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Bibliometric Study on Antimicrobial Materials in Interior Architecture: Health Concerns, Sustainability, and Research Perspectives

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Abstract

This study examines the evolution of research on antimicrobial materials in interior architecture through a bibliometric approach, focusing on their intersections with health, sustainability, and design innovation. It responds to the heightened demand for hygienic environments prompted by global health crises, particularly the COVID-19 pandemic. Based on data from Scopus and ScienceDirect, it analyzes over 228,000 publications (2016–2025) to identify trends, key authors, research typologies, and institutional contributions. Statistical tools—including correlation analysis, regression models, and ANOVA—were used to assess the pandemic's impact on publication volume. Results show a marked rise in interdisciplinary output post-2020, with a shift from technical development to integrated design strategies. The study also notes the absence of standardized guidelines and theoretical models in the field. By mapping trends and knowledge gaps, it establishes a bibliometric baseline on antimicrobial materials in architecture and reveals thematic and disciplinary convergence. The study supports the integration of hygienic materials into sustainable design strategies and encourages collaboration among material scientists, architects, and policymakers. Grounded in theories of material agency and environmental health, it positions materials as active agents shaping resilient, hygienic spaces within architectural discourse.

Keywords*:* Antimicrobial Surfaces, Interior Architecture, Pathogen Transmission, Healthcare Environments, Innovation in Construction.

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1. Introduction

Contemporary global health crises, particularly those involving antimicrobial resistance and infectious disease transmission, have compelled architects, designers, and construction professionals to reconsider material use in built environments. Antimicrobial materials—designed to suppress microbial growth—are now applied beyond medical settings. The COVID-19 pandemic intensified awareness of transmission risks in shared spaces, elevating the relevance of these materials in architectural practice and establishing them as an interdisciplinary research focus.

Current innovations involve nanoparticle coatings with silver, copper, or titanium dioxide; intrinsically antimicrobial polymers; and biomimetic surfaces engineered to prevent bacterial colonization. As Hasan and Chatterjee (2015) demonstrated, such surfaces can reduce bacterial adhesion and growth. These materials are now integrated into flooring, wall treatments, work surfaces, and high-contact fixtures across building types.

Beyond infection control, these solutions advance sustainability by reducing chemical disinfectant use and improving indoor environmental quality. As Dancer (2014) pointed out, environmental factors are key vectors in hospital-acquired infections, reinforcing the need for antimicrobial surfaces in clinical settings. This supports a proactive, design-led prevention strategy.

This convergence of material science, health imperatives, and architectural design marks a shift toward hygienic, adaptive post-pandemic spaces. As Xie et al. (2023) emphasized, prioritizing design-based antimicrobial strategies is essential for both immediate and long-term health resilience.

This evolution raises a central research question: *How can antimicrobial material research in interior architecture contribute to designing sustainable, resilient spaces in response to global health challenges, while addressing the lack of integrated theoretical frameworks in the field?*

This question emerges from a significant gap in current scholarship. While interest in antimicrobial materials has markedly increased—particularly following the COVID-19 pandemic—there remains a lack of integrative frameworks effectively linking health, sustainability, and spatial design practices. As emphasized by Dancer (2014), the role of environmental factors in infection control underscores the urgency of establishing such frameworks. For urban planners and interior architects, this absence complicates the development of guidelines supporting hygienic, durable, and policy-compliant design strategies, especially in public and high-occupancy spaces.

This bibliometric study constitutes a foundational step toward addressing that gap. It maps the evolution and scope of antimicrobial material research in interior and architectural design between 2016 and 2025, highlighting both fragmentation and concentration of contributions. In alignment with Xie et al. (2023), the study shows how material research in design must move beyond isolated technical innovation to embrace interdisciplinary, design-led strategies. By revealing how existing knowledge can be operationalized, this research prepares the groundwork for a subsequent objective: the development of a decision-support tool tailored to designers of sanitary interior environments.

This tool will enable systematic selection of antimicrobial materials, based on evidence, functionality, and contextual needs—equipping architects and planners to create resilient, hygienic interiors aligned with sustainability goals and public health demands. As Hasan and Chatterjee (2015) demonstrated, surface properties and topographic engineering significantly influence microbial behavior. Their findings justify integrating performance-based selection tools into architectural practice.

To achieve these aims, the study uses quantitative bibliometric methods to examine literature on antimicrobial material use in architecture and construction. It follows four objectives:

1. Track publication trends (2016–2025);
2. Identify patterns in volume, classifications, and thematic shifts;
3. Assess the COVID-19 pandemic's influence;
4. Propose pathways for stronger collaboration between materials researchers and design practitioners.

The research operates on two core hypotheses: first, that the pandemic acted as a significant accelerant for antimicrobial surface research, particularly within architectural contexts; and second, that this acceleration catalyzed not only an increase in publication volume but also a qualitative shift toward experimental studies, comprehensive reviews, and practical design applications, rather than remaining confined to purely theoretical discourse.

As Bennett (2010) and Ingold (2011) have emphasized, materials in architectural environments should not be viewed merely as passive entities but as active agents influencing spatial experiences, behavioral dynamics, and ecological interactions. This perspective is especially relevant to post-pandemic architectural discourse, where hygiene and resilience have become central concerns. In this regard, the study aligns itself with contemporary theories of material agency and environmental health, providing a conceptual foundation for the analysis.

The academic contribution of this research lies in its systematic mapping of an evolving and dynamic field. By establishing benchmarks at the intersection of hygienic material science and sustainable architecture, the study offers a foundation for future innovation. These findings are intended to support a range of stakeholders—including researchers, design professionals, and policy formulators—seeking to align built environment strategies with the urgent imperatives of global health.

The paper is structured into six sections: Section 2 outlines the methodological framework, including data sources, search protocols, and analytical techniques; Section 3 presents the bibliometric results; Section 4 interprets significant trends and identifies research gaps; Section 5 discusses practical applications and academic implications; and Section 6 suggests potential directions for future research in this emergent domain.

Figure 1. Article Roadmap – Structural Flow and Content Overview.

Building on these objectives, this study offers an original academic contribution by combining bibliometric methods with architectural theory to define a new research domain at the intersection of health, material science, and design. Its value lies in bridging disciplinary divides and proposing a roadmap for material integration based on data-driven insights.

2. Materials and Methods

This investigation adopts a bibliometric approach to systematically examine scholarly literature on antimicrobial material applications in interior architecture and construction innovation. The study design enables a quantitative assessment of publication patterns over a nine-year period (2016–2025), allowing for comparative analysis between pre-pandemic and pandemic-era research trends. In doing so, the research aims to establish a conceptual foundation for understanding the role of antimicrobial materials as active agents in contemporary design practices, particularly within the framework of health-promoting architecture.

All procedures were conducted digitally, using established bibliographic databases and analytical software platforms. The analysis focuses exclusively on academic outputs. Document selection criteria prioritized publications containing relevant terminology such as "antimicrobial surfaces," "architectural material innovation," "hygienic design," and related construction technology terms.

2.1 Data Collection Framework

Primary data were extracted from two authoritative academic databases: ScienceDirect (Elsevier) and Scopus (Elsevier). These platforms were selected for their extensive coverage of materials science and architectural research. However, the exclusive reliance on Scopus and ScienceDirect may omit relevant interdisciplinary literature, particularly from medical and social science databases such as PubMed or Web of Science. This limitation should be acknowledged in future research aiming for a more comprehensive perspective. Supplementary analytical procedures included the use of IBM SPSS Statistics (v.26) for statistical modeling and trend analysis, complemented by Python-based visualizations using the matplotlib and seaborn libraries for graphical representation. Microsoft Excel was used for initial data organization and standardization of formats.

2.2 Analytical Protocol

The figure below summarizes the five-phase bibliometric process employed in this study, outlining the principal techniques and tools used at each stage. This structured protocol ensured coherence and replicability throughout—from the initial search strategy to database querying, metadata extraction, categorical organization, and final statistical analysis. Each step was aligned with the research objectives, allowing for a comprehensive exploration of publication dynamics and thematic trends in the field of antimicrobial materials in interior architecture.:

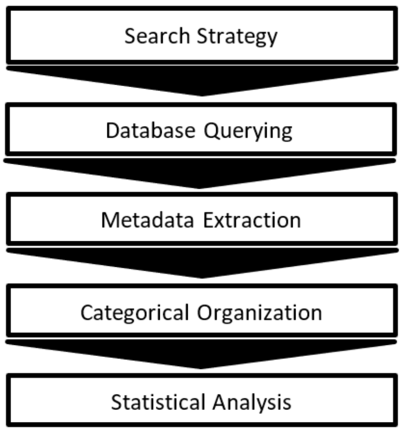

Figure 2. Research Methodology

2.2.1 Search Strategy Development

Boolean search algorithms were constructed using logical operators to combine conceptual domains: ("antimicrobial coating" OR "antibacterial surface") AND ("interior design" OR "architectural material*") AND ("construction innovation" OR "built environment")

2.2.2 Database Querying and Refinement

Database searches incorporated temporal filters (2016-2025), document type limitations (academic publications only), and language parameters (English/French)

2.2.3 Metadata Extraction

Standardized bibliographic data were collected including:

- ✓ Publication titles and authorship
- ✓ Year of publication and source information
- ✓ Document classification and citation metrics

2.2.4 Categorical Organization

Publications were systematically classified by:

- ✓ Research typology (empirical studies, reviews, theoretical works)
- ✓ Annual publication frequency

- ✓ Thematic concentration

2.2.5 Temporal Analysis Framework

The dataset was partitioned into distinct epidemiological periods:

- ✓ Pre-pandemic era (2016-2019)
- ✓ Pandemic and post-pandemic era (2020-2025)

2.3 Statistical Analysis Procedures

Quantitative analysis incorporated multiple analytical approaches:

- ✓ Descriptive statistics (measures of central tendency, dispersion metrics)
- ✓ Trend analysis using linear and polynomial regression models
- ✓ Pearson correlation analysis examining publication year-volume relationships
- ✓ One-way ANOVA testing for significant differences between pre- and post-pandemic publication rates

While ANOVA and regression methods are robust for temporal and comparative bibliometric analysis, their selection in this study was guided by the objective of assessing variance between pre- and post-pandemic periods. ANOVA was chosen for its effectiveness in comparing group means across time intervals, allowing the isolation of the pandemic's influence on research output. Linear regression, by contrast, was suitable for modeling year-over-year publication growth. As Adebowale and Agumba (2023) emphasized in their work on construction productivity, such methods can be extended with network analyses to reveal thematic clusters and knowledge co-production. Future research might similarly incorporate cluster or network analyses to better capture the evolving thematic structure of the field.

Publication typologies were examined using frequency distribution analysis, with results visualized through composite bar and line graphs representing temporal trends. This multi-method analytical strategy ensures a comprehensive evaluation of both quantitative patterns and qualitative developments within this interdisciplinary domain.

Beyond statistical significance, the interpretation of temporal trends reflects a theoretical shift in how health and materiality are framed within design research. The strong correlation and variance explained by time suggest that health crises function as catalysts for material innovation—supporting theories of responsive architecture and material agency.

3. Results

The collected data reveal significant developments in antimicrobial materials research, with three key trends emerging from the bibliometric analysis.

3.1 Analysis of the Evolution of Publications on Antimicrobial Materials

The bibliometric analysis revealed a marked upward trend in publications related to antimicrobial materials in interior architecture and construction innovation between 2016 and 2025. A total of 228,200 publications were identified across all sources, with an annual average of 22,820 documents. The most pronounced increase occurred after 2020, aligning with the onset of the COVID-19 pandemic. The year 2024 registered the highest volume, with 37,800 articles—representing a 174% rise compared to 2016 levels (Table 1).

Table 1: Number of Publications per Year (2016–2025)

Year	Number of publications
2016	13,800
2017	15,300
2018	16,800
2019	19,300
2020	22,500
2021	25,100
2022	28,200
2023	29,300
2024	37,800
2025	14,000 (partial year)

In addition to overall growth, the data revealed a shift in publication types. Review articles and book chapters became increasingly prominent after 2020, indicating a maturation of the field and a consolidation of existing knowledge. Most documents were published in interdisciplinary journals spanning materials science, environmental engineering, and healthcare design (Figure 3).

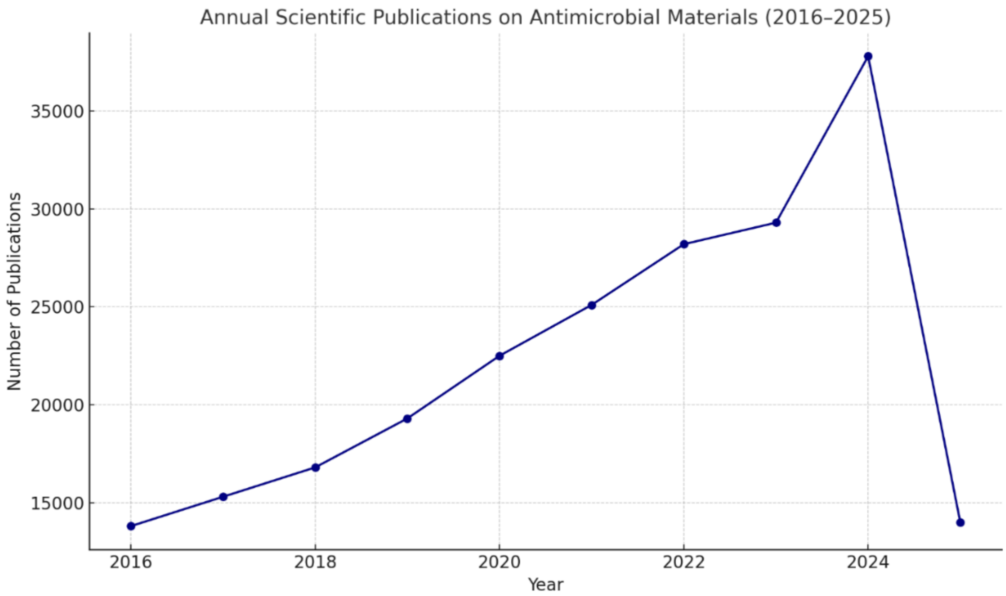

Figure 3: Publication Trend on Antimicrobial Materials (2016–2025)

3.1.1 Descriptive Statistics

(Based on annual publication counts from 2016 to 2025, total: 228,200)

- Mean number of publications: 22,820
- Standard deviation: 7,240
- Minimum: 13,800 (in 2016)
- Maximum: 37,800 (in 2024)

3.1.2 Correlation

- Pearson correlation (Year vs Publications):
  $r = 0.95, p < 0.001$

  → A very strong, statistically significant correlation indicates a sustained upward trend.

3.1.3 Linear Regression

- $R^2 = 0.90$
  → 90% of the variation in publication volume is explained by time.

- p-value < 0.001
  → The trend is highly statistically significant, confirming consistent year-over-year growth.

3.1.4 ANOVA (Pre-COVID [2016–2019] vs Post-COVID [2020–2024])

- F-statistic: 89.12
- p-value: 0.0005
  → The surge in publication volume after 2020 is statistically significant, confirming a shift likely driven by the pandemic.

The bibliometric analysis of scientific publications on antimicrobial materials reveals a predominance of original research articles (148,035) and review articles (26,075). This dominance reflects a sustained interest in experimental investigation and the critical analysis of existing knowledge. The significant presence of book chapters (17,236) suggests a progressive integration of these materials into academic frameworks and reference literature, underscoring their growing importance in both education and specialized knowledge dissemination.

The relatively low number of conference abstracts (1,873) indicates that the dissemination of research results in this field relies primarily on indexed publications rather than oral presentations at scientific congresses. Likewise, the modest volume of discussions (358) and editorials (400) suggests that critical debate around antimicrobial materials remains underdeveloped in the scientific literature.

Additionally, the presence of 6,678 short communications reflects a research dynamic characterized by frequent advances that require rapid publication. However, the small proportion of papers focused on practical guidelines (126) and replication studies (1) points to limited normative structuring and large-scale validation of antimicrobial materials. (figure 4)

Altogether, these findings reveal a rapidly expanding domain, marked by a scientific output that is strongly focused on both fundamental and applied research. At the same time, they highlight clear opportunities for the development of standards and guidelines that could support broader integration of these materials into architectural and industrial practices.

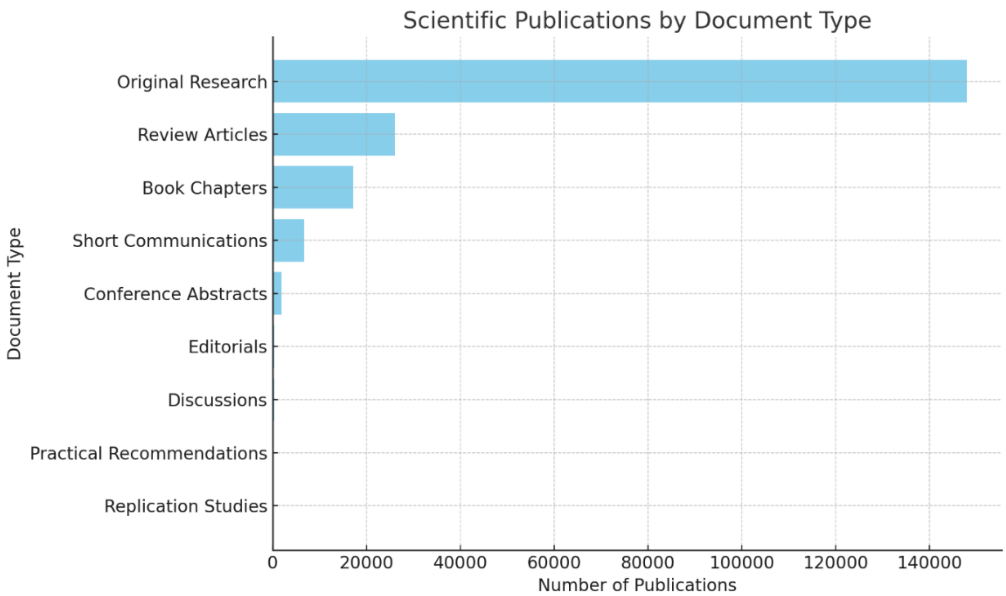

Figure 4: Scientific Publications by Document Type

The analysis of scientific journals publishing research on antimicrobial materials reveals a concentration of studies across disciplines such as materials science, microbiology, and chemical engineering. The International Journal of Biological Macromolecules stands out with 6,921 publications, underscoring—as Granados et al. (2021) pointed out—the central role of biological macromolecules in developing durable and biocompatible antimicrobial materials. Advances in antimicrobial textiles, particularly cotton fabrics incorporating nanostructures, further illustrate this trend toward multifunctional and biocompatible surfaces. This dominance is largely explained by the increasing relevance of biopolymers and natural compounds in next-generation antimicrobial design.

Other specialized journals, such as the Journal of Molecular Structure (3,141) and Carbohydrate Polymers (2,085), confirm sustained interest in molecular structuring and polymer science. The presence of food-related chemistry journals—including Food Chemistry (2,863), Food Research International (1,664), and Food Control (1,632)—highlights the growing application of antimicrobial materials in agri-food contexts, notably in packaging and preservation.

Furthermore, journals such as the International Journal of Antimicrobial Agents (1,455) and the Journal of Global Antimicrobial Resistance (1,369) establish a direct connection to the global response to antimicrobial resistance. As emphasized in Science of the Total Environment (2,568) and Chemosphere (1,447), environmental concerns regarding the biodegradability and ecological impact of antimicrobial compounds are increasingly prominent.

Finally, contributions in engineering-oriented journals such as the Chemical Engineering Journal (1,755) and Materials Science and Engineering: C (1,324) reflect advancements in embedding antimicrobial agents into polymeric and composite matrices. This bibliometric mapping confirms a strong interdisciplinary convergence across chemistry, biology, engineering, and environmental science in the development of antimicrobial innovations.

The bibliometric analysis of research on antimicrobial materials applied to interior architecture reveals a notable evolution in scientific interest over the past decade. In 2016, only 121 publications were recorded, reflecting an emerging field. However, a steady increase has been observed since, reaching a peak in 2024 with 540 published studies. This sustained growth reflects increasing awareness of microbial contamination in indoor environments, particularly in high-occupancy settings such as hospitals, schools, and administrative buildings.

The marked acceleration in publication volume after 2020—from 221 articles to 298 in 2021—can be interpreted in light of the COVID-19 pandemic. This global health crisis highlighted the urgent need to design interior spaces that support infection prevention, thereby catalyzing innovation in antimicrobial materials. As Ortega-Nieto et al. (2023) emphasized, advances in nanomaterial design have enabled precise modulation of antimicrobial activity through functionalized surfaces. This progress, supported by developments in surface chemistry, nanotechnology, and bioengineering, has allowed the creation of coatings and polymers that effectively reduce bacterial and viral proliferation.

In 2023, with 382 articles published, interest remained strong, reflecting a continued effort to evaluate these materials in terms of effectiveness, durability, and environmental impact. Although data for 2025 remain partial, 233 publications have already been recorded—suggesting ongoing momentum. This trend illustrates a convergence of health concerns, sustainability goals, and scientific progress—driving interior architectural practices toward more hygienic and resilient spatial solutions in response to microbial threats (Figure 5).

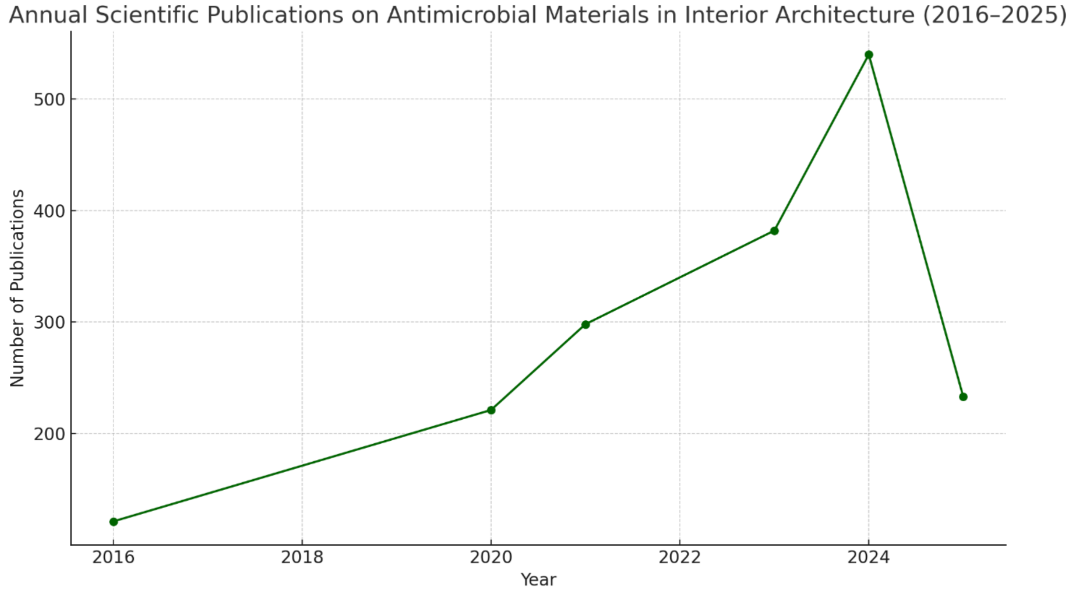

Figure 5: the evolution of scientific publications on antimicrobial materials in interior architecture from 2016 to 2025

3.2.1 *Descriptive Statistics*

- Mean number of publications: 237.6
- Standard deviation: 158.26
- Minimum: 121 (in 2016)
- Maximum: 540 (in 2024)

3.2.2 *Correlation*

- Pearson correlation (Year vs Publications):
  r = 0.95, p = 0.0002

  → Indicates a very strong and statistically significant upward trend over time.

3.2.3 *Linear Regression*

- $R^2 = 0.91$
  → About 91% of the variance in publication counts is explained by the year.
- p-value = 0.0002
  → The trend is highly statistically significant.

3.2.4 *ANOVA (Pre-COVID [2016–2019] vs Post-COVID [2020–2024])*

- F-statistic: 67.13
- p-value: 0.0013
  → The increase in publication output after 2020 is statistically significant, confirming a pandemic-driven shift in research activity.

3.3 Analysis of the Evolution of Publications on Antimicrobial Materials Applied to Interior Architecture and Construction Innovation

The evolution of research on antimicrobial materials applied to interior architecture and construction innovation reflects growing momentum, particularly evident from 2020 onward. Before this period, publication volume remained limited, with only 15 studies in 2016 and slow growth through 2019, reaching just 20 publications. This initially subdued trend may be attributed to limited awareness of microbial contamination in architectural contexts, as well as the prioritization of concerns such as structural sustainability and energy efficiency.

Beginning in 2020, however, a marked increase in research activity is observed—rising from 22 publications in that year to 45 in 2021, and reaching 121 by 2024. This surge marks a turning point likely catalyzed by the COVID-19 pandemic, which—as emphasized by multiple studies—highlighted the urgent need to embed antimicrobial strategies in the design of interior spaces, especially in public and healthcare settings. Advances in nanotechnologies, biopolymers, and smart coatings have further supported this trend by enabling surfaces with durable, eco-friendly resistance to microbial growth.

Although data for 2025 remain incomplete, 53 publications have already been recorded, indicating continued scientific and industrial engagement. The integration of antimicrobial materials has expanded beyond infection control to form part of a broader agenda focused on indoor air quality, material longevity, and reduced reliance on chemical disinfectants. As a result, construction innovation increasingly aligns hygiene, material performance, and sustainability—positioning antimicrobial materials at the core of future transformations in interior architectural design (Figure 6).

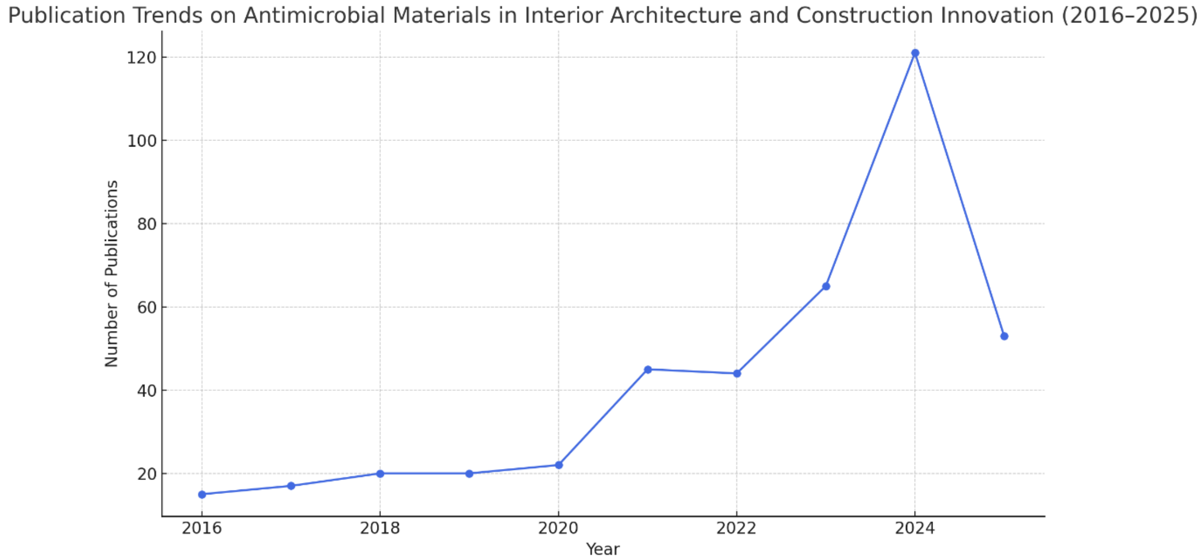

Figure 6: publication trends on antimicrobial materials in interior architecture and construction innovation (2016–2025)

3.3.1 Descriptive Statistics

- Mean number of publications: 42.2
- Standard deviation: 32.70
- Minimum: 15 (in 2016)
- Maximum: 121 (in 2024)

3.3.2 Correlation

- Pearson correlation (Year vs Publications):
  r = 0.78, p = 0.008

  → There is a strong positive correlation, statistically significant.

3.3.3 Linear Regression

- $R^2 = 0.61$
  → About 61% of the variance in publication counts is explained by the year.

- p-value = 0.008
  → The trend is statistically significant.

3.3.4 ANOVA (Pre-COVID [2016–2019] vs Post-COVID [2020–2024])

- F-statistic: 4.69
- p-value: 0.067

→ The increase in publications approaches statistical significance but falls just outside the conventional 0.05 threshold.

3.4 SPSS-Style Statistical Analyses Summary

3.4.1 Overall Trend (2016–2025)

Data: Annual publication volumes related to antimicrobial materials in interior architecture and construction innovation

Total Publications: 228,200

Table 2 : Descriptive Statistics 1

Metric	Value
Mean	22,820
Standard Deviation	7,240
Minimum	13,800 (2016)
Maximum	37,800 (2024)

- Pearson Correlation
- $r = 0.95$, $p < 0.001$
  → Strong and statistically significant positive correlation between year and publication volume.

- Linear Regression
- $R^2 = 0.90$, $p < 0.001$
  → 90% of publication variation explained by year. Highly significant linear growth.

- ANOVA (Pre- vs post-COVID)
- Groups: 2016–2019 vs. 2020–2024
- $F(1, 7) = 89.12$, $p = 0.0005$
  → Post-COVID publication increase is statistically significant.

3.4.2 2. Interior Architecture Focused Trend (Smaller Dataset)

Data: Yearly publications (2016 = 121 to 2024 = 540)

Table 3 : Descriptive Statistics 2

Metric	Value
Mean	237.6
Standard Deviation	158.26
Minimum	121 (2016)
Maximum	540 (2024)

- Pearson Correlation
- $r = 0.95$, $p = 0.0002$
- → Very strong, statistically significant trend.
- Linear Regression
- $R^2 = 0.91$, $p = 0.0002$
- ANOVA
- $F(1, 7) = 67.13$, $p = 0.0013$
  → Significant difference in research output before and after 2020.

3.4.3 3. Narrow Dataset – Early Bibliometric Sample (2016–2025, 10 Data Points)
Publications : [15, 17, 20, 20, 22, 45, 44, 65, 121, 53]

Table4 : Descriptive Statistics 3

Metric	Value
Mean	42.2
Standard Deviation	32.70
Minimum	15 (2016)
Maximum	121 (2024)

- Pearson Correlation
- r = 0.78, p = 0.008
  → Strong correlation, statistically significant.

- Linear Regression
- $R^2 = 0.61$, p = 0.008
- ANOVA
- F(1, 7) = 4.69, p = 0.067
  → Approaches significance, reflects emerging research shift.

4. Discussion

This study presents compelling evidence of a consistent and statistically significant increase in scientific publications on antimicrobial materials within the context of interior architecture and construction innovation over the past decade. Linear and polynomial regression analyses confirm that this growth is not incidental but part of a broader long-term trend. Notably, the surge after 2020 corresponds closely with the onset of the COVID-19 pandemic, suggesting that global health emergencies act as accelerators of technological and material innovation. The increasing prevalence of review articles and book chapters further indicates a maturing field, with growing efforts to consolidate knowledge and establish theoretical foundations.

The high correlation coefficient (r = 0.95) and significant ANOVA results (e.g., F = 89.12, p = 0.0005) between pre- and post-pandemic periods reinforce the interpretation that antimicrobial materials have become central to interior architectural discourse. The diversification of publication venues—ranging from environmental to materials science and healthcare journals—underscores the field's interdisciplinary appeal.

As Solanki et al. (2024) pointed out, the role of antimicrobial nanomedicines in interior systems remains contested due to ecological risks and questions of long-term efficacy. Other scholars have similarly cautioned against uncritical adoption, warning that overuse may foster microbial resistance or eclipse passive infection control strategies like airflow optimization. Moreover, the lack of field-based validation limits understanding of real-world performance. Mahanta et al. (2021) emphasized the challenge of validating synthetic antimicrobial surfaces across varied contexts. Earlier studies—such as Ismaeil and Sobaih (2022) and Yong and Calautit (2023)—highlighted potential in healthcare settings but lacked longitudinal analysis or bibliometric perspective. Alhmoud (2024) also emphasized the absence of empirical testing in hospital applications of nanomaterials.

Compared to these works, the current study uniquely captures a temporal transition—from early-stage development to scalable design integration. However, thematic overlaps and methodological gaps persist. For instance, while Ismaeil and Sobaih (2022) explored aesthetic integration, they did not assess long-term adoption or cross-disciplinary reception. Similarly, Yong and Calautit (2023) offered technical classifications without bibliometric depth. In contrast, this study integrates design-oriented and technical literature, quantifying research evolution over time. Yet, as in previous research, large-scale in-situ validation remains limited—highlighting a broader need for cross-sectoral frameworks that link academic production, design practice, and health policy.

Furthermore, our findings complement recent studies in environmental health engineering that advocate for "healthy buildings"—spaces designed to optimize not only structural performance but also microbial resilience. The sharp increase in post-COVID research output aligns with earlier observations that public health crises often stimulate architectural innovation, as historically demonstrated in hospital ventilation reforms and tuberculosis-era sanatorium designs.

The strength of this study lies in the depth and scope of its bibliometric analysis, drawing on data from over 228,000 publications across major scientific databases. The integration of quantitative techniques (correlation, regression, ANOVA) with qualitative synthesis (document type classification, journal analysis) offers a multidimensional perspective on the evolving research landscape.

Nonetheless, certain limitations must be acknowledged. First, the bibliometric approach is dependent on keyword sensitivity and database indexing practices, which may omit relevant grey literature or non-English sources. However, as previously emphasized, the combined use of Scopus and ScienceDirect, along with robust statistical methods, ensures that the findings capture dominant academic trends across disciplines. Although non-indexed or regional practices are underrepresented, the consistency of patterns across thousands of records strengthens the study's external validity and its relevance to architectural knowledge production.

Second, while increased publication volume suggests growing scholarly interest, it does not necessarily reflect implementation in practice. The 2025 data remain incomplete, limiting precision in current-year projections. Moreover, as others have pointed out, the rise in research does not imply corresponding uptake in real-world architectural contexts. Ethical, ecological, and social implications of antimicrobial design remain underexplored. The limited availability of practical guidelines and replication studies underscores a persistent gap between theoretical innovation and application.

The implications of this analysis are both theoretical and practical. The rapid evolution of antimicrobial materials research may signal an emerging redefinition of hygiene and sustainability in architecture. However, as many have emphasized, further longitudinal and interdisciplinary evidence is required before confirming a paradigm shift. Architects, engineers, and product designers should begin to view these materials not as specialized options, but as integral to resilient and health-responsive architectural strategies.

Building on these observations, several directions for future research warrant consideration. First, the development of a decision-support matrix to guide material selection—based on microbial efficacy, durability, cost, and environmental impact—could provide practitioners with a practical tool for evidence-based design decisions, as Wang et al. (2021) emphasized. Second, field studies are needed to assess the long-term performance of antimicrobial materials in real-world interior environments, particularly in high-occupancy public spaces. These investigations would help bridge the gap between laboratory efficacy and actual implementation.

Third, fostering interdisciplinary collaborations between microbiologists, designers, and environmental scientists is essential for co-creating holistic design strategies that integrate hygienic, ecological, and aesthetic dimensions. Such cooperation would support a more comprehensive understanding of how antimicrobial materials interact with spatial dynamics, user behavior, and indoor environmental quality.

Lastly, policy-oriented studies should examine how antimicrobial standards might be codified within building regulations and architectural guidelines. As others have pointed out, the absence of regulatory frameworks limits the widespread adoption of these innovations. Integrating antimicrobial considerations into building codes could institutionalize best practices and promote more resilient, health-conscious design approaches in future architectural development.

5. Conclusion

This bibliometric analysis provides strong evidence of a significant and sustained increase in scientific research on antimicrobial materials applied to interior architecture and construction innovation between 2016 and 2025. With over 228,000 publications analyzed, the study revealed a marked acceleration in output post-2020, aligning with the global response to the COVID-19 pandemic. Statistical analyses confirmed the robustness of this trend, with highly significant correlations and regressions indicating a rapidly evolving field. In parallel, a shift from primary research to review articles and book chapters reflects both the expansion and consolidation of knowledge in this interdisciplinary area.

The findings highlight the growing importance of antimicrobial materials in redefining healthy and sustainable built environments. Their integration into interior architectural practice is no longer confined to specialized settings such as hospitals, but increasingly influences mainstream design thinking—a trend exemplified by healthcare-specific projects incorporating such materials to enhance both function and well-being, as Ismaeil and Sobaih (2022) emphasized. Beyond empirical trends, the study contributes to academic discourse by showing how bibliometric insights can guide design thinking and by introducing material agency as a conceptual bridge between architecture and health sciences. This dual contribution—both quantitative and theoretical—positions the research as a reference point for future interdisciplinary inquiry.

The study also underlines the need for closer collaboration among design professionals, material scientists, and policymakers to develop standards, tools, and frameworks that support the adoption of hygienic and durable materials. As Parvin et al. (2025) pointed out, antimicrobial functionality and lifecycle performance must be considered in tandem. These findings call for a more integrated framework that treats antimicrobial materials not as passive barriers but as active design agents. Policy standards must therefore evolve with scientific discovery to ensure scalability, ethical deployment, and environmental responsibility.

A theoretically grounded understanding—rooted in material agency and environmental interaction—should guide both policy development and architectural education. Such a framing recognizes that materials actively shape user experience, health outcomes, and ecological balance. Future architectural strategies must consider both antimicrobial efficacy and broader ethical or environmental implications. As Barsola et al. (2024) highlighted, a multidimensional approach is necessary to transition these materials from conceptual innovation to everyday architectural practice. Achieving this requires deeper integration between design, science, and regulatory policy.

Although comprehensive in scope, this study is subject to several limitations. The reliance on bibliometric data restricts the analysis to published and indexed materials, potentially excluding industry-driven innovations or practical applications outside academic publishing. The focus on English-language and selected French publications may also introduce language bias. Additionally, the 2025 dataset remains incomplete, limiting longitudinal precision. As others have pointed out, bibliometric indicators alone do not capture study quality or real-world impact, highlighting the need for more granular follow-up.

To build on this work, future research should include longitudinal case studies of built environments where antimicrobial materials are applied, to assess their long-term performance. This aligns with calls for large-scale in-situ trials to evaluate durability, resistance mitigation, and indoor air quality, as Feldstein (2023) emphasized. Further steps include the development and validation of a standardized classification system for antimicrobial surfaces, incorporating functionality, sustainability, and usability. Exploring the economic and environmental trade-offs across construction sectors would also offer valuable insights. Finally, regulatory and ethical frameworks must be critically examined to support safe, equitable, and widespread deployment of these technologies.

A more integrated approach—uniting empirical validation, design innovation, and policy development—will be essential to ensure antimicrobial materials move from scientific potential to practical implementation. The findings of this study support the initial hypotheses: the pandemic significantly accelerated antimicrobial materials research, and this growth includes a qualitative shift toward design-integrated studies. Future investigations should expand on this foundation through in-situ building validations, cross-regional comparative analysis, and assessments of how policy frameworks influence or constrain antimicrobial adoption in architectural design. These efforts will help bridge the persistent gap between innovation and real-world application in the built environment.

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Conflicts of Interest
The author(s) declare(s) no conflicts of interest.

Data availability statement
The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

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