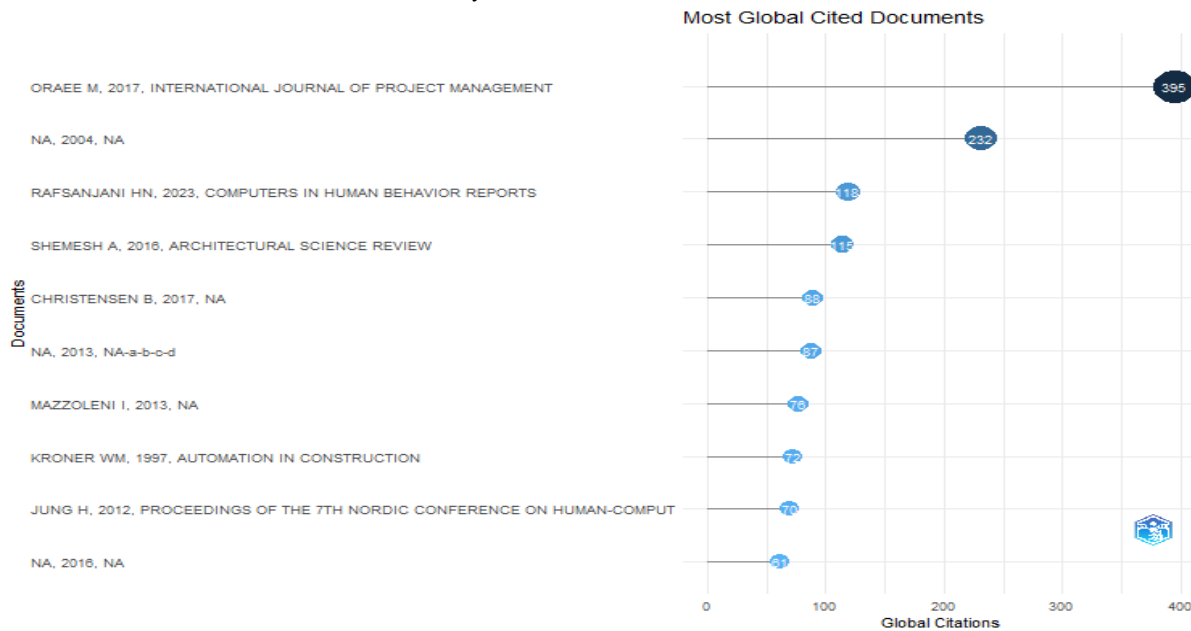


Source: Biblioshiny. Cumulative occurrences by year for the five most productive journals.

### Most Cited Documents

The ten most cited publications are visualized in Figure 9 and detailed in Table 2. Oraee et al.'s (2017) BIM-collaboration bibliometric review leads with 395 citations, followed by Kolarevic's (2004) landmark compilation with 232 citations. Notably, Rafsanjani et al.'s (2023) paper on human-centered AI in AEC has accumulated 118 citations within just two years of publication, signalling the field's accelerating orientation toward human experience as a fundamental design criterion.

**Figure 9**  
*Most Globally Cited Documents in the Dataset*



Source: Biblioshiny analysis of Dimensions database. Bubble size proportional to citation count.

**Table 2. Top 10 Most Cited Documents in the Dataset**

Title	Author(s)	Year	Citations
Collaboration in BIM-based construction networks: A bibliometric-qualitative literature review	Oraee et al.	2017	395
Architecture in the Digital Age, Design and Manufacturing	Kolarevic	2004	232
Towards human-centered AI in AEC	Rafsanjani et al.	2023	118
Affective response to architecture: investigating human reaction to spaces	Shemesh et al.	2016	115
Analysing Design Thinking: Cross-Cultural Co-Creation	Christensen B	2017	88
The Digital Turn in Architecture 1992–2012	Carmo	2013	87
Architecture Follows Nature: Biomimetic Principles	Mazzoleni I	2013	76
An intelligent and responsive architecture	Kroner WM	1997	72
Digital form and materiality	Multiple	2012	70

Source: Biblioshiny analysis. Ranked by total citation count.

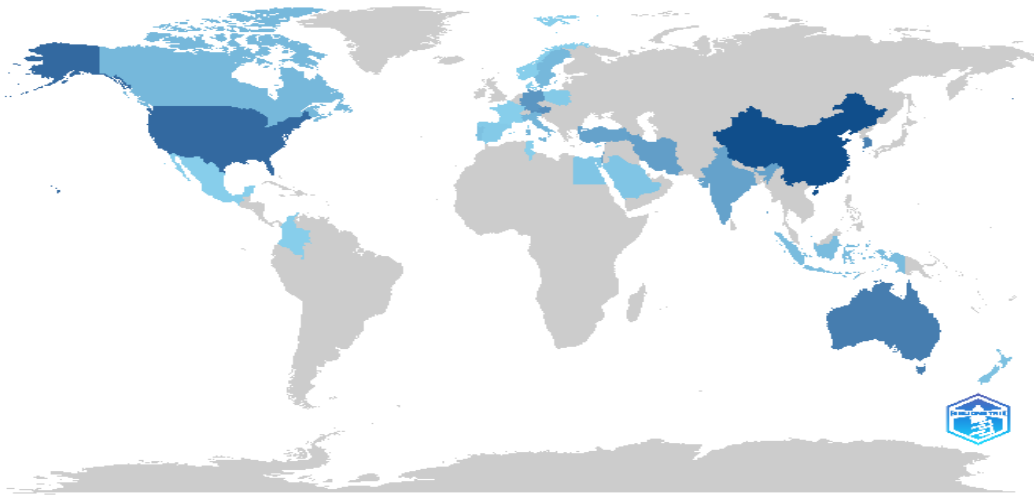
### Country-Level Scientific Production

Research activity spans a broad international community. Figure 10 presents the country scientific production choropleth map, revealing concentrated dark-blue intensity in the USA, China, and Australia. Figure 11 shows the international collaboration world map, where the dominant USA–Europe arc is the single recorded multi-country collaboration link—indicating that most research is still conducted within single-country boundaries. Figure 12 disaggregates corresponding author countries by single-country versus multi-country publications, revealing China's particularly high ratio of multi-country collaboration. Figure 13 reveals that Australia leads all nations in citation impact (450 citations) despite producing fewer documents than the USA or China, indicating a concentration of high-quality, widely-cited research.

**Figure 10**

*Country Scientific Production Map*

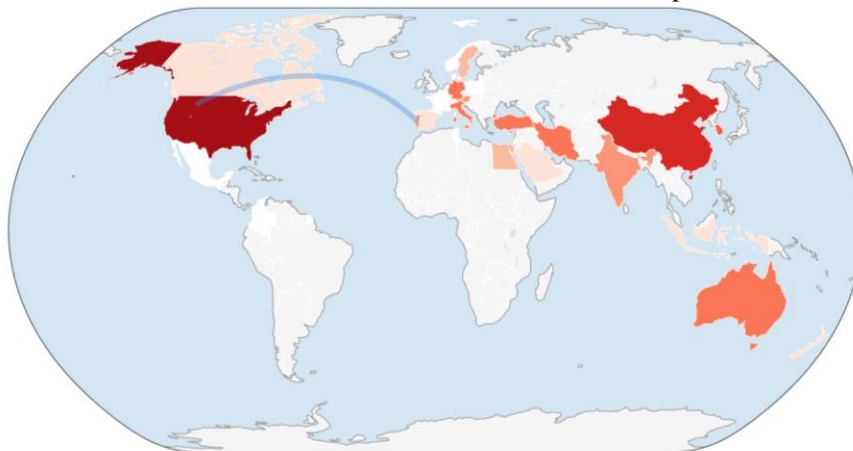
### Country Scientific Production



Source: Biblioshiny. Darker shading indicates higher publication volume. Grey = no publications.

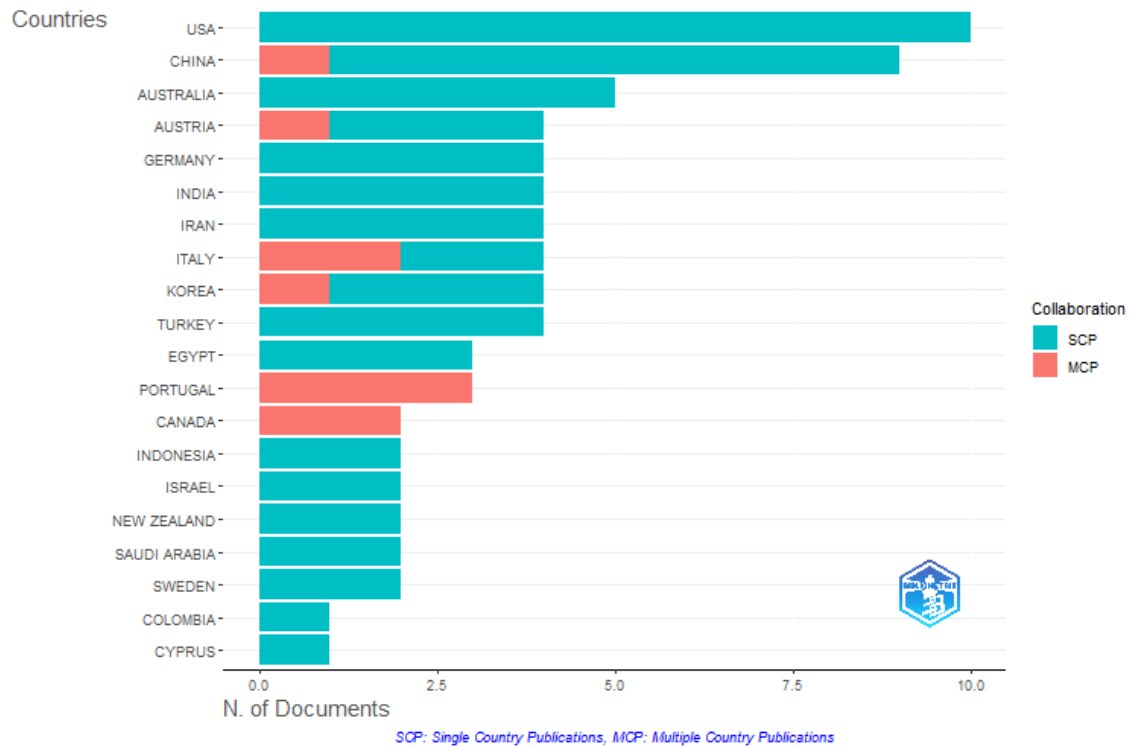
**Figure 11**

*International Collaboration World Map*



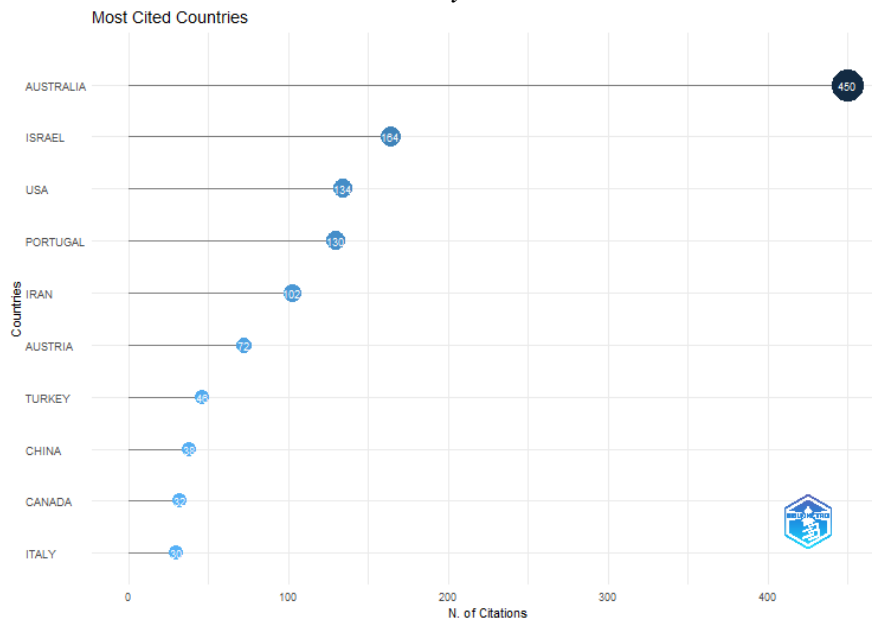
Source: Biblioshiny. Arc indicates the primary USA–Europe international collaboration corridor.

**Figure 12**  
*Corresponding Author Countries: single-country versus multi-country Publications*  
**Corresponding Author's Countries**



Source: Biblioshiny. SCP = Single Country Publications; MCP = Multi-Country Publications.

**Figure 13**  
*Most Cited Countries by Total Citation Count*



Source: Biblioshiny analysis of Dimensions database.

**Table 3. Country-Level Scientific Production and Primary Research Focus**

Country	Documents	Primary Research Focus
China	12	Smart infrastructure, digital construction, AI integration
United States	12	Computational design, HCI, digital fabrication
Australia	7	Sustainable design, smart environments, occupant systems
Germany	5	Parametric systems, adaptive structures, biomimicry
Italy	5	Responsive environments, ecological intelligence
Austria	4	Digital ecosystems, computational methods
South Korea	2	Smart buildings, robotic construction
Canada	2	AI-assisted design, human-computer interaction

Source: Biblioshiny analysis. Ranked by document count.

China's emergence as a co-leader reflects national investment in smart cities and AI-integrated infrastructure. The USA contributes through computational design and digital fabrication research. Australia's citation dominance despite moderate document volume suggests a concentration on high-quality human-centered and sustainable building systems research with broad international resonance. European contributions particularly Germany, Italy, and Austria—tend toward parametric, ecological, and adaptive approaches.

### Leading Authors and Institutional Affiliations

Figure 14 presents the most relevant authors by publication count. Grobman YJ leads with 4 publications while 10 further scholars hold 2 publications each. Figure 15 reveals important temporal dynamics: Grobman YJ's contributions span over a decade (2013–2024), establishing him as a foundational contributor; Fersch P has been active since 2015; while Ghorbany S, Globa A, and Melis A concentrate their output in the recent 2021–2025 window, representing the field's newest generation.

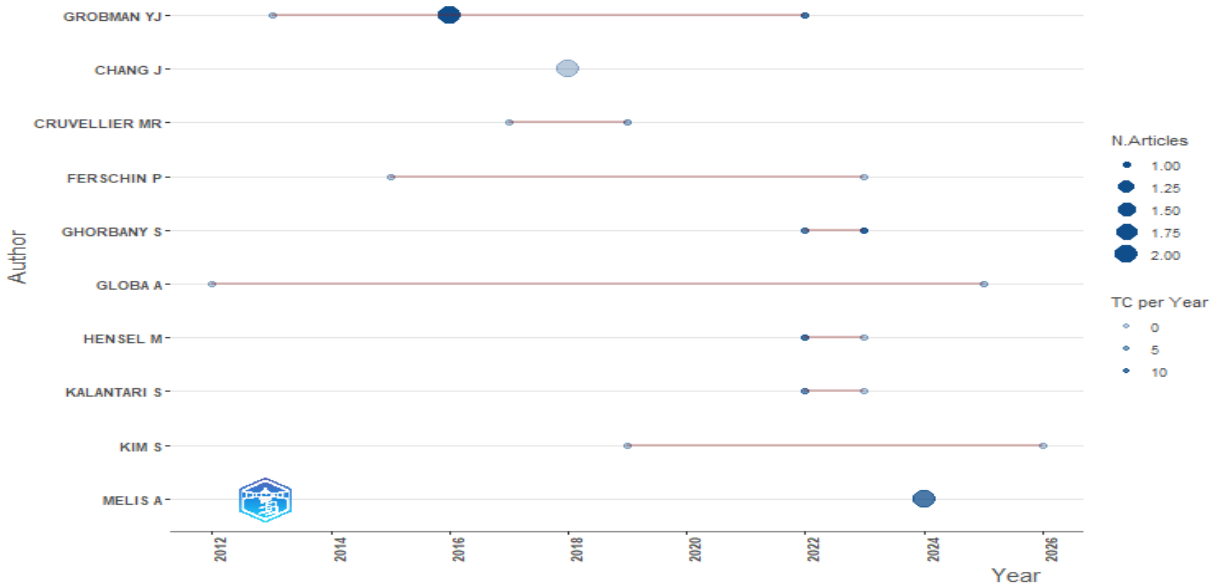
**Figure 14**

*Most Relevant Authors by Number of Publications*



Source: Biblioshiny. TC per year encoded in bubble size.

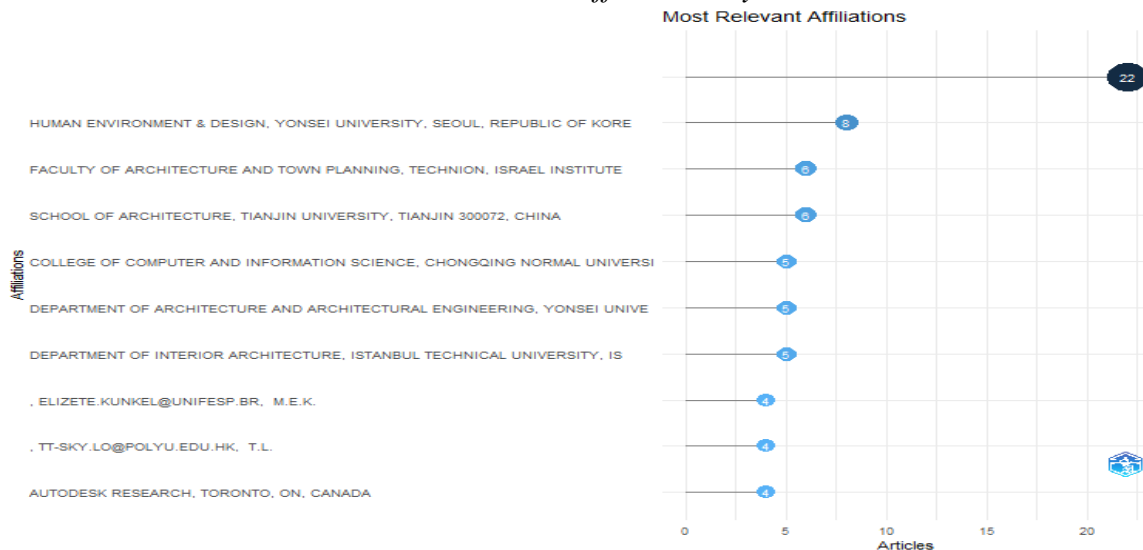
**Figure 15**  
*Authors' Production over Time*  
**Authors' Production over Time**



Source: Biblioshiny. Horizontal bar indicates active publishing period; bubble size = number of articles; shade = citations per year.

Figure 16 visualises the most relevant institutional affiliations. The top-ranked affiliation (22 articles under a broadly aggregated NA category) is followed by substantive institutional presences at Yonsei University's Human Environment & Design department (8 articles), Technion's Faculty of Architecture and Town Planning (6), Tianjin University's School of Architecture (6), and Chongqing Normal University (5). This spread across South Korea, Israel, China, and Turkey reflects the genuinely global distribution of productive research communities in the domain.

**Figure 16**  
*Most Relevant Institutional Affiliations by Article Count*



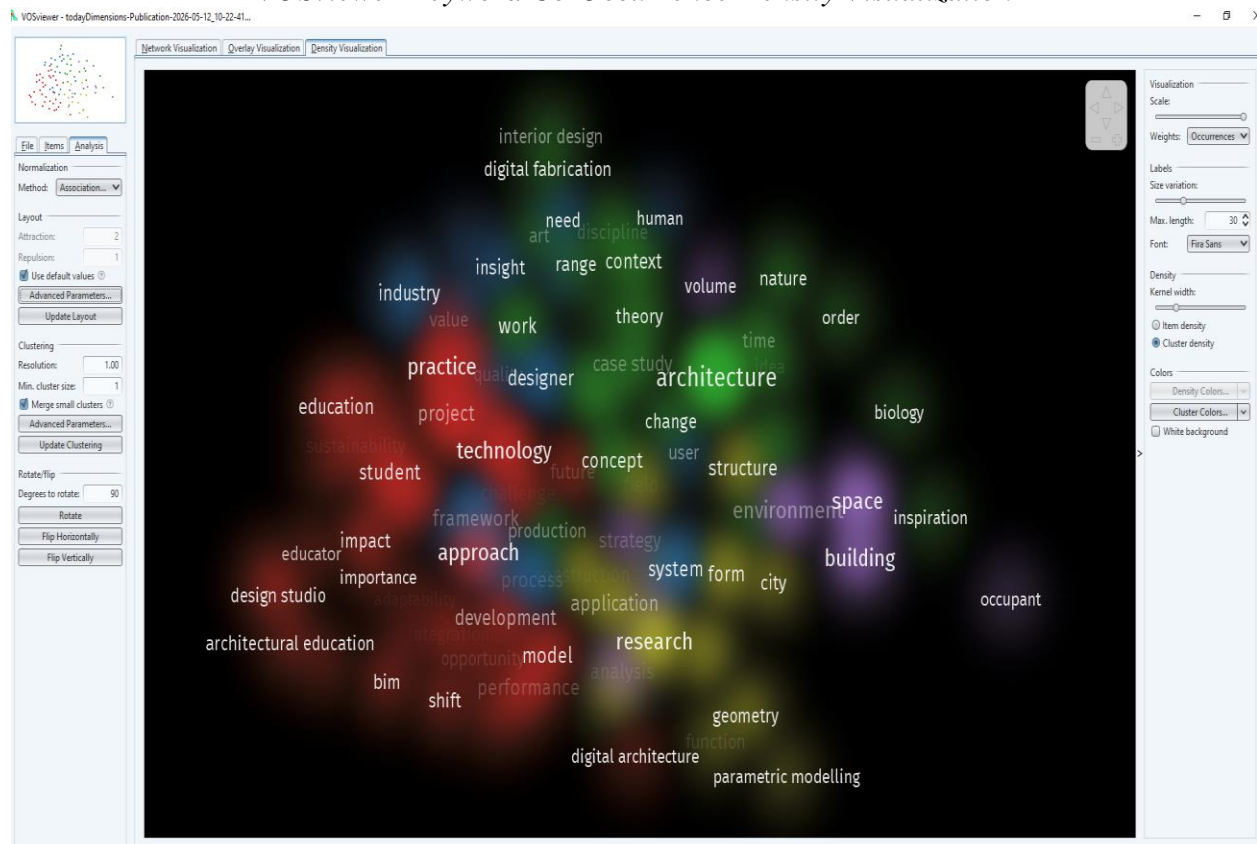
Source: Biblioshiny analysis of Dimensions database.

## Intellectual Structure Analysis

### Keyword Co-Occurrence Analysis: Thematic Mapping

The VOSviewer keyword co-occurrence analysis generates a network in which nodes represent keywords and edges represent co-occurrence relationships. Node size reflects keyword frequency; edge thickness reflects co-occurrence strength; spatial proximity reflects thematic relatedness. Two complementary visualizations are presented: the density visualization (Figure 17), which reveals thematic concentration through colour intensity, and the network visualization (Figure 18), which maps the relational structure of the three dominant keyword clusters.

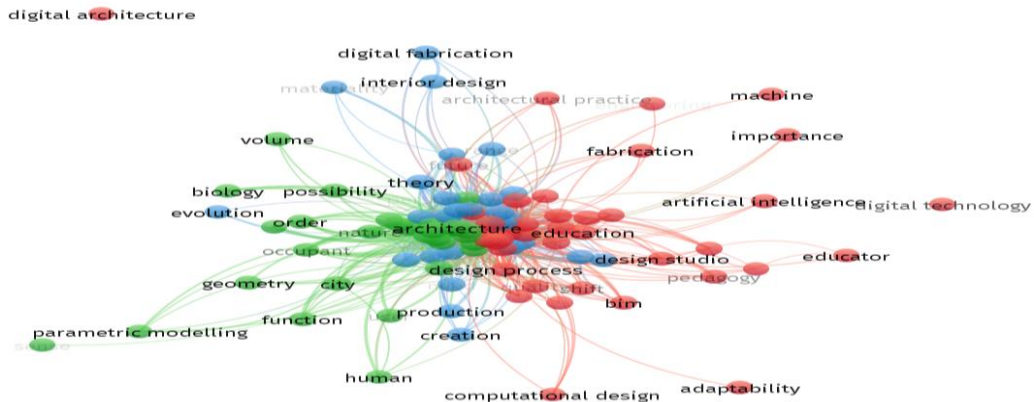
**Figure 17**  
*VOSviewer Keyword Co-Occurrence Density Visualization*



*Source: VOSviewer. Brighter colours indicate higher keyword frequency and stronger co-occurrence intensity. "Architecture" is the central hub term connecting all thematic clusters.*

The density map reveals "architecture" as the dominant and most central term, around which three major thematic concentrations organize. The highest-density zone encompassing technology, research, system, building, and space reflects the core AI-computational discourse. A second concentration clusters around education, design studio, student, and architectural education, reflecting the pedagogical transformation cluster. A third concentration toward the periphery biology, nature, geometry, parametric modelling, occupant, and inspiration signals the biomimetic and human-centered clusters. Crucially, terms such as "occupant," "biology," and "sustainability" appear as peripheral nodes, confirming the research gaps analyzed in Section 6.

**Figure 18**  
*VOSviewer Keyword Co-Occurrence Network Visualization*



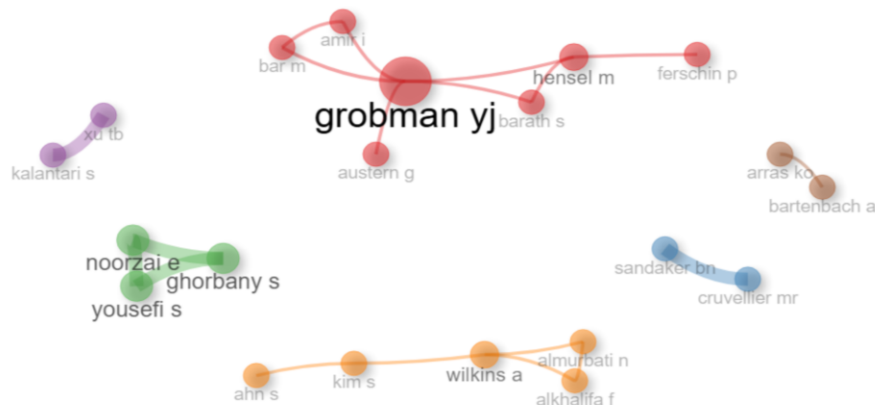
Source: VOSviewer. Colours represent distinct thematic clusters: Red = AI/technology/education; Blue = digital fabrication/materiality; Green = parametric/biomimicry. Node size reflects keyword frequency; edge thickness reflects co-occurrence strength.

The network visualization (Figure 18) confirms three clusters. The Red cluster encompasses artificial intelligence, digital technology, machine learning, fabrication, BIM, computational design, design studio, educator, and pedagogy reflecting the integration of intelligent technologies with both practice and education. The Blue cluster centres on digital fabrication, interior design, materiality, and architectural practice, representing production-oriented research. The Green cluster organizes around parametric modelling, geometry, evolution, biology, nature, and city, representing generative and biomimetic approaches. Bridging nodes design process, theory, and production—mediate between all three clusters.

**Author Collaboration Network Analysis**

The author collaboration network (Figure 19), generated through Biblioshiny analysis, reveals the social architecture of the research community. Six colour-coded clusters are identifiable. The dominant Red cluster, centred on Grobman YJ (the largest node, reflecting highest productivity and centrality), connects Hensel M, Ferschlin P, Barath S, Austern G, Amir I, and Bar M. The Orange cluster organises around Wilkins A, Kim S, Ahn S, Almurbati N, and Alkhalifa, F. The Green cluster (Noorzai E, Ghorbany S, Yousefi S) and isolated dyads Kalantari S Xu Tb (purple); Sandaker Bn Cruvellier MR (blue); Arras Ko—Bartenbach a (brown) reflect specialized peripheral communities.

**Figure 19**  
*Author Collaboration Network*



*Source: Biblioshiny. Node size reflects author productivity; node colour identifies collaboration cluster; edge thickness reflects co-authorship frequency. Grobman YJ dominates as the most productive and most connected author.*

The network confirms that internal collaboration within clusters is strong, but cross-cluster collaboration remains structurally limited with no direct edges between, for example, the Red cluster and the Orange or Green clusters. This fragmentation is characteristic of an emerging interdisciplinary field and represents a key structural vulnerability: the field's knowledge integration is dependent on a small number of bridging researchers.

### **Thematic Synthesis: Six Research Clusters**

Building on both the keyword co-occurrence network and the descriptive analysis, we synthesize the intellectual content of the dataset into six thematic clusters. Table 4 provides a structural overview.

**Table 4 Six Thematic Clusters in AI and Computational Architecture Research**

<b>Cluster Theme</b>	<b>Key Keywords</b>	<b>Core Research Questions</b>
AI & Computational Design	artificial intelligence, machine learning, generative design, optimization, parametric modelling	How do AI algorithms transform architectural form generation and decision-making?
Robotics & Digital Fabrication	digital fabrication, BIM, additive manufacturing, automation, WAAM, robotic construction	How do robotic and automated systems change construction practice and material innovation?
Human-Centered Environments	occupant, human, user, comfort, well-being, affective response, post-occupancy	How can intelligent environments be designed around occupant experience, health, and spatial quality?
Smart & Sustainable Environments	sustainability, performance, smart building, adaptive system, energy, environment	How do AI and IoT enable adaptive, energy-responsive, and ecologically intelligent buildings?
Architectural Education & Pedagogy	education, design studio, student, pedagogy, digital literacy, virtual studio	How must architectural curricula evolve to integrate computational intelligence and digital tools?
Biomimicry & Generative Systems	biology, nature, evolution, geometry, bioinspired, structure, form, ecology	How do bio-inspired principles and evolutionary algorithms drive novel structural and spatial innovation?

*Source: Synthesis of VOSviewer keyword co-occurrence analysis and bibliometric descriptive findings.*

### **Cluster 1: AI-Assisted Computational Design**

This cluster encompasses research investigating how machine learning, generative adversarial networks, optimization algorithms, and other AI-based tools are transforming the architectural design process. Studies examine AI's capacity to assist schematic design generation, evaluate performance against multiple criteria simultaneously, and enable design exploration computationally intractable through manual methods. A defining tension concerns the relationship between computational efficiency and design intentionality—the most sophisticated contributions investigate

human-machine collaboration frameworks that leverage complementary strengths of computational search and human interpretive judgment (Calixto et al., 2025).

### **Cluster 2: Robotics, Digital Fabrication, and Construction Automation**

The second cluster addresses the physical realization of computationally generated forms through robotic and automated manufacturing technologies. Wire arc additive manufacturing (WAAM), CNC milling, robotic concrete printing, and drone-assisted construction each appear as significant research themes. The landmark "Weaving Love" pavilion in Hong Kong constructed using WAAM technology, representing the region's first major outdoor 3D-printed metal structure illustrates the trajectory from research prototype to built realization (So et al., 2025). A notable subtheme involves integration of structural analysis and manufacturing simulation within unified digital models.

### **Cluster 3: Human-Centered Intelligent Environments**

The third cluster investigates the relationship between intelligent building systems and their human occupants. Research addresses occupant comfort, spatial well-being, affective response to architectural environments, post-occupancy evaluation, and adaptive systems that respond to human presence and physiological states. The foundational premise that technological performance and human experience are inseparable dimensions of architectural quality represents a crucial corrective to purely technical orientations. The rapid citation accumulation of Rafsanjani et al.'s (2023) paper on human-centered AI in AEC reflects the field's growing recognition of this necessity.

### **Cluster 4: Smart and Sustainable Built Environments**

The fourth cluster addresses AI-driven energy optimization, adaptive building envelopes, IoT-enabled environmental monitoring, and climate-responsive design. The field increasingly recognizes that decarbonizing the built environment accounting for approximately 40% of global energy consumption requires dynamic, data-driven, adaptive systems. Adaptive facades responding to solar radiation, wind pressure, and thermal gradients through actuated or morphing systems represent a particularly active subtheme.

### **Cluster 5: Architectural Education and Digital Pedagogy**

The fifth cluster examines how architectural education responds to digital transformation. Research addresses AI tool integration into studio curricula, pandemic-driven shifts to virtual design studios, generational differences in digital literacy, and what core competencies should anchor architectural education as the profession undergoes structural change. Iranmanesh and Onur's (2022) comparative analysis of student and educator perspectives in virtual studios illustrates the methodological innovation occurring at this intersection.

### **Cluster 6: Biomimicry, Generative Systems, and Evolutionary Design**

The sixth cluster encompasses research drawing on biological systems as sources of design inspiration, structural logic, and generative algorithms. Biomimetic studies investigate how mechanical, optical, thermal, and behavioral properties of organisms can inform architectural components, envelopes, and spatial configurations. Evolutionary computation applies natural selection principles to explore design solution spaces. Kunkel et al.'s (2025) international course combining biomimetic principles with additive manufacturing illustrates how this research cluster is being translated into educational practice.

### **Research Gaps and Future Directions**

The bibliometric analysis reveals not only the current structure of the field but also its absences domains that are underrepresented, connections that remain unmade, and questions that remain

inadequately theorized. We identify five primary research gaps, each grounded directly in evidence from the visualizations presented above.

### **The Integration Gap: Technology and Human Experience**

Perhaps the most consequential gap is the insufficient integration of AI and computational design research with systematic investigation of human experience, occupant well-being, and spatial quality. The density visualization (Figure 17) clearly shows that terms such as "occupant," "well-being," "experience," and "comfort" are peripheral to the dominant technological cluster rather than integrated within it. The network visualization (Figure 18) confirms that "human" and "occupant" appear as peripheral, weakly-connected nodes. Future research should embed occupant well-being as a generative constraint within computational design processes, requiring methodological innovation at the intersection of AI system design, environmental psychology, and user experience research.

### **The Social Sustainability Gap**

The vocabulary of social sustainability, cultural responsiveness, community participation, and inclusive design is largely absent from the keyword co-occurrence map (Figures 17–18). Future research should investigate how AI-assisted design tools can support social equity, cultural diversity, heritage conservation, and community empowerment. This may require new AI training datasets incorporating socially diverse design knowledge and new participatory design methodologies leveraging computational tools to amplify community voice.

### **The Urban Scale Gap**

Despite growing smart city discourse, the co-occurrence visualization reveals limited integration between building-scale AI applications and urban-scale intelligent systems. Keywords "city" and "urban" appear in the Green (generative) cluster but are not strongly connected to AI or smart building terminology. The collaboration world map (Figure 11) also reveals limited cross-continental research partnerships that might drive urban-scale comparative studies. Future research should investigate multi-scale relationships between building-level AI systems and urban intelligence frameworks.

### **The Ecological Design Gap**

Although biomimicry appears as a distinct Green cluster in Figure 18, its connections to the dominant Red AI cluster remain weak as visible in both Figures 17 and 18. The application of AI to living building systems, bio-receptive facades, ecological corridors, and regenerative building materials appears underdeveloped. Future research should explore how machine learning and computational optimization can be applied to biologically complex design challenges measured in ecological terms such as biodiversity support and carbon sequestration.

### **The Cross-Cluster Collaboration Gap**

The author collaboration network (Figure 19) confirms that while strong internal collaboration exists within each cluster, cross-cluster collaboration is entirely absent—no edges connect the Red, Orange, Green, Blue, or peripheral clusters. This structural fragmentation makes the field's knowledge integration dependent on a very small number of bridging researchers. Future research should cultivate cross-cluster collaboration through targeted funding mechanisms, joint working groups, and publication forums that explicitly bring together computational design researchers, ecologists, social scientists, and educational researchers.

## Discussion

The findings position this research domain at a distinctive developmental stage. In the terminology of Audretsch et al. (2019), it currently occupies a high-growth developmental phase characterized by exponential publication growth (Figure 1), increasing geographic diversification (Figures 10–13), fragmented but intensifying collaboration networks (Figure 19), and the emergence of distinct thematic clusters beginning to be bridged by intellectual mediators. The life cycle model (Figure 2) projects that publication growth will peak around 2028, after which consolidation is anticipated. The emergence of human-centered AI as a rapidly growing subfield evidenced by the high citation velocity of the Rafsanjani et al. (2023) paper (Figure 9) suggests that the research community is developing frameworks for evaluating AI systems not only by computational performance but by their capacity to support human flourishing. This is a healthy corrective to the predominantly technical orientation of the field's earlier period. Australia's unexpectedly high citation impact relative to document volume (Figure 13)—450 citations versus considerably fewer publications than China or the USA—merits specific attention, likely reflecting institutional concentration on high-quality human-centered and sustainable design research with broad international resonance. The comparison with entrepreneurial ecosystem bibliometric (Velt et al., 2020) is instructive: both fields share exponential post-2015 growth, high interdisciplinary dispersion, dominance by technologically advanced economies, and a small number of highly cited foundational texts. The primary difference is that AI-computational architecture research is organized around a set of intersecting technologies whose relationship to architectural practice remains itself a matter of ongoing theoretical contestation making this field simultaneously more dynamic and more theoretically fragile.

## Conclusion

This study has provided the first comprehensive bibliometric portrait of research at the intersection of AI, computational design, and smart built environments in architecture. Analysing 224 publications from 1997 to 2026 using Biblioshiny and VOSviewer, and presenting 19 original figures derived from that analysis, we have documented an exponentially growing, interdisciplinary, and geographically diverse research domain transforming both architectural practice and architectural knowledge.

Six thematic clusters structure the field: AI-assisted computational design; digital fabrication and robotic construction; human-centered intelligent environments; smart and sustainable built environments; architectural education and digital pedagogy; and biomimicry and generative systems. Three principal scholarly communities form the social architecture of the domain, with cross-cluster integration structurally limited and mediated by a small number of bridging researchers. Critical research gaps have been identified and directly evidenced through the bibliometric visualizations presented throughout this article.

The central challenge for the next decade is not merely to extend the frontier of what AI and computational tools can do in architecture, but to develop ethical, theoretical, and methodological frameworks ensuring these capabilities are deployed to enhance human well-being, support social equity, promote ecological regeneration, and enrich the experiential quality of the built environments in which human life unfolds.

## Limitations

This study is subject to several limitations. The Dimensions database does not index all relevant publications, and works in non-English languages or grey literature may have been omitted. The keyword-based search strategy may have missed publications addressing relevant themes without the specific terminology included. Bibliometric analyses reflect structural patterns at the level of

publications and keywords and do not capture the qualitative content or empirical findings of individual studies. The rapidly evolving nature of the field means that patterns identified here may already be evolving in the current literature. Future research should complement the present study with systematic narrative reviews of individual thematic clusters, multi-database searches, and longitudinal analyses.

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