mekansal araştırmalar dergisi
journal of spatial research

e-issn: 3023-493X

BIBLIOMETRIC ANALYSIS OF RESEARCH ON 21st CENTURY LEARNING ENVIRONMENT REQUIREMENTS

Ela HAYEK[1], Hakkı Can ÖZKAN[2]

Review Article

Author Information

[1] Fatih Sultan Mehmet Foundation University, Department of Architecture, Istanbul, Turkey, ela.akta.1@gmail.com
0000-0001-5007-3900
Corresponding Author

[2] Fatih Sultan Mehmet Foundation University, Department of Architecture, Istanbul, Turkey, hcozkan@fsm.edu.tr
0000-0002-8042-7519

Arrived: 16.01.2026
Accepted: 29.04.2026
DOI: 10.71298/maddergi.1864862

This article is produced from Ela Hayek's doctoral dissertation entitled "Determining The Design Criteria of 21st Century Learning Spaces: A Conceptual Model Proposal For Turkiye" which is ongoing in the Architecture Programme of Fatih Sultan Mehmet Foundation University under the supervision of Assist. Prof. Dr. Hakkı Can Özkan

Cite as:

Hayek, E. & Özkan, H. C. (2026). Bibliometric analysis of research on 21st century learning environment requirements, *Mekansal Araştırmalar Dergisi*, *4*(1):134-152. https://doi.org/10.71298/maddergi.1864862

Abstract

Education systems continuously evolve, resulting in significant changes in how learning environments are designed and perceived. Previous studies demonstrate that physical space directly influences student achievement; however, existing learning environments largely fail to meet the expectations of twenty-first-century education. This article examines the requirements of contemporary learning environments through a bibliometric analysis based on publications indexed in the Web of Science database. A search conducted on June 19, 2025, identified 2213 relevant studies. The metadata was analysed using Biblioshiny to examine frequently used authors' keywords, temporal trends, and conceptual relationships through co-occurrence networks. Thematic mapping and trend topic analyses reveal core themes, emerging concepts, and active research areas related to twenty-first-century learning spaces. The aim of this study is to examine educational spaces from an architectural perspective and to bridge the gap between these fields. As a result of this examination, it has been observed that learning spaces are no longer considered merely "physical spaces", but rather as a system component that shapes the learning experience. The findings suggest that existing learning environments need to be updated to meet the evolving demands of contemporary learners. Additionally, the results highlight the importance of expanding academic research, strengthening global collaboration, and prioritizing spatial innovation to enhance learning experiences and better prepare students for future challenges.

Keywords: 21st century skills, 21st century education, bibliometric analysis, flexible learning spaces, learning environments

21. YÜZYIL ÖĞRENME ORTAMI GEREKSİNİMLERİNE İLİŞKİN ARAŞTIRMALARIN BİBLİYOMETRİK ANALİZİ

Özet

Eğitim sistemlerinin sürekli gelişimi öğrenme ortamlarının tasarlanması ve algılanmasında önemli değişikliklere neden olmaktadır. Önceki çalışmalar, fiziksel mekânın öğrenci başarısını doğrudan etkilediğini göstermektedir; ancak mevcut öğrenme ortamları, yirmi birinci yüzyıl eğitiminin beklentilerini karşılamada büyük ölçüde yetersiz kalmaktadır. Bu makale, Web of Science veri tabanında indekslenen yayınlara dayalı bibliyometrik analiz yoluyla çağdaş öğrenme ortamlarının gereksinimlerini incelemektedir. 19 Haziran 2025 tarihinde gerçekleştirilen bir tarama ile 2213 ilgili çalışma belirlemiştir. Yazarların sıklıkla kullandığı anahtar kelimeleri, zamansal eğilimleri ve eş kullanım ağları aracılığıyla kavramsal ilişkileri incelemek için meta veriler Biblioshiny kullanılarak analiz edilmiştir. Tematik haritalama ve trend konu analizleri; yirmi birinci yüzyıl öğrenme alanlarıyla ilgili temel temaları, yeni ortaya çıkan kavramları ve aktif araştırma alanlarını ortaya koymaktadır. Bu çalışmanın amacı, eğitim alanlarını mimari bir perspektiften incelemek ve ilgili alanlar arasında köprü kurmaktır. Bu inceleme sonucunda, öğrenme alanlarının artık yalnızca "fiziksel mekânlar" olarak değil, öğrenme deneyimini şekillendiren bir sistem bileşeni olarak görüldüğü gözlemlenmektedir. Bulgular, mevcut öğrenme ortamlarının çağdaş öğrenicilerin gelişen taleplerini karşılamak için güncellenmesi gerektiğini öne sürmektedir. Ek olarak sonuçlar; öğrenme deneyimlerini geliştirmek ve öğrencileri gelecekteki zorluklara daha iyi hazırlamak için akademik araştırmaları genişletmenin, küresel iş birliğini güçlendirmenin ve mekânsal inovasyona öncelik vermenin önemini vurgulamaktadır.

Anahtar Kelimeler: 21. yüzyıl becerileri, 21. yüzyıl eğitimi, bibliyometrik analiz, esnek öğrenme mekanları, öğrenme ortamları

1. INTRODUCTION

School buildings are one of the most important areas where future generations are raised. In order to provide education for future generations in the most efficient way, learning spaces must be able to adapt to systemic and periodic changes required by the needs of the age. In this context, the relationship between learning space and student outcomes was discussed in the literature by Joan (2013), Kariippanon et al. (2019) and Krajewski and Khoury (2021), in their studies. Accordingly, when the education reforms that Türkiye has undergone from the past to the present are examined, it is understood from the previous studies and observations that the reforms applied to the education system alone are not sufficient to improve student participation and results. Also, Kariippanon et al. (2019) argue in their study that the effect of space on student performance is a criterion that cannot be ignored. From another perspective, Caena and Redecker (2019) emphasize the importance of educators and state that they must receive ongoing training constantly and strive to improve themselves in order to meet the learning needs of the 21st century at an adequate level. The study also discusses the integration of technology in this context and its place in innovation (Caena & Redecker, 2019).

Recognizing inadequate student performance in 2012, McLaughlin et al. (2014), in their study titled "Flipped Classroom", transformed learning spaces from a teacher-centered to a student-centered system. As a result of this study, student interaction began to be observed as more active (McLaughlin et al. 2014). Furthermore, Anderson and Shattuck (2012), whose work stand out with the highest number of citations, emphasized the importance of the "Design-Based Research" method. This method bridges the gap between learning and experience, leading to the testing and development of the module learned. He also suggested that this method was more widely used in the education sector (Anderson & Shattuck, 2012). Accordingly, providing environments that support experimentation within the context of the needs of 21st century learning spaces stands out as a key element.

From another perspective, Jacobson and Wilensky (2006) argue that students from elementary school through high school should experience complex educational systems at a fundamental level. In this context, they emphasize the importance of observing students' diverse performances in various areas and encourage their integration into learning and educational systems (Jacobson & Wilensky 2006). In addition, Garcia and Sylvan (2011) emphasize the importance of multilingual education in their study, highlighting that multilingual institutions should consider eight principles in their design to provide the most effective education and support various types of advanced and sophisticated learning. These eight principles include student-centered classrooms and spaces that support student interaction with both each other and teachers. Furthermore, classrooms that provide a variety of experiences and foster experiential learning are among the primary needs (Garcia & Sylvan, 2011).

On the other hand, Tang et al. (2020) discuss the term "Computational Thinking" in education, which is a key element of 21st century educational requirements. While emphasizing the importance of integrating Computational Thinking into 21st century education, he introduces it as:

> "A system that reflects creativity, algorithmic thinking, critical thinking, problem-solving, collaborative thinking, and communication skills, which form the foundation of the fields of science, technology, engineering, and mathematics, and are among the important needs of the 21st century" (ISTE, 2015, as cited in Tang et al., 2020, p. 7).

In this context, while addressing the impact of flexible classroom designs on student outcomes in effective learning, Voogt and Roblin (2012), ranked third among the most-cited international studies in the WoS database, attempted to identify 21st century learning needs in their own study. Similarly, other studies investigated how schools can adapt to changing conditions to improve student outcomes. Furthermore, studies also emphasize the need for further studies on the relationship between student learning and motivation in educational spaces that will appeal to Generation Alpha, whose needs define the learning spaces of the 21st century. Consequently, flexible learning spaces are needed to support and adapt to potential curriculum reforms.

However, given that most schools have traditional, teacher-focused, and inflexible designs, they have become incapable of meeting the learning needs of the 21st century. In other words, educational buildings restrict the effective education of new generations of students (Kariippanon et al., 2020; Kowaltowski et al., 2024). Since schools are among the most important spaces where future generations are raised and educated, this article will conduct a bibliometric review of publications on the requirements of 21st century learning spaces. On the other hand, in addition to pedagogical reforms, the physical and spatial characteristics of learning spaces must also align with this transformation. Architectural principles such as flexible design, spatial adaptation, and user-centered arrangement stand out as fundamental elements supporting the educational needs of the 21st century.

Nevertheless, according to the review conducted within this study, the existing literature reveals that studies on 21st century learning environments are quite limited in the field of architecture. This study aims to address this gap by examining the subject from an architectural perspective and bridge the gap between architecture and education. Furthermore, this study serves as a resource for architects and interior designers interested in the design of educational spaces, education policymakers and school administrators, and academics researching 21st century learning environments.

The purpose of this study is to identify the key elements necessary for more efficient learning environments, based on existing research in the literature. Furthermore, it emphasizes that learning spaces influence student performance and should be designed with flexibility to adapt to future developments. A bibliometric investigation was additionally performed to identify a set of resources examining the requirements of learning environments in the 21st century. The Web of Science Database, recognized for its comprehensive and rigorous data indexing capabilities, was chosen as the primary source for bibliometric analysis. Biblioshiny, a web interface for R-Studio, was then used to analyse the extracted data. In this context, based on the results of the research conducted through Biblioshiny, the most frequently cited authors, studies, and countries on relevant topics were analysed. Countries' Collaboration Research Networks were also identified. Furthermore, a set of the most frequently used author keywords was obtained. Finally, a resource group and concept list were compiled that can form the basis for future studies on the needs of 21st century learning spaces (Figure 1).

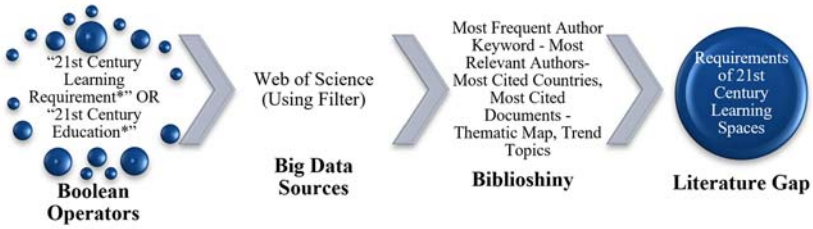

Figure 1. Progress of the study (Prepared by the authors).

2. METHODOLOGY

This study was conducted using the bibliometric analysis method. Among the scientific data analysis methods in the literature, the bibliometric analysis method is a quantitative scientific research method capable of statistical analysis. Bibliometrix is a programming tool developed in the R programming language specifically designed for conducting bibliometric analyses, capable of executing statistical evaluations and data visualization. In contrast, Biblioshiny constitutes a web-based graphical user interface that facilitates analyses conducted using the Bibliometrix tool within the R environment, thereby eliminating the necessity for coding proficiency. It is an interface that can fluently visualize data analysis and create statistical maps (Aria & Cuccurullo, 2017). In short, the R software is essentially coding software. R-studio, which can only run within the R software interface, can be used without coding knowledge. After defining the Bibliometrix package in the R-studio interface, the package allows the use of the included biblioshiny software. Biblioshiny is a program that can perform statistical and graphical data analysis, which can be opened in the web interface. For this study, data analysis was performed on Biblioshiny (Aria & Cuccurullo, 2017, p. 973). Unlike other analysis methods, bibliometric analysis is a method capable of detailed analysis of the increasing data load and number of sources in literature.

> "Bibliometric analysis is an analysis method that can systematically analyze big data from a broad perspective, track the evolution of concepts over time, and identify active authors and countries. It is also a method that can present the researcher with a larger picture in graphical form by classifying concepts and themes according to data statistics published overtime" (Crane, 1972. As cited in Aria & Cuccurullo, 2017, p. 959).

2.1. Limitations of The Study and Database Selection

This research was conducted using the Web of Science database. The Web of Science database was chosen because it offers comprehensive access to interdisciplinary studies and is widely accepted internationally for its

academic indexing standards. In addition, the database's ability to download data in bulk in ".bibtex" format was considered a technical requirement for creating an analysis environment compatible with Biblioshiny software. Databases such as Google Scholar and ScienceDirect were excluded because they do not offer reliable data download in ".bibtex" format.

2.2. Bibliometric Data Collection

In order to ascertain the positioning of the principal subject to be scrutinized within the existing literature and to execute statistical evaluations of authors, citation frequencies, and keywords, a comprehensive search was undertaken. Keywords formulated employing Boolean operators ("21st Century Learning Requirement*" or "21st Century Education*") were investigated within the Web of Science database by selecting "All Fields". These keywords were selected from among commonly used terms in the literature that were deemed, as a result of preliminary research, to most comprehensively represent the educational needs of the 21st century. Following this phase, the resultant filtered information was systematically downloaded in batches of 500 utilizing the ".bibtex" format, contingent upon the allowable quantity of source downloads. The option for "full record and cited references" was chosen for the downloading process. Given that the data acquired in increments of 500 needed to be uploaded to the Biblioshiny software simultaneously, it was consolidated into a singular zip file and subsequently uploaded to the Biblioshiny software operating on the web interface via the "import raw data" tab to facilitate comprehensive data analysis concurrently. A total of 2213 resources were accessed on 19 June 2025. To provide a transparent explanation of the filtering process, the inclusion and exclusion steps are presented in the form of a PRISMA flowchart (Figure 2). Subsequently, to ensure the accuracy of the analysis results, synonymous keywords e.g. "*21st century abilities*", "*21st-century abilities*", "*21st-century skills*" were merged into"*21st century skills*" and "*higher education*" were merged into "*education*" prior to analysis. In this context, the following limitations should be considered when interpreting the findings of this study:

This study only includes studies retrieved as a result of the relevant Boolean Operators search done within the Web of Science interface on June 19, 2025; studies published after this date are not included in the findings. This analysis is also limited to selected subject categories within the Web of Science interface; studies published outside these categories were not included. Furthermore, it only includes studies conducted in Turkish and English; studies in other languages are excluded from the evaluation. Additionally, a quantitative method, bibliometric analysis, was used as the research method. This research method does not allow for in-depth qualitative evaluation of individual studies.

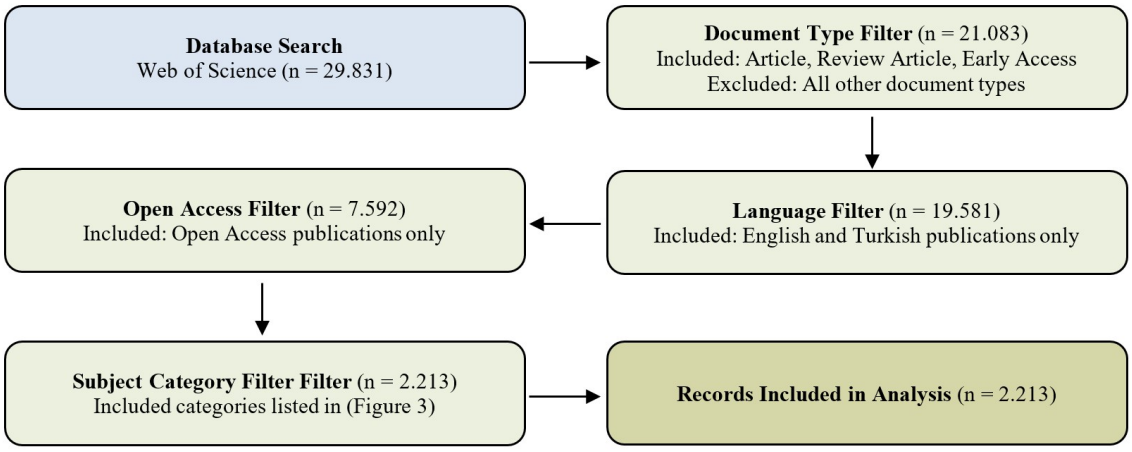

Figure 2. PRISMA flowchart, (Prepared by the authors).

In the bibliometric search, Google Scholar and ScienceDirect databases were omitted due to the inability to reliably retrieve data in (.bibtex) format. Furthermore, data analysis was limited to those within the architecture domain. The Inclusion and Exclusion Criteria were established based on the categories present in the Web of Science interface (Figure 3). Additionally, the interdisciplinary nature of the study was taken into consideration when determining the subject area categories. The architecture and urban studies categories were included to represent the

spatial dimension, while the education and social sciences categories were included to encompass the pedagogical perspective. Furthermore, the rationale for including the selected fields is illustrated in Figure 4.

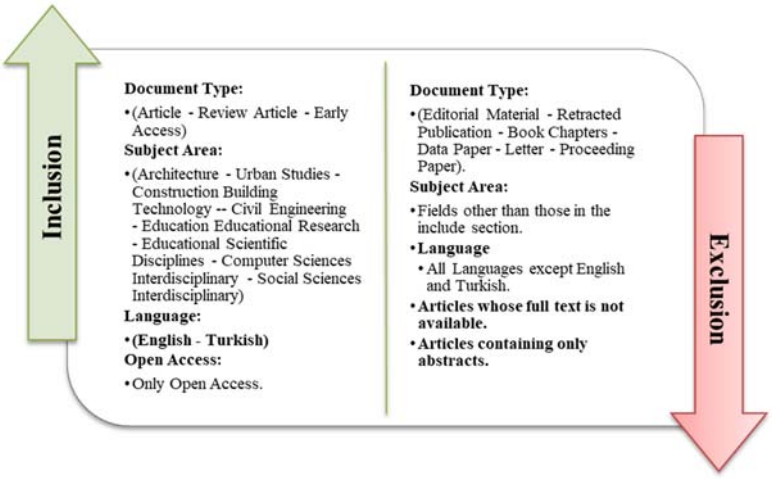

Figure 3. Inclusion and exclusion filters implemented in the Web of Science database, (Prepared by the authors).

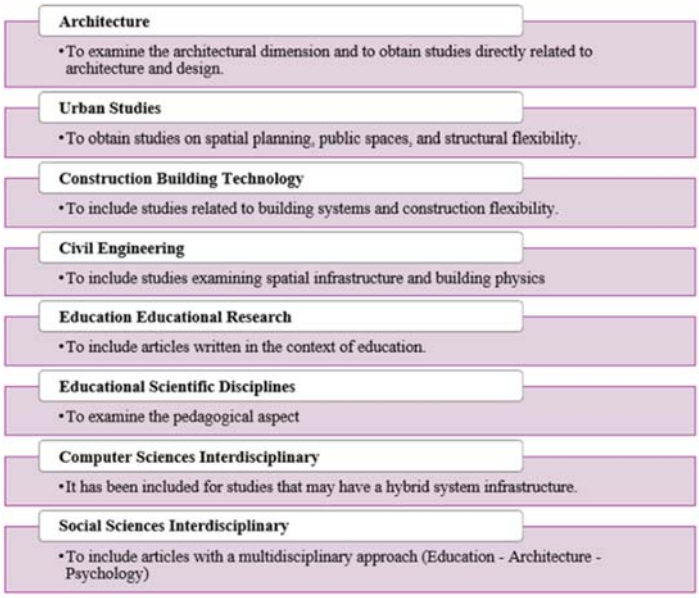

Figure 4. Included categories and reasons for inclusion, (Prepared by the authors).

Subsequently, to conduct statistical analyses of the data downloaded in (.bibtex) format, the Bibliometrix – Biblioshiny interface within the bibliometric search application R-Studio, developed by Aria and Cuccurullo (2017), was utilized. Within the R-Studio interface, without the need for coding expertise, "Bibliometrix" was entered, and "biblioshiny" was chosen from the pop-up menu. The analyses depicted in Figure 5 were executed using Biblioshiny.

3. FINDINGS AND EVALUATION

The Web of Science database was selected as the basis for this study because it contains comprehensive and organized resources. As shown in Figure 2, the preliminary search findings, obtained before applying inclusion and exclusion criteria by searching the database using Boolean operators covering the main theme of the study, yielded 29.831 results from WoS for the search *"21st Century Learning Requirement*" or "21st Century Education*"*.The preliminary search was conducted on June 19, 2025. Subsequently, the findings were filtered to eliminate outside-the-field information and focus on relevant topics, subjecting the outcomes to the inclusion and exclusion criteria in

Figure 3 and 4. The filtering feature offered in the Web of Science interface was used to filter the preliminary outputs. Consequently, the final results obtained after filtering yielded 2,213 results from WoS for the search *"21st Century Learning Requirement*" or "21st Century Education*"*. The last search was conducted on June 19, 2025, and the relevant resources were downloaded in (.bibtex) format. After that to avoid repetition of keywords that could affect the results of the analyses synonymous keywords e.g. "*21st century abilities*", "*21st-century abilities*", "*21st-century skills*" were merged into"*21st century skills*", and "*higher education*" were merged into "*education*" prior to analysis. Within the scope of this study, the analyses in Figure 5 were conducted using Biblioshiny, using data retrieved from the Web of Science for the relevant topic.

Figure 5. Analyses made in Biblioshiny, (Prepared by the authors).

3.1. Main Information and Annual Scientific Production

An examination of Figure 6 shows that the obtained sources were published between 1995 and 2025. The analysed sources comprise 2213 sources written by 6584 authors. Furthermore, as can be excluded from the analysis done, it is indicated that the interest in the topic of 21st century learning requirements has been steadily increasing in recent years towards 2025. The number of studies published in 2015 increased from 44 to 360 in 2024. The annual growth rate of the number of publications was determined to be 14.49%, while the rate of international co-authorship remains relatively limited at 17.17%. Furthermore, according to the search criteria used in this study within the Web of Science database, only 16 publications in the field of architecture were found at the time of the data analysis, contributing only 0.82% to the literature (WoS Database). Based on past analyses and results, it is anticipated that interest in this field will increase further in the coming years, indicating that the relevant topic is underrepresented in the field of architecture and is open to further study. On the other hand, this rapid growth shows that spatial research needs to keep pace with this momentum.

Figure 6. Main information of data uploaded to Biblioshiny, (Prepared by the authors using Biblioshiny).

3.2. Most Relevant Sources

Based on the data analysis from the WoS database (Figure 7), the journal "Problems of Education in the 21st Century" ranks first in terms of the number of publications, with 338. Second and third place, respectively, are "Education Sciences" and "Frontiers in Education". What is remarkable is that the entire list consists of education-focused journals. Moreover, the journal that ranked first was identified as being directly related to the researched topic based on its name. However, the absence of any architecture, urban design, or built environment journal from this list concretely demonstrates that research on 21st century learning environments has yet to gain significant representation in architectural journals/publications. This situation confirms the originality of the study and the gap it fills in the field.

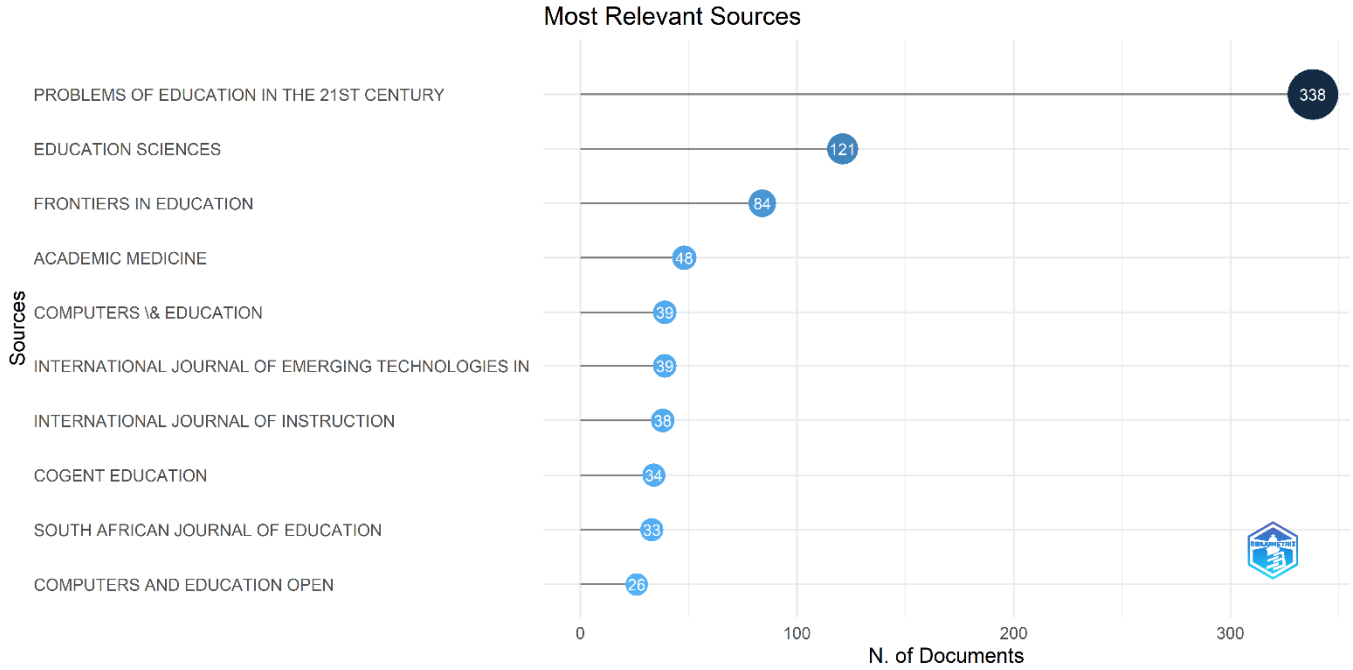

Figure 7. Most relevant sources, (Prepared by the authors using Biblioshiny).

3.3. Most Relevant Authors and Authors' Production Over Time

As can be seen from the analyses in Figure 8 and Figure 9, within the scope of the reviewed literature, authors interested in the field of 21st century learning needs have been active since 2018. The author "Siew Nyet Moi", active between 2020 and 2024, stands out with nine studies. From another perspective, the author "Babincakova Maria", whose publications date from 2020 to 2024, is the most prominent, with the highest number of citations in her 2020 works compared to her works from other years (Figure 8). It is also observed that the author "Suherman Suherman" was active from 2022 to 2025 and has 7 studies on the subject. Furthermore, Figure 9 shows that his work in 2024 received the highest number of citations. Among the authors ranked 3rd and 4th, "Retnawati Heri", who has six studies on the subject, was active only between 2018 and 2021, while "Rochovska Ivana" was active between 2019 and 2024. As a result of the analysis, it has been noticed that all authors work in the fields of education and natural sciences and only one of the top 10 authors with extensive work on the subject in the WoS database appears to be active today.

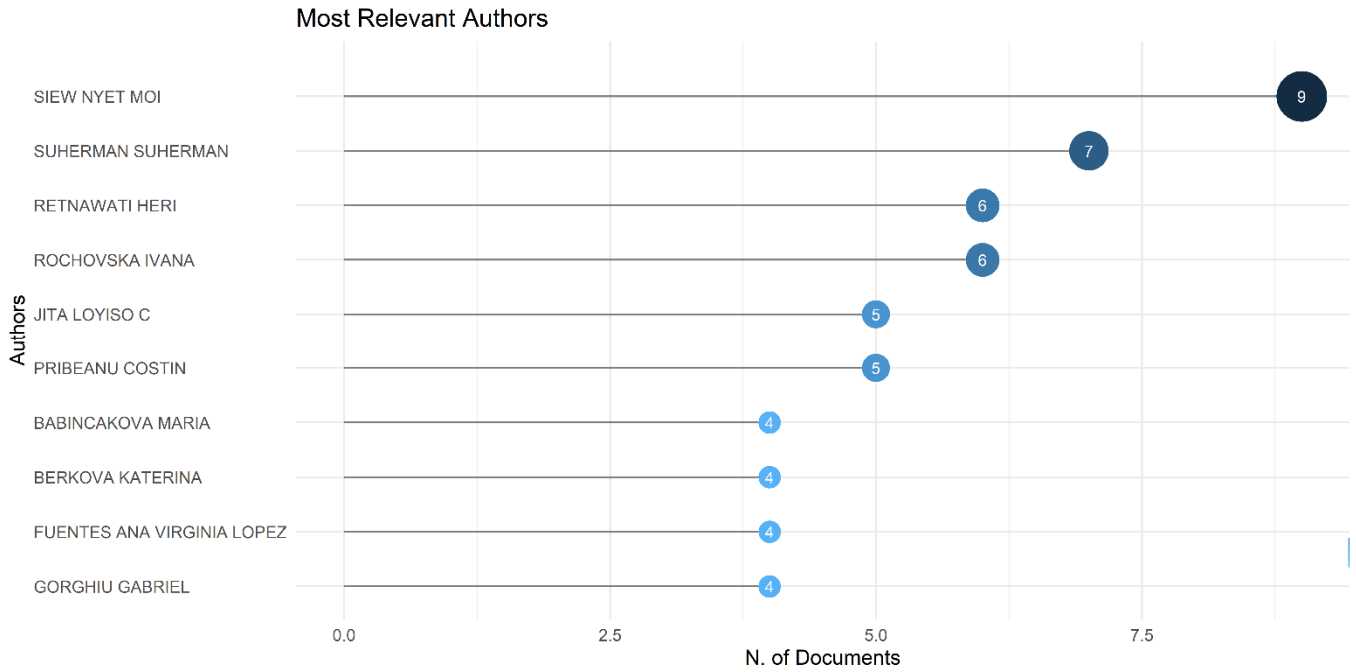

Figure 8. Most relevant authors, (Prepared by the authors using Biblioshiny).

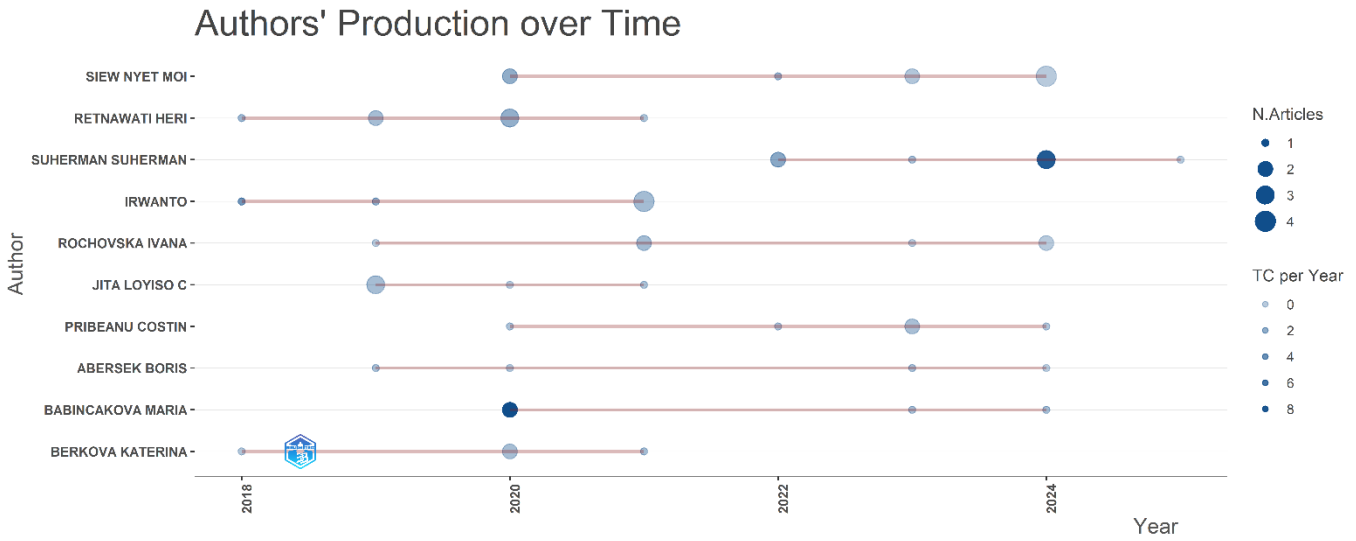

Figure 9. Authors' production over time, (Prepared by the authors using Biblioshiny).

3.4. Most Cited Countries and Countries' Collaboration Network

According to data from the WoS database, the United States predominates with the most studies on the subject, with 8069 citations, leading the way by a large margin. Canada comes in second with 2784 citations. The United Kingdom comes in third with 2202 citations. Türkiye also ranks 7th among the top 10 most-cited countries on this topic, according to WoS data, with 663 citations. Based on this analysis, Anglo-Saxon countries have the highest number of studies and citations on the topic of 21st century learning space needs. Moreover, the Netherlands, Spain, and Australia stand out with their high citation counts, exceeding 1000. Furthermore, Türkiye, China, Germany, and Norway are emerging research centers on the subject (Figure 10).

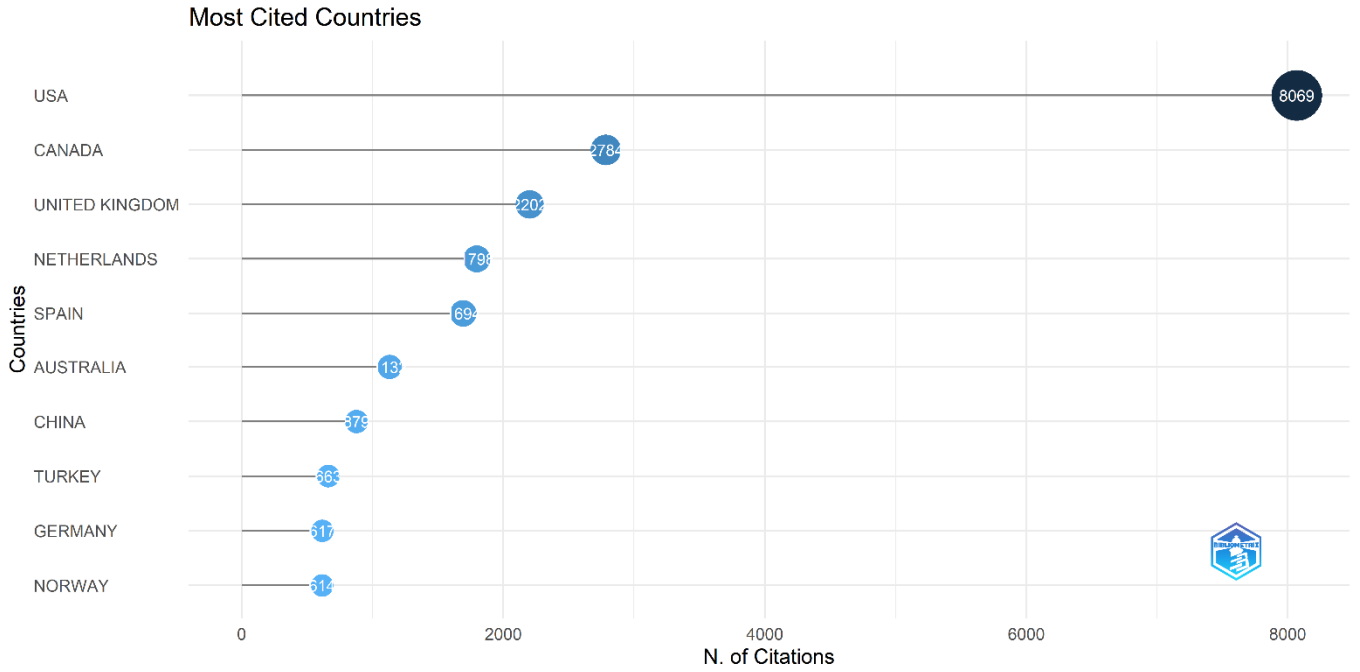

Figure 10. Most cited countries, (Prepared by the authors using Biblioshiny).

An examination of international cooperation in Figure 11 reveals that the largest node is located in the United States. Therefore, along with other countries, the United States is among the countries with the most intensive exchanges. On the other hand, Figure 11 demonstrates that while Serbia, Croatia, and Hungary, located in the red cluster, have limited exchanges among themselves, international exchange appears to be restricted. Indonesia and Vietnam, located in the yellow and brown clusters, demonstrate weak international interaction. Furthermore, countries like Russia, Greece, and Romania in the blue cluster, and Australia, Finland, and Norway in the purple cluster, have moderate levels of information exchange both among themselves and with the green cluster including the US, Canada, and the UK, which possess the largest international networks.

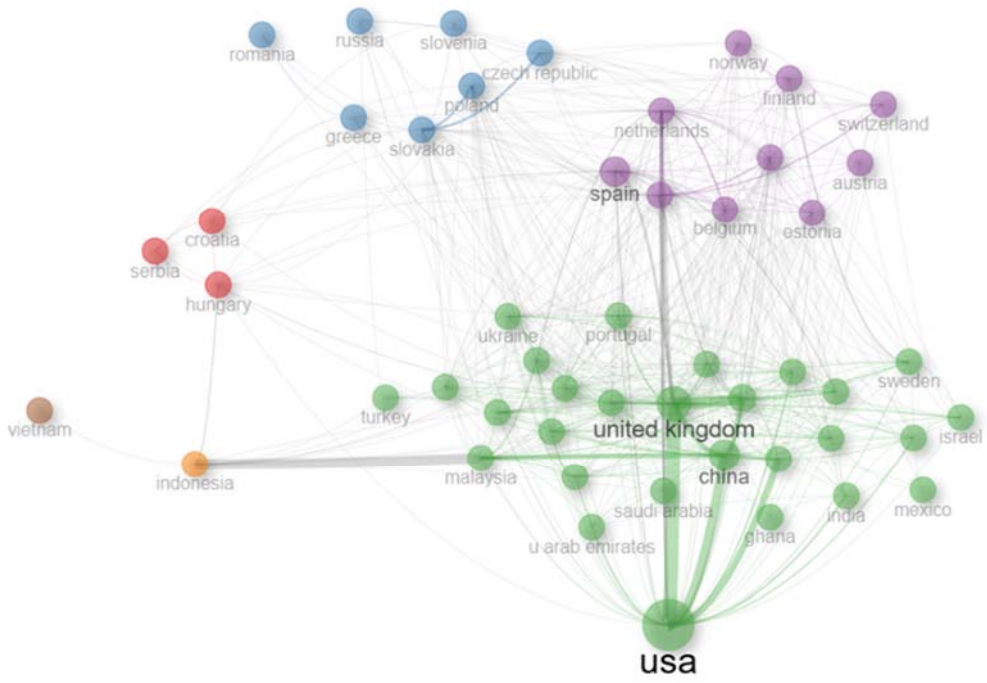

Figure 11. Countries' collaboration network, (Prepared by the authors using Biblioshiny).

3.5. Most Relevant Author Keywords and Words' Frequency Overtime

After downloading the data collected from the WoS database by applying certain filters on the search of 21st Century Learning Spaces, synonymous keywords like "*21st century abilities*", "*21st-century abilities"*, "*21st-century skills*" were merged into"*21st century skills"* and "*higher education"* were merged into "*education*" within the "*.bibtex*" file prior to analysis. Subsequently, the merged "*.bibtex*" file was uploaded into Biblioshiny's interface in order to make the analysis. Moreover, the most frequently used word cloud in Figure 12 was created as a result of the analysis by selecting the Authors' Keywords option from the filtering options.

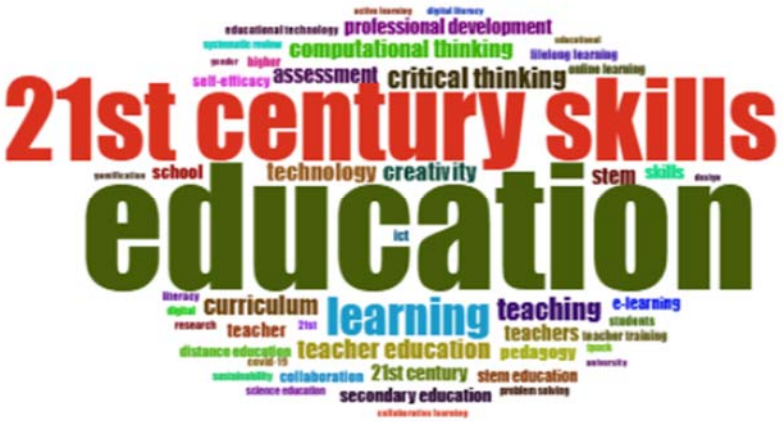

Figure 12. Most relevant word cloud- (authors' keywords) for the 21st century learning requirements and 21st century education search, (Prepared by the authors using Biblioshiny).

The analysis of the most frequently used authors' keywords reveals that the word *"education"* is the leading word, appearing in 279 sources, while "*21st century skills*" is in second place with 179 sources. Furthermore, the terms "*learning*", "*teaching*", "*critical thinking*", "*teacher education*", "*curriculum*", "*creativity*", "*technology*" and "*computational thinking*" are among the top 10 most frequently used authors' keywords, (Figure 13). On the other hand, the word "*design*" is included in a relatively small but noticeable way within first 50 frequent word cloud, (Figure 12).

Figure 14 shows a rapid increase in interest since 2019 in the terms "*Education*" and "*21st century skills*", which are the former within the top 10 authors' keywords, towards 2025. Meanwhile, the term "*Curriculum*" has been steadily increasing since 2015. "*Technology*", on the other hand, has become more prominent since 2018.

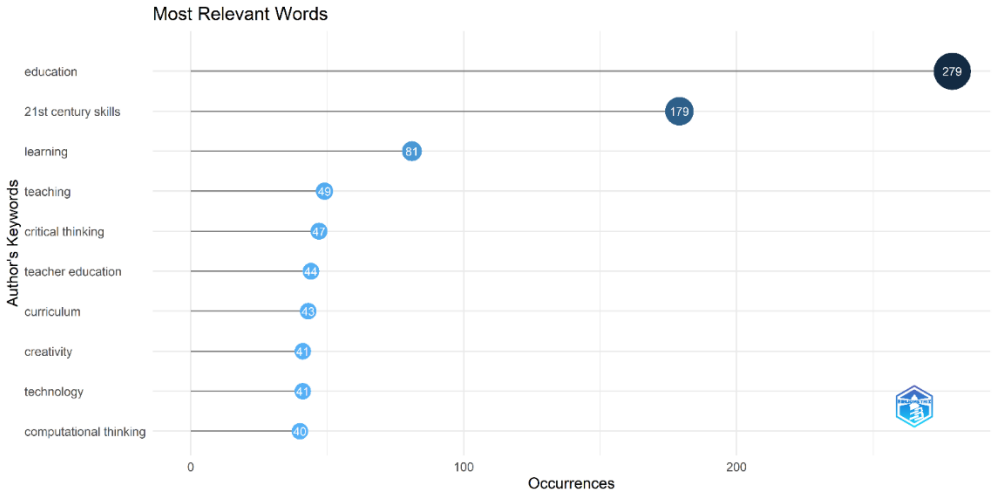

Figure 13. Most Frequent words, (Prepared by the authors using Biblioshiny).

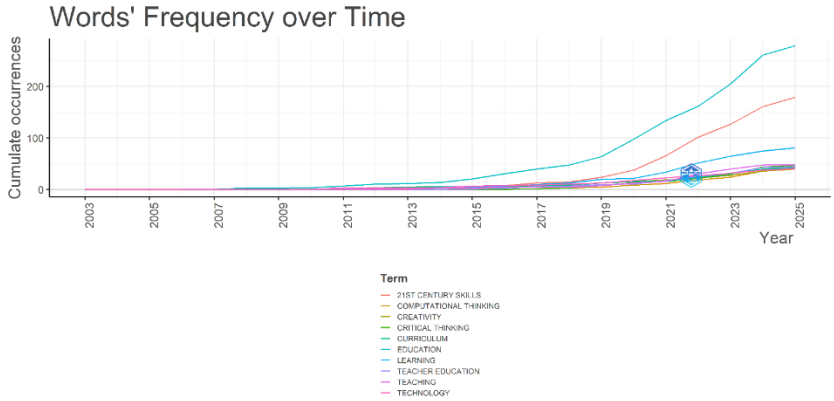

Figure 14. Words' frequency over time, (Prepared by the authors using Biblioshiny).

3.6. Authors' Keywords Trend Topics

One of the analyses performed in the Biblioshiny interface is the "Trend Topics" graphic. This analysis method graphically displays the times when terms that have been popular in recent years emerged and peaked, based on their frequency of use. Using this analysis technique, the "Authors' Keywords" filter was selected, resulting in Figure 15.

The Trend Topics chart reveals that the term "*education*", ranked first in the analysis of authors' keywords, emerged in 2020 and peaked in 2022; in contrast, analysing the term "*21st century skills*", ranked second in the analysis of authors' keywords, it appears that it emerged in 2021 and peaked in 2022. Moreover, it is noteworthy that the latest trending terms "*critical thinking*", "*computational thinking*" and "*educational innovation*" has emerged lately between 2020-2022 and peaked in 2023-2024. Furthermore, the term "*technology*" was used between 2018 and 2023, whereas the term "*pedagogy*" was popular between 2016 and 2023. Furthermore, it is notable that the term *"ICT in education"*, featured in the chart, emerged 15 years ago and remains popular to this day.

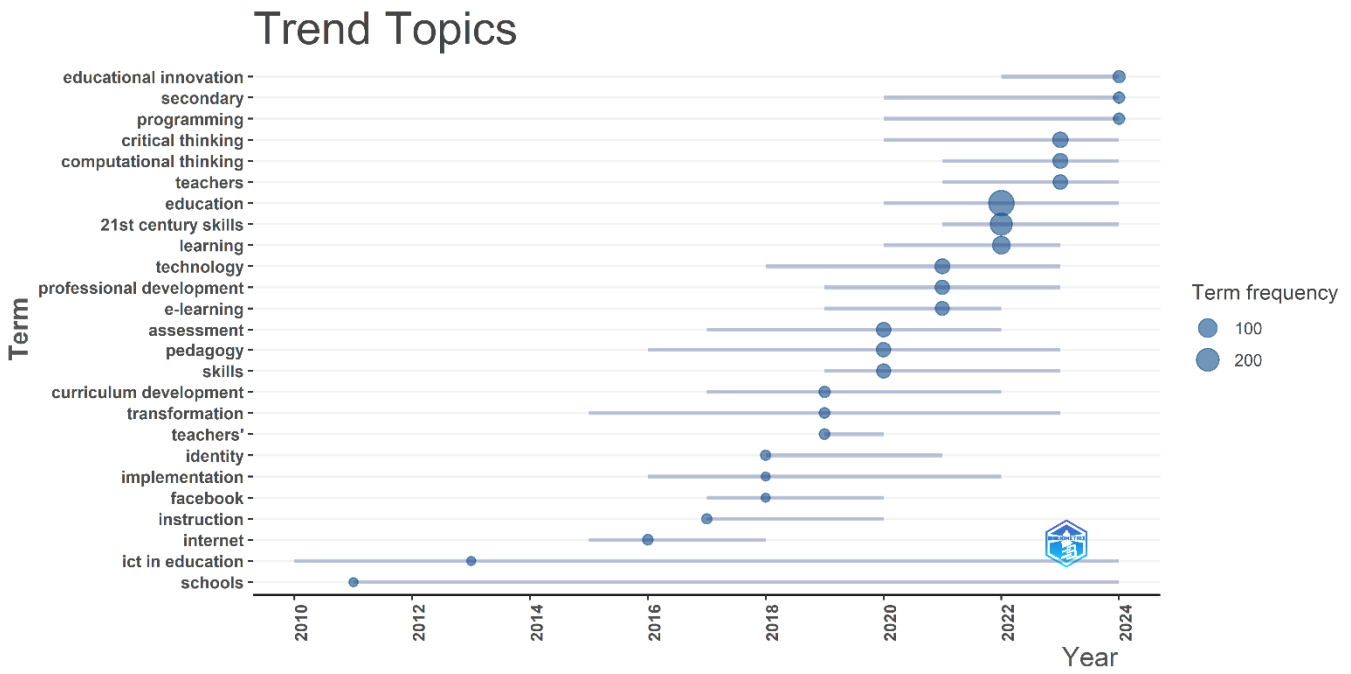

Figure 15. Trend topics (authors' keywords), (Prepared by the authors using Biblioshiny).

3.7. Author's Keywords Co-occurrence Network

An "Authors' Keywords Co-occurrence Network" analysis was conducted by loading data from the WoS database for research on the requirements of 21st century learning spaces after merging synonymous keywords like "*21st century abilities*", "*21st-century abilities"*, *"21st-century skills*" into"*21st century skills"* and *"higher education"* into "*education*" within the "*.bibtex*" file prior to analysis, and applying the Authors' Keywords filter in the Biblioshiny interface, R-Studio's web interface "Biblioshiny" was used for bibliometric analysis. Based on the study, Figure 16 was created, depicting the co-occurrence network of common authors' keywords.

As can be seen in Figure 16, keywords are divided into clusters based on interest and usage. The most dominant cluster is green. The green cluster emerges as the central cluster, containing terms related to education and types of education. "*education*" and "*21st-century skills*" are the two dominant nodes of the network. They have very strong connections with each other and with other concepts. "*STEM – curriculum - secondary education – teaching* and *learning*" are tightly linked to this center. "*collaborative learning - active learning – design - university - research* and *higher*" are located in the same cluster but in the peripheral region with weaker connections. It is noteworthy that, although the concept of "*design*" is located in the green cluster, it is situated in the periphery region of the network and exhibits only a weak, one-way connection with the concept of *"education"*. No connection is observed between "*design*" and concepts representing 21st century skills such as "*critical thinking, creativity, and collaboration*, while the brown cluster contains more technology- teaching oriented concepts, such as "*technology – ICT - teacher* and *teacher training*", indicating that technology integration is being explored in conjunction with teacher training. On the other hand, the purple cluster includes more pedagogical terms such as "*Skills - pedagogy - tpack - 21st century* and *gender*". TPACK represents the technology-pedagogy-content knowledge model. Furthermore, the light pink cluster contains terms related to skills, such as, "*critical thinking - creativity - collaboration - problem solving and assessment*" are all included together, which forms the concrete content of 21st century skills. Moreover, the blue, gray and pink clusters include digital learning concepts such as "*digital literacy - e-learning - digital - educational technology, covid-19, distance education* and *online learning"*, together reflecting the digital transformation that has been strengthened in the post-pandemic era. The highest co-occurrence rate was observed in the green cluster.

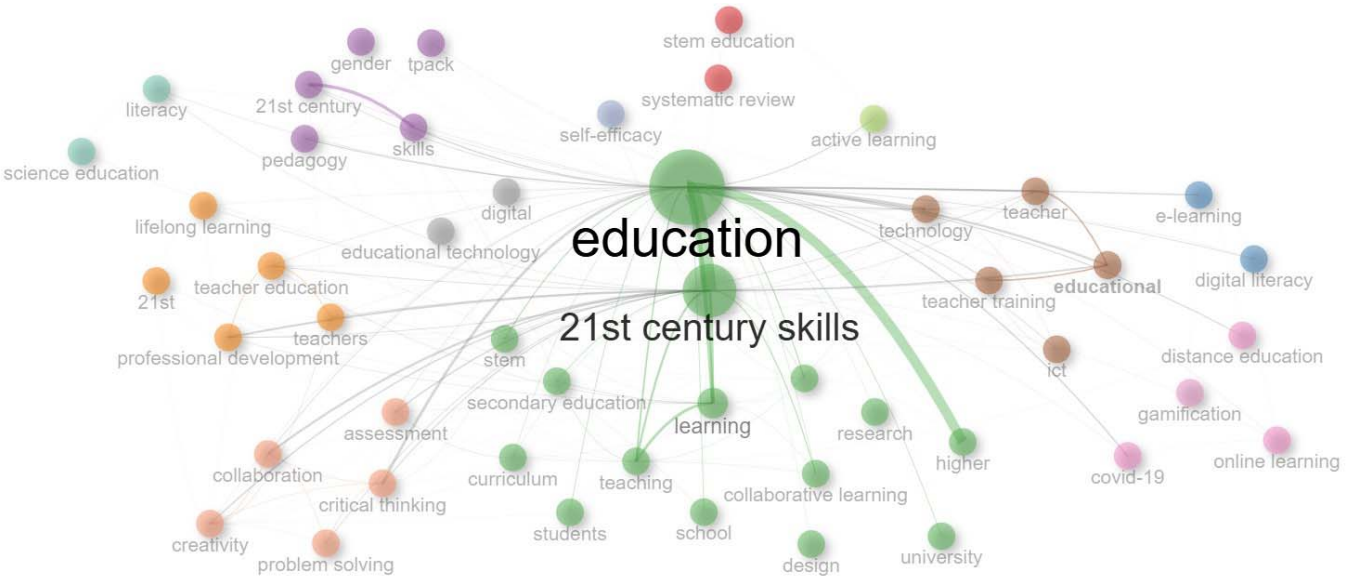

Figure 16. Co-occurrence network (authors' keywords), (Prepared by the authors using Biblioshiny).

3.8. Authors' Keywords' Thematic Map

The analysis in Figure 17 was created using the "Thematic Map" Authors' Keywords filter under the "Conceptual Structure" tab, one of the analysis categories in Biblioshiny's interface. This analysis features evaluating authors' keywords by dividing them into four themes, each defined by centrality (relevance) and density (development) axes.

The terms in the "Emerging or Declining Themes" theme, located in the bottom left, are either emerging terms that will approach the center and show a high intensity of usage through the years, or they will become forgotten concepts and disappear in the future, as well as the terms in the "Niche Theme", located in the top left, contain important but not yet widely researched terms. The "Basic Themes" are located in the bottom right; the terms in this area consist of the most important fundamental concepts in the relevant field. The concepts in the "Motor Theme", located in the top right, contain the most frequently researched and most strongly interconnected popular terms in the literature. Additionally, the bubble size indicates the weight of this cluster in the literature. Analysis will be conducted taking into account relevant criteria. On the other hand, terms located close to the vertical and horizontal centrality axes that divide both axes in the middle, or get closer over time, are the most frequently used terms.

An examination of Figure 17, created by taking into account the relevant criteria, reveals that the appearance of the concept of "*21st-century skills*" in two different clusters on the thematic map indicates that this concept has generated separate research agendas in the literature in different contexts, skills development and curriculum policy. Moreover, the concept of "*21st-century skills*" within the yellow cluster has a high density, and it is positioned at the very beginning of the motor skills theme. This indicates that it is emerging from a niche theme and is newly integrated into the motor skills theme. Also, "*Teaching, 21st century, secondary education*" terms are located within the motor theme. These concepts exhibit both high centrality and high density. That is, they are the most frequently researched and most strongly interconnected themes in literature. "*Secondary education*" is particularly noteworthy here because the secondary education level has become central to the research agenda in recent years. In other words, it is rapidly evolving and may soon move towards the center of the motor skills theme.

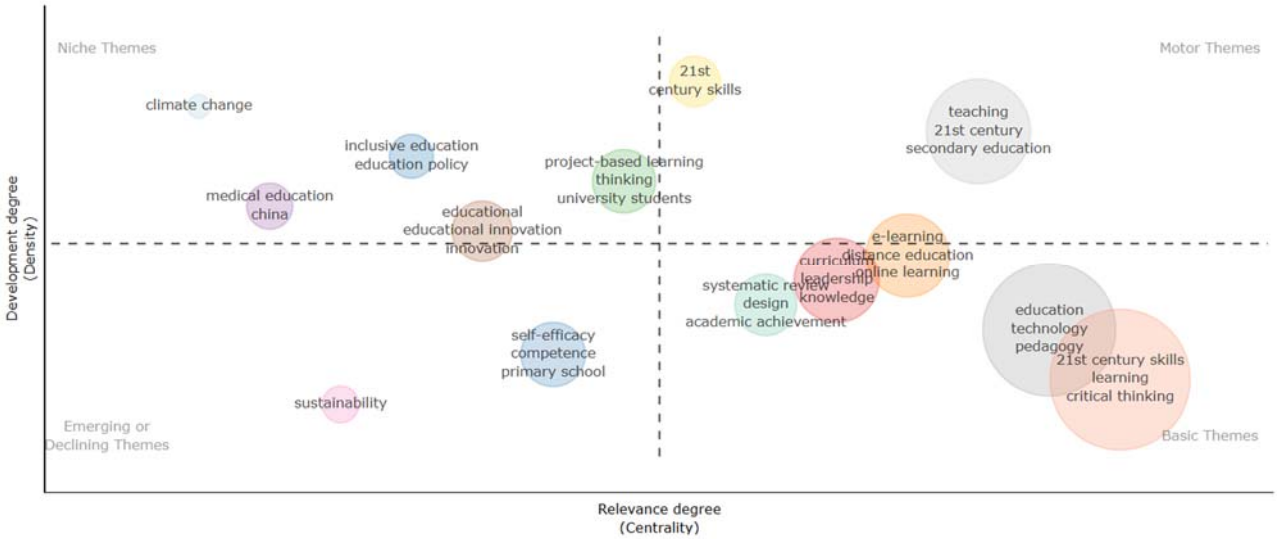

Figure 17. Thematic map (authors' keywords), (Prepared by the authors using Biblioshiny).

Furthermore, "*Education, technology, pedagogy, 21st-century skills, learning, critical thinking*" terms are located within the basic themes. Since the bubble size indicates the weight of this cluster in the literature, they are located within the largest cluster. The core concepts form the backbone of the field. Their high centrality shows that these concepts are indispensable reference points in the literature on 21st-century learning environments. However, their low density suggests that the relationships and depths between these concepts have not yet been fully developed. In other words, these concepts are frequently used, but the theoretical connections between them have not been strongly established. On the other hand, "*Design*" is clustered within the basic thematic area, near the center, alongside "*systematic review*, *academic achievement*" and next to "*knowledge, curriculum*, *leadership*" and "*e-learning, distance education, online learning*". The concept of "*design*" occupies a moderately central and widespread position in the literature. It is among the fundamental research topics. However, its inability to transition to a more central theme indicates that this concept has not yet become a dominant and leading research area.

The niche theme includes terms encompassing policy-focused and inclusivity-oriented studies, such as "*inclusive education, education policy*", active learning approaches, such as "*project-based learning, thinking, university students*" and concepts of educational innovation, such as "*educational, educational innovation, innovation*" and "*climate change*". On the other hand, the concepts of "*sustainability*", "*self-efficacy*, *competence*

and *primary school*" are included in the emerging or declining theme located in the lower left corner. The inclusion of "*sustainability*" here can be interpreted in two ways: either it is a research area that is still developing, or it is losing popularity. Looking at current literature trends, the former seems more likely.

3.9. Most Global Cited Documents

According to data from the WoS database, examining the results of the analysis of the top 10 most-cited international studies using the Biblioshiny interface shows that the study by Anderson and Shattuck (2012), published in the journal "Educational Researcher", holds the leading position globally, receiving the highest number of citations with 1009 citations. Furthermore, the study by Mclaughlin et al. (2014), published in the journal "Academic Medicine", ranked second with 687 citations, while the study by Voogt and Roblin (2012), published in the journal "Journal of Curriculum Studies" ranked third with 666 citations (Table 1). This ranking indicates that the authors are influential in their respective fields. An examination of the most-cited authors' studies reveals that they are from diverse fields. At the same time, although all the studies have been carried out in different fields, they converge at a common point and discuss the ideas about the design of learning spaces in order to keep the quality of healthy and current education at the highest level (Table 1).

Table 1. Most global cited documents names, (Prepared by the authors using Biblioshiny).

Top 10 Authors and Publishing year	Source	Title of The Publishing	Total Citations
ANDERSON T, 2012	Educational Resercher	*Design-Based Research: A Decade of Progress in Education Research?*	**1009**
MCLAUGHLIN JE, 2014	Academic Medicine	*The Flipped Classroom: A Course Redesign to Foster Learning and Engagement in a Health Professions School*	**687**
VOOGT J, 2012	Journal of Curriculum Studies	*A comparative analysis of international frameworks for 21st century competences: Implications for national curriculum policies*	**666**
ADLER NJ, 2009	Academic of Management Learning and Education	*When Knowledge Wins: Transcending the Sense and Nonsense of Academic Rankings*	**578**
WARSCHAUER M, 2010	Review of Research in Education	*New Technology and Digital Worlds: Analyzing Evidence of Equity in Access, Use, and Outcomes*	**383**
JACOBSON MJ, 2006	Journal of The Learning Sciences	*Complex Systems in Education: Scientific and Educational Importance and Implications for the Learning Sciences*	**349**
TANG X, 2020	Computers and Education	*Assessing computational thinking: A systematic review of empirical studies*	**345**
GARCIA O, 2011	The Modern Language Journal	*Pedagogies and Practices in Multilingual Classrooms: Singularities in Pluralities*	**334**
KENNY NP, 2003	Academic Medicine	*Role Modeling in Physicians' Professional Formation: Reconsidering an Essential but Untapped Educational Strategy*	**313**
CAENA F, 2019	Eurpian Journal of Education	*Aligning teacher competence frameworks to 21st century challenges: The case for the European Digital Competence Framework for Educators*	**289**

3.10. Documents Co-citation Network

As can be seen from the Documents Co-citation map created in the Biblioshiny interface, the authors of research published in the WoS database on the requirements of 21st-century learning spaces are clustered under five main headings. Furthermore, among other studies, Voogt J. and Roblin's (2012) study, "A Comparative Analysis of International Frameworks for 21st Century Competences: Implications for National Curriculum Policies", is the third-highest cited study with 666 citations, located in the blue cluster. The inclusion of constructivist learning

theorists such as Vygotsky (1978) in the green cluster reveals the theoretical basis of 21st-century learning environment research. On the other hand, Voogt (2012) and Ananiadou (2009) are positioned in the blue cluster, representing 21st-century competency frameworks. When examining the cluster relationships, the blue and green clusters exhibit a dense citation network within themselves, while there is also a network of studies with other clusters. Conversely, the red, orange, and purple clusters have fewer citation networks, while the studies in the brown cluster have a limited network (Figure 18). Moreover, Vygotsky (1978) is the originator of the concept of "Zone of Proximal Development". This refers to a developmental zone where a student cannot develop independently but can do so with support. This theory forms the basis of constructivist learning. The inclusion of Vygotsky in this study means that researchers are basing their discussions of 21st-century education on it. Furthermore, Vygotsky's constructivist theory is highly significant from an architectural perspective: Constructivist learning envisions learning through active participation, collaboration, and experience. This pedagogical approach cannot be applied independently of physical space. Flexible spaces, group work areas, workshop-type arrangements, and convertible furniture systems are direct spatial reflections of this theory.

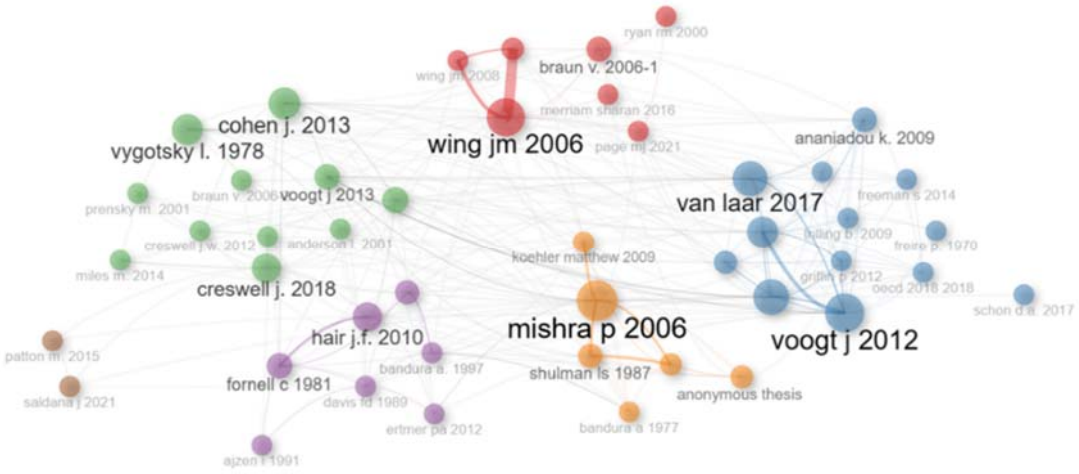

Figure 18. Documents co-citation network, (Prepared by the authors using Biblioshiny).

4. CONCLUSION AND RECOMMENDATIONS

Based on the results of the research, the volume of research focusing on the requirements of 21st-century learning spaces is steadily increasing. Data obtained from the WoS database on June 19, 2025, was filtered and analyzed using the Biblioshiny interface, a bibliometric analysis tool running on the R language web interface. Synonymous keywords like "*21st century abilities*", "*21st-century abilities", "21st-century skills*" were merged into*"21st century skills",* and *"higher education"* were merged into "*education*" within the "*.bibtex*" file prior to analysis. The results of this analysis revealed that research into 21st-century learning environments is growing rapidly. Despite this high growth rate, the low level of international collaboration indicates that the field is not yet mature. However, this growth is centered on pedagogy and educational technology. Architecture, spatial design, and the built environment dimension are represented in only 0.82% of the literature. This constitutes the main research finding of this article and provides empirical evidence of the critical need for interdisciplinary research.

Furthermore, an examination of the relevant authors' network based on the data retrieved from the WoS database revealed that authors Siew Nyet Moi and Suherman Suherman, who have published work on the subject, are prominent figures in the field. An examination of the work of both authors reveals that both have conducted research on STEM education and learning skills. While "Siew Nyet Moi" has examined critical and future-oriented approaches in her work, "Suherman Suherman" has focused more on mathematics education. However, it is noteworthy that the fact that none of the most prolific authors come from the fields of architecture or spatial design clearly reveals the interdisciplinary gap in the field. This finding provides strong evidence that works produced from an architectural perspective remain extremely limited in both quantity and visibility.

From another perspective, it has been seen that the journal titled "Problems of Education in the 21st Century",

which is among the journals that have published the most on the topic of 21st century learning spaces requirements, has a direct connection to the theme. In addition, while the journals named Academic Medicine and Computers and Education are in the top 10, two studies from Academic Medicine and one study from Computers and Education, published in those journals, are in the top ten rankings as the most-cited publications. At the same time, although the studies in the top ten rankings are in different fields, most of them have conducted research on the same theme and addressed the requirements of 21st century learning spaces as a topic of discussion.

For example, McLaughlin et al. (2014) addressed the student-centered classroom concept through the "Flipped Classroom" model. In addition, Garcia and Sylvan (2011), Anderson and Shattuck (2012), and Jacobson and Wilensky (2006) emphasized the importance of experiencing different performances on various platforms; learning through experience, the "Design-Based Research" method, and the relationship between experimentation and learning emerged as common themes in these studies. Furthermore, Tang et al. (2020) stands out with his study on *"Computational Thinking",* defined as a key element in 21st-century learning spaces, and the features it provides to students. On the other hand, Voogt and Roblin (2012) attempted to identify 21st-century learning needs. According to the findings of all these studies in the literature, it was determined that existing learning spaces are insufficient. Furthermore, examining the requirements of 21st-century learning spaces and conducting studies on them is beneficial in filling gaps in the literature, and it has been concluded that learning quality, student performance, and the design of learning spaces play a significant role.

On the other hand, the common thread among the most-cited documents is their approach to both the physical and pedagogical dimensions of learning environments. For instance, Anderson and Shattuck's "design-based research" approach and McLaughlin's student-centered spatial transformation directly point to the importance of user-centered and evidence-based approaches in the architectural design process. Furthermore, the inclusion of Vygotsky's constructivist learning theory in the Documents Co-citation network is particularly significant from an architectural perspective. Since the constructivist approach centers on the active participation of students in learning environments in the 21st century, it theoretically reinforces the need for spatial configurations that support collaboration and experiential learning. In other words, it necessitates flexible and transformable spatial design. This theoretical framework directly lays the groundwork for architectural design decisions.

Additionally, terms such as "*21st century skills and critical thinking, computational thinking, technology, ict in education, educational innovation, and education*" have been prominent in recent literature. The inclusion of the term "*design*" in the word cloud indicates that 21st-century educational literature partially encompasses the spatial design dimension. However, the limited visibility of this term reveals that the architectural perspective is not yet adequately represented in the literature.

From another perspective, when examining the co-occurrence network, skills such as "*critical thinking*, *creativity, collaboration, problem solving, assessment* and *lifelong learning*" are evaluated independently of the physical space. However, "*critical thinking, creativity, and collaboration*" skills cannot be fully supported without open-plan arrangements, flexible furniture systems, and multifunctional spaces. The lack of a connection between this cluster and "*design*" is a critical gap. On the contrary, the vast majority of the most frequently used terms are pedagogical and curriculum-oriented concepts. The absence of architectural concepts like spatial design, flexibility, or built environment from the list of most frequently used words, and the absence of co-occurrence networks among fundamental concepts, concretely confirms the architectural gap in the literature and clearly demonstrates that spatial design has not yet been integrated with pedagogical transformation.

On the other hand, the rise of "*technology*" and "*e-learning*" after 2018, appeared at the trend topics diagram, in the post-pandemic period is directly related to the interest in hybrid learning environments. This period coincides with a phase in which learning spaces are being re-evaluated in terms of flexibility and transformability principles. This situation supports the need, from an architectural perspective, for physical learning spaces to be redesigned to accommodate technology integration. However, the literature has addressed this transformation from a pedagogical perspective, not a spatial design perspective. For example, when examining the co-occurrence network diagram, it is seen that technology integration is clustered together only with teachers and teacher training. Therefore, it shows that the dimension of adapting space through architectural design to technology has not yet found sufficient place in literature. Conversely, when the thematic map is examined, the inclusion of the concept of "*Secondary education*" within the basic theme indicates that research into the spatial transformation of secondary education buildings is beginning to mature. This supports the idea that secondary school buildings should move away from traditional classroom typologies and transform into flexible, multifunctional spaces suitable for technological integration. However, these studies are still pedagogy centric. The architectural design dimension has not yet been included in

this theme. This finding supports the need to redesign secondary education buildings in terms of flexible spatial arrangements, social learning areas, and technology integration.

Furthermore, the inclusion of "*technology*" and "*pedagogy*" within the basic theme is critical from an architectural perspective. Given that technology integration and pedagogical transformation cannot be truly implemented if the physical space cannot adapt to this change. For instance, flexible partitioning systems, equipment arrangements suitable for technology infrastructure, and acoustic solutions constitute the spatial manifestations of these two concepts.

Also, the concept of "*project-based learning*" constitutes a mature research area in itself within the niche theme. However, this depth has not yet been integrated into the central focus of the 21st-century learning environment literature. This indicates that the spatial flexibility process of integrating flexible, workshop-type spaces, makerspaces, and transformable workspaces that support project-based learning into the pedagogical literature is not yet complete. On the other hand, the inclusion of the concept of "*inclusive education*" within the niche theme is also critical from an architectural perspective. Inclusive education directly addresses architectural requirements such as universal design principles and accessibility standards. For instance, creating inclusive spaces that respond to different learning needs improving the user-centered design idea. However, this connection has not yet been sufficiently established in the literature.

Moreover, the inclusion of the concept of "*sustainability*" in the emerging/declining theme shows that research on sustainable school design is not yet mature. Architectural sustainability criteria, which influence the environmental psychology, such as energy efficiency, natural lighting, acoustics, green roof applications, and carbon footprint have not yet found a central place in educational research literature. This points to a significant research gap in terms of environmental psychology and post-occupancy assessment studies. In addition to this, the bibliometric findings show that research on 21st-century learning environments and learning spaces is concentrated around specific countries, concepts, and academic networks. For instance, the dominant position of Anglo-Saxon countries is directly related to the investments made in education policy and spatial innovation in these countries. For example, comprehensive school design initiatives such as the "Building Schools for the Future" program in the United Kingdom partially account for the dense concentration of references. On the other hand, the central position of the United States, both in terms of publication volume and citation network, reveals that the country continues to play a globally influential role in educational research. This can be explained not only by the volume of academic output but also by the size of funding allocated to educational research in the US, the established interdisciplinary research culture, and the strong university-policy-technology collaborations. Furthermore, addressing learning environments in conjunction with pedagogical transformation is directly related to the long-standing support for innovative learning models in US-based education policies.

Türkiye, however, appears to occupy a "rising but peripheral" position in the analyses. This situation can be explained by the fact that, despite the increasing academic interest in learning spaces, flexible learning, and educational technologies in the country in recent years, research mostly remains within a local context and is only integrated to a limited extent into international citation networks. Moreover, the fact that a significant portion of the studies in this field in Türkiye are descriptive in nature tend to relatively limit conceptual framework production or theoretical discussion depth. This makes it difficult for Türkiye to position itself as a central knowledge producer, despite its visibility in the literature. Türkiye's rising position, on the other hand, offers a significant window of opportunity for original studies at the intersection of architecture and education research. Furthermore, it demonstrates the potential for involvement in international architecture and education research collaborations. However, for this potential to translate into tangible results, architecture-focused interdisciplinary projects need to be integrated into international networks.

In conclusion, bibliometric findings reveal that the field of 21st-century learning environments is growing rapidly, but research is largely concentrated in specific geographies and exhibits a fragmented conceptual structure. In this context, developing unique contextual approaches, producing studies that deeply address the relationship between space and pedagogy, and establishing stronger ties with the international literature constitute an important opportunity for countries with developing research ecosystems like Türkiye.

Accordingly, the findings show that the literature on 21st-century learning environments largely focus on pedagogical and technological dimensions, while spatial and architectural dimensions are still treated as secondary. This indicates a significant research gap in integrating architecture-based approaches more strongly into educational research. Thus, it was concluded that current 21st-century traditional learning spaces are insufficient to support

student needs and performance. Furthermore, the analysis of the most frequently cited studies revealed that curriculum development alone is not sufficient, and that learning spaces must adapt to the ever-changing curriculum. Consequently, the analyses conducted in this study have identified the essential features of 21st-century learning requirements that can guide future research:

1. Spaces that provide opportunities to experience a variety of environments and performances.
2. Student-centered designs,
3. Technology integration,
4. Computational thinking,
5. Critical thinking,
6. Problem solving,
7. Collaborative thinking,
8. Communication skills development areas (student-student), (student-teacher),
9. Spatial flexibility (Flexible spaces),
10. Creativity,
11. Algorithmic thinking.

Finally, it has been determined that there is a gap in literature regarding the needs of 21st-century learning spaces. In this context, based on the analyses carried out in this study, transforming learning spaces from teacher-centered to more student-centered designs, and generally incorporating environments that support diverse experiences, allow observation of different settings, and foster communication skills, are among the most important learning needs of the 21st century. Thus, the principle of spatial flexibility should be adopted in the design of learning environments, transcending the rigid, teacher-centric paradigms of the past. At the same time, technology plays an indispensable role in meeting the needs of 21st-century learning spaces. Furthermore, while it is important for learning spaces to support computational thinking, problem-solving, and collaborative thinking, creating areas that encourage creativity and critical thinking has also been identified as a key element. In this context, based on the reviewed literature, designing flexible spaces has been shown to help meet these criteria.

Moreover, universal design principles and an inclusive spatial approach should be made an integral part of the design process of school buildings. Furthermore, post-occupancy evaluation studies, which assess physical learning environments in terms of environmental psychology parameters, should be included in the research agenda. Accordingly, when the findings are considered as a whole, it is clear that 21st-century learning environments require not only a pedagogical but also a spatial transformation. Concepts such as spatial agency, environmental psychology, spatial flexibility, user-centered design, and learning space typologies form the architectural pillars of this transformation. Therefore, interdisciplinary international research conducted at the intersection of architecture and education should be encouraged. This study proposes that learning spaces be designed considering the main elements of 21st-century learning space needs, which were obtained according to the results of this study, and provides a foundational road map for interdisciplinary studies to be conducted at the intersection of architecture and education research.

Conflict of Interest Statement: The authors declare that there is no conflicts of interest in this study.

Research and Publication Ethics Statement: This study which does not require ethics committee approval and/or legal/specific permission complies with the research and publication ethics.

Funding Statement: This study did not receive any financial support for the preparation of the article or the research conducted.

Author Contribution Statement:

Ela Hayek: Conceptualization (equal), methodology (equal), writing - original draft (equal), writing - review & editing (equal), visualization (equal), investigation (equal), formal analysis (equal), supervision (equal), validation (equal).

Hakkı Can Özkan: Conceptualization (equal), methodology (equal), writing - original draft (equal), writing - review & editing (equal), visualization (equal), investigation (equal), formal analysis (equal), supervision (equal), validation (equal).

ACKNOWLEDGMENTS

The study is human written. The authors conducted this study by interpreting the results of the analysis obtained on June 2025 from the Biblioshiny database.

REFERENCES

Anderson, T., & Shattuck, J. (2012). Design-based research: A decade of progress in education research. *Educational Researcher*, *41*(1), 16-25. https://doi.org/10.3102/0013189X11428813

Aria, M., & Cuccurullo, C. (2017). Bibliometrix: an r-tool for comprehensive science mapping analysis. *Journal of Informetrics, 11*(4), 959-975. https://doi.org/10.1016/j.joi.2017.08.007

Caena, F., & Redecker, C. (2019). Aligning teacher competence frameworks to 21st century challenges: The case for the european digital competence framework for educators (Digcompedu). *European Journal of Education*, *54*(3), 356-369. https://doi.org/10.1111/ejed.12345

Garcia, O., & Sylvan, C. E. (2011). Pedagogies and practices in multilingual classrooms: singularities in pluralities. *The Modern Language Journal*, *95*(3), 385-400. https://doi.org/10.1111/j.1540-4781.2011.01208.x

Jacobson, M. J., & Wilensky, U. (2006). Complex systems in education: Scientific and educational importance and implications for the learning sciences. *The Journal of The Learning Sciences*, *15(1),* 11-34. https://doi.org/10.1207/s15327809jls1501_4

Joan, D. R. (2013). Flexible learning as new learning design in classroom process to promote quality education. *Journal on School Educational Technology*, *9*(1), 37-42. https://doi.org/10.26634/jsch.9.1.2401

Kariippanon, K. E., Cliff, D. P., Lancaster, S. J., Okely, A. D., & Parrish, A. M. (2019). Flexible learning spaces facilitate interaction, collaboration and behavioural engagement in secondary school. *PloS one*, *14*(10), e0223607. https://doi.org/10.1371/journal.pone.0223607

Kariippanon, K. E., Cliff, D. P., Okely, A. D., & Parrish, A. M. (2020). The 'why'and 'how' of flexible learning spaces: A complex adaptive systems analysis. *Journal of Educational Change*, *21*(4), 569-593. https://doi.org/10.1007/s10833-019-09364-0

Kowaltowski, D. C. C. K., Gonçalves, P. P., & Cleveland, B. (2024). Better school architecture through design patterns. *Learning Environments Research*, 27(3), 619-647. https://doi.org/10.1007/s10984-024-09494-0

Krajewski, S., & Khoury, M. (2021). Daring spaces: Creating multi-sensory learning environments. *Learning and Teaching*, *14*(1), 89-113. https://doi.org/10.3167/LATISS.2021.140105

McLaughlin, J. E., Roth, M. T., Glatt, D. M., Gharkholonarehe, N., Davidson, C. A., Griffin, L. M., ... & Mumper, R. J. (2014). The flipped classroom: A course redesign to foster learning and engagement in a health professions school. *Academic medicine*, *89*(2), 236-243. DOI: 10.1097/ACM.0000000000000086

Tang, X., Yin, Y., Lin, Q., Hadad, R., & Zhai, X. (2020). Assessing computational thinking: A systematic review of empirical studies. *Computers & Education*, *148*, https://doi.org/10.1016/j.compedu.2019.103798

Voogt, J., & Roblin, N. P. (2012). A comparative analysis of international frameworks for 21st century competences: Implications for national curriculum policies. *Journal of Curriculum Studies*, *44*(3), 299-321. https://doi.org/10.1080/00220272.2012.668938

Vygotsky, L. S. (1978). Mind in society: The development of higher psychological processes. *Harvard University Press.* https://doi.org/10.2307/j.ctvjf9vz4