Neuroscience and Spatial Design Bibliometric Analysis in Web of Science Database

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This paper presents a comprehensive bibliometric analysis on the convergence of neuroscience and spatial design research. Using a two-step process, an initial keyword search identified 296 papers with terms like 'EEG' and 'Neuro' alongside 'Architecture,' 'Urban Design,' 'Product Design,' and 'Interior Design.' Subsequent filtering by publication date (2003-2023), language (English), document type, and categories refined this to 64 papers. Recent trends show a shift from architecture-focused studies to those emphasizing interior architecture and the use of virtual reality as a research tool. The increase in publications since 2018, peaking in 2022, indicates growing scholarly interest. This study underscores the potential of integrating neuroscience in spatial design to improve human well-being and highlighting future research directions for spatial designers. The findings reveal an evolving focus on stress reduction, biophilic design, and the enhancement of human well-being through design. This paper aims to provide a scientific foundation for user-centered and aesthetically pleasing environments.

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Web of Science Veritabanında Nörobilim ve Mekânsal Tasarım Bibliyometrik Analizi

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Bu makale, nörobilim ve mekânsal tasarım araştırmalarının kesişimi üzerine kapsamlı bir bibliyometrik analiz sunmaktadır. İki aşamalı bir süreç kullanarak, ilk anahtar kelime araması 'EEG' ve 'Neuro' gibi terimlerle birlikte 'Mimarlık,' 'Kentsel Tasarım,' 'Ürün Tasarımı' ve 'İç Mimarlık' terimlerini içeren 296 makale belirlemiştir. Yayın tarihi (2003-2023), dil (İngilizce), belge türü ve kategorilere göre yapılan sonraki filtreleme ile bu sayı 64 makaleye indirilmiştir. Son trendler, mimarlık odaklı çalışmalardan iç mimarlık ve sanal gerçekliğin bir araştırma aracı olarak kullanıldığı çalışmalara doğru bir kayma olduğunu göstermektedir. 2018'den bu yana artan yayın sayısı, 2022'de zirve yaparak, akademik ilginin arttığını göstermektedir. Bu çalışma, insan refahını artırmak için nörobilimin mekânsal tasarıma entegrasyonunun potansiyelini vurgulamakta ve mekânsal tasarımcılar için gelecekteki araştırma yönlerini öne çıkarmaktadır. Bulgular, stres azaltma, biyofilik tasarım ve insan refahının tasarım yoluyla iyileştirilmesine yönelik evrilen bir odağı ortaya koymaktadır. Bu makale, kullanıcı merkezli ve estetik açıdan hoş mekanlar için bilimsel bir temel sağlamayı amaçlamaktadır.

Anahtar Kelimeler: İç mimarlık, Mekansal Tasarım, Bibliyometrik analiz, Nörobilim.

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1. INTRODUCTION

In recent years, interdisciplinary studies have grown in popularity, with neuroscience and spatial design research standing out for their effective and insightful multidisciplinary collaborations. Exploring these topics through bibliometric analysis provides a valuable chance to better understand the focus and convergence of neuroscience and spatial design, offering information on the changing environment of these collaborative initiatives. Such an analysis will not only outline the current state of research, but will also highlight emerging trends and promising areas for future investigation, making a significant contribution to the literature. This study seeks to illustrate the dynamics of multidisciplinary research by mapping the intersections and divergences within different areas, emphasizing their importance in furthering our understanding of the complex link between neural mechanisms and environmental settings.

Taşlı Pektaş (2021) conducted a bibliometric analysis to research spatial cognition in neuroscience and architecture. Our research stands out by providing a greater bibliometric scope, advanced analytical approaches, and in-depth temporal insights, thereby enriching our understanding of multidisciplinary research dynamics.

This study investigates the studies in the fields such as;

- interior architecture (Higuera-Trujillo et al., 2020; Hu et al., 2021; Yeom et al., 2021; Bacevice & Ducao, 2022; Jung et al., 2022; Kalantari, et al., 2022; Kong et al., 2022; Wang et al., 2022; Awada et al., 2023; Hu et al., 2023; Jung et al., 2023; Mostafavi et al., 2023),
- architecture (Salingaros & Masden, 2010; Nanda et al., 2013; Essawy et al., 2014; Masden & Salingaros, 2014; Gallese & Gattara, 2015; Hsu, 2015; Erkan, 2018; Ambrosini et al., 2019; Chang & Jun, 2019; Djebbara et al., 2019; Rad et al., 2019; Ahlquist, 2020; Ji et al., 2020; Cheng et al., 2021; Erkan, 2021a; Li et al., 2021; Shemesh et al., 2021; Krauze & Motak, 2022; Mostafavi, 2022; He et al., 2023; Merhav & Fisher-Gewirtzman, 2023),
- landscape architecture (Kim et al., 2019; Allahyar & Kazemi, 2021; Herman et al., 2021; Nasab et al., 2022; Wei et al., 2022; Asim et al., 2023),

• and urban design (Hollander & Foster, 2016; Mavros et al., 2016; Al-Barrak et al., 2017; Albdour et al., 2022; Aliverdilou et al., 2021; Asim et al., 2023; Baumann & Brooks-Cederqvist, 2023; Erkan, 2023),

• including furniture/product design.

• Some of the studies investigates all built environment (Kaklauskas et al., 2019; Vijayan et al., 2019; Hu & Roberts, 2020; Karakas & Yildiz, 2020; Li et al., 2020; Azzazy et al., 2021; Erkan, 2021b; Kalantari et al., 2021; Mazzone & Khosla, 2021; Djebbara et al., 2022; Gharib et al., 2022; Shemesh et al., 2022; Domjan et al., 2023; Halligan et al., 2023; Guizzo et al., 2023; Rhee et al., 2023; Yu et al., 2023; Zur et al., 2023).

This broad inclusion provides a thorough analysis of how neuroscience overlaps with numerous design domains, aided by the purposeful use of "neuro" alongside "EEG" to catch research that employ different brain activity measurement methods such as EEG and MRI. This methodology ensures a comprehensive investigation of design and architecture.

The purpose of this project is to investigate how neuroscience and spatial design research have emerged as key topics for effective and meaningful multidisciplinary cooperation. This work uses a bibliometric analysis to find focal spots and intersections between neuroscience and spatial design, which will provide significant insights into their convergence. The study seeks to not only describe the present state of research, but also to identify new trends and prospective areas for future research, thereby significantly contributing to the literature. This work aims to map the intersections and divergences between many domains, emphasizing the necessity of comprehending the intricate relationships between neurological mechanisms and environmental circumstances, and thereby demonstrating the dynamics of multidisciplinary research.

2. METHODOLOGY

Figure 1 represents a two-stage bibliometric analysis procedure. The first stage entails a keyword search, which yields 296 papers using

phrases like "EEG" and "Neuro," as well as fields like "Interior Design," "Product Design," and "Urban Design." The second stage involves filtering these publications according to several criteria, including publication date (January 1, 2003 to December 31, 2023), document type (article, review article, book chapters, early access), language (English), and category (Multidisciplinary Sciences, Behavioral Sciences, Environmental Studies, Architecture, Construction Building, Urban Studies, Regional Urban Planning). This refinement method reduces the pool to 64 papers, with the goal of narrowing the study emphasis based on certain criteria.

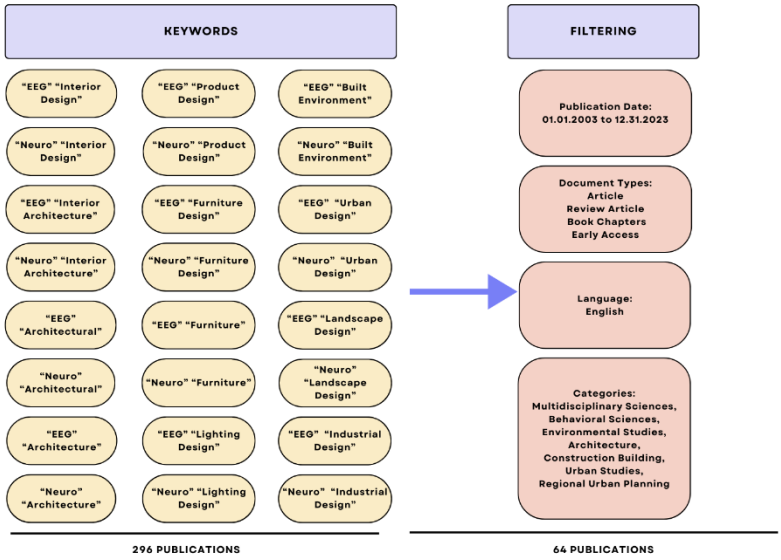

Figure 1: Two-Stage Bibliometric Analysis Procedure

3. FINDINGS

Figure 2 depicts the distribution of publications over time. From 2003 to 2017, the number of publications was quite low and consistent. However, there is a significant increase in frequency beginning in 2018, with a peak in 2022. This upward trend indicates an increase in academic interest in the study's themes and criteria during these years. The year 2023 also has a significant number of publications, indicating that research effort in the field has been ongoing up to that point.

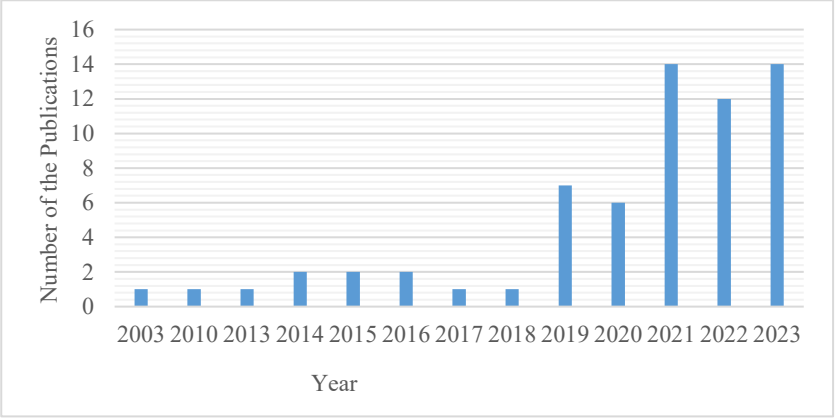

Figure 2: The Distribution of Publications Over Time

Table 1 includes the journals that have featured publications connected to the study, with a concentration on those with the most publications. Notably, 'Architectural Science Review' has the most publications, with seven, suggesting its popularity as a favored platform for communicating research in this discipline. 'Buildings' and 'Building and Environment' come close behind, with six and five articles each, indicating their importance in the academic discourse of the study's topic area. The journals 'Journal of Environmental Psychology' and 'Journal of Building Engineering' are also notable, with four and three articles, respectively, demonstrating their significance to the environmental and engineering components of the research. Lesser-cited journals, with two or one publication each, help to diversify dissemination channels, but the majority of research appears to be concentrated in the aforementioned main journals. This distribution emphasizes the study's interdisciplinary nature by incorporating architectural, environmental, psychological, and engineering elements.

Table 1: The List of the Journals Where Publications have been Featured

Journal	Number of Publications	Journal	Number of Publications
Architectural Science Review	7	Frontiers of Architectural Research	1
Buildings	6	Frontiers in Behavioral Neuroscience	1
Building and Environment	5	Heliyon	1

Journal of Environmental Psychology	4	Indoor and Built Environment	1
Journal of Building Engineering	3	International Journal of Architectural Computing	1
Sustainability	3	International Journal of Sustainable Built Environment	1
Archnet-IJAR: International Journal of Architectural Research	2	Journal of Architecture and Urbanism	1
Building Research & Information	2	Journal of Asian Architecture and Building Engineering	1
Intelligent Buildings International	2	Journal of Regional and City Planning	1
Scientific Reports	2	Landscape Architecture Frontiers	1
Urban Forestry & Urban Greening	2	MANZAR, the Scientific Journal of Landscape	1
Applied Spatial Analysis and Policy	1	Neuroscience & Biobehavioral Reviews	1
Automation in Construction	1	Open House International	1
Computer-Aided Civil and Infrastructure Engineering	1	Proceedings of the National Academy of Sciences	1
Cortex	1	PLOS ONE	1
Developments in the Built Environment	1	TEKA Commission of Architecture, Urban Planning and Landscape Studies	1
Energy and Buildings	1	Trends in Cognitive Sciences	1
Energy Research & Social Science	1	Urban Science	1

Figure 3 shows a VOSviewer network visualization displaying the co-occurrence of author keywords in a bibliometric dataset. The parameters suggest that the minimal number of occurrences for a keyword was set at one, with 256 keywords satisfying this condition and 192 of them interconnected.

The term "EEG" (electroencephalography) appears to be a central node in the network, indicating that it is a key focus within the study area. It is surrounded by clusters of related phrases that indicate the many sub-themes or fields of study related to EEG. Among these are "virtual reality," "environmental psychology," "neuro-architecture," and

"biophilic design," all of which point to interdisciplinary study intersections between neuroscientific methodologies and environmental design.

The thickness of the connecting lines and the distribution of nodes indicate the strength of the links between concepts. Thicker lines indicate more frequent co-occurrences, showing stronger or more researched field linkages. Terms like "aesthetics," "built environment," and "evidence-based design" are closely related, showing that these topics are frequently discussed in the literature together.

This visualization can help academics identify critical areas of concentration, emerging trends, and potential gaps in the literature by assisting in the understanding of complicated interactions between concepts. It also demonstrates the research's multifaceted nature, embracing areas of design, psychology, technology, and environmental studies.

The keywords "greenspace" and "healing garden" are frequently used in urban planning, showing a strong preference for incorporating natural features into urban surroundings. This relationship is further emphasized in Figure 3, where the term "environmental psychology" emerges as a key focus. This finding is scarcely surprising. The interaction of spatial design and neuroscience frequently centers on the emotional and psychological states of either the designer or the user. When the emphasis is on the user's experiences within a given setting, the bulk of analyses naturally fall under the scope of "environmental psychology". This emphasizes the importance of psychological concerns in the design and evaluation of urban areas, advocating for a design approach that prioritizes human well-being by incorporating natural features and therapeutic landscapes.

Figure 3: VOSviewer Network Analysis of Author Keyword Co-Occurrence in Multidisciplinary Research (Minimum Occurrence: 1)

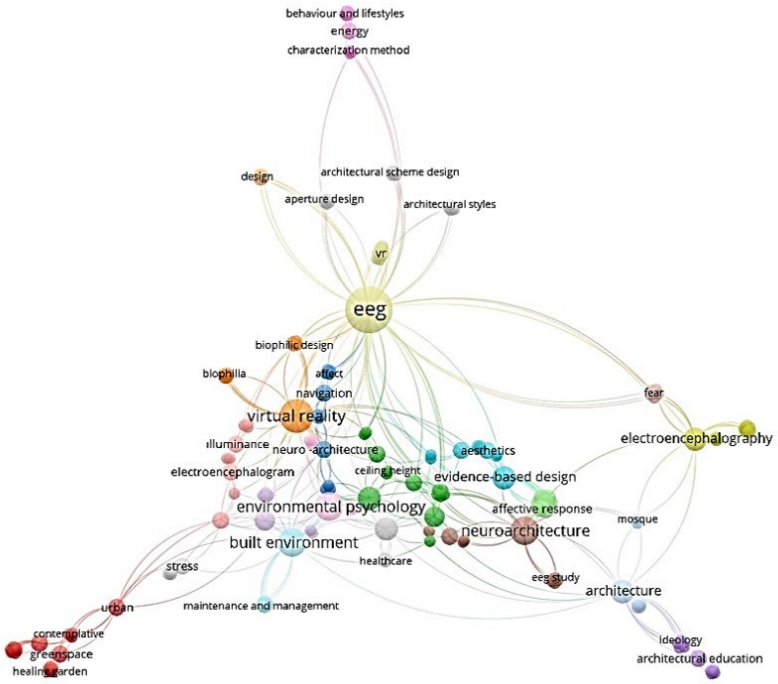

Figure 4 shows a VOSviewer network visualization map with a temporal overlay that depicts the spread of keywords over time in a set of publications. The nodes (keywords) are color-coded by year of occurrence, with the gradient spanning from 2018 to 2023. This temporal aspect helps us to see not only the links between keywords, but also how the research topic may have moved or evolved over time.

The color gradient indicates that certain themes have gained prominence in recent years. Keywords with a yellow to orange tint (for the years 2022 and 2023) may indicate emerging trends or a recent surge in interest within the research community. Keywords with a blue color (indicating earlier years) may, on the other hand, represent fundamental subjects that have maintained steady appeal over time.

The primary node, "EEG," is linked to several additional nodes, indicating its prominence in the scientific landscape throughout multiple years. The keywords associated with “EEG”, such as “virtual reality”, "environmental psychology", “built environment”, “neuro-architecture”, and “biophilic design” demonstrate an interdisciplinary study strategy that merges neuroscience with environmental design and technology. “Built environment” is associated with “stress” and

"urban" keywords in the recent years works. "Urban" is also connected to "greenspace" and "healing garden" keywords. "Biophilic design" is also a trend topic in this area. It is understood that a great number of current neuroscience and spatial design related works are focusing on the green usage in the spaces. "Architectural education", "ideology", and "aesthetics" are relavitely old subjects in neuroscience based spatial design studies.

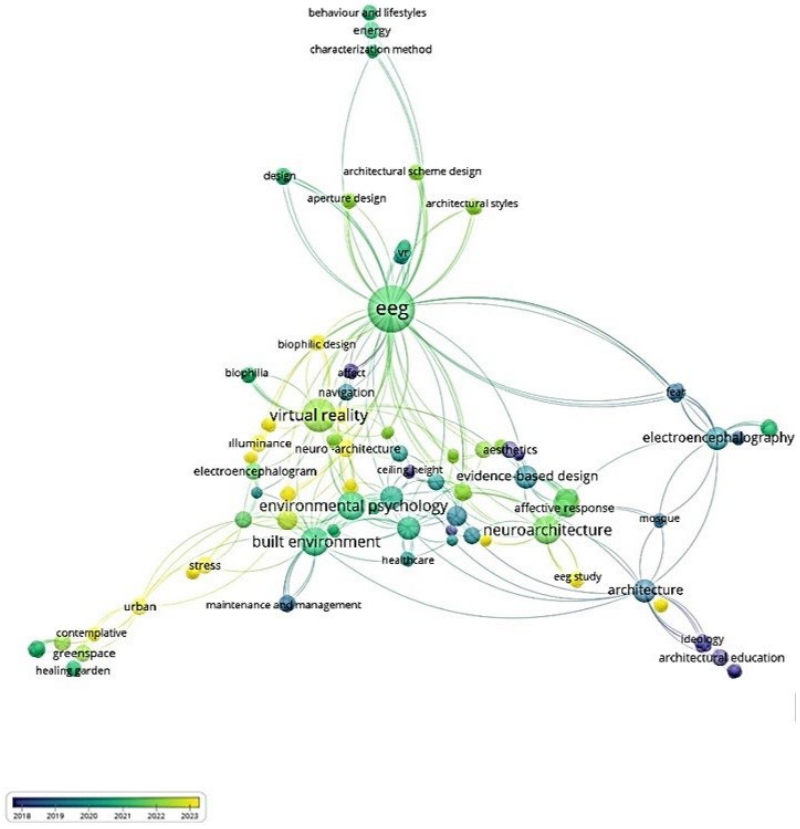

Figure 4: VOSviewer Co-occurrence Network of Author Keywords in Interdisciplinary Studies (Minimum Occurrence: 1)

Figure 5 illustrates a VOSviewer network visualization map with a set of 12 keywords, each of which appears at least three times, indicating a more focused area of study attention. All of these terms are connected, showing that they are commonly used together in the literature, implying a unified study domain.

The network's heart is "EEG," which is likely a core theme of the research and is linked to "virtual reality," indicating a convergence of neuroscientific research and immersive technology. "Neuroarchitecture" appears twice, possibly due to a difference in the

dataset or as separate entries, and it forms connections with "environmental psychology" and "evidence-based design," indicating an interest in the application of neuroscience to architectural design while taking psychological effects and empirical design principles into account.

Other phrases such as "built environment" and "well-being" are related, indicating that the research is likely focused on the impact of the physical environment on human health and comfort. The phrase "electroencephalography" is linked to the term "neuroscience," indicating the methodological approach that underpins the research.
This visualization aids in identifying the fundamental concepts within the dataset and understanding how they relate to one another, providing insights into the field's interdisciplinary character, which includes neuroscience, architecture, psychology, and technology.

As stated in the "IFI Interiors Declaration" by the International Federation of Interior Architects/Designers (IFI), interior designers and architects combine human and environmental ecologies to translate science into beauty that appeals to all senses (IFI, 2011). This statement highlights the importance of the human condition and well-being in the practice of interior design and architecture. As a result, the link of the "built environment" keyword with phrases such as "well-being" and "environmental psychology" in Figure 5 gives strong evidence that study into human well-being includes both physical and mental components. The rise of transdisciplinary studies incorporating neurology and spatial design is expected to improve our understanding of the human element, which is the primary emphasis of the interior design profession. This greater understanding will, in turn, improve our ability to assess the effects of interior designs on humans, bringing design results closer to the objective of improving human well-being inside built settings. This approach emphasizes the profession's commitment to promoting human-centered design principles, ensuring that the environments we live in are not only aesthetically beautiful but also beneficial to our general health and happiness.

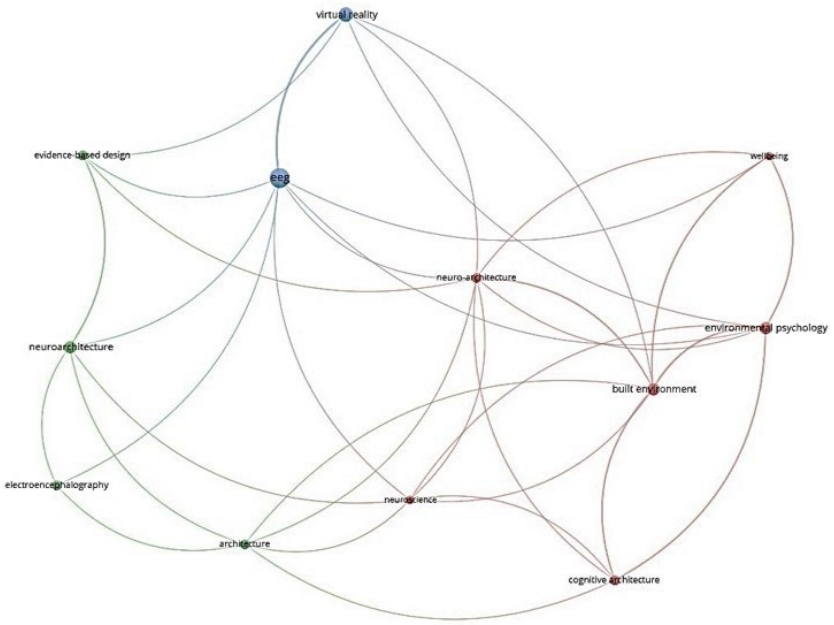

Figure 5. VOSviewer Network Analysis of Author Keyword Co-Occurrence in Multidisciplinary Research (Minimum Occurrence: 3)

Figure 6 illustrates the strong relationship between EEG and virtual reality, particularly from 2020 onward. This connection highlights the increasing interest in neuroscience-based spatial design studies where EEG is used to assess user experiences in virtual environments. The temporal dimension of the visualization further emphasizes the growing trend in this interdisciplinary field, underscoring the importance of integrating technological advancements in future spatial design research.

The main keyword "EEG" is a repeating center point, linked to a variety of research topics such as "virtual reality," "neuroarchitecture," "environmental psychology," and "wellbeing." The color coding of the lines suggests that these relationships have been active over time, with some subjects maybe gaining more attention in subsequent years, as evidenced by the shift to yellow. According to this color coding in Figure 6, “EEG-virtual reality”, “EEG-well-being” connections are the most recent connections. “Neuroscience”, “architecture”, “cognitive architecture”, and “evidence-based design” are relatively older to the other ones. Even though “neuroscience” and “architecture” keywords are losing their trend in recent years, a mix of them which is “neuro-architecture” is gaining interest in the implications of neuroarchitecture for wellness and environmental psychology. Such

insights are useful for identifying patterns, understanding the current research landscape, and planning future research.

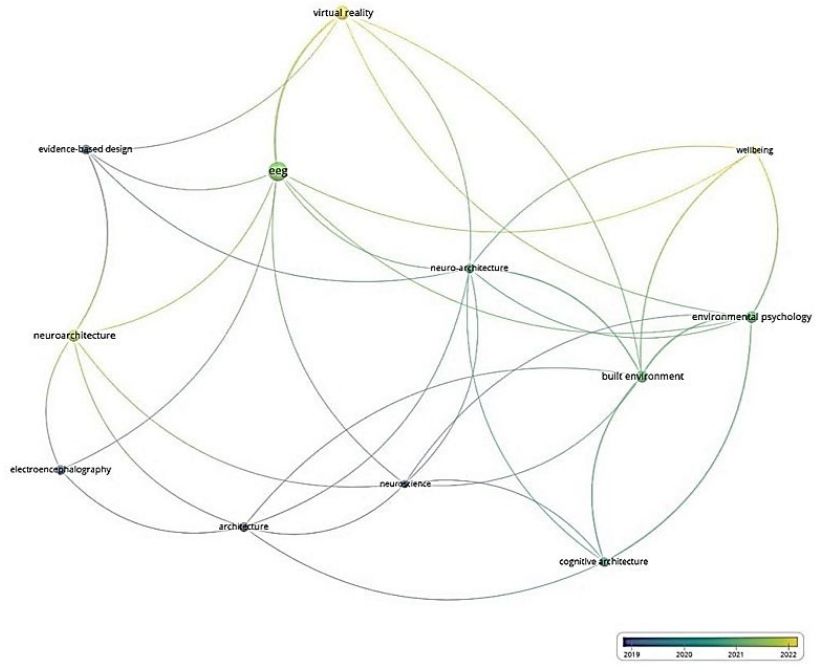

Figure 6: VOSviewer Temporal Analysis of Keyword Co-Occurrence in EEG-Related Research (2019-2022)

Figure 7 shows the collaborative network of researchers utilizing EEG in spatial design studies. Cornell University emerges as a significant hub, indicating its critical role in advancing research at the intersection of neuroscience and design. Such collaborations are vital for fostering interdisciplinary research and promoting innovative approaches in understanding human responses to architectural spaces.

The size of the nodes (representing individual authors) in such a network often corresponds to the number of documents published by the author, whilst the thickness of the lines between nodes frequently represents the number of co-authored articles. The visualization in this network emphasizes collaborative links rather than citation impact, with the threshold set for a minimum of two documents per author and no minimum citation count.

This type of study is useful for understanding the collaborative structure of a field, determining which scholars collaborate closely, and even estimating the importance of certain author clusters within the academic community.

According to Figure 7, the fact that just six academics worldwide have published at least two papers in the subject demonstrates the young but growing interest in the interdisciplinary topic of neuroscience and spatial design. Among these, Dr. Jesus Gabriel Cruz-Garza from the University of Houston has the most publications, as well as collaborations with all of the other well-known scholars. Notably, Cornell University appears as a major hub for this study topic, with researchers including Dr. Armin Mostafavi, Dr. James Dalton Raunds, Dr. Saleh Kalantari, Dr. Julia Kan, and Vidushi Tripathi, an undergraduate research assistant. Except for Dr. Cruz-Garza, this concentration of experts at Cornell emphasizes the university's critical role in the field's advancement.

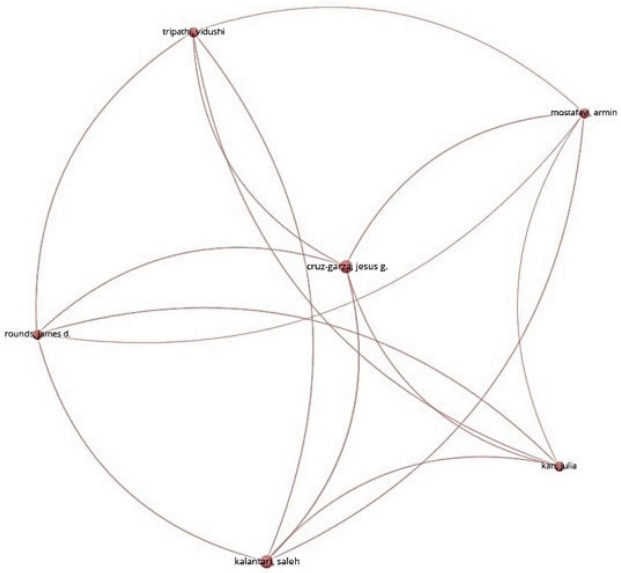

Figure 7: VOSviewer Co-Authorship Analysis of Researchers with a Minimum of Two Documents

Figure 8 appears to be a VOSviewer depiction of a co-authorship network focused on organizations that have contributed to a body of literature, with each organization publishing at least four documents. Various organizations are depicted as nodes in this network, and the links between them often signify collaborative activities between different groups in producing research output.

However, no links are displayed in the visualization, implying that the organizations named have not co-authored documents that satisfy the stated threshold or that the collaborations are outside the scope of the data obtained. It is possible that these groups are working separately in

the same field or on similar themes but have not worked directly on publications that match the minimum document criteria.

Based on collaborative networks, this type of visualization can assist in identifying major institutions in a research field and their potential significance. However, the lack of connections suggests the possibility of future collaboration or an opportunity to develop collaborations between these businesses.

According to Figure 8, the universities featured in the context of interdisciplinary study at the junction of neuroscience and spatial design, such as Cornell University (USA), Qingdao University (China), Süleyman Demirel University (Turkey), and Israel Institute of Technology (Israel), play critical roles. These institutions are known for creating conditions that encourage innovative study undertaken by researchers who are committed to improving our understanding of how spatial environments influence human neurological and psychological outcomes.

Figure 8: VOSviewer Network of Organizational Co-Authorship in Scholarly Publications (Minimum Document Threshold: 4)

4. CONCLUSION

The purpose of this project is to investigate how neuroscience and spatial design research have emerged as key topics for effective and meaningful multidisciplinary cooperation. This work uses a bibliometric analysis to find focal points, connections, and intersections between neuroscience and spatial design, which will provide significant insights into their convergence. The study seeks to not only describe the present state of research, but also to identify new trends and prospective areas for future research, thereby significantly contributing to the literature, and thereby exhibiting the dynamics of multidisciplinary research.

Interdisciplinary research of neurology and spatial design, which have been accelerating since 2020, indicate that this issue is ripe for further investigation and has significant potential contributions. Early research usually focused on architecture from a neuroscience perspective, while recent trends show a shift toward interior design. With an increasing emphasis on human well-being, virtual reality has emerged as an important instrument in these investigations. Notably, research has evolved toward stress reduction and the incorporation of biophilic and urban design elements, highlighting the evolving goals of this multidisciplinary approach. This shift reflects a better understanding of how designed places can influence human psychological and physiological states, opening up new avenues for research and practical applications that prioritize health and well-being in spatial design.

Future research is likely to focus on the integration of EEG and virtual reality as robust tools for evaluating user experiences in spatial design. The findings of this study suggest that combining these methodologies will contribute to a deeper understanding of how design decisions impact psychological and physiological responses. Particularly, the use of EEG in the design of biophilic environments and stress-reducing spaces is expected to grow, offering significant potential for enhancing human well-being through design. Moreover, expanding the application of neuroscientific methods in spatial design could lead to more user-centered, emotionally responsive design solutions, thereby improving the overall quality of built environments.

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