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REVIEW

Digital transformation towards sustainability in higher education: state-of-the-art and future research insights

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Abstract
The technological revolution has contributed to environmental and social issues around the world. However, in the context of higher education institutions (HEIs) – key stakeholders for sustainable development - there is a theoretical gap regarding systematic reviews on the topic. In order to address this need, this study explores how digital transformation (DT) can contribute to sustainability in HEIs by identifying the general state of the art, the theoretical perspectives in the field, and future research insights. A multi-methods approach was adopted, which consisted of a quantitative bibliometric review and a qualitative content analysis. Consistent with this approach, the Scopus database was used for the bibliometric analysis of 672 publications, which was conducted with the support of VOSviewer software. Subsequently, a content analysis of 72 publications was carried out using the software ATLAS.ti and Zotero. The findings suggest three areas of current research: ensuring sustainability competencies through DT, smart and sustainable campus approaches, and theorisation of sustainability in higher education through DT. The theoretical perspectives of the field were divided and discussed into seven main clusters. Lastly, five research lines for further studies on DT towards sustainability were identified. This study has both theoretical and practical implications since it may be the first literature review on this subject, providing theoretical insights to the academic community, guiding sustainability and digital practices in HEIs - through the identification of tools, approaches, and strategies - and then supporting the implementation of the United Nations Sustainable Development Goals.

Keywords Sustainability · Digital transformation · Higher education · Universities · Bibliometric analysis · Content analysis

1 Introduction

Given the great tragedies, catastrophes, climate change, pandemics, and wars experienced by humanity, there is an increasing need for a new education that combines the concern with short-term economic gains with the medium and long term, considering the right of

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future generations to a sustainable planet. Higher Education Institutions (HEIs) have a key responsibility regarding the sustainable development of society (Kräusche & Pilz, 2017), particularly in the education of future leaders and in the public awareness of sustainability (Amaral et al., 2015).

HEIs also represent a crucial stakeholder in the promotion and implementation of the United Nations (UN) 2030 Agenda for sustainable development (Vallez et al., 2022) and the digitalisation of society by producing knowledge for new technologies and social innovation (Carayannis & Morawska-Jancelewicz, 2022). Therefore, HEIs should support sustainable development in their physical infrastructure, decision-making processes, and pedagogical issues (Fuchs et al., 2020) to guide actions towards sustainability throughout the entire university system, which includes education, research, campus operations, community outreach, and assessment and reporting (Lozano et al., 2013; Kapitulčinová et al., 2018).

This implies offering a sustainable experience to students, who will be able to lead different types of organizations in the future and act in ways that promote the Sustainable Development Goals (SDGs) and help to mitigate climate change (Leal Filho et al., 2020). After all, HEIs are where leaders are educated. Thus, training and qualifying these individuals with adequate knowledge about sustainability is extremely relevant (Amaral et al., 2015). In this respect, digital transformation (DT) is central to supporting the 2030 Agenda, driving its dissemination, and the attainment of the SDGs (Arnold et al., 2021). Hence, linking quality education with technology allows students to obtain knowledge, skills, and motivation quickly to understand and address the challenges related to the SDGs (Abad-Segura et al., 2020b).

However, access to knowledge is no longer restricted to the physical space of HEIs; it is also found in different platforms, applications, encyclopedias, and open-source browsers that support people who wish to learn about different subjects (Valdés et al., 2021). From this perspective, HEIs - which have been the centre of knowledge production and dissemination for centuries - are experiencing a set of relevant changes induced by the social and technological trends of DT (Nikou & Aavakare, 2021; Nurhas et al., 2021). This implies a paradigm shift throughout institutions, a redefinition of business models and an ostensible transformation of their structures (Rodríguez-Abitia & Bribiesca-Correa, 2021; Benavides et al., 2020).

Although there is already a trend toward convergence of digital imperatives and sustainability in practice (George et al., 2021), there is a lack of systematic and rigorous academic research that rethinks management models based on sustainable development using digital technologies, especially in the context of higher education (Pu et al., 2022). It calls for more research and perspectives on it (Eltawil et al., 2021). Therefore, through a mixed method that involved both a quantitative bibliometric review and qualitative content analysis, this study aims to analyse how DT can contribute to sustainability in higher education by addressing the following research questions (RQ):

RQ1 What is the general state of research on sustainability and digital transformation in higher education?

RQ2 What are the theoretical perspectives in this field?

RQ3 What are the possible directions for future research?

To address these objectives, this study conducted a bibliometric review of publications related to digital transformation to sustainability in higher education. A content analysis of data clustering was conducted to further improve the study's scope and identify research lines for future studies. The findings of this study have both theoretical and practical contributions by offering a bibliometric mapping of the general state and current trends and a future research agenda. It supports theoretical insights for the academic community and helps to guide sustainability and digital practices in HEIs. In addition, this study provides methodological originality, considering that, to the best of our knowledge, it is the first systematic review on the topic that has used both bibliometric and content analyses.

2 Methodology

This study adopted a multi-methods approach, which consisted of a quantitative bibliometric review and a qualitative content analysis. A bibliometric analysis is based on the citations' compilation to determine the impact of specific categories, such as the subject, authors, institutions, countries, journals, and keywords (Zupic and Cater, 2015). A qualitative content analysis aims to systematise and describe a phenomenon through concepts and categories (Elo & Kyngäs, 2008).

Scopus and Web of Science (Terán-Yépez et al., 2021) are the two databases most used to carry out bibliometric analyses. This study selected Scopus because it is the largest multidisciplinary database of peer-reviewed literature in social science research (Donthu et al., 2020). Therefore, this research started with identifying search terms in the Scopus database. The initial search used the combination of terms related to digital transformation, sustainability, higher education, and the Boolean operators "AND" and "OR". The best combination of terms was based on previous studies in the field (Colás-Bravo et al., 2021; Alonso-García et al., 2019; Benavides et al., 2020). Hence, the final search was held on April 11, 2022, with the following search strings: ("virtual*" OR "digital*" OR "ICT" OR "information and communication technolog*" OR "emerging technolog*") AND ("sustainability" OR "sustainable develop*" OR "SDG*" OR "2030 Agenda") AND ("higher education" OR "HEI*" OR "universit*").

The process followed in selecting the sample conforms to the flowchart in Fig. 1, according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Moher et al., 2009). In phase 1 (Identification), 1971 publications from the Scopus database were identified, considering the option of "article title, abstract, and keywords", all types of publications, and all data in the range (all years to 11 April 2022). In phase 2 (Screening), the publications were limited to the subject areas of Social Sciences, Environmental Science, and Business, Management, and Accounting, resulting in 1187 publications. Then, to ensure the study's quality, only articles and reviews were selected as the type of document, resulting in 686 publications. The search language was set at "English, Portuguese or Spanish", so 14 publications were excluded. Hence, the final sample included 672 publications, both open-access and non-open-access.

For content analysis, 72 publications were selected, which were identified with the support of VOSviewer software and by reading the publications' titles and abstracts. The process of content analysis is further explained in the sequence. Two-independent researchers were involved in the publications' selection and followed the guidelines established in the search protocol.

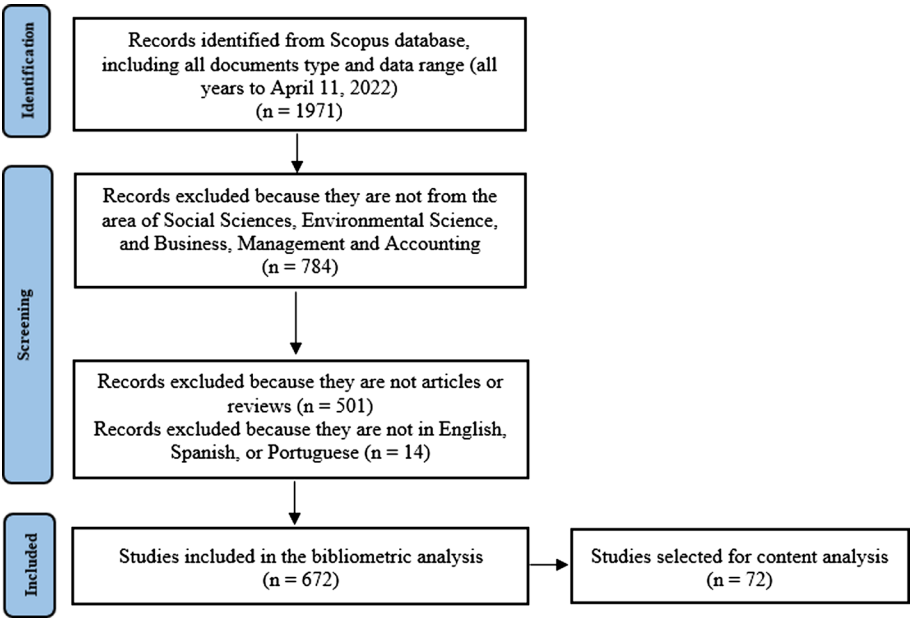


Fig. 1 Process of the publications' selection for bibliometric and content analysis, based on PRISMA.

To address the general state-of-the-art on sustainability and digital transformation in higher education (research question 1), a descriptive analysis of the field was conducted, showing the number of publications by year, most productive journals, institutions, and countries. In addition, other analyses were conducted: a co-authorship analysis based on the authors' geographic locations provided a countries' cooperation network (Uddin, 2012); through a co-occurrence analysis, the popular keywords on the topic were identified (Arita, 2017); then, a bibliographic coupling was conducted to map the research trends (Kessler, 1963). These analyses were supported by VOSviewer software (Van Eck & Waltman, 2021), version 1.6.17.

The researchers set the software to identify the 50 most important publications for content analysis through the bibliographic coupling technique. The bibliographic coupling uses the number of references shared by two publications as a measure of the similarity between them. The more the bibliographies of two publications overlap, the stronger their connection (Zupic & Cater, 2015). The software identified 46 publications with the greatest total link strength. After reading their abstracts, 26 publications were selected for deep content analysis (Elo & Kyngäs, 2008). The other 20 publications did not address the topic of sustainability in higher education through DT in a deep way. Subsequently, VOSviewer software clustered the 26 publications into three groups according to their similarity.

To address the second research question of this study - the theoretical perspectives in the field - data clustering through a co-citation analysis was carried out. This analysis is defined as the frequency with which two publications are cited together by other publications (Small, 1973). The publications resulting from this analysis are the most important references for the sample of 672 publications selected in the Scopus database. The researchers requested the VOSviewer software to identify the publications with more than two citations. Hence, the software identified 46 publications distributed in 7 clusters, which

were all selected for deep content analysis. Considering both content analyses - bibliographic coupling (26 publications) and co-citation analysis (46 publications) - a total of 72 publications were read.

Finally, to address the third research question - possible directions for future research in the field - a co-occurrence of the keywords used by publications from 2019 to 2022 was carried out. This process was conducted along with the bibliographic coupling and content analysis of the 26 publications already performed, considering that bibliographic coupling analysis has great potential to identify emerging literature (Zupic & Cater, 2015).

3 Results and discussion

3.1 General state of the art on digital transformation towards sustainability in higher education

As shown in Fig. 2, the number of publications on the topic had increased over time (1995–2021), reflecting that the research interest in the digital transformation towards sustainability in higher education is growing in general, with a significant volume of publications in 2020 (118 publications) and 2021 (142 publications), in line with the period when COVID-19 started. The implementation of technology in universities has already been increasing in the last decades (Rodríguez-Abitia & Bribiesca-Correa, 2021). However, the COVID-19 pandemic led universities to an urgent DT process, requiring changes in their models and activities (Nurhas et al., 2021), which also demanded academic research on new practices, strategies, and tools in their context.

The bibliometric analysis shows that publications are distributed in 159 journals. Table 1 lists the top 5 journals, with the number of publications, citations, and impact factor (IF). The most productive journal identified is Sustainability, with 142 publications and 1270 citations. Journal of Cleaner Production ranks 2nd with 16 publications and 337 citations, followed by the International Journal of Sustainability in Higher Education (15 publications), the Journal of Industrial Ecology (9 publications), and the International Journal of Emerging Technologies in Learning (7 publications).

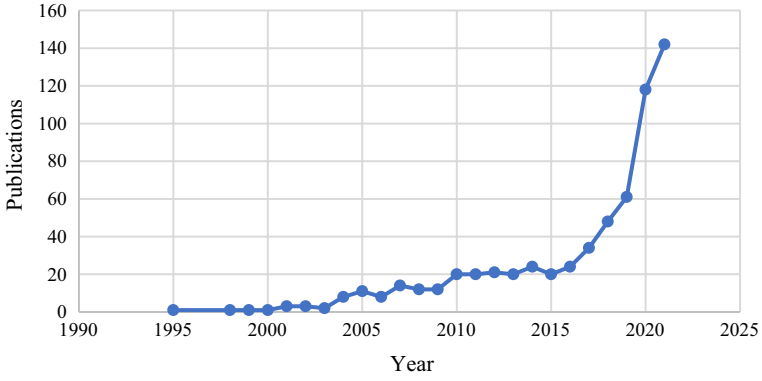


Fig. 2 Publications on digital transformation towards sustainability in higher education (1995–2021)

Table 1 Top 5 journals per number of publications

Journal	Number of publications	Citations	Impact factor (2021)
Sustainability	142	1270	3.889
Journal of cleaner production	16	337	11.072
International journal of sustainability in higher education	15	96	4.120
Journal of industrial ecology	9	608	7.202
International journal of emerging technologies in learning	7	15	2.587

Regarding the most productive institutions on the topic, as shown in Fig. 3, Universidad de Granada (Spain) is the leader, with 12 publications, followed by Arizona State University (United States), Universiti Teknologi Malaysia (Malaysia), University of South Africa (South Africa), Universitat de València (Spain), Universitat d'Alacant (Spain), The Open University (United Kingdom), University of Florida (United States), and University of Michigan (United States).

Regarding the countries, Fig. 4 shows that the United States is the most productive country on the topic, with 125 publications, followed by Spain, with 88 publications, the United Kingdom (60), Australia (43), China (35), Germany (32), Italy (30), Malaysia (23), Canada (22), Portugal (19), South Africa (19), Brazil (18), and others.

To understand the cooperation network between the countries, Fig. 5 shows the co-authorship analysis. It is possible to identify four clusters. The first one (red) comprises Australia, Canada, Colombia, Ecuador, France, Ghana, India, Mexico, the Netherlands, Norway, South Africa, Spain, Sweden, Switzerland, and the USA. The second (green) is composed of Argentina, Austria, Belgium, Brazil, Finland, Greece, Hungary, Italy, Poland, Portugal, Romania, Russian Federation, Serbia, Slovakia, and Ukraine. The third (blue) is composed of Chile, China, Germany, Hong Kong, Japan, Nigeria, Singapore, South Korea, Taiwan, and the United Kingdom. The fourth cluster (yellow) comprises the Czech Republic, Indonesia, Iran, Malaysia, Pakistan, Saudi Arabia, and Turkey.

The popular keywords on the topic were identified through a co-occurrence analysis. The analysis started with a total of 2351 keywords. After excluding keywords with

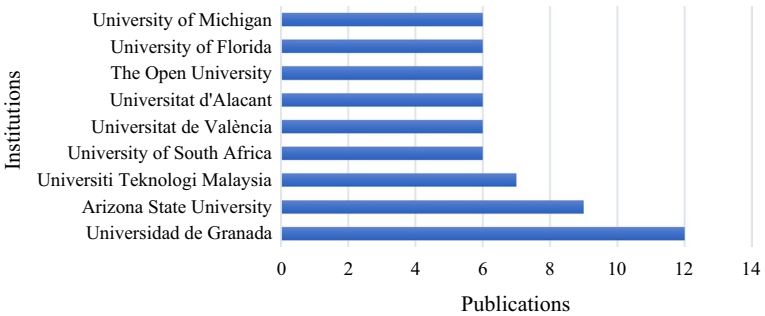


Fig. 3 Most productive institutions on digital transformation towards sustainability in higher education (1995–2021)

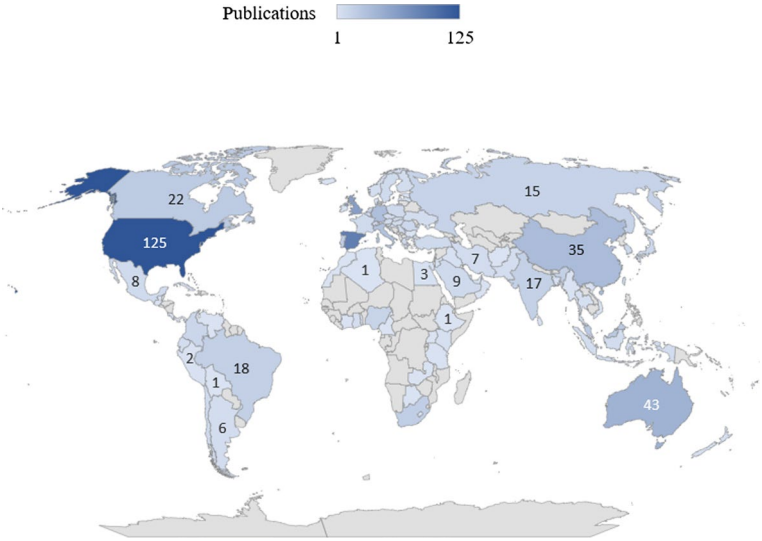


Fig. 4 Publications by countries on digital transformation to sustainability in higher education

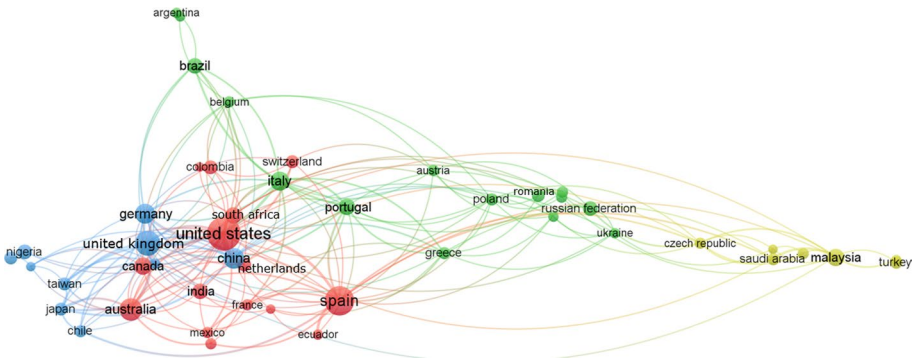


Fig. 5 Countries' cooperation network on digital transformation to sustainability in higher education based on co-authorship analysis

frequencies less than three and others with no meaning, 113 popular keywords emerged, as shown in Fig. 6.

It is possible to observe the evolution of the research area over time. For instance, from 2014 to 2016, the studies involved topics such as industrial ecology, carbon footprint, sustainable consumption, the internet, digital libraries, and green information technology (IT). From 2016 to 2018, research on the topic approached information and communication technology (ICT), sustainable development, e-learning, globalisation, education for sustainable development (ESD), innovation, virtual reality, and technology. From 2018 to 2019, studies focused on virtual education, climate change, digitalisation, digital competence, gamification, social media, online courses, flipped classrooms, teacher training, transdisciplinary, blended learning, smart cities, and social media. From 2020, research has focused on COVID-19, Sustainable Development Goals (SDGs), digital transformation (DT), artificial intelligence (AI), blockchain, online education, digital sustainability,

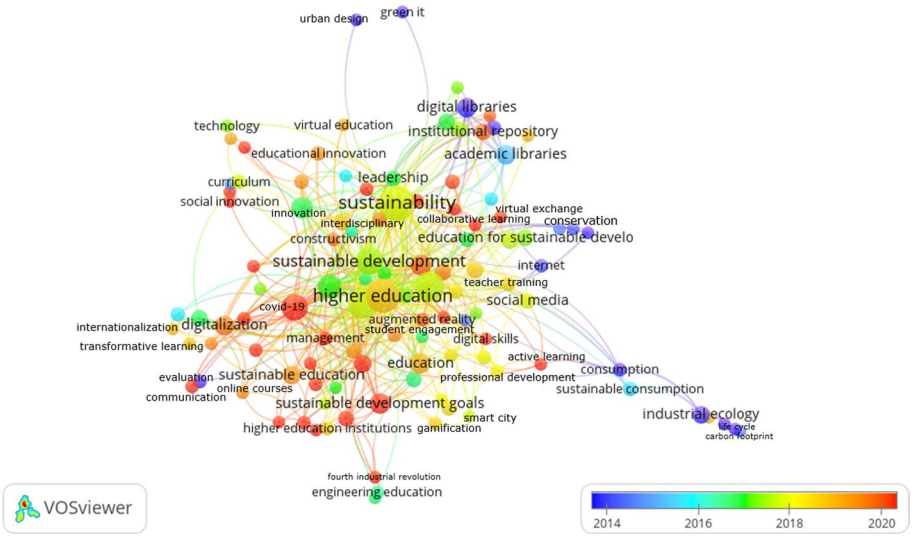


Fig. 6 Keywords network based on co-occurrence

augmented reality (AR), virtual exchange, and industry 4.0. Thus, it seems to be an evolution of research focused on the facilities of the HEIs campuses for educational technologies, digital competence, e-learning, and COVID-19.

To understand how digital transformation has contributed to sustainability in higher education, a content analysis was carried out on 26 publications with the support of the software VOSviewer, ATLAS.ti, and Zotero. The publications were selected based on the greatest total link strength - measured through VOSviewer software. Figure 7 shows the clusters network between the publications, and Table 2 describes the clusters.

Cluster 1 (red) has the largest number of publications - seventeen between 2013 and 2022. Most of them use quantitative methods based on surveys or experiments, although there are some publications with qualitative approaches based on interviews, action research, and content analysis. In general, this cluster addresses the development of

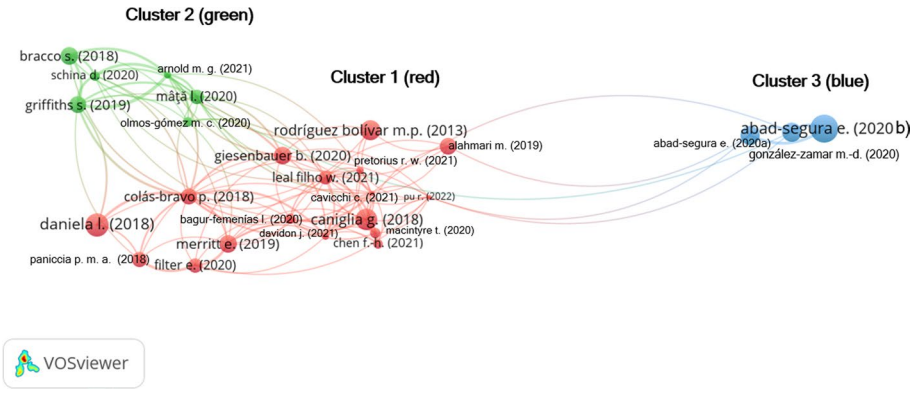


Fig. 7 Clusters network based on bibliographic coupling analysis

Table 2 The top 26 publications with the greatest total link strength on digital transformation towards sustainability in higher education

Cluster 1 (red): ensuring sustainability competencies through digital transformation	Cluster 2 (green): smart and sustainable campus approaches	Cluster 3 (blue): Theorisation of sustainability in higher education through digital transformation
Alahmari et al. (2019)	Arnold et al. (2021)	Abad-Segura et al. (2020a)
Bagur-Femenías et al. (2020)	Bracco et al. (2018)	Abad-Segura et al. (2020b)
Caniglia et al. (2018)	Griffiths et al. (2019)	González-Zamar et al. (2020a)
Cavicchi (2021)	Mâță et al. (2020)	
Chen (2021)	Olmos-Gómez et al. (2020)	
Davidson (2021)	Schina et al. (2020)	
Giesenbauer and Müller-Christ (2020)		
Leal Filho et al. (2021)		
Macintyre et al. (2020)		
Pretorius et al. (2021)		
Pu et al. (2022)		
Rodríguez Bolívar et al. (2013)		
Colás-Bravo et al. (2018)		
Daniela et al. (2018)		
Filter et al. (2020)		
Merritt et al. (2018)		
Paniccia and Baiocco (2018)		

sustainability competencies using digital transformation tools at the professor, student, and institution levels. Then, the cluster was titled "ensuring sustainability competencies through digital transformation". At the professor level, researchers have focused on analysing the benefits of incorporating augmented reality technology in HEIs (Alahmari et al., 2019), as well as the role of technology in improving teaching and learning activities for sustainable development (Daniela et al., 2018), the professors' level of sustainable consciousness (Colás-Bravo et al., 2018), and potential changes in values, sense of agency, and consumption practices by using pedagogical technological tools (Merritt et al., 2018).

At the student level, some studies have addressed the impact of the COVID-19 pandemic on education for sustainable development in higher education (Leal Filho et al., 2021), opportunities to diversify pedagogies via an e-learning environment (Cavicchi, 2021; Chen, 2021), also using virtual reality technology to stimulate pro-environmental behaviour (Filter et al., 2020), and combining virtual transnational collaboration for sustainability (Caniglia et al., 2018). Regarding the institution level, the literature has proposed strategies and models to integrate technologies into higher education for increasing sustainable development (Giesenbauer & Müller-Christ, 2020), including technology transfer activities (Paniccia & Baiocco, 2018) and helping to communicate sustainability actions developed at universities, providing accountability and legitimacy to them (Rodríguez Bolívar et al., 2013).

Cluster 2 (green) has six recent publications with different method approaches: quantitative, qualitative, and mixed. The main topic of this cluster addresses HEIs as smart campuses for sustainability. Then, it was titled "smart and sustainable campus approaches". A smart campus can be defined as "an intelligent infrastructure where smart sensors and actuators collaborate to collect information and interact with the machines, tools, and users of a university campus" (Fraga-Lamas et al., 2019, p. 1). The literature on cluster 2 provides insights into different technologies deployed across campus facilities to improve sustainability (Bracco et al., 2018; Griffiths et al., 2019). Furthermore, this cluster addresses the professor's knowledge of smart city concepts (Olmos-Gómez et al., 2020), their attitude toward digitalisation in higher education (Mâță et al., 2020), as well as students' ability to integrate SDGs aspects into robotics projects (Schina et al., 2020), and how HEIs can carry out their teaching activities sustainably (Arnold et al., 2021).

Lastly, cluster 3 (blue) is composed of literature reviews that conceptualise digital transformation and sustainability in higher education through the analysis of research trends (Abad-Segura et al., 2020a), academic publications on educational technologies (Abad-Segura et al., 2020b), and information and communication technologies management for sustainability in higher education (González-Zamar et al., 2020a). The cluster was titled "theorisation of sustainability in higher education through digital transformation".

A deep content analysis of the above publications showed that digital transformation for sustainable development at HEIs is an emergent topic in the literature and has contributed to different activities to ensure sustainability in higher education. In the context of education for sustainable development, technologies such as virtual reality, gamification, augmented reality, robotics, and digital approaches such as virtual exchange and blended learning, among others, have been used by the studies previously analysed to enhance teaching and learning activities due to their capacity to foster pro-environmental consciousness and behaviour like in-person approaches. Moreover, engaging pedagogies that involve high levels of thinking and collaboration between students seem to impact this process positively. Regarding the campus infrastructure context, it was identified that HEIs worldwide are concerned with managing their resources. Therefore, smart and sustainable campus approaches are emerging to provide suitable places for learning, health, and well-being for

the university's community, energy and water efficiency, waste management, sustainable mobility, emissions control, governance, and other physical resource-saving. The implementation of these smart practices can have both environmental and economic impacts at universities, helping to reduce, for instance, carbon footprint, global climate warming, and air pollution, as well as consumption and costs.

3.2 Theoretical perspectives on digital transformation towards sustainability in higher education

To understand the theoretical perspectives in the field (research question 2), a content analysis of 46 publications was conducted using co-citation analysis. The publications were selected by the link strength in the VOSviewer software, which means that those with more links are more prominent than others. The 46 publications were divided into 7 clusters and titled as follows: e-learning, behavioural aspects of sustainability education, online education approaches, sustainability performance in education, education for sustainable development proposals and assessments, general topics on digital transformation and corporate social responsibility, and virtual education (Table 3). These publications are the main literature to the publications discussed in the previous section. Particularly, they guide the topic of sustainability in higher education through digital transformation.

3.3 Future research agenda

To understand the possible research lines for future studies on digital transformation toward sustainability in higher education, an analysis of keywords co-occurrence of publications from 2019 to 2022 was carried out, along with the content analysis discussed in the previous subsections. The density visualisation for keywords co-occurrence is shown in Fig. 8.

The keywords co-occurrence analysis started with a total of 1416 keywords. After excluding keywords with frequencies less than two and others with no meaning, 114 popular keywords came out. The items presented in red in Fig. 8 are hot topics in the literature as they have been significantly addressed by recent studies, such as higher education, sustainability, e-learning, university, COVID-19, digital learning, sustainability reporting, Sustainable Development Goals, sustainable development, artificial intelligence, digital transformation, management, digital technology, innovation, education for sustainable development, student, and blended learning.

Based on this study's findings and considering the higher education institution's core elements - education, campus operations, research, community outreach, and assessment and reporting - (Lozano et al., 2013; Kapitulčinová et al., 2018), five lines for future research were identified: digital education for sustainable development, sustainable campuses through smart technologies, research cooperation for sustainability, innovation and sustainability for the university community, and digital governance in higher education. Table 4 presents the established lines of research and their associated suggestions for future research questions.

The first research line for future studies refers to digital education for sustainable development (ESD). ESD's effective blended learning and flipped classroom pedagogies are currently being extensively investigated. Then, future research could investigate, through longitudinal studies, whether the long-term use of virtual reality, augmented reality, and artificial intelligence leads to sustainability knowledge gains. Furthermore, the literature suggests that collaborative learning in virtual environments can foster intercultural

Table 3 The theoretical perspectives on digital transformation towards sustainability in higher education

Cluster	Topic	Authors	Description
1	E-learning	Aristovnik et al. (2020), Benta et al. (2015), Bozkurt and Sharma (2020), Brudermann et al. (2019), Coman et al. (2020), Espino-Díaz et al. (2020), Hodges et al. (2020), Lorente et al. 2020, Popa et al. (2020), Zamora-Polo and Sánchez-Martin (2019), Zhang et al. (2020)	Studies on cluster 1 address the e-learning topic by analysing it at the political and governmental levels (Zhang et al., 2020, Lorente et al., 2020), examining the impact of the COVID-19 pandemic on educational activities (Coman et al., 2020, Popa et al., 2020, Aristovnik et al., 2020, Benta et al., 2015), and proposing improvements to teaching practices using digital technologies (Zamora-Polo and Sánchez-Martin, 2019, Brudermann et al., 2019)
2	Behavioural aspects of sustainability education	Evans et al. (2017), Gómez-Galán (2020), Murga-Menoyo (2015), Rieckmann (2012), Ryan and Deci (2000), Wiek et al. (2011), Zhu (2015)	Cluster 2 discusses intrinsic and extrinsic motivations that can influence the educational process (Ryan & Deci, 2000), innovative approaches to teaching and learning activities (Evans et al., 2017, Gómez-Galán, 2020, Zhu, 2015), and key sustainability competencies (Wiek et al., 2011, Rieckmann, 2012, Murga-Menoyo, 2015)
3	Online education approaches	Bruggeman et al. (2021), Edelhauser and Lupu-Dima (2020), Kioupi and Voulvoulis (2019), Manca (2020), Murphy (2020), Volery and Lord (2000)	Most of the literature on cluster 3 focuses on tools, approaches, and strategies to support online education, that is, what is the impact of social media platforms on teaching and learning activities (Manca, 2020), which are the key professors' attributes (Bruggeman et al., 2021), and the critical success factors/methods in online education (Volery & Lord, 2000)
4	Sustainability performance in education	González-Zamar et al. (2020a), Muñoz-Rodríguez et al. (2020), Napal et al. (2020), Owens (2017), Jarillo et al. (2019), Velazquez et al. (2006)	Cluster 4 evaluates and describes sustainability in education (Owens, 2017), through the analysis of the progress made in learning sustainability competencies by students (Muñoz-Rodríguez et al., 2020), proposing indicators for the development of sustainability competencies (Napal et al., 2020), making suggestions on how institutions can approach the Sustainable Development Goals through online learning (Jarillo et al., 2019), examining the research area (González-Zamar et al., 2020a), and proposing a model for a sustainable university (Velazquez et al., 2006)

Table 3 (continued)

Cluster	Topic	Authors	Description
5	Education for sustainable development proposals and assessments	Azeiteiro et al. (2015), Dziubaniuk and Nyholm (2021), Lambrechts et al. (2013), Lozano et al. (2017), Molderez and Fonseca (2018), O'Riordan et al. (2020)	Cluster 5 analyses education for sustainable development by exploring new teaching sustainability practices (Dziubaniuk & Nyholm, 2021, Lozano et al., 2017), evaluating its effectiveness (Azeiteiro et al., 2015, Lambrechts et al., 2013), and investigating the role of universities on meeting the Sustainable Development Goals (O'Riordan et al., 2020)
6	General topics on digital transformation and corporate social responsibility	Abad-Segura et al. (2019), Akçayır and Akçayır (2017), Barbier and Burgess (2019), González-Zamar et al. (2020b), Li and Kirkup (2007)	Cluster 6 approaches different topics, ranging from augmented reality in teaching activities (Akçayır and Akçayır, 2017), student attitudes regarding technologies (Li & Kirkup, 2007), Sustainable Development Goals progress evaluation (Barbier & Burgess, 2019), to the corporate social responsibility (CSR) relevance for organisations (Abad-Segura et al., 2019)
7	Virtual education	Cabedo et al. (2018), Merchant et al. (2014), Potkonjak et al. (2016), Redel-Macías et al. (2016), Salmerón-Manzano and Manzano-Agugliaro (2018)	Cluster 7 mainly discusses virtual education by approaching virtual reality, virtual laboratories, virtual worlds, and their implications onteaching and learning (Merchant et al., 2014, Potkonjak et al., 2016, Redel-Macías et al., 2016, Salmerón-Manzano & Manzano-Agugliaro, 2018)

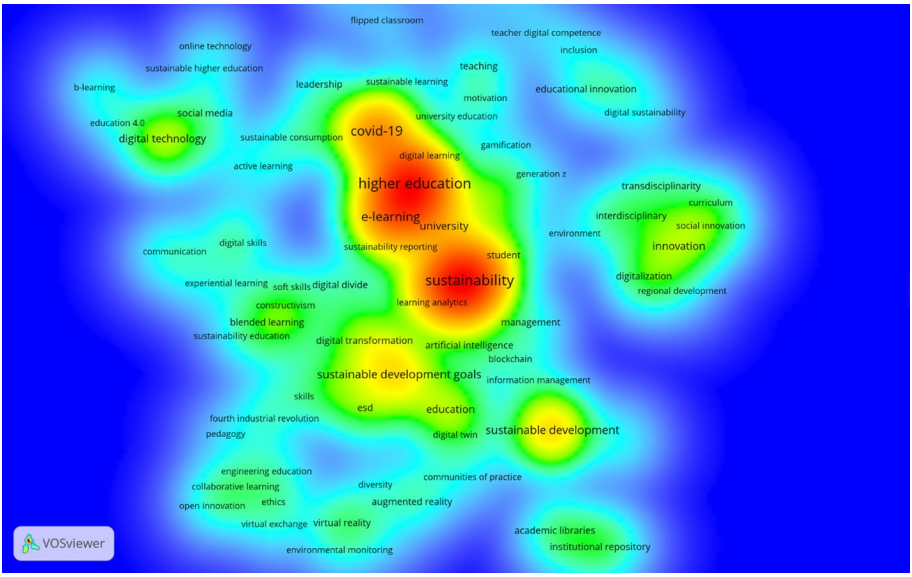


Fig. 8 Keywords co-occurrence by density visualisation (2019–2022)

awareness, improve language proficiency, facilitate virtual student mobility, and empower citizens with digital skills to face global challenges (Laufer et al., 2021; Bruhn-Zass, 2021; Núñez-Canal et al., 2022). Hence, future research could approach new kinds of collaborations and partnerships for education for sustainable development around the world. An example of a recent practice that is worth investigating is a virtual exchange, which is a higher education modality of internationalisation (Garcés & O'Dowd, 2021). Future studies may also investigate whether online approaches contribute to increasing students' engagement in internationalisation activities, reducing social inequality, and reducing humankind's carbon footprint due to decreased displacement.

As a second research line, future studies may address sustainable campuses through smart technologies. The growing number of publications on the subject shows that digital technologies have been deployed in HEIs worldwide. However, few studies are mapping the type of technologies implemented on campuses to ensure sustainability, as well as their connection to the UN SDGs, the drivers, and barriers to their implementation, and the environmental and social benefits in HEIs, for instance, the impact on carbon and water footprint, energy saving, transport and logistics, waste management, food supply chain, and other campus facilities. Concerning research cooperation for sustainability, future studies may explore how digital transformation can benefit connections among students, professors, and researchers around the world; that is, how artificial intelligence, augmented reality, big data, blockchain, and other types of technologies can support research cooperation for sustainability worldwide, helping to process data, evaluate, and manage sustainability impacts on the planet. In addition, future research can identify researchers' technological training needs to provide the necessary solutions.

Related to innovation and sustainability for the university community, that is, the interaction of HEIs with internal and external stakeholders, future research can address how digital transformation can support the contribution of HEIs to sustainable regional development, social innovations, entrepreneurship, dissemination of the 2030 Agenda, and the

Table 4 Research agenda for future studies on digital transformation towards sustainability in higher education

Research lines	Future research questions
Digital education for sustainable development	How do digital technologies lead to sustainable knowledge gains over extended periods of teaching and learning activities? What are the possible virtual collaborations and partnerships for education for sustainable development around the world? What is the impact of online educational approaches on social inequality and carbon footprint?
Sustainable campuses through smart technologies	What types of technologies have been deployed across campus facilities to ensure sustainability? What are the drivers and barriers to implementing technology for sustainability on campuses? What are the environmental, social, and economic benefits of implementing technologies for sustainability in universities?
Research cooperation for sustainability	How have technologies supported research cooperation worldwide? How have technologies helped to process sustainability data research? What are the researchers' technological training needs?
Innovation and sustainability for the university community	How can technology support universities' contribution to sustainable regional development, social innovations, entrepreneurship, dissemination of the 2030 Agenda, and achieving the UN Sustainable Development Goals?
Digital governance in higher education	How can technologies support sustainability reporting in higher education? How can technologies support the mapping of sustainability actions in higher education? How can technologies help link sustainability activities carried out on campuses and the UN Sustainable Development Goals?

achievement of the Sustainable Development Goals. Lastly, regarding digital governance in higher education, Raji and Hassan (2021) highlighted that reporting activities mitigate the asymmetries between HEIs and their stakeholders. Then, future research may address technological approaches to support sustainability reporting in higher education, map sustainability actions carried out on campuses, and identify their links with the UN SDGs.

4 Conclusion

The technological revolution has changed society in different ways. In the educational context, the COVID-19 pandemic accelerated the process of digital transformation in universities, as the use of digital technologies supported the continuity of their teaching and learning activities. Moreover, given the sustainability challenges currently faced by humankind, higher education institutions (HEIs) have been considered key stakeholders in the education of responsible citizens and leaders. Therefore, providing students with

sustainability skills with the support of technology is both an opportunity and a challenge for these institutions. By linking digital transformation and sustainability activities, it is believed that HEIs can collaborate to face global challenges, such as climate change, social inequality, energy, quality of education, responsible consumption and production, among others, through the education of responsible citizens and the dissemination of a sustainability culture throughout the university system.

In the literature, there is a gap in the theoretical panorama regarding the contribution of digital transformation to sustainability in HEIs, which highlights the innovation of this study. Specifically, it collaborates by identifying the general state of research on the topic, theoretical perspectives in this field, and the possible directions for future studies. To address these questions, a mixed review method was carried out, which involved quantitative bibliometric analysis and qualitative content analysis. This study may be the first literature review on digital transformation to sustainability in higher education that carried out both bibliometric and content analyses, providing theoretical subsidies to the academic community and guiding sustainability and digital practices in HEIs. Specifically, the several studies explored in this study show different types of technologies, approaches, and strategies that can support sustainability actions in HEIs.

A bibliometric analysis was conducted on 672 publications using VOSviewer software. A descriptive analysis was then carried out, along with popular keywords analysis by co-occurrence technique and qualitative content analysis of 26 publications distributed among 3 clusters using the bibliographic coupling technique. The findings suggest three important research areas in this field: ensuring sustainability competencies through DT, smart and sustainable campus approaches, and theorisation of sustainability in higher education through DT. Subsequently, a co-citation analysis was carried out to identify theoretical perspectives in the field. The findings highlighted 46 publications, distributed in 7 clusters and titled as follows: e-learning, behavioural aspects of sustainability education, online education approaches, sustainability performance in education, education for sustainable development proposals and assessments, general topics on DT and corporate social responsibility, and virtual education. Lastly, a co-occurrence of the keywords used by publications from 2019 to 2022 was carried out along with the bibliographic coupling technique and co-citation analysis previously conducted. Then, five research lines for further studies on DT towards sustainability were identified: digital education for sustainable development, sustainable campuses through smart technologies, research cooperation for sustainability, innovation and sustainability for the university community, and digital governance in higher education.

There are limitations of this study that should be mentioned. The Scopus database was the only one considered to collect data. Future studies could use other well-known scientific databases, such as the Web of Science, to provide additional perspectives on the topic.

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Declarations

Conflict of interest The authors have no competing interests to declare that are relevant to the content of this article.

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