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Article

Interdisciplinarity in the Built Environment: Measurement and Interdisciplinary Topic Identification

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Abstract: Interdisciplinary research plays a crucial role in addressing the intricate scientific and social challenges confronting society. The field of built environment, as an interdisciplinary discipline, has benefitted from cross-pollination with various fields such as architecture, environment, medicine, and psychology, leading to a range of interdisciplinary advancements. Nevertheless, there remains a gap in the systematic documentation of interdisciplinary outcomes within this field. This paper utilized the cosine index and the Rao–Stirling index to assess the level of interdisciplinarity within the built environment field. This was followed by the screening of literature achievements with a high interdisciplinary nature, the identification of interdisciplinary topics based on the latent Dirichlet allocation (LDA) model, and the analysis of the evolution path of interdisciplinary topics based on time series. The results demonstrate that the field of built environment exhibits a high degree of interdisciplinary integration, with the most prevalent crossovers observed with medicine, psychology, and public health science, and fewer crossovers with electrochemistry, crystallography, and nanotechnology, which represent potential emerging directions. Over the past three decades, 17 core interdisciplinary topics have emerged in the field, and the overall evolutionary trend over time has been one of divergence, followed by contraction and then divergence. This study provides scholars with up-to-date knowledge from an interdisciplinary perspective, and facilitates the development of interdisciplinary research and cooperation in this field.

Keywords: built environment; indoor air quality; indoor environment; interdisciplinary measurement; topic identification; topic evolution; LDA modeling

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1. Introduction

The contemporary global landscape is characterized by the emergence of big science, necessitating the integration of knowledge from diverse disciplines to effectively address complex scientific challenges [1]. Interdisciplinary research has thus become the predominant research paradigm, serving as a crucial mechanism for advancing fundamental research, fostering original and disruptive innovation, and facilitating the development of novel technologies [2]. Interdisciplinary research has garnered global recognition among scholars and societies, as evidenced by initiatives such as the National Science Foundation (NSF) in the United States, which provides funding for interdisciplinary research projects and promotes collaborative research across traditional disciplinary boundaries [3]. Similarly, the European Union's Horizon 2020 funding program was established to facilitate the exploration and development of emerging cross-disciplinary fields through interdisciplinary funding mechanisms. This enhances the efficacy of scientific research, fosters scientific and technological advancements, and streamlines the conversion of scientific and technological innovations into tangible outcomes by eliminating obstacles to innovation across various disciplines [4]. The Chinese government has implemented strategies, such as the national medium- and long-term scientific and technological development plan, which establish interdisciplinary research institutions and laboratories and promote backing for interdisciplinary research and innovation. The trend toward interdisciplinarity is a pervasive phenomenon in scientific advancement, as all areas of research are increasingly transitioning from intra-field investigations to interdisciplinary approaches in the pursuit of innovative breakthroughs.

Researchers define the built environment as encompassing all buildings, spaces, and products that are created or modified by people [5]. It includes the indoor and outdoor physical environments (e.g., thermal environments, acoustic environments, light environments, climatic conditions, and air quality) [6] as well as the social environments (e.g., urban design of cities, villages, and neighborhoods, transport systems, and land-use planning and policies) [7]. The current definitions of the built environment are relatively broad because they cover a wide range of disciplinary areas, and as an interdisciplinary subject, the built environment has been cross-fertilized with a number of disciplines such as architecture, physics, materials science, medicine, psychology, biology, and computing. As a space inseparable from human production and life, architecture and environment have far-reaching impacts on many aspects of human beings. Currently, part of the research by scholars on the built environment has focused on how buildings meet people's basic needs such as the building scale, building structure, building function, and layout, while others have focused on the challenges of providing adequate access (roads, motorways, infrastructure, public transport), urban sprawl, air pollution due to increased traffic, lack of pavements, and degradation of the natural environment as well as exploring the impact of the built environment on human physical and mental health and quality of life.

Interdisciplinary research in various subject areas foreshadows the direction of future research and major scientific breakthroughs. An escalating number of academics are demonstrating a growing interest in exploring interdisciplinary matters. For example, Jang et al. [8] employed the Glänzel–Schubert–Schoepflin model to project the anticipated citation frequency within the realm of nanotechnology and forecasted its potential for interdisciplinary collaboration in the forthcoming years based on the diversity index. Zeng et al. [9] constructed an interdisciplinary weighted average citation index space within information science and library science (LIS) by extracting knowledge elements through a Lexicon-LSTM model for measuring interdisciplinary features and contributions based on knowledge elements. Alasehir and Acarturk [10] proposed a literature similarity approach to quantify the interdisciplinarity of cognitive science and designed and developed a model to analyze the cognitive science domains using Doc2Vec.

Overall, interdisciplinary situations have been researched in various fields. However, scholars have not yet explored the mining of interdisciplinary situations and topic identification for the built environment. Therefore, how to identify the characteristics of the interdisciplinary in this field as well as the potential interdisciplinary topics and discover the future research frontiers in the field of built environment are the focus and novelty of this study. Although there has been a lot of research on the built environment, most scholars have focused on specific content in this area of the built environment, however, few scholars have used interdisciplinary research methods to review and explore, across disciplines, the overall research in this area of the built environment, identify the research hotspots and trends, and summarize the relevant research from a more comprehensive perspective.

In order to fill this considerable gap, this paper explored and analyzed the interdisciplinary situation in the field of the built environment through bibliometrics, interdisciplinary measures, and machine learning to identify interdisciplinary research topics and evolutionary trends in the field. Our results provide scholars with up-to-date knowledge from an interdisciplinary perspective, facilitate the development of interdisciplinary research and cooperation in this field, and the in-depth analyses of the research conclusions will provide important references and guidance for future architectural design and environmental planning.

The remainder of the article is structured as follows. Section 2 outlines the data sources and methodology employed in this study including the methods and indicators utilized for interdisciplinary measurement and theme identification. Section 3 presents the results of the interdisciplinary measurement and the distribution and evolutionary path of interdisciplinary themes within the field of the built environment. Section 4 analyzes and discusses the results. Section 5 provides a summary of the study, identifies research limitations, and presents the contributions of this study.

2. Data and Methods

2.1. Data Acquisition

In order to examine the interdisciplinary nature of the built environment field, it is imperative to gather a diverse array of literature as a foundation for research. This approach facilitates a more impartial evaluation of the field's interdisciplinary attributes and the detection of emerging interdisciplinary themes. This paper used the Science Citation Index Expanded (SCI), the Social Sciences Citation Index (SSCI), and the Arts and Humanities Citation Index (A&HCI) as data sources for the literature search in the field of built environment. The search terms used were "building* environment*" and "built environment*". The search formula was as follows:

TS = ("building* environment*" OR "built environment*")

Regarding the data and methodology section, this study refers to Saunders' research onion [11]; the research philosophy of this study was to explore the interdisciplinary situation in the field of the built environment; the type of research was a mixed-methods study; the time horizon of the study was from 1995–2023; the data collection method was the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (the sampling and screening process of the data is shown in Figure 1); and the data analysis techniques used were R programming techniques and LDA topic model. This study strictly applied the PRISMA statement for retrieval and screening [12] as it is a systematic data collection method following the four-step process of identification, screening, eligibility, and inclusion of the records. Similar studies have adopted this approach for the review process and content analysis [13,14]. Figure 1 explains the collection process through the PRISMA.

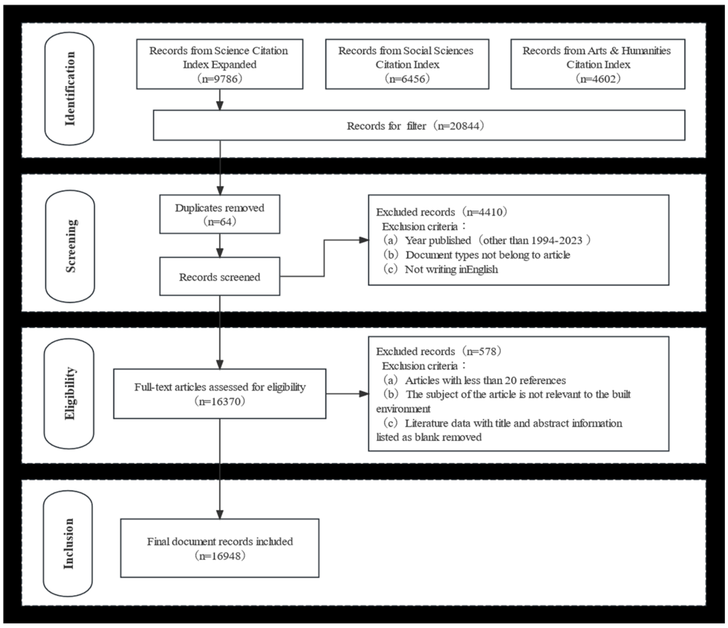


Figure 1. Inclusion and exclusion flowchart for articles.

The literature search encompassed titles, abstracts, and keywords spanning 1995 to 2023, resulting in an initial retrieval of 20,844 documents. Subsequent data cleaning procedures led to the acquisition of 16,948 literature data records, as detailed in Table 1.

Table 1. Detailed list of the literature titles.

Type of Information	Number of Messages
Number of literature data	16,948
Literature timeframe	1995–2023
Number of references	353,009
Download catalog content	Author, title, year of publication, keywords, abstract, country, institution, source journal, citations, etc.

2.2. Methods

2.2.1. Interdisciplinary Measures

The measurement of interdisciplinarity is a current topic of concern in various fields. Existing methods mainly focus on measuring disciplinary diversity, such as the Shannon entropy, Brillouin index (BI), cross-citation index (COC), and Rao–Stirling index. The Shannon entropy evaluates the degree of interdisciplinary knowledge exchange within a field by examining the balance of interdisciplinary [15]. Brillouin and Hellwarth [16] proposed the Brillouin index (BI) to measure diversity based on the principle of information entropy calculation. Porter and Chubin [17] proposed the cross-citation index (COC), which measures the degree of intersection in a specific field by using the proportion of references in a given disciplinary field that come from other disciplinary fields. Chen et al. [18] proposed an improved weighted citations outside category (WCOC) index to characterize the diversity of other subject areas in detail. Stirling [19] proposed the Rao–Stirling index in 2007, which integrates the richness of the number of disciplines, the balanced distribution of disciplines, and the differences between disciplines, and has become an important indicator for measuring the degree of knowledge integration.

When assessing the level of interdisciplinarity within a particular field, scholars have primarily focused on indicators of disciplinary diversity and equilibrium, predominantly through the lens of the quantity of disciplines engaged. It is imperative to recognize that while an article may incorporate numerous disciplines, if they are closely interconnected, the extent of interdisciplinarity may be limited. The degree of interdisciplinarity within a field can be gauged by the variance among the disciplines involved. The presence of diverse disciplines within a field can facilitate the overcoming of cognitive barriers and foster creativity, ultimately resulting in the emergence of novel knowledge, ideas, and technologies. Consequently, the degree of disciplinary difference serves as a pivotal determinant of interdisciplinarity. This study aimed to identify interdisciplinary topics in the field of the built environment and explore new knowledge from a disciplinary difference perspective. To measure interdisciplinarity, a variant of the Rao–Stirling indicator was used. The methodology is as follows:

(1) Generating a co-occurrence matrix for disciplines

This paper analyzed the disciplinary relationships within the field of the built environment using the retrieved literature data. To achieve this, a disciplinary co-occurrence matrix was established by constructing a "journal abbreviation-journal full name-discipline mapping table" [20] based on references. The process is shown in Figure 2.

By analyzing the co-occurrence of a discipline with other disciplines, it is possible to obtain the internal structure of a discipline $SC_i = (SC_{i,1}, \ldots SC_{i,j}, \ldots SC_{i,n})$. After analyzing all n disciplines in the SC system, the co-occurrence structure of disciplines in the entire system can be obtained and denoted as:

$$SC = (SC_1, \ldots SC_i, \ldots SC_n)^T = \begin{bmatrix} SC_{1,1} & \cdots & SC_{1,n} \\ \cdots & SC_{i,j} & \cdots \\ SC_{n,1} & \cdots & SC_{n,n} \end{bmatrix}$$

where $SC_{i,j}$ denotes the number of co-occurrences between discipline i and discipline j. Discipline i is assigned an n-dimensional feature quantity $SC_{i,j}$ is based on its internal structure SC_i. The association characterizing discipline i with discipline j is transformed into a relationship between feature vectors SC_i and SC_j. The discipline co-occurrence matrix C, generated in this study, was a 237-order symmetric square matrix. The diagonal numbers represent the frequency of each discipline's appearance in the 16,948 article citations.

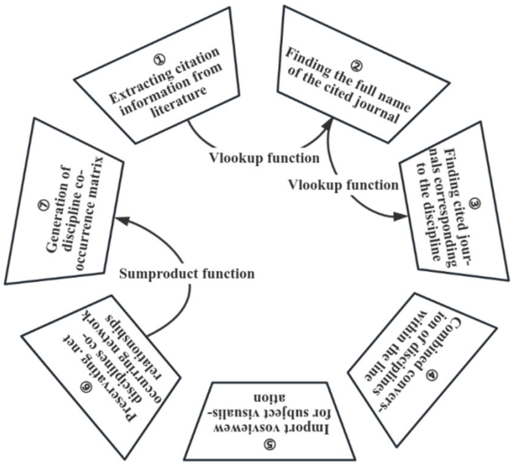


Figure 2. Flowchart showing the co-occurrence of disciplines.

(2) Measurement of disciplinary similarity

Disciplinary similarity pertains to the extent of resemblance among distinct academic disciplines. A greater similarity indicates a closer relationship between disciplines, while a lower similarity suggests a greater divergence. Various methods, such as cosine similarity [21] and the Jaccard similarity coefficient [22], can be employed to quantify disciplinary similarity. Lancho-Barrantes and Cantu-Ortiz [23] utilized the cosine similarity formula in their examination of research preferences in comparative disciplinary fields to determine the degree of similarity between research universities, while Chen [24] conducted an investigation into the presence of user interest similarities between Web of Science (WoS) and Springer by employing Jaccard similarity coefficients, statistical rankings, and superposition mapping. In a similar vein, Hamers et al. [25] juxtaposed the Salton cosine and Jaccard index metrics to analyze disciplinary disparities, ultimately determining that the Salton cosine metric generally outperformed the Jaccard index. Consequently, this study opted to utilize the widely accepted Salton index for the assessment of disciplinary similarity. The formula for the Salton index is as follows:

$$\text{Cosine}(x,y) = \frac{\sum_{i=1}^{n} x_i y_i}{\sqrt{\sum_{i=1}^{n} {x_i}^2}\sqrt{\sum_{i=1}^{n} {y_i}^2}} \tag{1}$$

This study employed the cosine similarity algorithm to determine the degree of similarity between disciplines within the literature of the built environment field, utilizing a discipline co-occurrence matrix. The resulting discipline similarity matrix, denoted as R, represents the similarity values between disciplines. The formula for calculating the discipline similarity is outlined as follows:

$$SC_{ij} = COS(SC_i, SC_j) = \frac{\sum_{k=1}^{n} SC_{i,k} SC_{j,k}}{\sqrt{\sum_{k=1}^{n} {SC_{i,k}}^2}\sqrt{\sum_{k=1}^{n} {SC_{j,k}}^2}} \tag{2}$$

(3) Calculating disciplinary differences

In 1994, Stirling introduced the diversity theory and subsequently formulated the Rao–Stirling indicator. This indicator holistically evaluates the abundance of disciplines, their equitable distribution, and their divergences, rendering it a significant instrument for assessing the extent of knowledge integration. The Rao–Stirling indicator is capable of delineating distinctions between disciplines at their intersections. A higher Stirling value signifies more pronounced disparities among disciplines and a heightened level of interdisciplinarity. The formula for the measurement is shown below:

$$\Delta = \sum_{ij} (d_{ij})^{\alpha} (p_i p_j)^{\beta} \quad (3)$$

where p_i and p_j represent the probability distributions of different disciplines, d_{ij} represents the distance between different disciplines in the disciplinary network, and α and β are measurement parameters. Allowing all possible permutations of exponents α and β to take values of 0 and 1 results in four variants of the heuristic Δ [19]. Each variant effectively reflects one of the four interdisciplinary attributes: variety, balance, differentiation, and diversity, as shown in Table 2.

Table 2. The four variants of Δ and the measurement properties.

Causality	α	β	Formulas
Type	0	0	$\Delta = \sum_{ij} \left(d_{ij}\right)^0 \left(p_i p_j\right)^0$
Balance	0	1	$\Delta = \sum_{ij} p_i p_j$
Difference	1	0	$\Delta = \sum_{ij} d_{ij}$
Variegation	1	1	$\Delta = \sum_{ij} d_{ij} p_i p_j$

This paper employed the third variant of the Rao–Stirling metric formula $\Delta = \sum_{ij} d_{ij}$ to measure the disciplinary difference of a single paper. The formula indicates that higher disciplinary similarity corresponds to lower differences [26].

2.2.2. Topic Identification

Three methods exist for identifying interdisciplinary topics within relevant fields. The first method, known as co-occurrence analysis, involves utilizing keywords to construct an interdisciplinary knowledge association network through the quantification of frequencies or the development of models to uncover implicit or potential interdisciplinary research topics [27]. For instance, Dong et al. [28] conducted a thorough examination of interdisciplinary topics within the realm of library intelligence by employing co-occurrence networks, high-TI words, burst monitoring, and various other methodologies. Another method used is co-citation analysis, which considers whether the jointly cited literature has similar research topics and constructs a co-citation network accordingly. The research topics are then represented based on the literature groups obtained from the network mining [29]. For instance, Chen [30] used the updated version of CiteSpace to analyze the diverse network of co-cited documents and key terms of cited documents to identify emerging topics. Additionally, there is another type of text mining that automatically extracts semantic information from unstructured text and identifies topics [31]. For instance, Raimbault [32] employed citation network analysis and semantic analysis to examine the interdisciplinary research topics of the Journal of Geography Generalists. This was achieved by constructing a large corpus of almost 200,000 articles.

Presently, text-mining techniques for topic identification predominantly utilize topic models, a prevalent method in the machine learning domain that effectively uncovers and refines implicit topic information from extensive text datasets. One of the most widely used topic models is latent Dirichlet allocation (LDA), which has been applied in various fields of text analysis including opinion monitoring, community discovery, and research hotspot detection. A hierarchical Bayesian model is used to identify the underlying semantic structure of a document. The LDA model was initially introduced by Blei et al. [33] in 2003. This model utilizes probability distributions to enforce the adherence of topics to a Dirichlet polynomial prior distribution, thereby yielding a coherent set of topics. Furthermore, the correlation topic model (CTM) was proposed as a dynamic topic model that incorporates considerations of topic correlation and timestamp information [34]. Subsequent advancements in the field include the author-topic model, the author-role-topic model, and the online LDA (OLDA) model, which build upon and extend the original LDA framework [35,36]. Due to its high semantic and contextual focus, strong predictive power, and extensive research, LDA is widely used for topic identification in various fields. Therefore, this study also employed LDA to identify interdisciplinary topics in the field of the built environment.

The LDA model typically evaluates clustering results using perplexity levels to determine the optimal number of topics. In articles, perplexity indicates the uncertainty of the number of topics trained by the LDA model. Lower perplexity indicates lower uncertainty and better clustering results. The formula to calculate perplexity is as follows:

$$perplexity(W) = \exp\left\{-\frac{\sum_{d=1}^{M}\sum_{w_i \in d}\log\left(p\left(w_i \middle| d_j\right)\right)}{\sum_{d=1}^{M} N_d}\right\} \tag{4}$$

where $p\left(w_i \middle| d_j\right)$ is the probability of each word's occurrence in the document set and is calculated as follows:

$$p\left(w_i \middle| d_j\right) = \sum_{q=1}^{k} P\left(z_q \middle| d_j\right) P\left(w_i \middle| z_q\right) \tag{5}$$

where $P\left(z_q \middle| d_j\right)$ represents the probability of each topic's occurrence in a document, and $p\left(w_i \middle| z_q\right)$ represents the probability of each word's occurrence under a topic. The denominator in the formula represents the total number of words in the document set. This study used Sklearn's LDA module to identify topics in the interdisciplinary literature related to the built environment.

To thoroughly examine the interdisciplinary nature of the built environment field, this study began by collecting the literature data related to the field and constructing a disciplinary co-occurrence matrix. The similarity between the disciplines involved in the field and the disciplinary differences of a single article were then measured using the cosine index and the Rao–Stirling index. Finally, we identified the interdisciplinary topics in the field of the built environment and their evolution through the LDA model. The research framework of this paper is shown in Figure 3.

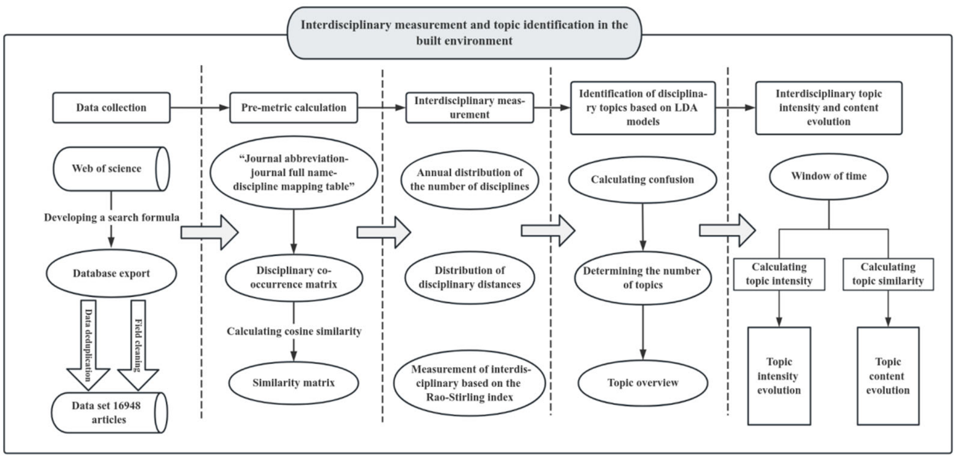


Figure 3. Diagram of the research idea.

3. Results and Analysis

3.1. Interdisciplinary Measurement in the Built Environment

3.1.1. Annual Distribution of the Number of Disciplines

(1) Disciplinary distribution of citing paper in the built environment

The disciplinary origin of the citing paper on the built environment revealed that it encompassed 237 disciplines. The most dominant category was Public Environmental Occupational Health, followed by Environmental Sciences, Engineering Civil, Construction Building Technology, and other disciplines. Figure 4 displays the top 10 disciplines with the highest number of publications. Regarding the time course, there was less focus on built environment issues before 2005. After that, the discipline of Public Environmental Occupational Health took the lead in paying attention to these issues, which then became a research hotspot. The number of articles per year steadily increased thereafter. In 2014, there was an increase in the attention paid by Environmental Sciences to built environment issues. Since then, the number of articles on this topic has increased rapidly. In the period of 2020–2023, the number of articles on built environment issues exceeded that of Public Environmental Occupational Health, making it a new area of research.

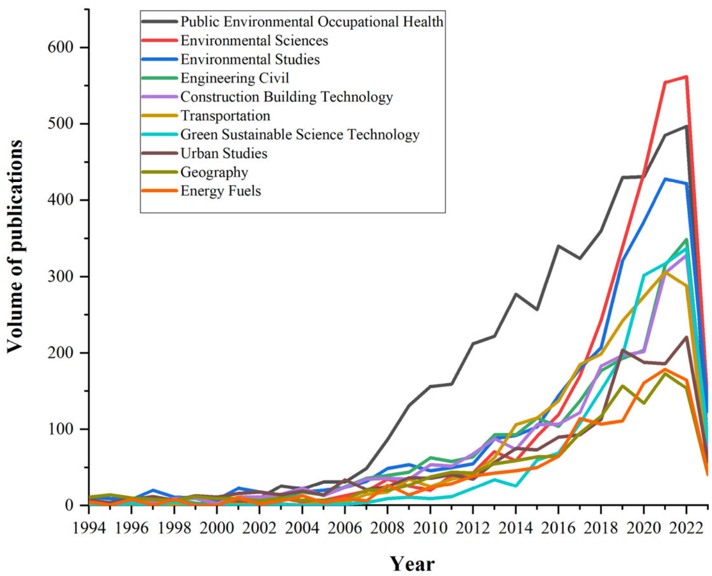


Figure 4. Line graph of the annual distribution of the disciplines of citing papers.

(2) Disciplinary distribution of cited paper in the built environment

The disciplinary provenance of the references about the literature in the field of the built environment indicates that there is a more extensive range of sources of knowledge in this field, as evidenced by the statistics in Figure 5. The main disciplines contributing to knowledge on the built environment were Public Environmental Occupational Health and Engineering Civil. Medicine General Internal, Geography, and Environmental Sciences also contributed, but to a lesser extent. This indicates that Public Environmental Occupational Health and Engineering Civil are the mainstream disciplines in this field. Occupational health is a hot issue of greater concern in the construction industry, and as one of the highest risk industries, the safety and health of construction workers has attracted the attention of scholars. Visual cues can effectively reduce the cognitive load of workers in the process of safety training, prompting workers to allocate more attention to the areas where safety hazards exist, thus detecting safety hazards more quickly [37]. Negative emotions play an important role in risk perception, and appropriately inducing fear arousal may enhance the construction workers' ability to avoid risk, particularly among those who have previously been injured [38]. In addition, cited papers covered a wider range of disciplines than cited papers such as Medicine General Internal, Geography, Multidisciplinary Sciences, Regional Urban Planning, and Economics.

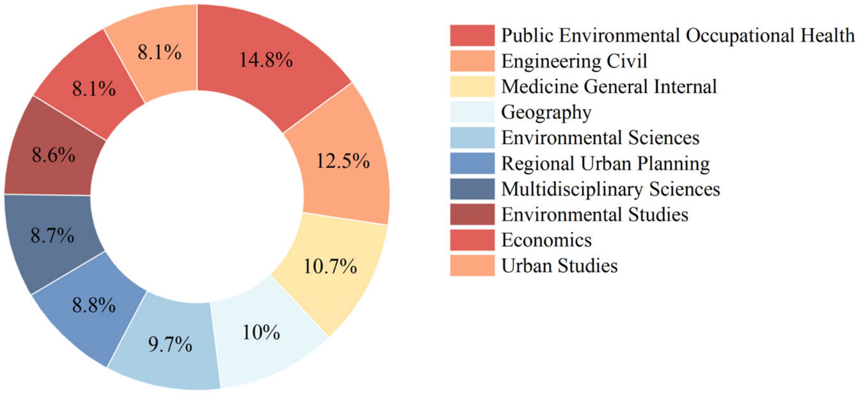


Figure 5. Distribution of cited papers' disciplines.

3.1.2. Disciplinary Distance Analysis

By employing the interdisciplinary measurement method detailed in Section 2.2.1, we could determine the distance between the disciplines of reference sources within the built environment field. This distance can be visualized in a 3D scatter plot utilizing the origin software, as depicted in Figure 5. The plot illustrates disciplines along the x and y axes, while the z-axis signifies the distance separating two disciplines. Notably, the highest frequency of discipline combinations with distances ranging from 0.4 to 0.6 was observed. Logic was mentioned in only one document, and co-occurred with only a few disciplines in this article, resulting in low similarity values between Logic and most other disciplines and large disciplinary distances. The disciplines with the largest disciplinary distances in Figure 6 were all intersections between Logic and other fields such as Literary Reviews, Asian Studies, Rheumatology, History, and Ornithology. These disciplines were cited in articles in the field of the built environment to provide an interdisciplinary idea and a theoretical basis for research. Therefore, it is suffice to say that the field of the built environment covers a wide range of research topics and has a high degree of interdisciplinary research.

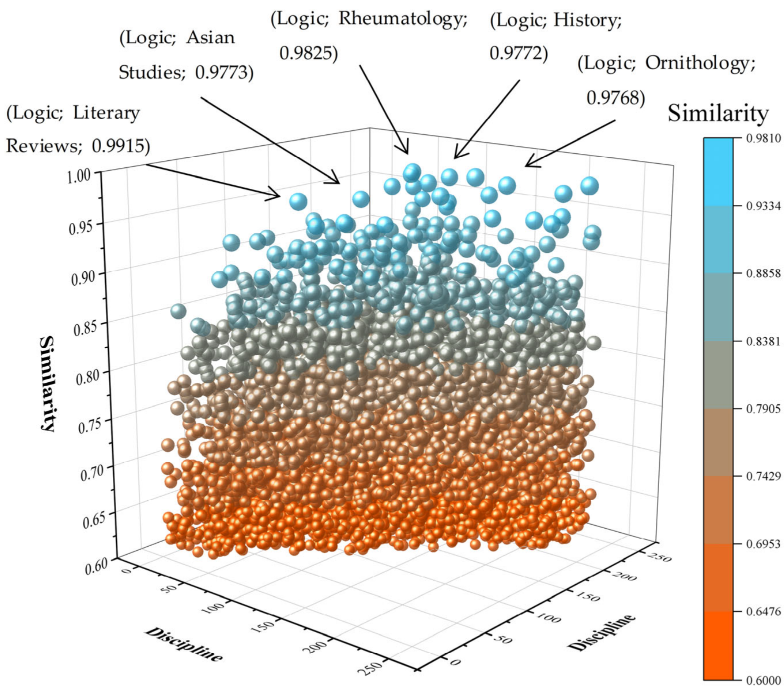


Figure 6. Scatter plot of disciplinary distances.

Furthermore, the intersection of the built environment field with other disciplines can be analyzed by considering two main disciplines—Public Environmental Occupational Health and Engineering Civil—as examples. Table 3 shows the disciplinary distances between Public Environmental Occupational Health and other disciplines. The greatest distance was with Microscopy, followed by some disciplines in Chemistry, Materials, and Physics. This suggests that the field of the built environment is concerned not only with occupational health issues, but also with incorporating knowledge from other disciplines to improve the built environment through Chemistry, Materials, and Physics.

Table 3. Co-occurring disciplines and disciplinary distance in Public Environmental Occupational Health.

Disciplinary	Disciplinary Distance	Number of Co-Occurring Papers
Microscopy	0.849	1
Electrochemistry	0.815	3
Materials science, ceramics	0.775	3
Physics, Atomic, Molecular, and Chemical	0.773	6
Chemistry, Inorganic, and Nuclear	0.771	2
Crystallography	0.76	2
Nanoscience and Nanotechnology	0.754	5
Materials Science, Composites	0.743	6
Mineralogy	0.742	3
Chemistry, Physical	0.729	22
Engineering, Petroleum	0.705	1

Table 4 illustrates the varying degrees of distance between the discipline of Engineering Civil and other disciplines. Engineering Civil was found to be the most distant from the discipline of Logic, which was supported by the fact that Logic was only referenced in one article and did not exhibit any interdisciplinary trends. Additionally, the proximity of Engineering Civil to the discipline of biology was highlighted, suggesting a growing collaboration between civil engineering scholars and scholars in the field of biology to examine built environment issues from a physiopathological perspective. Furthermore, the interdisciplinary nature of the built environment field was exemplified by the fact that Public Environmental Occupational Health as well as Engineering Civil were distinct from Chemistry and Materials Science. This field aims to integrate various disciplines to develop innovative solutions to issues of the built environment by utilizing theories and methods from other fields.

Table 4. Co-occurring disciplines and distance between disciplines in Engineering Civil.

Disciplinary	Disciplinary Distance	Number of Co-Occurring Papers
Logic	0.840	1
Electrochemistry	0.683	15
Mycology	0.678	12
Anatomy and Morphology	0.677	1
Ornithology	0.659	2
Physics, Atomic, Molecular, and Chemical	0.631	33
Chemistry, Organic	0.629	17
Chemistry, Inorganic, and Nuclear	0.628	12
Nanoscience and Nanotechnology	0.615	33
Crystallography	0.612	12
Materials Science, Coatings, and Films	0.597	11

3.1.3. Measurement of Interdisciplinary Based on the Rao–Stirling Index

This paper calculated the Rao–Stirling variability metrics of the 16,948 literature sources using R 4.3.2. We also carried out a frequency distribution of the disciplinary variability indices of literature in the built environment field, and present the results of the interdisciplinary measurement of the literature in this field, as shown in Figure 7. The disciplinary variability value of most literature was concentrated in the range of 0.1–0.4. The larger the index, the higher the degree of interdisciplinary. This article set a threshold value of 0.35 and defined literature with a Rao–Stirling index greater than 0.35 as highly interdisciplinary literature in the field of the built environment. Finally, 994 pieces of literature were selected for interdisciplinary topic identification research in the field of the built environment.

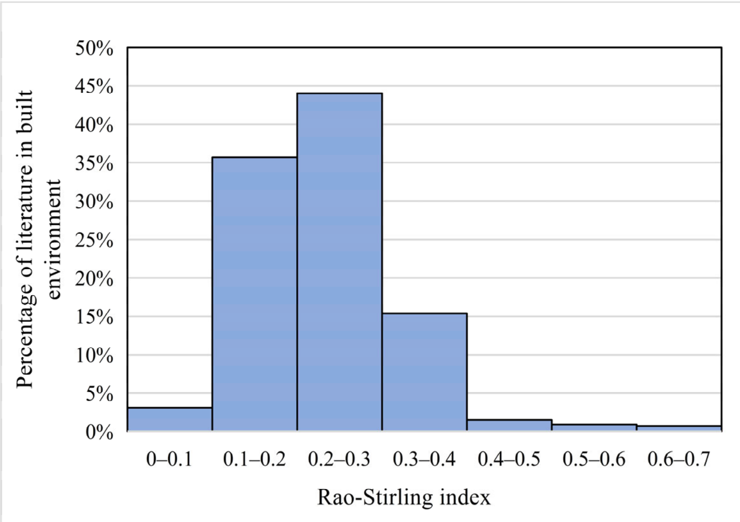


Figure 7. Histogram of the frequency distribution of the Rao–Stirling index.

3.2. Evolution of Interdisciplinary Topics in the Built Environment

3.2.1. Identification of Interdisciplinary Topics Using LDA

The identification of interdisciplinary topics can facilitate a scholarly exploration of novel research avenues and foster collaborative communication across various fields. In this study, abstracts from interdisciplinary documents within the built environment domain were analyzed using an LDA model to discern their underlying topics [39]. The Sklearn Python library was employed to automatically extract semantic topics from the documents, while the latent Dirichlet allocation algorithm was utilized to uncover the semantic structure of the documents by examining the statistical co-occurrence of words within a corpus of training documents. The algorithm, which utilizes Python 3.11.0, enables the selection of a range of 1 to 20 topics. The perplexity of each individual topic number was computed independently, leading to the generation of a perplexity curve, as depicted in Figure 8. Analysis of the curve revealed that selecting six topics yielded a lower model perplexity, hence the decision to set the model's number of topics to six.

The LDA model was trained on 994 documents with six selected topics. The results are presented in Figure 8, which shows a graphical representation of the LDA topics in the built environment domain. Each bubble in Figure 9a represents a topic, with the size of the bubble indicating the frequency of the topic's occurrence. When there is less or no overlap between the bubbles, it indicates a well-clustered set of topics. The distance between the bubbles represents the relevance of each topic, with a larger distance indicating a weaker relevance. Figure 9b displays the top 30 most frequently occurring terms in the corpus, with the length of each bubble representing the frequency of the corresponding term within the corpus.

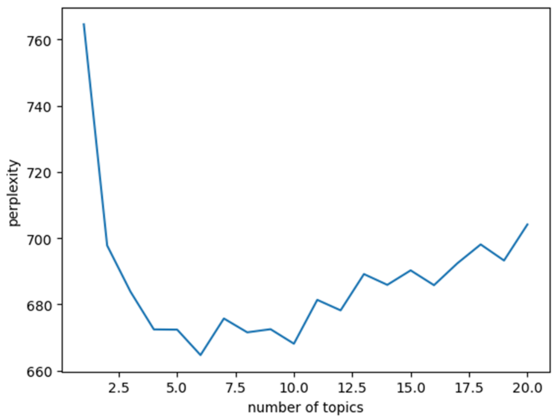
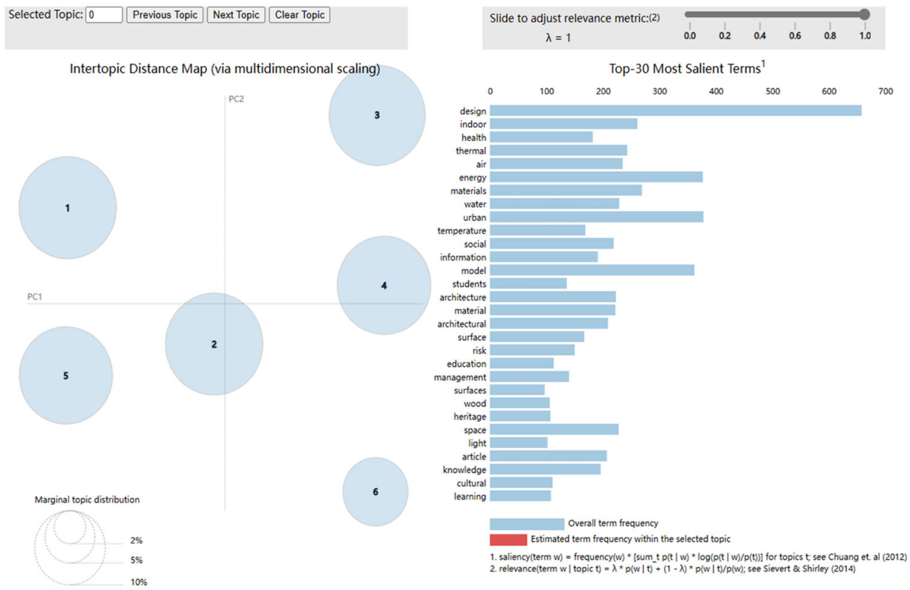


Figure 8. Confusion curve.



(**a**) (**b**)

Figure 9. (**a**) LDA intertopic distance map. (**b**) Term word frequency map.

Through the synthesis of terminology and an analysis of the relevant literature, six interdisciplinary topics within the field of the built environment were identified and are presented in Table 5. These topics included the landscape culture of historic buildings, information technology for building resilience, impact of microorganisms on the indoor environment, building thermal comfort, sustainable buildings, and indoor health issues under COVID-19.

Table 5. Interdisciplinary topics in the field of the built environment (λ = 0).

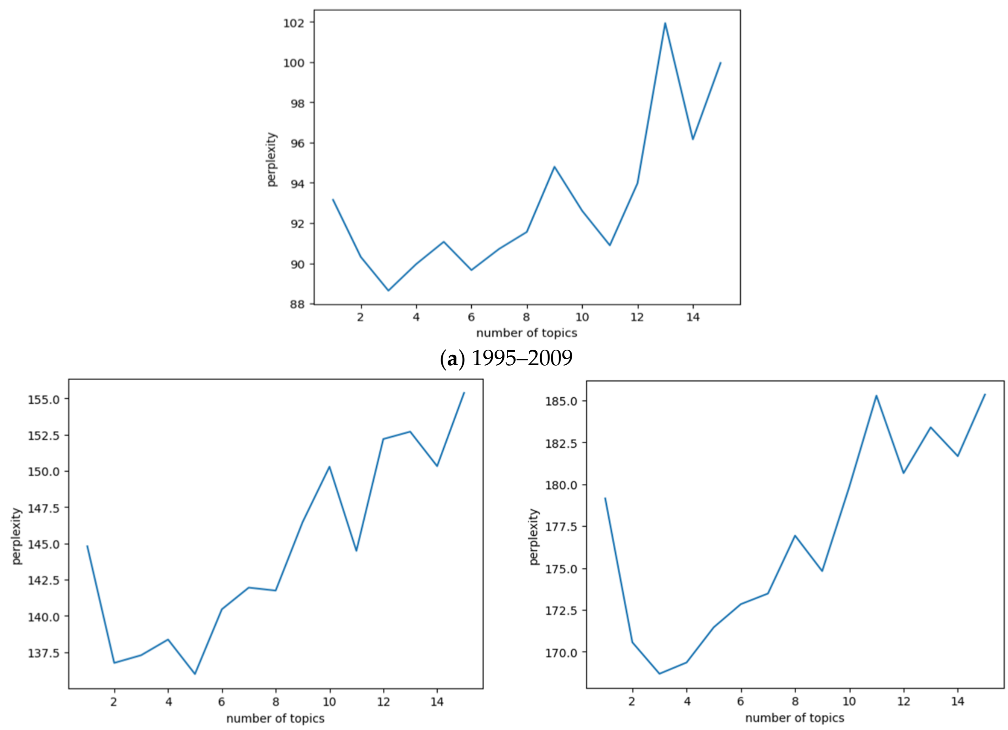
Serial Number	Topics Name	Each Cluster Includes the Terminology
# 1	Landscape culture of historic buildings	Heritage political archaeological identity landscapes colonial ancient landscape transformation settlements politics cultural historical century street settlement central societies history historic places
#2	Information technology for building resilience	Resilience emergency seismic earthquake navigation disaster robot evacuation adoption hazard disasters images security damage information management modeling map maps safety smart infrastructure 3d motion rural linear maintenance

Table 5. *Cont.*

Serial Number	Topics Name	Each Cluster Includes the Terminology
# 3	Impact of microorganisms on the indoor environment	Wood microbial species emissions solar oil dust moisture fungi absorption fungal molecular plant microbiome bio clay treatment renewable electricity cement profiles organic samples decay soil bacterial composition
#4	Building thermal comfort	Wind noise heating comfort conditioning filter regression sensation algorithm pedestrians stress fluid temperature physiological cooling sensor variables index accuracy parameters prediction temperatures perception average ambient subjective
#5	Sustainable buildings	Sustainability design students education virtual multidisciplinary principles universal designers aesthetic projects online technical professionals academic accessibility experiences interior ideas science questions opportunities conceptual
# 6	Indoor health issues under COVID-19	Transmission lighting window COVID-19 infection daylight disease pandemic windows cleaning usage homes glass care standards spread home health contact light surfaces visible airborne guidelines hospital code safe metrics

3.2.2. Classification of Interdisciplinary Topics Through Temporal Analysis

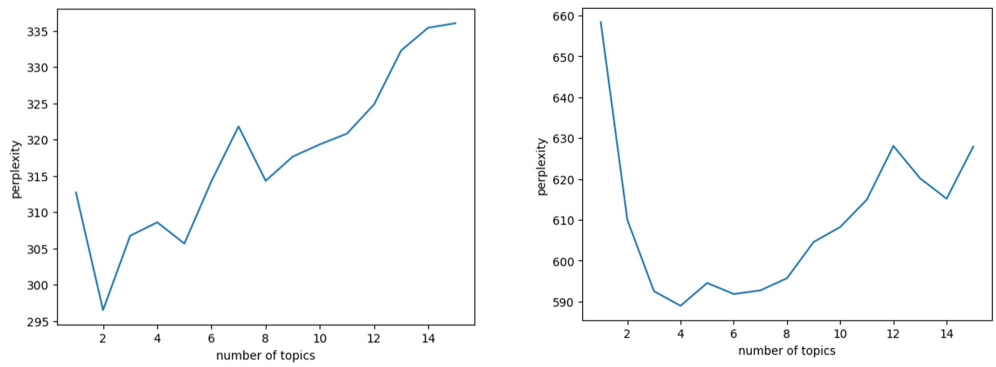
This study examined the interdisciplinary literature across five distinct time periods: 1995–2009, 2010–2013, 2014–2016, 2017–2019, and 2020–2023. The division of these phases was determined by the presence of adequate textual data, with approximately equal numbers of documents in each phase. The optimal number of topics within the literature for each time interval was identified using the perplexity parameter of the LDA model. Specific calculation results are presented in Figure 10.



(**a**) 1995–2009

(**b**) 2010–2013 (**c**) 2014–2016

Figure 10. *Cont.*



(**d**) 2017–2019 (**e**) 2020–2023

Figure 10. Confusion curve by time window.

In LDA models, the model's perplexity is typically calculated for each number of topics and compared to determine the optimal number of topics. Figure 10 displays the perplexity curves for various numbers of topics during different periods in the built environment domain. Smaller values indicate better model fitting. Therefore, the optimal number of topics for each time window was as follows: three for 1995–2009, five for 2010–2013, three for 2014–2016, 2 for 2017–2019, and four for 2020–2023. The LDA topic model was used to train the topics in the data in each time window, and the resulting distribution of featured topic terms is shown in Table 6.

Table 6. Distribution of topics within the time window.

Time Window	Topic	Topic Overview	Featured Topics
1995–2009	Topic 1 (P1)	Urban spatial landscape	Social city spaces space spatial landscape architectural environments historical climate
	Topic 2 (P1)	Building information modeling	Design building model knowledge based data environments information
	Topic 3 (P1)	Building insulation materials	Energy thermal building systems economic materials
2010–2013	Topic 1 (P2)	Sustainable development	Change climate sustainability sustainable technology environmental value development energy future
	Topic 2 (P2)	Indoor air quality	Indoor air design data model quality control health high
	Topic 3 (P2)	Water conservation in buildings	Building water materials simulation framework systems dynamic
	Topic 4 (P2)	Building thermal comfort	Buildings environmental risk thermal energy non groups local conditions low
	Topic 5 (P2)	Urban environment	Architecture urban city social space environments nature material architects development political
2014–2016	Topic 1 (P3)	Indoor environment	Building indoor data model environmental energy risk elsevier reserved health measurements solution systems exposure materials air
	Topic 2 (P3)	Urban planning and design	Urban design water architecture people environments architectural spatial cultural dynamics systems space material
	Topic 3 (P3)	Student education	Design knowledge information students building education learning framework study light university management engineering
2017–2019	Topic 1 (P4)	Population health	Model indoor building materials thermal water air human energy environments temperature health conditions chemical organic occupant
	Topic 2 (P4)	Digitization of historical heritage	Design urban social building development data architectural heritage city community cultural historical political smart visual digital infrastructure
2020–2023	Topic 1 (P5)	Indoor disease infections	Indoor air thermal building temperature COVID-19 environmental comfort ventilation particle physiological pollution sensors respiratory infection
	Topic 2 (P5)	Landscape restoration of historical heritage	Urban social heritage data cultural space natural historic landscape climate archaeology resilience
	Topic 3 (P5)	Sustainable design	Design building research paper study spatial sustainable materials sustainability information energy models knowledge stakeholders originality industry
	Topic 4 (P5)	Indoor effects of microorganisms	Water microbial surface wood carbon concrete monitoring microbiome emissions neural bacterial fungal moisture organic molecular

The results of the LDA topic model can be used to calculate the intensity of the topic under each time window [40]. This is defined as topic hotness or topic attention, which indicates the degree of attention to a topic over a specific period. This quantitative index can be used to assess whether a research topic is a scientific research hotspot. Origin 2021 was employed to generate a topic heat map (Figure 11). The graph displays the intensity of topics through varying colors, with darker shades denoting higher levels of intensity and lighter shades denoting lower levels. The numerical value corresponds to the intensity of the topic. The figure illustrates the concentration of hot topics in the field of the built environment, namely population health, digitization of historical heritage, indoor environment, building information modeling, and urban planning and design. Among the most prominent intersections in the field of the built environment were those related to population health, the digitalization of historical heritage, and the indoor environment. These were followed by building information modeling, urban planning and design, urban environment, and then building insulation materials, sustainable design, and so on. The built environment exerts a profound influence on the health and well-being of residents. This is evident in the planning and design of cities, the provision of community amenities, the greening of urban areas, and the construction of roads, among other factors. The discipline of built environment research draws on a range of theoretical frameworks including urban planning, environmental psychology, behavioral geography, and others. The protection and renovation of historic buildings represent a significant aspect of urban renewal. Some scholars have employed BIM (building information modeling) technology and visualization technology to create three-dimensional digital models and digital platforms for historical buildings, intending to achieve the protection and renovation of historical buildings.

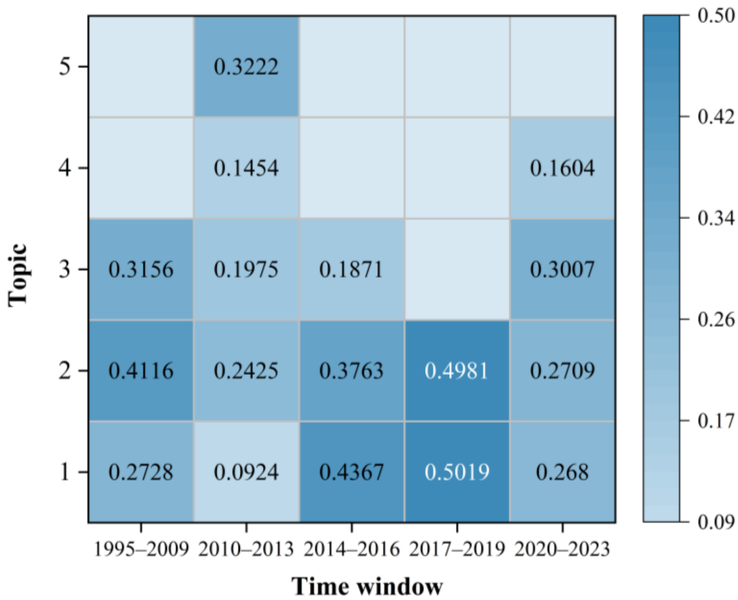


Figure 11. Heat map of disciplinary interdisciplinary topics.

3.2.3. Evolutionary Trajectory of Interdisciplinary Topics

In this study, feature words were selected based on their Top 8 distribution probability within each topic. The evolutionary relationship between topics across neighboring time windows was determined by calculating their similarity [41]. A higher similarity suggests a greater likelihood that topics in later stages evolved from those in earlier stages. Consequently, a similarity threshold of 0.95 was established in this research. When the similarity threshold exceeds 0.95, it signifies the presence of an evolutionary correlation among the topics, enabling the creation of a Sankey diagram illustrating the evolution of topics, as depicted in Figure 12, utilizing Origin 2021. The topic names within the diagram aligned with those in Table 6, with the lines connecting topics symbolizing the progression and interconnection of topic evolution, and the varying thickness of the lines indicating the level of similarity between topics.

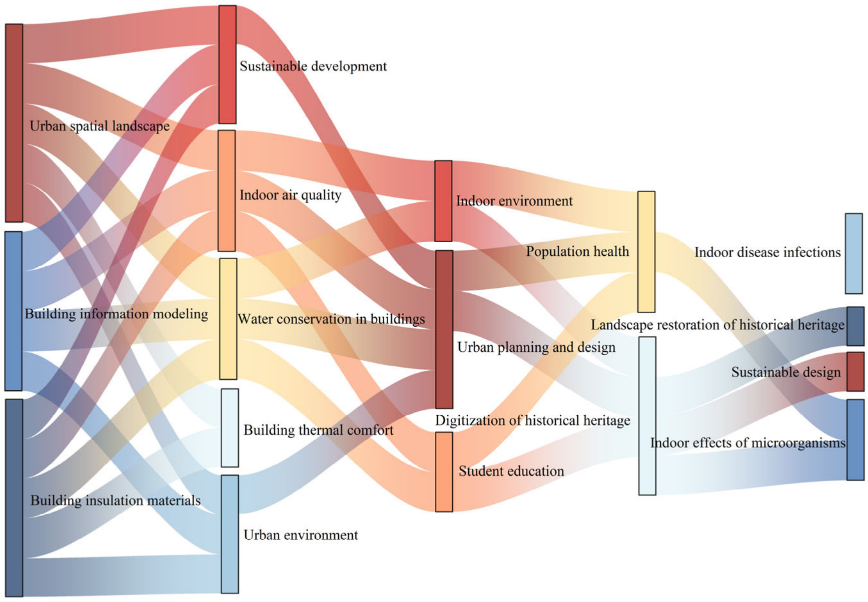


Figure 12. Evolution of disciplinary interdisciplinary topics.

As illustrated in Figure 11, the second phase topics can be seen to have evolved from the fusion of the previous phase topics. Sustainable development and the urban environment in the second stage evolved into urban planning and design in the next stage, in addition to which research on urban planning and design also involved indoor air quality and water conservation in buildings. Indoor environments and student education in the third stage had an evolutionary relationship with indoor air quality and water conservation in buildings in the second stage. In the fourth stage, the topics of indoor environment, urban planning and design, and student education, which were integrated into the third stage, generated the topics of population health and the digitization of historical heritage. In the final phase, the topic of population health evolved into the indoor effects of microorganisms, and the topics of landscape restoration of historical heritage and sustainable design were separated from the digitization of historical heritage.

Another area of interest is the research on building thermal comfort, which emerged in 2010–2013 and was linked to previous research on building insulation materials. However, since then, the focus of this research has gradually decreased. Additionally, the outbreak of the New Crown epidemic in 2019 led scholars in the field to focus on healthy indoor environments with viral transmission, which led to the emergence of a nascent topic on indoor disease infections and its widespread interest among scholars.

In terms of evolutionary history, there was a certain connection between topics at different stages. The study of urban spatial landscapes gave rise to sustainable development, and then scholars began to focus on urban planning and design. In 2002, building information modeling (BIM) was introduced as a new tool for architecture, engineering, and civil engineering, and subsequent applications of BIM technology in improving indoor air quality in buildings and building drainage design were carried out. Indoor air quality has given rise to scholarly research on indoor environments, and indoor environments and urban planning and design have subsequently led to scholarly research on the topic of population health. Various factors including urban planning and design, community amenities, greening rates, and indoor environments have been shown to impact health outcomes by influencing individual behavioral activities. Scholars have utilized building information modeling (BIM) technology and virtual reality to generate 3D digital models, establish digital platforms for historic structures, renovate historical buildings, and safeguard and restore cultural heritage sites.

4. Discussion

This study developed a disciplinary similarity formula based on 16,948 articles in the field of the built environment collected by WoS through the citation relationship of the literature. This formula was then used to measure the interdisciplinary characteristics of the literature in the field of the built environment. Second, for the 994 documents with a high degree of interdisciplinarity, the interdisciplinary topics in the field were identified on the basis of the LDA model. This was followed by the calculation of topic intensity under each time window and topic similarity in the neighboring time windows through temporal analysis. This was undertaken to explore the evolution path of interdisciplinary topics in the field of the built environment. In light of the results presented in the preceding section, this study will now proceed to address the following points.

4.1. Discipline Relationship Analysis

Through this paper, it is known that the development in the field of built environment showed a trend of slow, then steady, and then rapid growth from 1995 to 2023. The field of the built environment has a wide range of disciplines and is prone to cross disciplines. According to the target literature and references in the field of the built environment, the field of the built environment encompasses 237 related disciplines, exhibiting a wide range of disciplinary distributions and sources of knowledge. Among these, the most significant disciplines in this field were Public Environmental Occupational Health and Engineering Civil. By calculating the subject similarity and the distance between subjects, it is possible to understand that the disciplines most closely related to the field were medicine, psychology, environmental studies, economics, and regional urban planning. Those more distantly related were electrochemistry, physics, atomic, molecular and chemical, chemistry, inorganic, and nuclear, crystallography, and nanoscience and nanotechnology.

4.2. Interdisciplinary Topic Identification

Based on the LDA model, the top 30 terminology words with the highest frequency of occurrence were selected and clustered to obtain six main interdisciplinary topics in the field of the built environment. These were the landscape culture of historic buildings, information technology for building resilience, impact of microorganisms on the indoor environment, building thermal comfort, sustainable buildings, and indoor health issues under COVID-19. The following is an analytical discussion of the interdisciplinary topics:

(1) Landscape culture of historic buildings. Through understanding relevant studies, it was found that historical and cultural landscapes and urban landscapes integrate historical and spatial information related to regional cultures, collective memories, urban patterns, living habits, etc., and are an important place to express the spatial value of the city [42]. Historical buildings are not only witnesses to history, but also carriers of culture. They reflect the esthetic taste and artistic level of each era, and contain national spirit and cultural connotation. The landscape of historical buildings not only has historical and cultural connotations, but also has esthetic and usage functions, implying or showing the fruits of human labor.

(2) Information technology for building resilience. By reading the relevant literature, it can be understood that the research on the informatization of buildings' disaster resilience includes the construction of a seismic disaster assessment platform based on smartphones and drones and computer vision recognition technology of the internal and external seismic damage of building structures to comprehensively obtain big data information on the seismic damage of structures in urban building complexes and set up a visual platform for seismic disaster risk perception and disaster assessment of urban building complexes [43]. There is also research on the application of building construction technology in natural disaster response: building construction technology plays a key role in disaster prevention

by mitigating the vulnerability of buildings and enhancing their ability to withstand natural disasters through innovative methods such as seismic design, flood prevention technology, intelligent monitoring systems, and early warning systems [44].

(3) Impact of microorganisms on the indoor environment. Microorganisms are present in every part of the built environment: they are found in the air, on the surfaces of objects, and on building materials, and are usually spread by humans, animals, and outdoor sources. These microbial communities and their metabolites are thought to cause alterations to the indoor environment that can affect the health of the occupants [45]. The primary focus of microbiome research in the built environment has been on the places where humans live, work, and produce food, which informs policy and management decisions that promote human health [46]. Therefore, the microbiome of the built environment has been a major focus of research on the health of humans.

(4) Building thermal comfort. The built environment includes the indoor and outdoor physical environments, and a healthy and comfortable thermal environment as a part of it has been a field and core concern in the built environment. Providing a comfortable thermal environment contributes to people's health and improves efficiency and productivity [47]. For example, thermal comfort affects the well-being and physical health of elderly people in care facilities [48], and the indoor conditions of thermal comfort affect the sleep quality of the occupants [49]. By optimizing thermal comfort, it is possible to improve employee satisfaction and productivity (i.e., alertness, concentration levels and work efficiency) in office buildings [50]. Research on thermal comfort in buildings provides a scientific basis for the creation of healthier, more comfortable, and energy-efficient built environments that help to reduce energy consumption and achieve sustainable development goals.

(5) Sustainable buildings. Sustainable development is urgently needed at all levels of society, and the UN's 17 Sustainable Development Goals (SDGs) are one way of framing the global challenges facing the planet and humanity [51,52]. Buildings are responsible for 50 per cent of global carbon emissions, from raw material production to overbuilding, and from building use through to demolition. Sustainable buildings have been a hotspot of research for scholars in the built environment field in recent years, for example, the application of wall and insulation materials in green buildings [53], the integration of BIM and LEED systems in the conceptual design phase of sustainable buildings [54], research on factors influencing the dissemination of green building projects [55], and research on the use of natural resources to create regenerative buildings and designs that can regenerate themselves and decompose completely when they are finished with use [56].

(6) Indoor health issues under COVID-19. The sudden COVID-19 outbreak in late 2019 has raised the awareness of the importance of indoor environments, which influence human health and biorhythms. Recently, scholars have investigated the impact of four key themes of the indoor environment (indoor air quality, indoor thermal quality, lighting and visual comfort, and acoustic comfort) on COVID-19 infection and recovery rates [57]. The built environment both influences and evolves with the spread of infectious diseases. For example, a study by Frumkin, H found that potential long-term impacts of COVID-19 on the built environment include changes in building design, an increase in telecommuting, reconfiguration of streets, changes in travel modes, provision of parks and green spaces, and a shift in population away from urban centers [58].

4.3. Interdisciplinary Topic Evolution

The evolution of interdisciplinary topics in the field of the built environment over the past three decades has been characterized by a trend of divergence and contraction, followed by divergence. Initially, there were three interdisciplinary topics in the first phase, which then diverged into five topics in the second phase. Subsequently, the two phases contracted, and with the increase in interdisciplinary research over the past three years, the interdisciplinary topics have once again expanded in the fifth phase. In the initial phase, the interdisciplinary topics were predominantly focused on building information modeling, building insulation materials, and urban environments. With the continuous expansion of research, the subsequent transition was made to studies on the indoor environment, urban planning and design, population health, and the digitization of historical heritage. The current emerging interdisciplinary topics are mainly related to the intersection of public health, medicine, environmental microbiology, and psychology.

This finding is in a large part related to the COVID-19 outbreak, which expanded research on the microbiology of the built environment such as the growth of microorganisms inside buildings caused by the improper use of building materials and inadequate indoor ventilation, which can lead to recurring health-related problems (respiratory diseases and allergies). The epidemic has also amplified the demand for 'health' in the built environment, bringing the concept of 'health architecture' back into the mainstream of research and practice. With the intersection of disciplines, data, and information technology, there are new possibilities for how the built environment can serve human health. Health is not only about physical well-being, but also about psychological healing, and interdisciplinary research between the built environment and medicine, psychology, public health, and microbiology in the context of epidemics aims to improve the quality of human health and well-being. This conclusion is consistent with Hu and Roberts' idea that the condition of the built environment affects human health through four main factors: (1) physical, (2) physiological, (3) biological, and (4) psychological [59].

5. Conclusions and Implications

This study examined the interdisciplinary situation in the field of the built environment in great detail, identifying cross-disciplinary topics and analyzing their evolutionary trends. The research demonstrates that the field of the built environment exhibits a high degree of interdisciplinary integration, with the most prevalent crossovers observed with medicine, psychology, and public health science, and fewer crossovers with electrochemistry, crystallography, and nanotechnology, which represent potential emerging directions. Over the past three decades, 17 core interdisciplinary topics have emerged in the field, and the overall evolutionary trend over time has been one of divergence, followed by contraction and then divergence.

However, several limitations in this research should be recognized. Firstly, the search term used in this article was 'building/built environment'. Although the acquired literature was highly relevant to the research field, it did not include all of the literature in the field of the built environment. Additionally, to determine the differences between disciplines, it was necessary to construct a "journal abbreviation-journal full name-discipline mapping table" based on the citation information. However, it should be noted that the citation information for earlier years may not have included this mapping, which may have led to a potential bias in interdisciplinary measurement.

To mitigate these limitations and further refine this study, the following improvements could be considered: the potential for broadening the search term's scope in subsequent research endeavors could enhance the thoroughness and objectivity of exploring interdisciplinary intersections within this field. Furthermore, further research could integrate journal information based on citation data, thus determining the disciplines to which the journals belong. This would facilitate the mapping of disciplinary categories.

This study provides scholars with up-to-date knowledge from an interdisciplinary perspective and facilitates the development of interdisciplinary research and cooperation in this field. Concurrently, these comprehensive analyses provide invaluable references and guidance for future building design and environmental planning. By conducting interdisciplinary research on the built environment, it is possible to make more efficient use of resources, enhance the energy efficiency and environmental sustainability of buildings, and mitigate the negative impact on the environment. Furthermore, it can provide a scientific basis for policy formulation and urban planning, enabling decision-makers to develop more effective policies and plans that facilitate the coordinated development of society, the economy, and the environment.

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