“Science mapping analysis of challenges surrounding cloud universities and their impact on the resilience of higher education”

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SCIENCE MAPPING ANALYSIS OF CHALLENGES SURROUNDING CLOUD UNIVERSITIES AND THEIR IMPACT ON THE RESILIENCE OF HIGHER EDUCATION

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Abstract

In the context of digital transformation, the education sector needs innovative solutions to ensure continuity and quality of the learning process amidst contemporary challenges. One solution is using cloud technologies, which allow for the virtualization and replication of key institutional processes, from academic programs to campus operations. In this regard, this article aims to identify the challenges associated with the concept of cloud universities and their impact on the resilience of higher education. A science mapping analysis is conducted based on the most relevant scientific papers indexed in the international Scopus database from 2000 to 2024 using Scopus and SciVal built-in tools and the Science Mapping Analysis Tool.

The results show a significant increase in the number of studies, especially within the fields of Computer Science and Social Sciences, dedicated to the use of cloud services and technology in education, with a growing focus on "digital twins". The application of science mapping tools revealed key trends in research development, which evolved from the development and optimization of cloud infrastructure and difficulties of technological usage and the adoption of new technologies by users to the deep integration of various technologies into the educational process, exploring their reception by students and teachers, as well as the effectiveness of these initiatives. The analysis identified key challenges cloud universities face, such as the need for reliable technical infrastructure, adherence to cybersecurity standards, preparing educators and students for working with new technologies, financial costs of implementing cloud technologies, and ensuring academic integrity.

Keywords bibliometric analysis, cloud service, cloud technology, digital twins, higher education, Scopus database, university

JEL Classification I23, I28, O33

INTRODUCTION

In recent times, the higher education (HE) sector across the globe has been facing unprecedented challenges arising from various disruptions and disturbances, including pandemics, natural disasters, social unrest, armed conflicts, and technological shifts. Instabilities and their consequences for the HE sector. Instability and its consequences for the higher education sector can last for weeks or even years, as the COVID-19 pandemic shows. Amidst such turmoil, higher education institutions (HEIs) face challenges in maintaining accessibility and continuity of their services and operations. Next to the need of keeping up normalcy for their staff and students, they have the missions to educate and empower the next generation as well as to generate knowledge and reach out to their environs – all three elements are equally important for the individuals concerned and the HE system and the country as a whole in terms of fostering resilience.

For maintaining continuity and accessibility of HEIs in crises, the cloud university model can be considered a valuable approach. This is recognized, amongst others, in a recently commenced EU project called "CLOUD HED,[1]" which is dedicated to establishing concepts for HEIs facing armed conflicts or other severe physical limitations to keeping up their operations. There is no universal definition of a cloud university model; it can be considered an HE system in which core learning, administration, and services are hosted and delivered through cloud-based platforms, i.e., on the internet. It can comprise online courses, virtual labs, digital libraries, collaboration tools, etc.

The cloud university model enables institutions to virtualize and replicate their key processes, from curriculum delivery to campus operations. It is particularly notable for its potential to facilitate relocation and enhance institutional flexibility through advanced cloud-based management systems and the implementation of so-called "digital twins". In the context of education and cloud universities, digital twins are virtual replicas of educational entities, such as classrooms, universities, or learning environments. They leverage real-time data, simulations, and AI to mirror the operations, interactions, and performance of their physical counterparts. In cloud universities, a digital twin can, for instance, represent the IT infrastructure of a cloud university, enabling administrators to monitor, optimize, and predict system performance. Moreover, through virtual classrooms and lab twins, students and faculty can interact, collaborate, and conduct experiments from anywhere in the world. Finally, digital twins can also optimize the management of physical resources like energy, classroom space, and equipment by providing actionable insights. Digital twins in education and cloud universities rely on the Internet of Things (IoT) for connecting physical and virtual systems, AI and machine learning (for analyzing and predicting patterns), and cloud computing to provide scalable, accessible platforms for virtual simulations and data storage.

1. LITERATURE REVIEW

Talking about the cloud university model, there are many theories and indicators involved that should be discussed in the following. The Cloud University combines technology and education. The integration of technology into higher education occurs through the processes of technology perception by educational service consumers, the interaction between consumers and providers of educational services with technology, and the adaptation to technological solutions.

The first block of theoretical statements is related to users' perception of technology and is based on theories such as the Technology Acceptance Model and the Unified Theory of Acceptance and Use of Technology, which explain how users perceive new technologies, considering user satisfaction and the technology adoption rate. As Budiyanto et al. (2025) emphasize, trust and financial behavior are crucial in shaping technology acceptance, which parallels the way students approach cloud-based educational platforms. Using the categories of the Innovation Diffusion Theory, it is possible to analyze how a new technology spreads among users. According to Febriandika et al. (2023), user demographics and cultural values significantly influence the adoption of digital banking, suggesting similar patterns in educational technology diffusion.

The second block characterizes the processes of adapting technologies to the learning process. The Task-Technology Fit model explains how well a technology aligns with educational tasks. Malik et al. (2025) argue that post-pandemic mobile wallet adoption is highly influenced by user involvement, indicating that active participation also facilitates better integration of learning technologies. The indicators of educational accessibility and institutional flexibility are critical factors in technology implementation, which are influenced by customization of learning and the principles of the Technology Acceptance Model.

The third block of theoretical issues defines the level of user interaction during the implementation of technology through customization of

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learning and student engagement, which are determined by the categories of the Theory of Planned Behavior. AlSokkar et al. (2024) demonstrate that the aesthetics of online campaigns significantly influence user decision-making, a factor that can enhance engagement in educational interfaces. Collaboration in learning stimulates technology adoption through user interaction. Berisha and Rayfield (2025) also show how internal fintech tools boost organizational outcomes, implying that internal educational technologies may strengthen institutional resilience.

These connections reflect how the theoretical frameworks influence or explain the key indicators that impact the resilience of higher education in the era of cloud universities.

By introducing an extended Technology Acceptance Model for online collaborative learning tools within the cloud-based context of top Malaysian universities, Yadegaridehkordi et al. (2018) contribute to addressing gaps in research on information systems (IS) adoption and online collaborative learning tools. This approach aligns with Nooruddin et al. (2022), who explore how commitment and perceived usefulness drive online banking adoption-lessons applicable to fostering user commitment in cloud-based education. The study emphasizes the importance of incorporating user feedback and expectations into the design of cloud-based learning tools to enhance user experience and meet user demands. The authors argue that for cloud universities, creating reliable, well-structured, and eco-friendly online resources, prioritizing support for sharing and collaboration, can distinguish these institutions in the competitive educational landscape.

Further extending the discussion of cloud technology's impact, Tóth et al. (2024) explore the sensitivity of university rankings, particularly for institutions in the Czech Republic, Hungary, Poland, and Slovakia. They highlight the need for a comprehensive strategy that goes beyond research output, incorporating elements like internationalization and industrial revenue to improve rankings. For cloud universities, the adaptability and scalability of cloud technologies could provide a strategic edge, allowing for quick responses to global educational demands and enhancing institutional performance metrics.

The integration of artificial intelligence (AI) also holds transformative potential for cloud universities. Okulicz-Kozaryn et al. (2023) investigate Eastern European students' perceptions of AI's role in education, revealing that 10% of surveyed students believe AI will replace professors within five years. While AI aligns with Sustainable Development Goal 4 (education quality), its rapid adoption also raises ethical and practical concerns. As Plastun and Kozmenko (2025) reveal, the Russian invasion has had devastating impacts on Ukrainian higher education, including the displacement and erasure of universities – underscoring the need for resilient and mobile educational models like cloud universities. Cloud-based educational models could leverage AI to provide dynamic learning experiences while addressing challenges related to inclusivity and the evolving roles of educators.

Chen et al. (2021) emphasize the growing focus on smart learning environments, such as mobile learning, MOOCs, and cloud-based ecosystems. They identify nine key areas of interest, including smart learning analytics and STEM education, underscoring how bibliometric analysis can guide cloud universities in targeting high-impact research areas. Similarly, Terzopoulos and Satratzemi (2020) highlight the potential of immersive learning technologies, including virtual reality and AI voice assistants, to enhance the learning experience. However, they caution that linguistic barriers, security concerns, and insufficient educator training remain hurdles to effective implementation.

The issue of data security in cloud-based educational contexts is critical. Jones et al. (2019) stress the fiduciary responsibilities of higher education institutions (HEIs) in managing student data, advocating for ethical and transparent practices that prioritize student interests. Similarly, Prinsloo and Slade (2017) argue for a balanced approach to data collection, aligning with cloud universities' need to build trust while safeguarding intellectual property and privacy.

Inclusivity and accessibility are additional challenges for cloud universities. Research into the impact of cloud-based education on underrepresented groups is vital to ensuring equitable access.

For instance, Rieznyk et al. (2023) emphasize the importance of impact investing in environmental protection and infrastructure projects in Ukraine, a principle that could be extended to support inclusive digital education infrastructure during post-war recovery. Tzavidas et al. (2020) discuss how ICT systems can facilitate university-industry collaboration, offering lessons for leveraging cloud technologies to improve organizational knowledge sharing and responsiveness to diverse learner needs.

Innovative case studies, such as Karo and Petsangsri's (2020) evaluation of an online mentoring program for pre-service teachers in Thailand, demonstrate the effectiveness of cloud-based professional learning communities. Similarly, Nemoto et al. (2022) detail how Tokyo University of Agriculture and Technology's Virtual Computer Classroom (TUAT-VCCR) leveraged cloud technologies to maintain operations during the COVID-19 pandemic. In this context, Matsenko et al. (2025) argue that transitioning Ukraine's housing sector toward decentralized and digitalized energy systems as part of an Industry 3.0 strategy could serve as a blueprint for transforming university campuses into energy-efficient, cloud-integrated ecosystems. These examples underscore the resilience and adaptability of cloud universities in navigating both routine and crisis scenarios.

To ensure success, cloud universities must continuously evaluate the adaptability of their frameworks to integrate emerging technologies. Aligning faculty readiness, instructional design, and institutional policies with the dynamic nature of cloud-based education is essential to maintaining relevance in an evolving global educational environment.

Thus, the cloud university represents a resilient and adaptive model of higher education, integrating theoretical frameworks such as the Technology Acceptance Model, Innovation Diffusion Theory, and Task-Technology Fit to ensure the successful implementation of digital tools, AI, and cloud infrastructure.

This paper aims to identify the challenges associated with the concept of cloud universities and their impact on the resilience of higher education.

2. DATA AND METHODOLOGY

For this study, bibliometric data from the international database Scopus were selected. This database is highly regarded for social, economic, and technical research due to its extensive collection of relevant scientific publications over a long period and its wide range of analysis and data import tools. The search terms used were combinations of words related to higher education, specifically:

- higher education;
- university.

Additionally, variations related to cloud universities included:

- cloud technologies;
- cloud education;
- cloud-based learning;
- cloud services;
- digital twins.

The search was conducted within the title, abstract, or keywords using Scopus Boolean operators (AND, OR). The study covered the period from 2000 to 2024, divided into three subperiods:

1) 2007–2012: marks the beginning of the active implementation of cloud technologies and the development of infrastructure for distance learning.

2) 2013–2018: during this period, there was an observable increase in the popularity of cloud technologies and their more active integration into educational processes.

3) 2019–2024: encompasses the COVID-19 pandemic, significantly accelerating the adoption and adaptation of technologies in higher education.

Exclusion criteria were applied based on the subject area of the research, which allowed for the elimination of numerous irrelevant studies focused on medical, biological, technical, and engineering topics. Specifically, the following fields were excluded: veterinary medicine, dentistry, immunology, microbiology, pharmacology, toxicology, pharmaceutics, nursing, neuroscience, health

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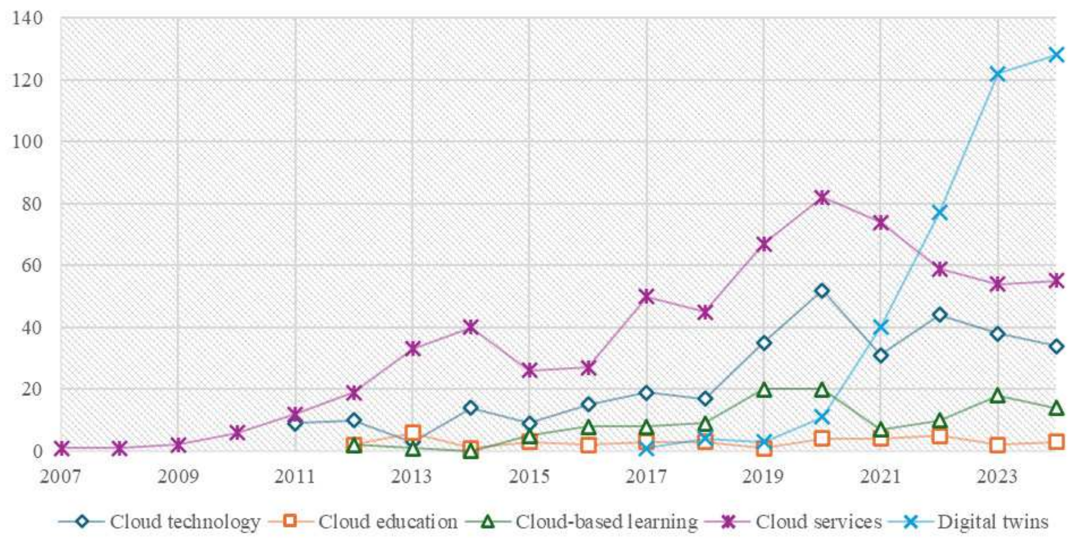
professions, chemical engineering, chemistry, biochemistry, genetics and molecular biology, medicine, physics and astronomy, earth and planetary sciences, agricultural and biological sciences, energy, engineering, environmental science, materials science, psychology, and arts and humanities.

The Scopus and SciVal built-in tools and the Science Mapping Analysis Tool (SciMAT) were used to conduct a bibliometric analysis. Specifically, data were analyzed regarding the number of scientific publications, their citation rates during the designated period, and their distribution across various subject areas and geographical locations. In this analysis, the SciVal topics were employed, which consist of a collection of publications centered around a common theme or scientific interest, taking into account their prominence or popularity at a given time (Klavans & Boyack, 2017). Additionally, tools proposed in Cobo et al.'s (2011, 2012) studies for the science mapping analysis were incorporated, including:

1) overlapping map, which allows analyzing the dynamics of movement and stability of keywords within the analyzed period;
2) evolution map, which reflects the formation of research clusters in specific periods, their origin, and relationships;
3) strategic diagram, which is built from two axes regarding density (y-axis) and centrality (x-axis) of thematic clusters and indicates the clusters' belonging to "motor", "highly developed and isolated", "emerging or declining", "basic and transversal" themes;
4) cluster network, which is used to analyze the connections between different research topics.

3. RESULTS

To evaluate the challenges that cloud universities face and their impact on the resilience of higher education, a comprehensive search was conducted using various queries. This approach helped identify the total number of publications, clarify the research field, and highlight the main thematic areas. An analysis of publication trends over the past 14 years revealed a growing interest in the topic of "digital twins," especially following a significant



Source: Scopus data.

Search Query	Scholarly Output	Citation Count
Cloud technology	330	2556
Cloud education	39	199
Cloud-based learning	122	1484
Cloud services	651	7684
Digital twins	388	3323

Figure 1. Dynamics of search queries on the challenges surrounding cloud universities

increase after 2020. This spike is likely linked to the rapid expansion of online learning due to the COVID-19 pandemic. Additionally, terms such as cloud services and cloud technologies are commonly used in the literature.

It is worth noting that the term cloud university is not yet widely used, as it is still in its formative stage and developing as a concept. However, its foundation has a clear connection with modern cloud technologies, cloud services, and innovative technologies such as digital twins, which are gradually being implemented in education.

Based on the analysis of search query data, while adhering to the methodological limitations, it was found that most studies fall within the fields of Computer Science and Social Sciences (see Figure 2). This indicates a multidisciplinary nature of the research. Additionally, a significant portion of the studies, accounting for up to 20%, is related to Economics and also falls under the category of Decision Sciences.

Among the countries most active in this research area, Ukraine, China, the United States, and several others stand out (see Table 1). Ukraine is currently taking the lead, actively exploring and applying various aspects of integrating cloud technologies into the educational process. This focus has become particularly important due to the pandemic and the ongoing full-scale war of russia against Ukraine, making cloud technologies a viable means of continuing education. Meanwhile, China and the United States are recognized as global leaders in developing and implementing advanced technologies such as cloud computing, artificial intelligence, and big data. Both countries invest substantial resources in research within these fields.

Figure 3 displays the top 1% of worldwide topics by prominence as generated by SciVal, highlight-

Table 1. Top 10 countries developing research on the impact of cloud technologies on the resilience of higher education

Source: Scopus data, SciVal tool.

No.	Countries	Scholarly Output	Views Count	Field-Weighted Citation Impact	Citation Count
1.	Ukraine	131	6,822	2.54	1,397
2.	China	120	3,319	1.32	1,355
3.	United States	93	4,595	1.99	1,689
4.	russian federation	61	2,830	0.99	352
5.	Malaysia	56	3,490	1.33	653
6.	United Kingdom	51	2,472	2.30	760
7.	Germany	46	1,431	0.90	349
8.	Indonesia	43	2,059	1.56	412
9.	India	41	2,491	1.41	477
10.	Australia	38	3,076	1.58	780

Source: Scopus data, SciVal tool.

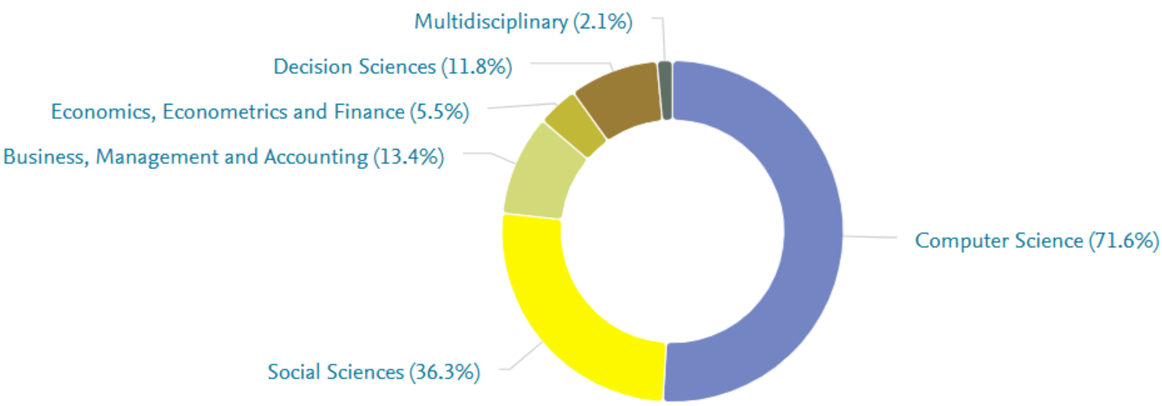


Figure 2. Subject area of research on the challenges surrounding cloud universities

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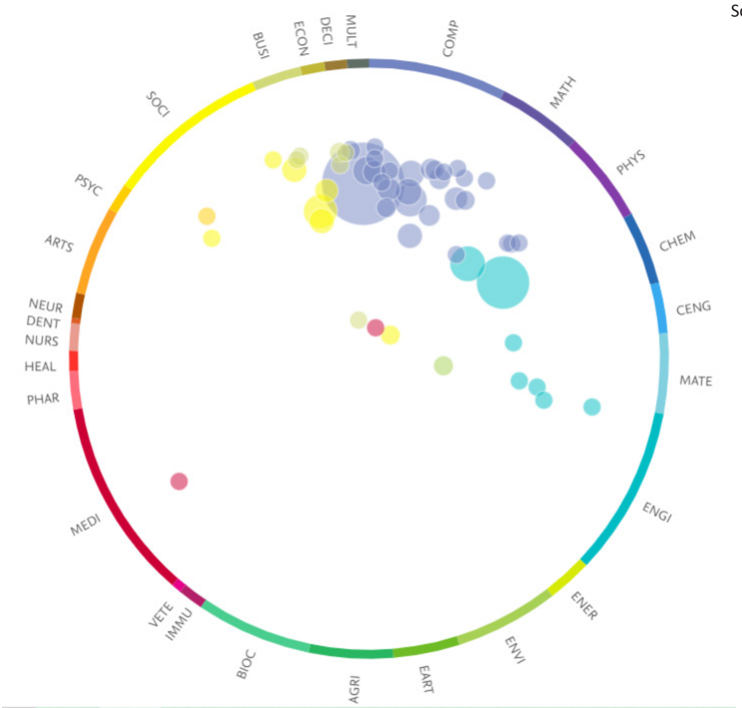
Source: Scopus data, SciVal tool.



Top 6 Topics	Scholarly Output	Publication Share	Prominence percentile
Technology Acceptance Model; E-learning; Adoption	38	0.77% growth	99.696
Cyber Physical Systems; Virtual Reality; Digital Twin	21	0.31% growth	99.961
Cyber Physical Systems; Embedded Systems; Industry 4.0	11	0.13% growth	99.965
Online Learning; E-learning; COVID-19	10	0.21% growth	99.834
Virtual Reality; E-learning; Computer-Aided Instruction	10	0.36% growth	99.49
Big Data; Decision-Making; Data Analytics	6	0.11% growth	99.749

Figure 3. Top 1% of worldwide topics among studies on the challenges surrounding cloud universities

ing their multidisciplinary and multi-faceted nature. Among the most prominent issues are the adoption of new technologies in the educational process, particularly various models of e-learning. Additionally, there are challenges associated with integrating innovative technologies such as virtual reality, cyber-physical systems, and Big Data, which serve as tools for simulations, process integration, and efficiency enhancement. Overall, these trends signify a growing demand for research and the implementation of modern digital technologies aimed at creating a flexible, accessible, and interactive learning environment.

The topics discussed provide a general understanding of the main challenges surrounding cloud universities and their impact on the resilience of higher education. A more detailed analysis can be conducted through science mapping. The resulting overlapping map in Figure 4 shows a rapid development in this field, with the number of keywords increasing from 58 before 2012 to 346 after 2019. Notably, 74-78% of the keywords remained consistent across these periods, indicating that the key research areas continue to attract the attention of scholars.

The evolution map developed enables the analysis of development dynamics and the gradual complexity of thematic clusters related to various challenges cloud universities face and their effects on the resilience of higher education (Figure 5).

A more detailed description of these thematic clusters is presented in Figure 6 through two-dimensional diagrams. From 2007 to 2012, the primary thematic cluster in research was “Cloud Computing Services.” This cluster served as a foundation for further innovative studies in cloud technologies and their applications in education. It exhibited high centrality and density, classifying it as a motor theme. The research predominantly

Source: Scopus data, SciMATT tool.

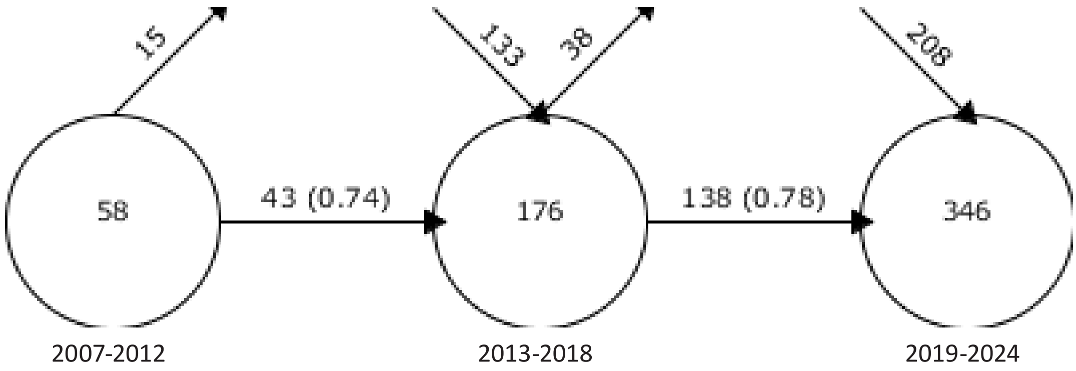


Figure 4. Overlapping map of research challenges surrounding cloud universities and their impact on the resilience of higher education

Source: Scopus data, SciMATT tool.

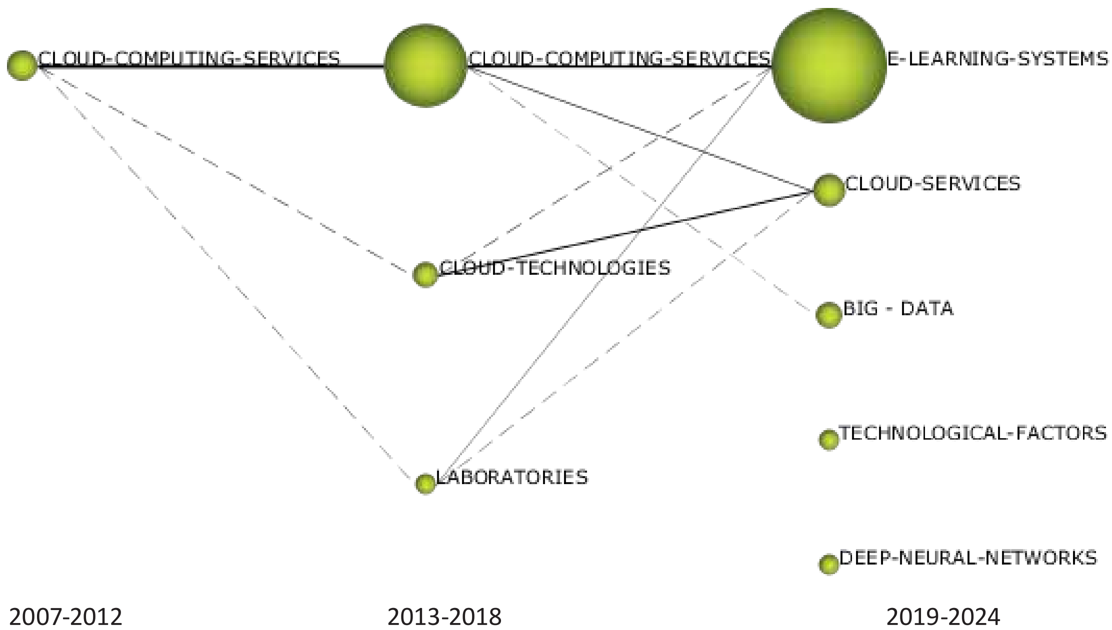


Figure 5. Evolution map of research challenges surrounding cloud universities and their impact on the resilience of higher education

focused on the development and optimization of fundamental cloud services, which provided essential infrastructure solutions for data storage, processing, and transmission (Thomas, 2011). Luo et al. (2011) concentrated on enhancing key components of cloud infrastructure, including core cloud services and cloud service management. This management involved mechanisms to ensure the reliable operation of cloud solutions and improve user access interfaces. Additionally, the literature addressed the financial support for cloud technologies in universities, particularly due to the high costs associated with technological infrastructure (Thomas, 2012), as well as the optimal utilization of resources through cloud computing solutions (Conghuan, 2011).

Between 2013 and 2018, the "Cloud Computing Services" cluster saw significant growth, including advancements in fundamental topics and the emergence of new specialized research in the field of cloud technologies. During this period, researchers conducted in-depth studies on the infrastructure aspects of cloud computing, focusing particularly on scalability, security, and resource management efficiency (Rodrigues et al., 2016).

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Source: Scopus data, SciMATT tool.

2007–2012 2013–2018 2019–2024

Figure 6. Strategic diagram thematic clusters of research challenges surrounding cloud universities and their impact on the resilience of higher education

Moreover, attention began to shift towards the challenges faced by developing countries in implementing cloud technologies within the educational sector. These challenges include socio-economic, technological, and political constraints (Sabi et al., 2016), which complicate and slow down the adoption of cloud solutions. Factors such as limited funding, inadequate infrastructure, lack of knowledge, and insufficient political support contribute to these difficulties.

The "Laboratories" cluster has emerged as a highly developed and isolated theme. Research within this cluster is deep and specialized, yet it has limited connections to other research topics. For instance, the studies by Pastor et al. (2013) and Al-Zoubi et al. (2015) investigate the creation of online laboratories using cloud technologies, which hold significant potential for experimental engineering research.

Another key cluster is "Cloud Technologies," which is foundational to this research area and connects with various other topics, often referred to as basic and transversal themes. This cluster encompasses the study of different models of university cloud infrastructure, including public, corporate, and hybrid clouds, as well as various service models such as Software as a Service (SaaS), Platform as a Service (PaaS), and Infrastructure as a Service (IaaS) (Shyshkina, 2018; Alharthi et al., 2015). Current research addressing the challenges associated with cloud technologies in educational environments often references the Technology Acceptance Model (TAM) criteria. Specifically, Alharthi et al. (2015) differentiate between external (technological factors like security, reliability, privacy, lock-in, and bandwidth) and internal (user-related factors such as acceptance, management, and the cultural and social beliefs of managers) influences on technology acceptance.

Since 2019, the field of cloud technology and higher education research has seen the emergence of increasingly diverse thematic clusters. This development has been driven by several factors, particularly the rapid advancement of new technologies during the pandemic and various scientific and technological achievements. One of the key themes emerging is the "E-learning system" cluster, which focuses on the integration of diverse technologies, including cloud computing, digital twins, and artificial intelligence. These technologies enhance the efficiency of educational processes and contribute to personalized learning experiences. There is significant discussion surrounding the potential of virtual reality (VR) and gamification tools, which create interactive learning environments and immerse students in realistic simulations. This approach is particularly beneficial for practical disciplines (Fromm et al., 2021; Lin et al., 2024). Additionally, the acceptance of distance learning and associated educational technologies by students and teachers, especially in light of the forced transition caused by the pandemic, has been a major topic of academic discussion (Alkhwaldi & Abdulmuhsin, 2022; Huda, 2023).

Zhang et al. (2022) explore the possibility of creating digital twins of instructors in higher education, which could optimize bureaucratic task performance and enhance information management efficiency. Ye (2024) extends this concept to the university level, suggesting the creation of an integrated information management system. However, Chamorro-Atalaya et al. (2024) point out that, despite the promising potential of digital twins, their implementation in higher education currently encounters several challenges. One major issue is the lack of regulatory standards and the necessary competencies among instructors for the effective use of digital twins.

Effective utilization of cloud technologies requires more than just technical implementation; all users must possess the appropriate skills and understanding of new tools and platforms. Numerous studies have focused on various aspects of teaching cloud technology usage to prepare future specialists across different fields (Volikova et al., 2019; Korobeinikova et al., 2019; Oleksiuk & Oleksiuk, 2019). Additionally, research has examined how to foster collaboration between students and teachers in scientific projects (Hevko et al., 2021).

The clusters "Technological Factors" and "Deep Neural Networks" are well-developed yet often isolated in research discussions. When examining technological factors related to cloud technologies, various aspects come into play, including security, infrastructure, user interfaces, performance, stability, scalability, and accessibility. In the study by Kankia et al. (2023), several key technological factors significantly influence students' perceptions of cloud technologies, facilitating their adaptation to these tools. Notable factors include awareness of innovation, perceived usefulness, ease of use, attitude toward technology, and reliability. Meanwhile, Juma and Tjahyanto (2019) highlight that critical technological factors for implementing cloud technologies in education encompass data security and the associated risks. Additionally, Bangkong et al. (2023) emphasize security concerns, particularly focusing on network security and data privacy as major challenges in implementing cloud technologies.

Deep neural networks serve to create complex prediction models, analyze data, and develop adaptive learning systems (Chen et al., 2021). They also play a role in ensuring data security and consistency (Majumder et al., 2024). However, these neural networks remain peripheral to the broader educational discourse, which accounts for their isolation in many discussions.

Source: Scopus data, SciMATT tool.

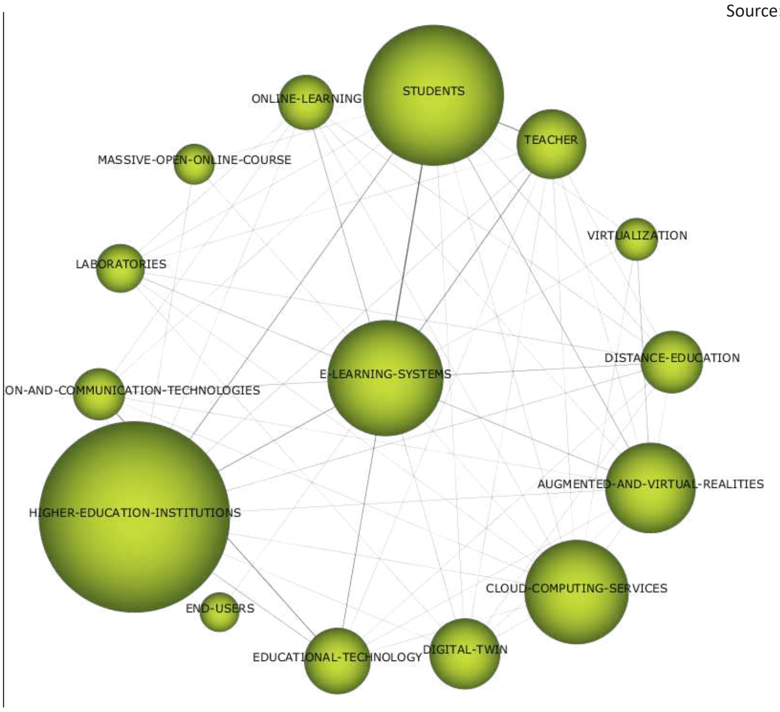

Figure 7. Cluster "E-Learning System" network, 2019–2024

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Source: Scopus data, SciMATT tool.

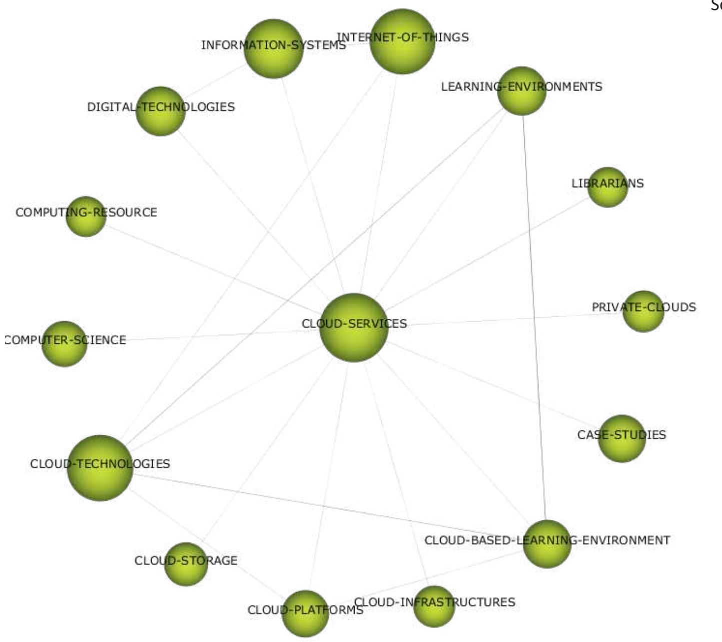

Figure 8. Cluster "Cloud Services" network, 2019–2024

From 2019 to 2024, key topics of focus include "Cloud Services" (Figure 8) and "Big Data" (Figure 9). These clusters emerged from the specialization of the "Cloud Computing Services" cluster. Cloud services serve as a foundation for implementing various educational technologies by providing infrastructure for data storage, integration with other services, resource sharing, and support for distance learning. Together, these elements have the potential to establish cloud universities.

Big data has become an essential part of the higher education system. It enables the collection, analysis, and application of information regarding learning processes, which helps educational institution managers better understand student needs, assess the effectiveness of educational programs, and enhance decision-making. This contributes to

Source: Scopus data, SciMATT tool.

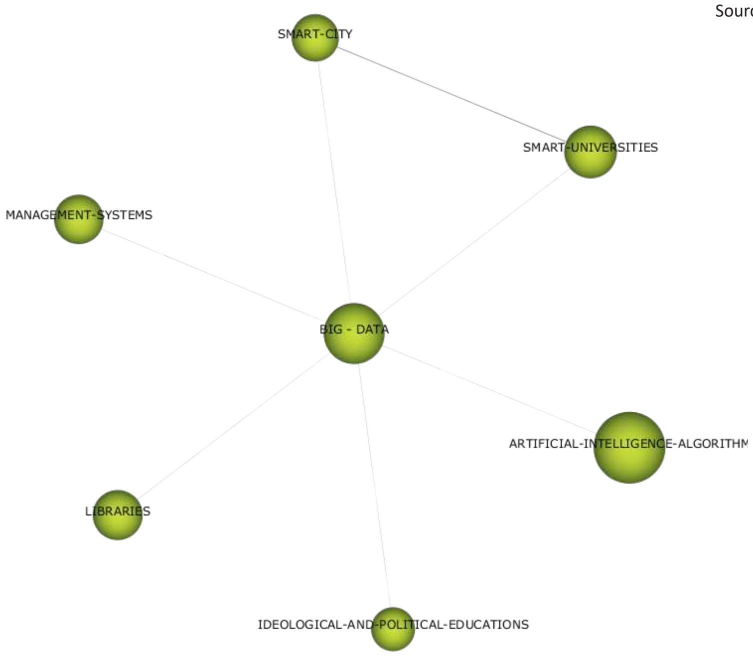

Figure 9. Cluster "Big Data" network, 2019–2024

the development of various models of smart universities (Xu et al., 2022). However, many universities still face challenges related to big data mining, utilization, and storage (Hadwer et al., 2019). Ensuring confidentiality and protecting information are critical issues, and one effective approach to address these concerns is through AI-driven machine learning and deep learning techniques (Mazhar et al., 2023).

Based on the conducted science mapping analysis, the most common challenges surrounding cloud universities and their impact on the resilience of higher education have been identified and systematized (Table 2).

These include technical challenges related to integrating cloud technologies into the structure and processes of universities, staff adaptation to new digital platforms, training of teachers and students to work with cloud technologies, and coordination between different university departments to ensure seamless access to data and tools. There are also financial challenges associated with the costs of implementing and maintaining cloud infrastructure, security concerns regarding information leaks, cyberattacks, and unauthorized access to confidential materials, as well as ethical and legal issues.

4. DISCUSSION

Research findings indicate a growing academic interest in the category of the "cloud university," particularly after 2020, which correlates with the challenges brought by the COVID-19 pandemic. Although the term "cloud university" is not yet firmly established in academic discourse, it is gradually taking shape at the intersection of studies on cloud services, digital twins, and innovative approaches in education.

Ukraine plays a leading role in developing research on cloud technologies in education. This is driven by the consequences of the 2020 pandemic as well as the full-scale war, which has intensified the need for remote learning. This conclusion is consistent with the findings of Korobeinikova et al. (2020).

China and the USA are the technological leaders in implementing cloud computing, artificial

Table 2. Systematization of challenges surrounding cloud universities and their impact on the resilience of higher education

Challenge	Description of a challenge	Impact on the resilience of higher education
Technical Infrastructure and Access	Limited availability of high-speed internet and equipment restrictions in remote or underprivileged areas	Cloud platforms allow for remote learning, expanding access to education in regions lacking physical educational infrastructure
Infrastructure Resilience	Risks of technical failures, including server outages and cloud platform disruptions	A reliable cloud infrastructure ensures the continuity of learning, allowing for quick restoration of access to resources in case of failures. Cloud infrastructure enables the replication of management process matrices in times of crisis
Lack of Readiness Among Educators	Insufficient technical competence among educators to effectively use cloud platforms and remote learning tools	Teachers need adaptation to new technologies, without which the quality of teaching and organization of learning may suffer
Cybersecurity and Data Protection	The need to protect personal data of students and educators, as well as securing learning platforms from cyber threats	Strengthening cybersecurity and data protection increases trust in cloud universities and supports the security of the educational process
Quality of Education	Lack of personal interaction with instructors and difficulty ensuring an adequate level of student engagement	Cloud universities can implement personalized learning, tailoring courses to students' needs and enhancing their engagement
Financial Costs of Implementation	Significant investment in developing and implementing cloud technologies, especially for less developed universities	Long-term reduction in infrastructure and building costs, allowing for resource redirection towards improving the quality of education
Academic Integrity	Increasing risks of academic dishonesty due to remote learning formats and the difficulty in monitoring task completion	Innovative monitoring systems allow for the automation of academic integrity control, preserving the reputation of the educational process
Ethical and Legal Issues	No clear legal framework regarding rights to learning materials, personal data, and ensuring fairness in access to education	The formation of new legal frameworks stimulates the development of unified standards for data protection and access to education in different countries

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intelligence, and big data analytics, which directly impact educational practices (Chen et al., 2021; Hadwer et al., 2019). A significant portion of the research focuses on the development of e-learning models, confirming their central role in transforming education systems (Alkhwaldi & Abdulmuhsin, 2022; Karo & Petsangsri, 2020). In particular, Alkhwaldi and Abdulmuhsin (2022) emphasize that the COVID-19 pandemic has significantly accelerated the adoption of digital formats in higher education institutions in Jordan. At the same time, the authors highlight the importance of considering factors that affect the sustainability of using such platforms in the long term (Alkhwaldi & Abdulmuhsin, 2022).

The growing role of digital twins and virtual reality technologies as tools for modeling educational processes and increasing their effectiveness is explored in the studies by Chamorro-Atalaya et al. and Fromm et al. (Chamorro-Atalaya et al., 2024; Fromm et al., 2021). Specifically, a study by Chamorro-Atalaya et al. (2024) on using digital twins in higher education confirms the importance of creating a regulatory environment and developing digital competencies for their effective implementation.

The Technology Acceptance Model also attracts scholarly interest as it helps explain the factors behind the successful integration of innovations into the educational environment (Alharthi et al., 2015; Juma & Tjahyanto, 2019). Keyword analysis in publications shows a dynamic shift from basic concepts such as "cloud computing" to more complex clusters such as "e-learning systems" and "digital twins" (Cobo et al., 2012; Chen et al., 2021).

Thematic clusters suggest that the core driver behind the development of the cloud university concept remains the technological infrastructure and its adaptability to educational needs. At the same time, the sustainability of such models directly depends on adequate funding and effective resource management in cloud environments, which aligns with the findings of Anak Bangkong et al. (2023). In developing countries, implementing cloud technologies faces several barriers: limited access to infrastructure, low levels of digital skills, and insufficient political support (Kankia et al., 2023; Juma & Tjahyanto, 2019).

An isolated but promising cluster is that of "laboratories," which shows potential for the development of remote STEM research. In particular, the work of Al-Zoubi et al. (2015) emphasizes the potential of remote laboratories as a tool for improving the quality of STEM education, which supports our conclusion about the promise of this area.

Thus, the study's findings confirm that cloud technologies have the potential to become the foundation of a flexible, resilient higher education system, especially relevant in times of pandemics, war, and socio-economic instability.

CONCLUSIONS

This study aimed to identify the multifaceted challenges surrounding cloud universities and their impact on the resilience of higher education. To achieve this, a science mapping analysis was conducted based on the most relevant scientific papers indexed in the international Scopus database within three subperiods:

1) 2007–2012 (beginning of the active implementation of cloud technologies);
2) 2013–2018 (increase in popularity of cloud technologies in educational processes);
3) 2019–2024 (significant rise in technology in HE due to the pandemic).

The study highlights a growing academic interest in the cloud university model, with a significant increase in publications related to cloud computing, digital twins, and AI integration in higher education since 2007. Despite this interest, the term "cloud university" remains underdeveloped in scholarly discourse, indicating a conceptual gap that future research should aim to address through clearer definitions and theoretical framing.

Science mapping revealed the evolution of research focus from foundational infrastructure and services to more applied and pedagogical uses of cloud technologies, particularly after the pandemic-driven shift to remote education. Key challenges identified include the need for secure, scalable infrastructure, digital readiness of educators and learners, legal and ethical considerations, and financial sustainability of cloud-based models.

Further research should investigate institutional strategies for integrating immersive and AI-driven tools, develop models for replicating university functions in cloud environments, and explore cross-national comparisons to understand regional disparities in cloud university implementation.

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